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Radiation-induced Growth in Zircaloy-4

by

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High-flux Advanced Neutron Application Reactor

Overview

- *Reasons for study*
- *Growth mechanisms*
- *OPAL and HANARO reflector vessels*
- *Samples and measurement technique*
- *Results*
- *Future work*
- *Acknowledgements*

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Reasons for Study

- *Zirconium alloys have been shown to grow under neutron irradiation*
- *There has been considerable study of growth in zirconium alloys but it is either at higher temperatures than experienced in research reactors or is for other alloys (for example Zr-2 or Zr-2.5Nb)*
- *In the design of the OPAL reflector vessel an allowance of 0.4% was made in the design to allow for growth*

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Growth Mechanisms

- *Growth is a process of shape change in the absence of applied stress. Comes from crystallographic/microstructural anisotropy*
- *Zirconium alloys have hexagonal close packed (hcp) structure*
- *The degree of anisotropy is altered when the material is subjected to cold work such as rolling*
- *Greatest growth expected along the rolling direction*
- *Residual stress may also have an effect on the magnitude of the growth*

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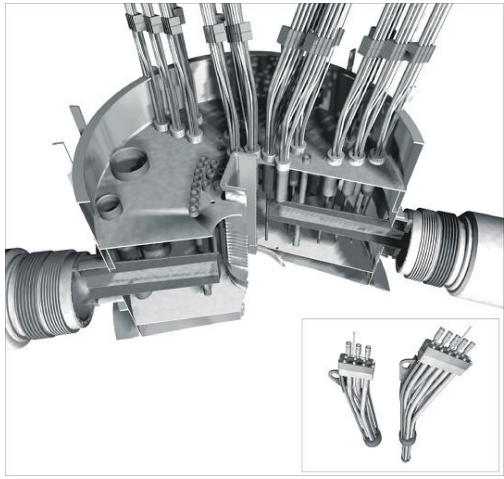
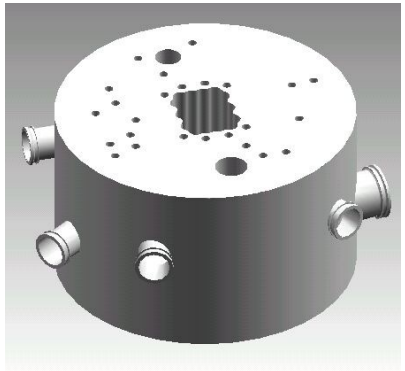
OPAL reflector vessel



HANARO reflector vessel



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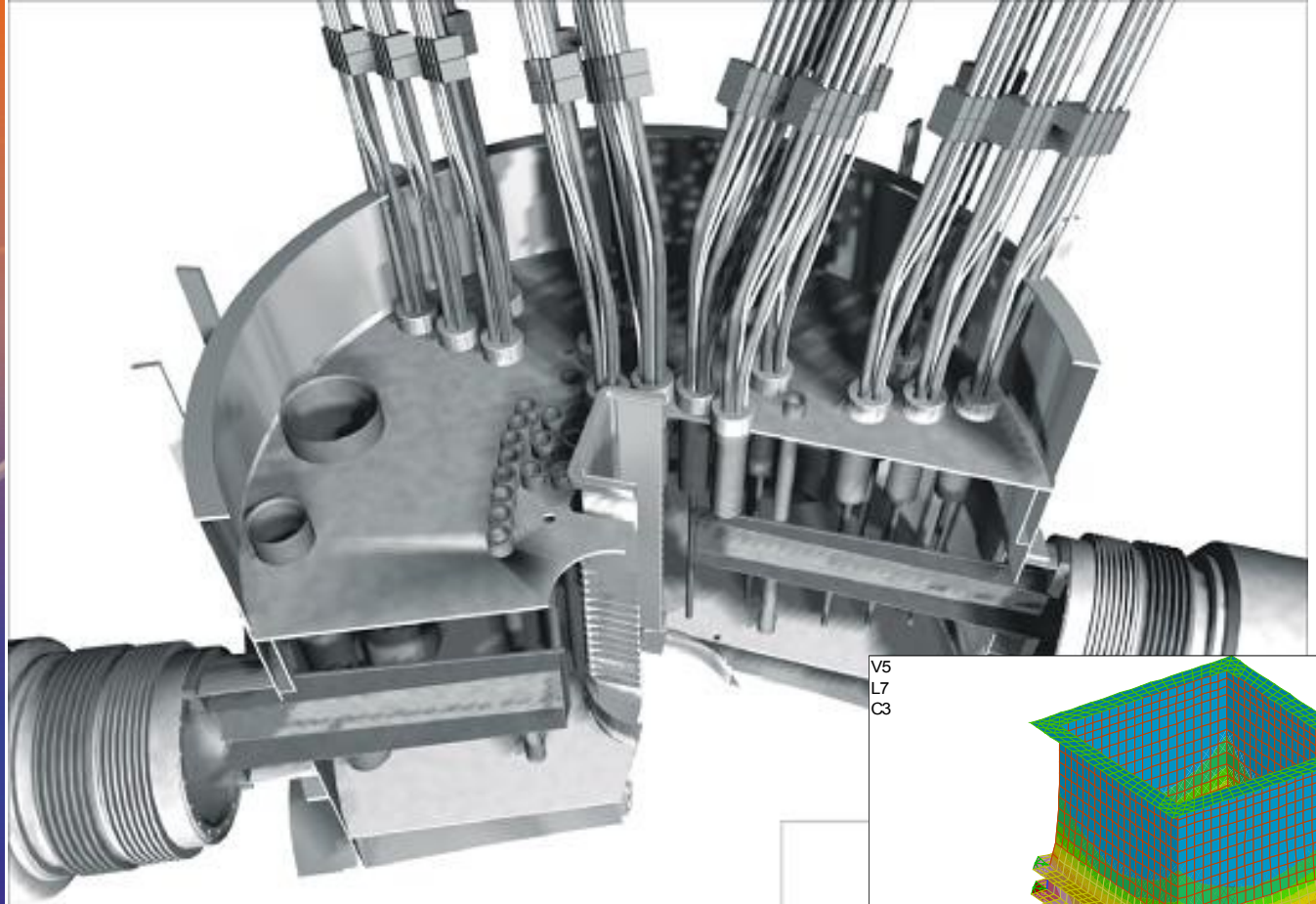
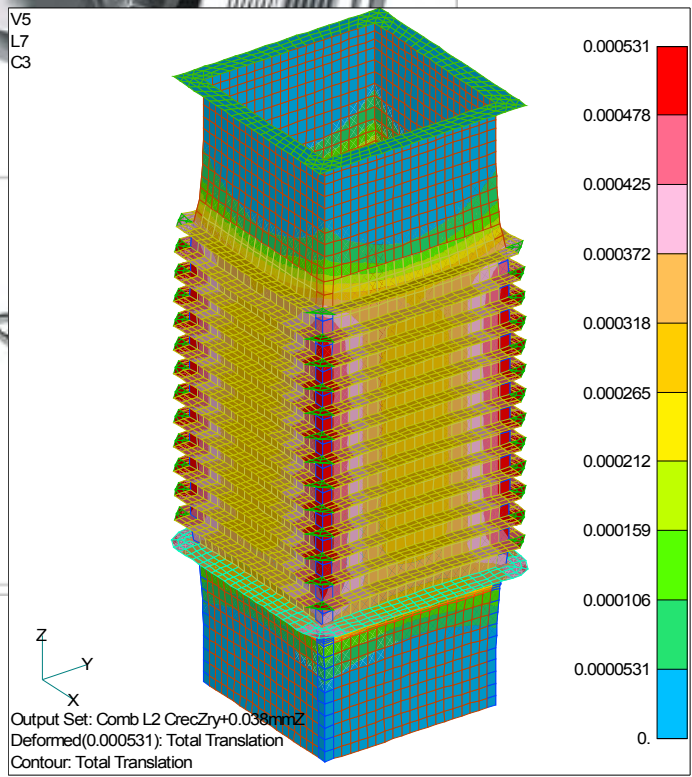


OPAL Reflector Vessel



Samples and Measurement Techniques

- *Samples are simple circular cross-section bars – 8 mm diameter and approximately 114 mm long*
- *The ends are machined parallel and then polished to provide a flat measurement surface*
- *Samples were given a stress-relief heat treatment prior to irradiation*
- *Measurement jig uses radiation-tolerant LVDT.*
- *Samples placed in HFE location "C" in fuel assembly C3. Fast flux in this position is approximately 2.8 x 10^{13} n/cm²/s*

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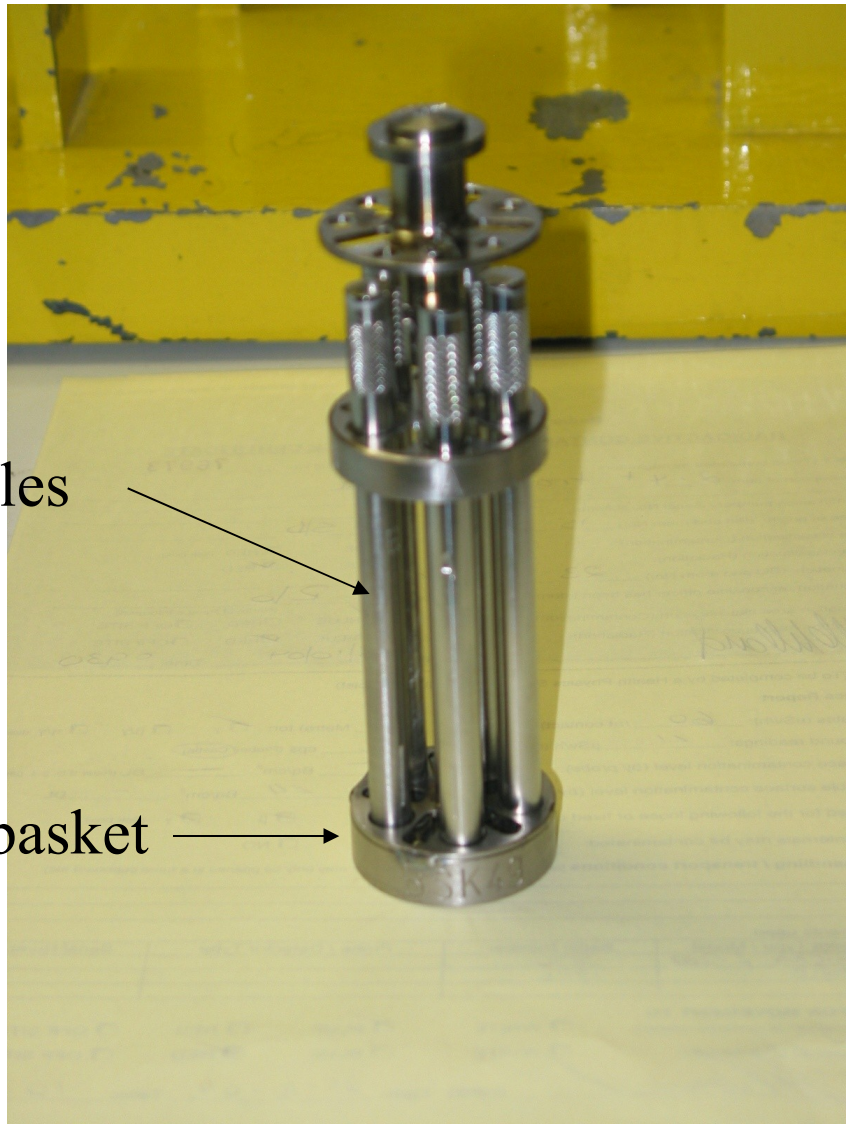
Calibration of Measurement Jig

- *Three calibration samples manufactured from stainless steel – 113.5, 114.0 and 114.5 mm long*
- *Samples stored along with the measurement jig in the hot cell*
- *Jig is calibrated using the calibration samples before each measurement*
- *Correction made to measured values to allow for temperature variations – two thermocouples mounted on jig v-blocks*

Growth Samples in Basket



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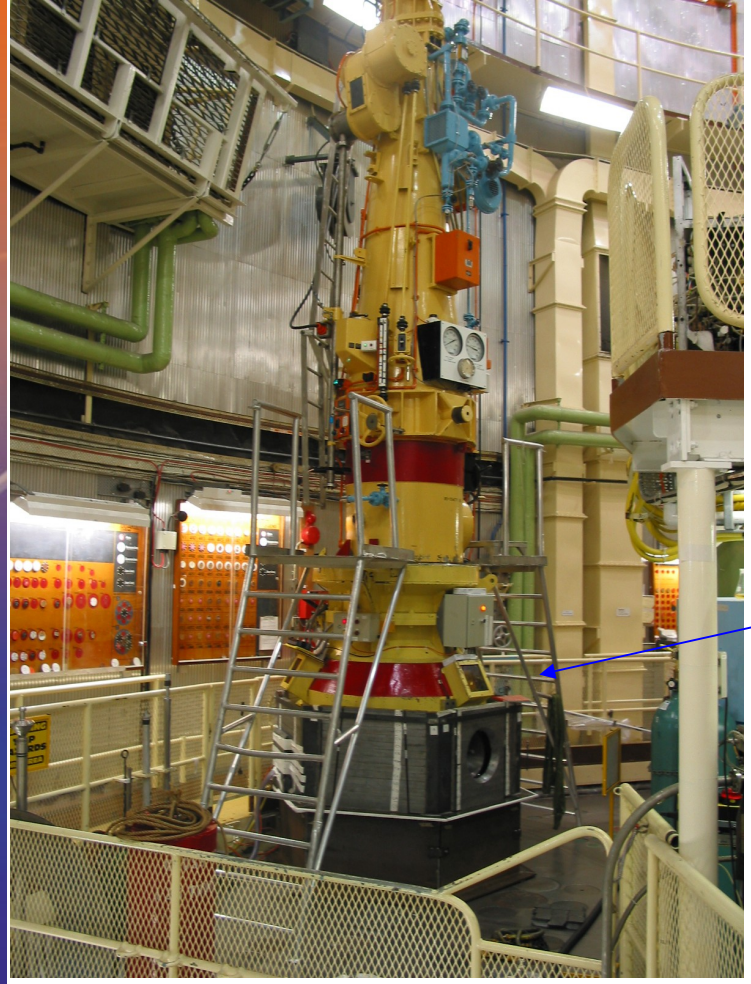
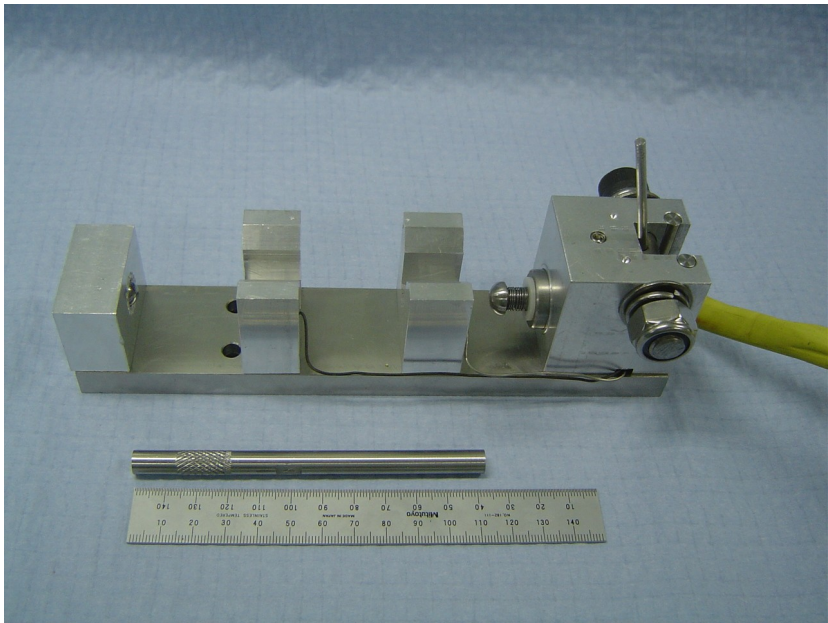


Inside HIFAR showing
Rig flask on top of PHC

Portable handling cell
(PHC)



Measurement jig with
Calibration sample

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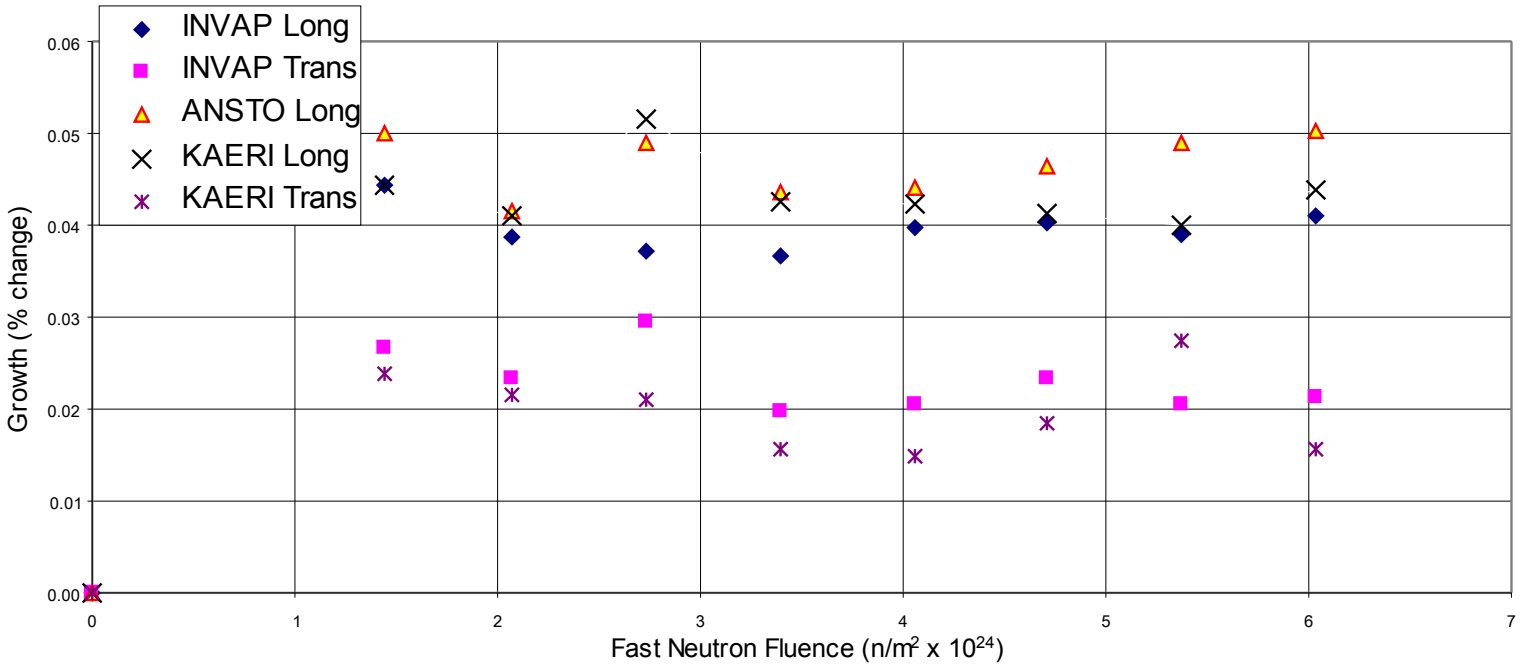
Results

- *Measurements taken at the end of each HIFAR operating program – every 5 weeks*
- *Fluence to date ~6 x 10^{24} n/m^2 (E > 1MeV)*
- *Maximum growth measured is ~0.05% in the rolling direction and ~0.03% in the transverse direction*
- *As growth is a zero volume process the third direction must be shrinking*

Measured Growth of Zircaloy-4



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Future Work

- *Continue to perform measurements on samples until HIFAR is closed (late 2006/early 2007)*
- *Investigate moving samples to OPAL (will require a change in measurement method)*

Acknowledgements

- *Materials & Engineering Science staff – for design and construction of jig*
- *HIFAR staff – for scheduling measurements to fit in with normal shut-down activities and preparation of target and canning specification.*
- *Active Handling crews – for enthusiastic participation in the measurements and useful advice on handling of radioactive samples*