Phase Stability in an Ion Irradiated Haynes 230 at High Temperatures

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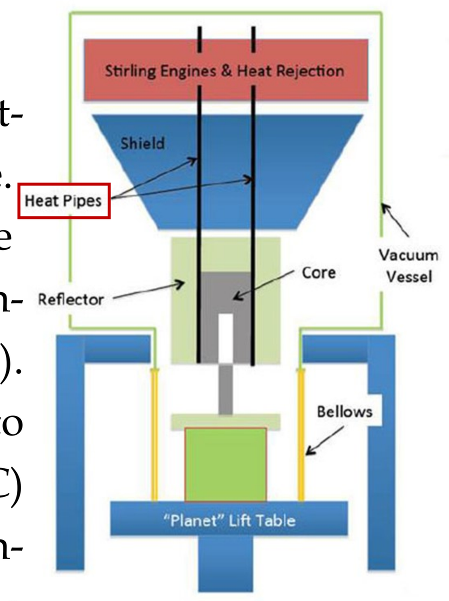
Motivation:

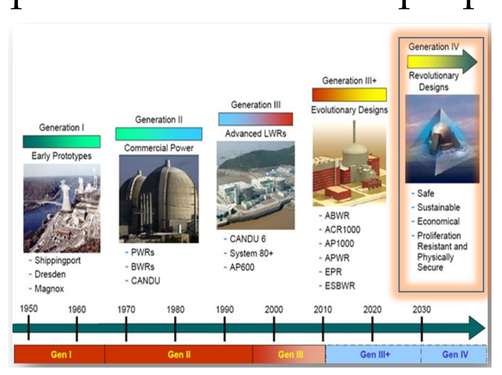
A small self regulating reactor's criticality is controlled by temperature. Heat pipes are used to transfer the heat from the reactor to the environment (Stirling Engine in this case). Therefore heat pipes are exposed to high temperatures (up to 1000 ºC) and low doses of radiation. As a candidate material for heat pipes, no published data on irradiation effects on Haynes 230 is available.

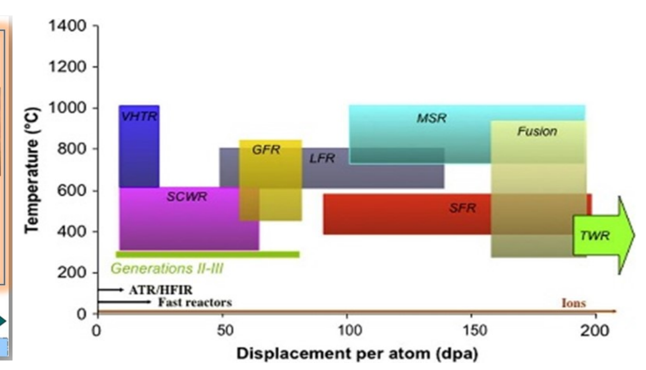


Self regulating reactor design for space application

Introduction:

Advanced alloys are being investigated for advanced reactors which are designed to operate at higher temperatures and radiation fluxes[1]. Nickel based super alloys (e.g. Inconel, Haynes) are being considered as candidate materials for advanced reactors because of their excellent high temperature mechanical properties and corrosion resistance.

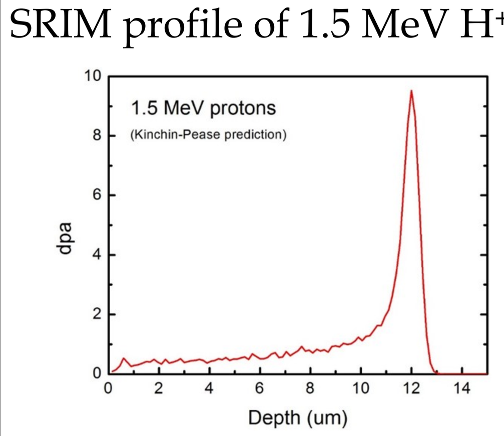


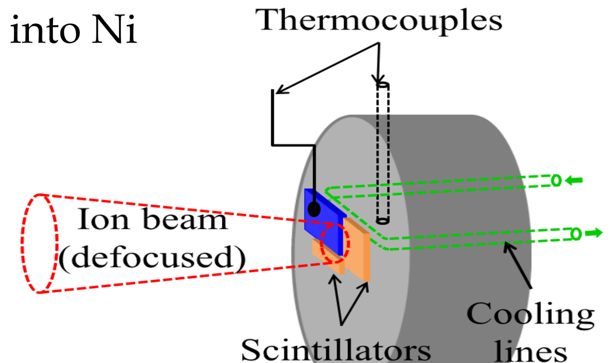


Ion irradiation is a cost effective, safe and quick alternative for investigating irradiation effects on materials. It has been widely used for investigations recently[2].

Ion Irradiation:

SRIM profile of 1.5 MeV H^+ into Ni





1.5 MeV H^+ beam (~1 dpa)

3 MeV Tandem Accelerator at LANL

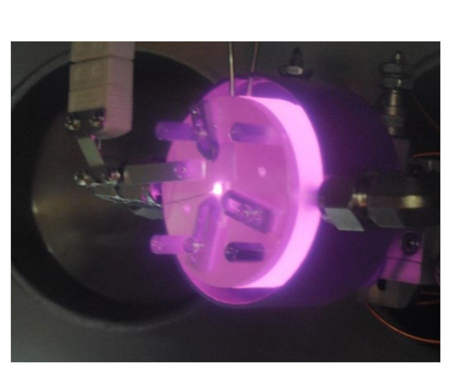


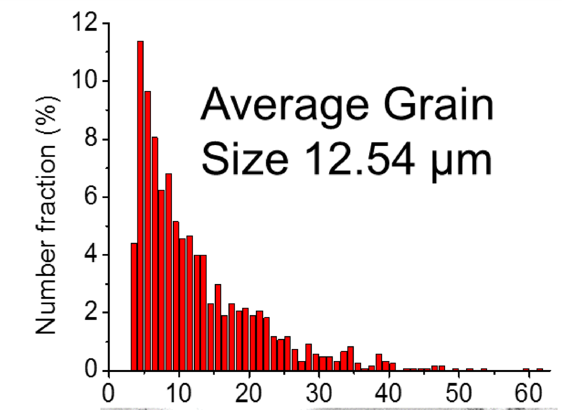
Image taken during 850ºC irradiation

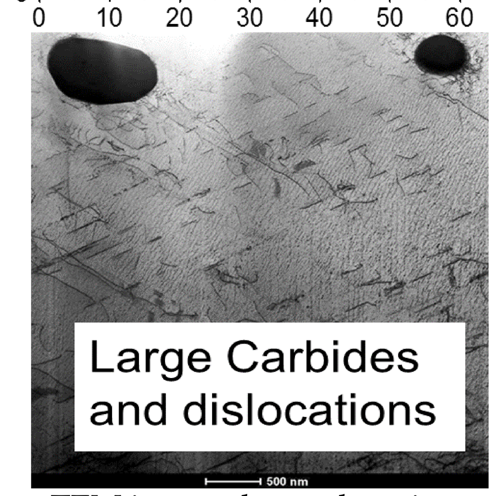
Haynes 230 Candidate Material:

- H230 was developed to perform at high temperatures (800-900°C) for extended periods of time with high oxidation resistant and high strength. H230 is currently being used in combustion linings on turbine engines[3].
- H230 forms equiaxed grains with a few twin densities.
- H230 has Cr rich $M_{23}C_6$ and W rich M_6C carbides that initially exist. The carbides provide creep and grain coarsening resistance along with a higher oxidation resistance .

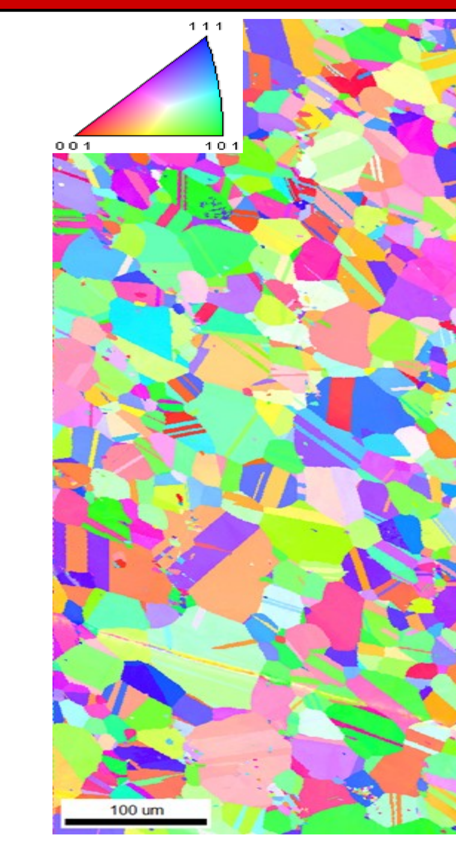
Elemental composition of Haynes 230 (Heat# 830547798) in wt% with Ni bal.

Cr	W	Fe	Mo	Mn	Si	Al	Co	C	Cu	La	Ti	P	B	S
22.01	13.59	1.95	1.23	.45	.37	.32	.16	.1	.04	.017	<.01	.005	.002	<.002



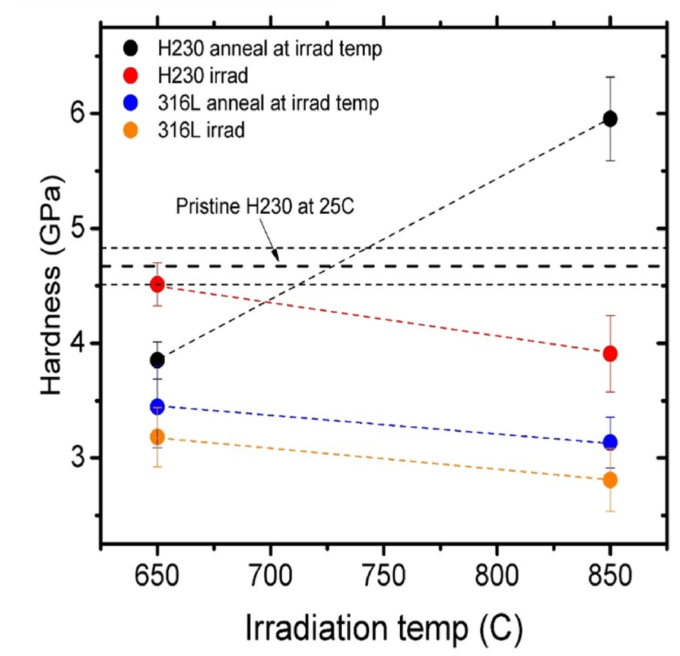


TEM image shows the microstructure

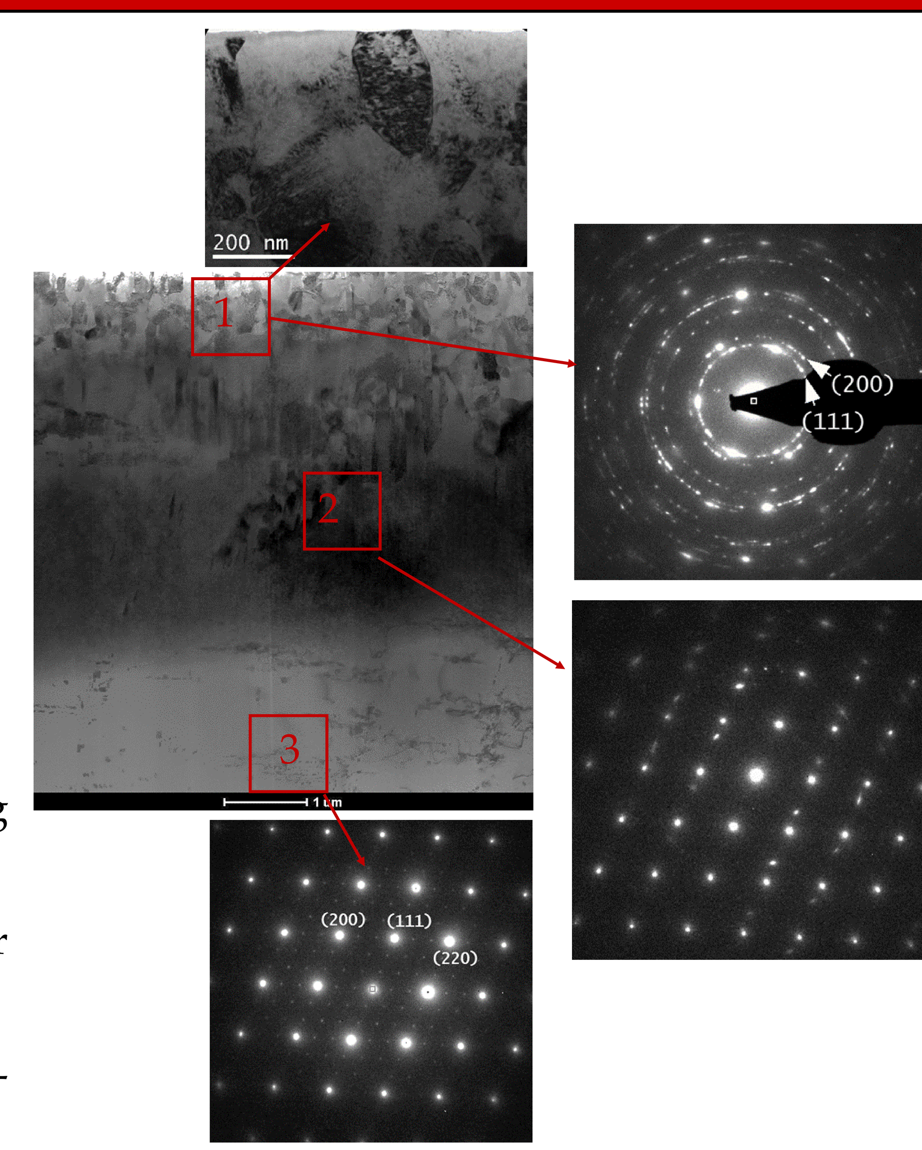


Electron Back Scatter Diffraction shows grain morphology

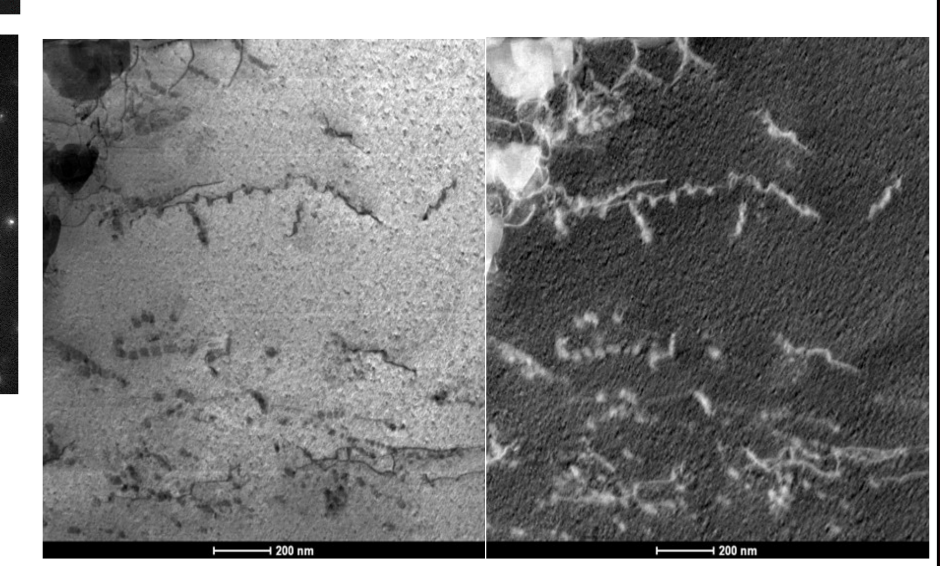
Results:

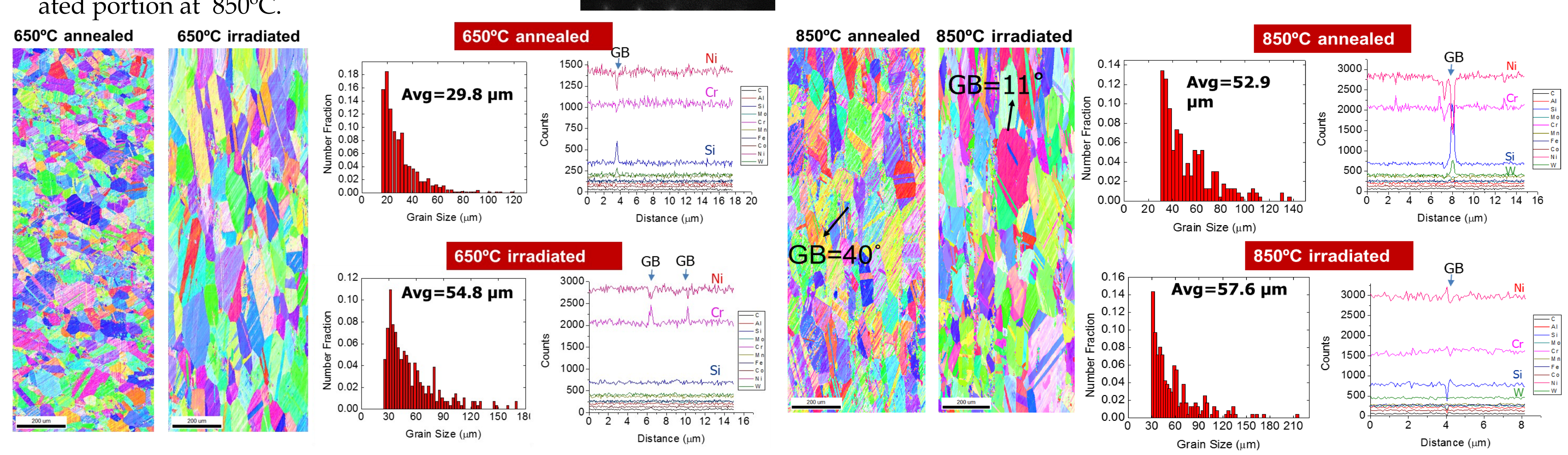


- Haynes 230 was irradiated along Stainless Steel 316L as a reference.
- Haynes 230 at 650ºC shows similar trend as 316L but not at 850ºC.
- Hardening observed in the unirradiated portion at 850ºC.



- In region 1, TEM bright field image and diffraction pattern indicate recrystallization at the surface of the specimen when compared to region 2.
- Region 3 shows new precipitates (presumably MC) formed under irradiation.
- Magnified image of region 3 shows (below) precipitates formed on dislocations





- At 650 ºC irradiated portion has larger grain size than the annealed. At 850 ºC the grain size grows to about 50 μm for both.
- EDX scan across the grain boundary shows segregation of the elements to and away from the GB.

Summary:

- Irradiation resistance of Haynes 230 was investigated at high temperatures using ion irradiations.
- Phase instability was observed after high temperature irradiations.
- Segregation leads to a change in grain boundary chemistry. While at 650°C it is not concern, at 850°C annealed portion shows significant decrease in Cr.
- Significant hardening was observed in the 850°C annealed (unirradiated portion) specimen.
- Grain growth was observed in addition to recrystallization at the specimen surface.

Future Work:

- Microstructure of unirradiated portion needs to be investigated in detail.
- Investigate recrystallization at the surface.
- Detailed characterization of precipitates forming.
- Systematic investigation of GB segregation .
- For high dose, investigation into Ni irradiation of Haynes 230 at 650 ºC and 850 ºC up 40 dpa.

Acknowledgments:

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References:

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[3] Rolled Alloys, Inc https://www.rolledalloys.com/alloys/nickel-alloys/230/en/

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