Information on Be properties

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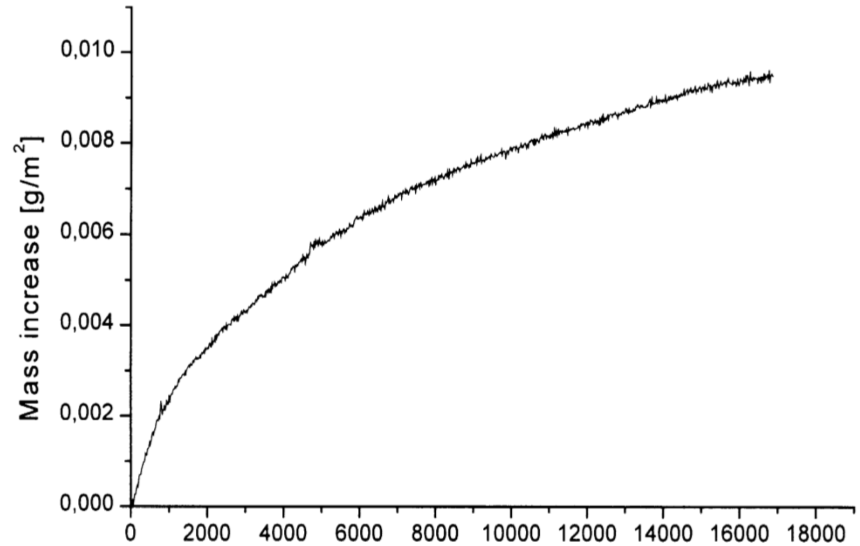
Properties and effects of irradiation exposure

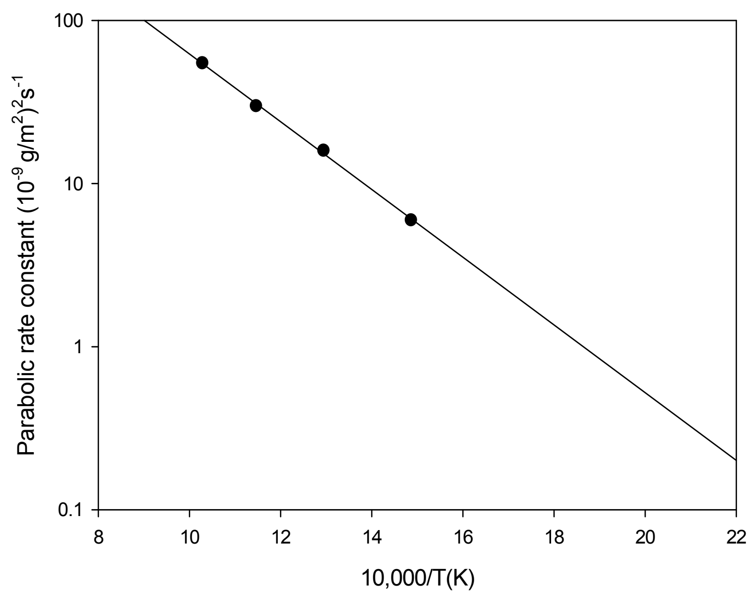
Topic	*Progress*
• Oxidation in air	Yes
• Thermal conductivity	Yes
• Elastic modulii and thermal expansion	No info
• Impurities on properties and structure	In progress
• Irradiation growth	Yes
• Thermal/irradiation creep and ductility	No info
• Stress relaxation	No info
• Swelling due to voids and gas generation	Yes
• Tensile strength and ductility	In progress
• Fracture toughness	In progress
• Cyclic stressing and interaction with creep	No info

- *Further information on any of these topics would be appreciated.*

Be oxidation - thermal

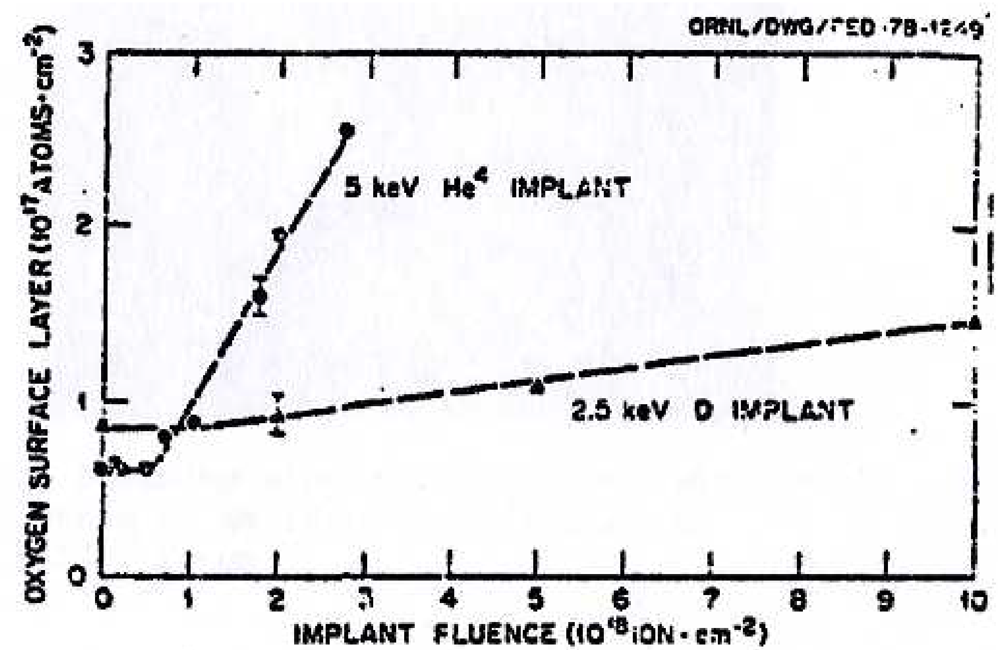
- Above 700ºC oxidation is non-protective, the scale is compressively stressed and surface blisters form.
- Below 700ºC oxidation is protective, initially parabolic in nature but then slowing further.
- Parabolic kinetics decrease at lower absolute temperatures following Arrhenius relation. Data at window operating temperatures of 200-300ºC can be obtained by extrapolation.
- Exposures of one year would produce oxide thicknesses of 6.8nm and 16.8nm at 200ºC and 300ºC respectively.
- Oxidation of this magnitude would not represent an operating problem.





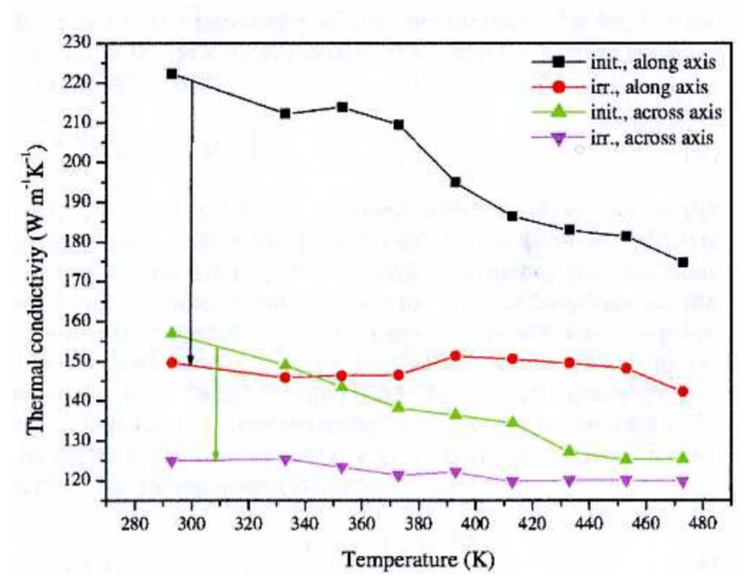
Irradiation and oxidation

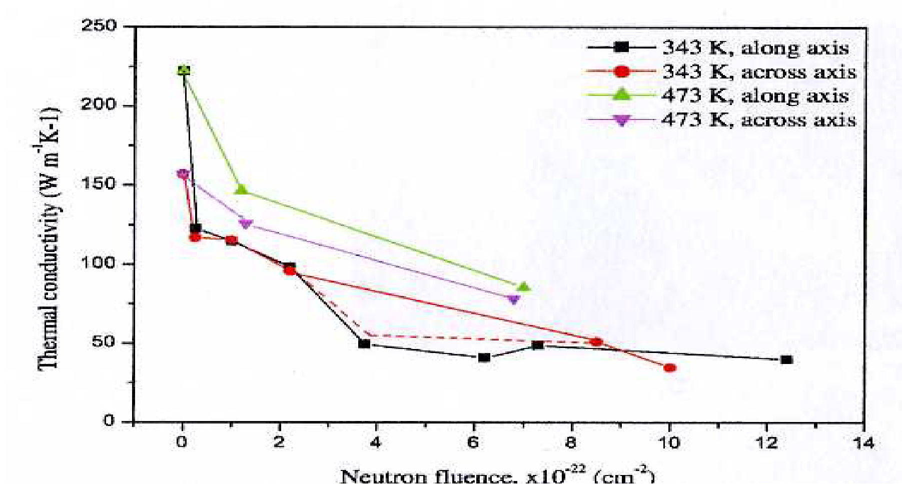
- Irradiation with 2.5keV D or 5keV He^4 gives oxidation of Be at 20ºC in a low pressure environment containing H_2O, CO, CO_2 and O_2 (at 10^{-8} torr).
- Fluxes of 1 - 3 $x10^{16}$ $ions.cm^{-2}.min^{-1}$.
- Short term experiments of a few hours duration.
- Oxidation was non-protective, was linear in time and was faster for He compared with D.
- Soon after irradiation with He started surface blisters were detected.
- Blisters increased from 1 to 5.5µm in diameter during exposure.
- No blisters found for D irradiation.
- As blisters developed the retention of He and D in the oxide was impaired.
- Need to examine ex-service Be windows for blister formation and to consider further ion irradiations in differing environments.



Irradiation and Be thermal conductivity (κ)

- Irradiation effects on κ have been examined for Be of differing textures, grain sizes and impurity levels (mainly the level of BeO).
- Irradiations were at 343Kelvin and 473Kelvin, doses of 2 – 58 dpa and He 840 – 20,600 appm (1dpa ~ 0.25 x 10^{22} n/cm^2 (E>0.1MeV).
- κ varies with test temperature and axial orientation (texture). After irradiation at 473 Kelvin (see top diagram) κ is reduced, the temp dependence is lost but texture effects remain.
- The most rapid irradiation-induced reduction in κ occur at the lower doses and irradiation temperatures (lower diagram).
- The main cause of the reduction in κ at low irradiation temperatures is radiation-induced dislocation loop formation with a contribution from He generation and small He clusters.
- So far there has been no quantitative analysis of the type and morphology of the defects present in relation to the observed reductions in κ.
- Need further work at low doses at 473K and on influence of transmutation gas.





Irradiation growth in Be

- Be cylinders were exposed at 70°C & 200°C to 1.3-14.2x10^{22}n/cm^2 (E>0.1MeV).
- Height & diameter measurements were made on cylinders pre-cut parallel or perpendicular to extrusion direction.
- Irradiations at 70°C of samples cut parallel to extrusion increased in diameter more than in length. Reverse trend for samples cut perpendicular to extrusion.
- Samples irradiated at 200°C were less sensitive to these orientation effects (fig2).
- No void swelling measurements made.
- X ray data showed unit cell "a" parameter increased and "c" parameter decreased on irradiation.
- TEM revealed vacancy loops on basal planes & interstitial loops on prismatic planes. Larger loops after 200°C irrad.
- 200°C irradiation produced high density of He-filled gas bubbles of 4.3nm diameter in grains and 6.8nm diameter in boundaries.

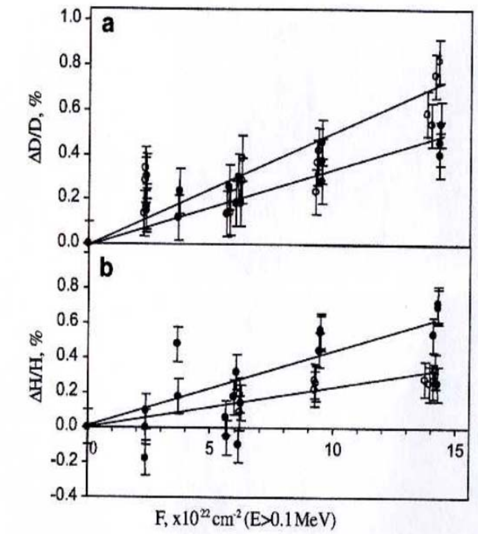


Fig. 1. Dependence of changes of diameter D/D (a) and height H/H (b) of beryllium samples for irradiation temperature of T_{irr} = 70 °C on neutron fluence F: ○ – along the axis; ● – across the axis.

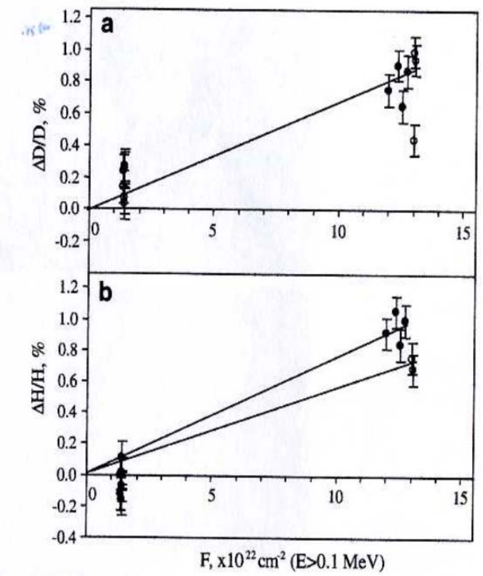


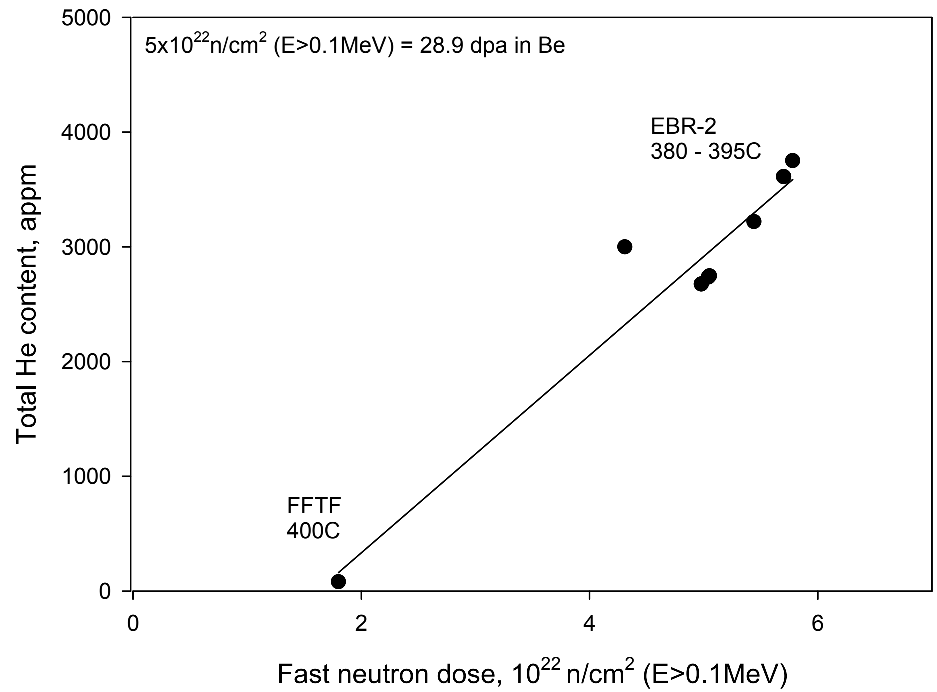
Fig. 2. Dependence of changes of diameter D/D (a) and height H/H (b) of beryllium samples for irradiation temperature of T_{irr} = 200 °C on neutron fluence F: ○ – along the axis; ● – across the axis.

3.2. X-rays investigation

- These data indicate small levels of Be growth at doses representative of window applications.

Swelling due to voids and gas generation

- Be spheres irradiated $4x10^{22}n/cm^2$ (E>0.1MeV) at 380°C below core in EBR-2. Immersion density swelling was 1.45%, He content 3000appm.
- TEM showed flat cavities on the basal plane (flattened internally stressed He bubbles).
- Bubbles were 5 - 25nm diameter with thickness/diameter ratio of 0.16. Nv was $2.0x10^{16}/cm^3$. TEM - estimated swelling was ~1% agreeing with density data.
- Exposures below core in FFTF at 400°C to $1.8x10^{22}n/cm^2$(E>0.1MeV) and 80ppm He gave evidence for cavity formation (c-type loops acting as sinks for He).
- He^4 predominates in all these tests so that He^4/He^3 ~200.



- Conclude that gas swelling may not be a problem in window dose applications but need to confirm that He:dpa ratios in windows are similar to available data.
- If not, could perform ion irradiation experiments

Tensile and toughness properties

- Thermal aging does not affect the strength of Be but its strength is reduced progressively as the test temperature is raised. Ambient proof strengths of 400MPa decrease to 200MPa at 600°C.
- Uniform ductility values are <5% at ambient temperature, rising to ~10% at 200°C before falling again at higher test temperatures.
- Fracture mechanism was transgranular cleavage at room temperature, with some ductile crack propagation at ~200°C and ductile dimple fracture at higher temperatures.
- All Be grades exhibit significant irradiation hardening after 0.8–2.6 dpa at 185 - 610°C irradiation temperatures.
- Severe irradiation embrittlement (uniform tensile ductility < 2%) is found for all irradiated conditions.
- The fracture toughness of unirradiated Be is test temperature sensitive but limited in magnitude. It rises from ~15 MPa.m$^{1/2}$ at ambient temperature to 60-80 MPa.m$^{1/2}$ at 400-500°C.
- Irradiation has an extremely detrimental effect on fracture toughness at all irradiation/test temperatures. Irradiated toughness values fall from 30-40 MPa.m$^{1/2}$ at 600°C to <10 MPa.m$^{1/2}$ at and below 200°C.
- Some limitations to Be operations may follow from the toughness property degradations.
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