Characterising Radiation Induced Mechanical and Microstructural Changes in Model Alloys for Nuclear Reactor Lifetime Extension

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Background

- Neutron irradiation induces defects and affects mechanical properties of alloys.
- Reactor pressure vessels (RPVs) are safety critical & the irreplaceable component of a nuclear plant.

Motivation

- Existing fracture toughness models inaccurate at high fluence.
- Clusters of Manganese, Nickel and Silicon observed at high fluence.
- Disagreements in the field on formation mechanisms and thermodynamic stability of these defects. [1]
- No proton irradiation with SANS and TEM studies on irradiated Fe-Mn-Ni-Si quaternary/tertiary alloys.

References

[1] Almirall et al, Scripta Materialia, 181, p. 134-139. (2020)
[2] J.C.van Duysen and G. Meric de Bellefon, Journal of Nuclear Materials, 484, p. 209-227. (2017)

Study Aim

- Characterise radiation induced defects.
- Quantify effects of solute concentration and fluence on Mn-Ni-Si cluster nucleation and growth.

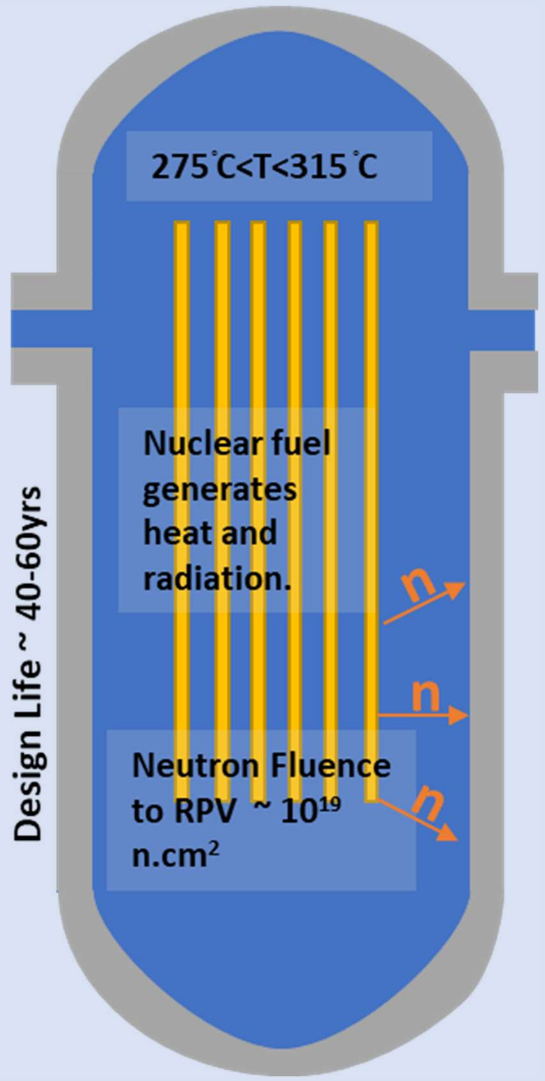

Figure 1: Simplified schematic of water-cooled reactor pressure vessel giving key points on design life and environmental conditions endured by RPV steel. Lifetime, fluence and temperature range acquired from [2].

Inducing Radiation Damage

- *Key challenge:* accelerating radiation damage to simulate late stages of reactor operation.
- *Solution:* Use proton irradiation. Strong proton interactions lead to small damage volumes and Bragg peak damage profile.

This study:

- 2.9MeV proton irradiation of model alloys.
- Samples produced with dose of 0.1dpa and 0.2dpa.

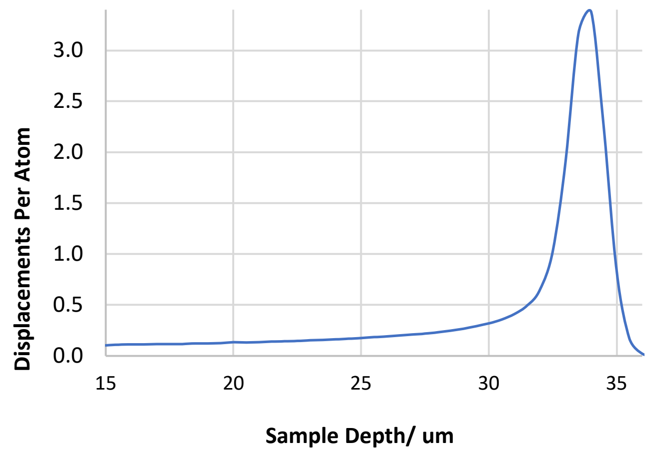

Figure 2: Displacements Per Atom simulated using SRIM for 2.9MeV protons incident on FeMnNiSi model alloy.

Table 1: Complementary characterisation techniques to be used in this study to characterise the microstructure and mechanical effects of radiation induced defects.

Method	Defect Size	Defect Shape	Number Density	Size Distribution	Defect Composition	Images	Mechanical Properties	Crystal Structure/ Order of Defects
Small Angle Neutron Scattering	-	-	✓	✓	✓(relative)	-	-	-
Transmission Electron Microscopy	✓	✓	✓	-	✓	✓	-	✓
Nanoindentation	-	-	-	-	-	-	✓	-
Micro-Pillar Compression	-	-	-	-	-	-	✓	-

Characterising Radiation Damage

- *Key challenge:* characterising nanoscale defects in small sample volumes ~ 30um depth.
- *Solution:* use various advanced techniques to characterise different properties (see Table 1.)

This study:

- Micro and nano-mechanical testing.
- Small Angle Neutron scattering (nuclear and magnetic).
- Transmission Electron Microscopy.

Applications

- Decisions on reactor lifetime extension
- In – situ radiation damage recovery processes for reactor pressure vessels.
- Development of new RPV steels.