Post Irradiation Examination of an Alloy 718 Beam Window

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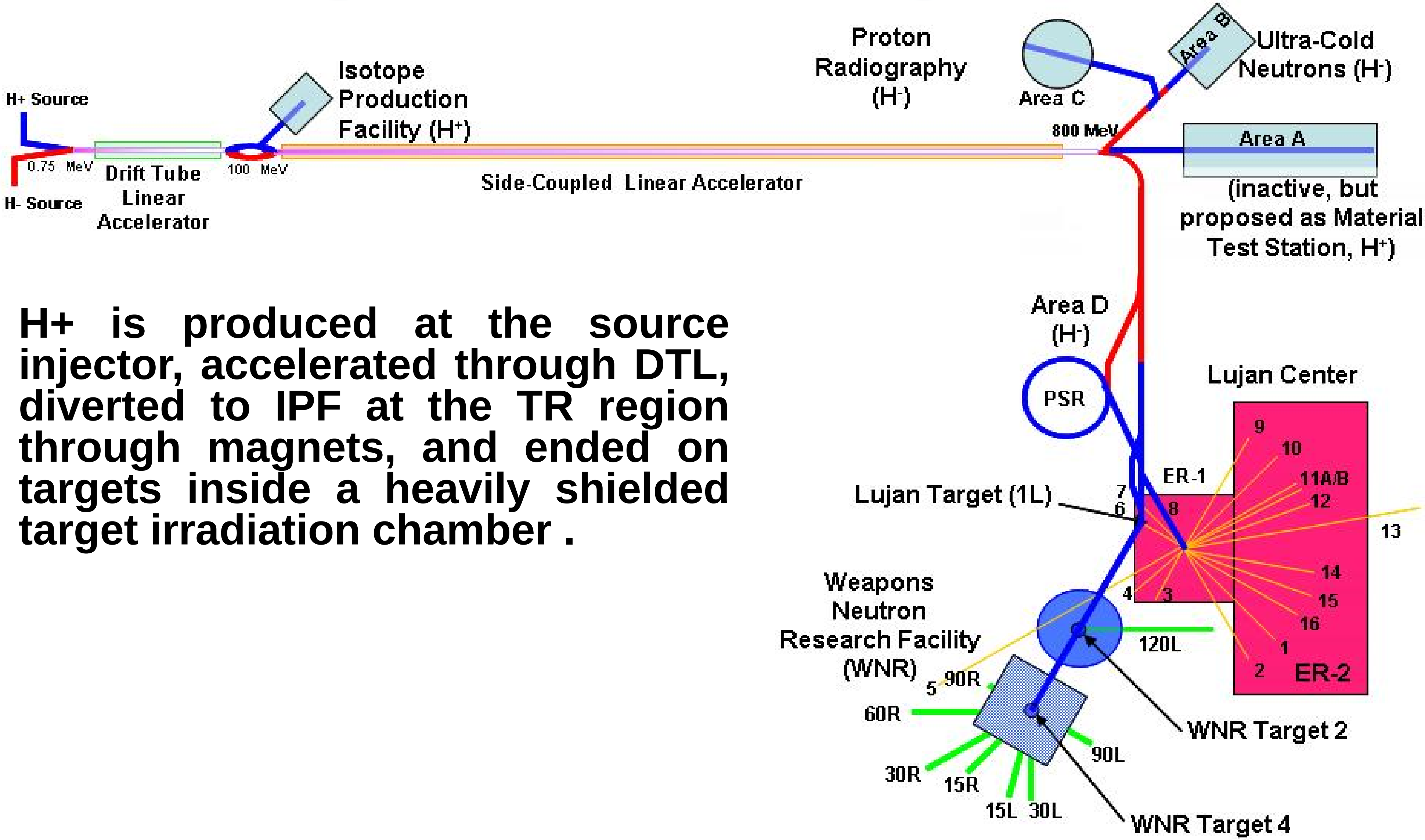
Outline

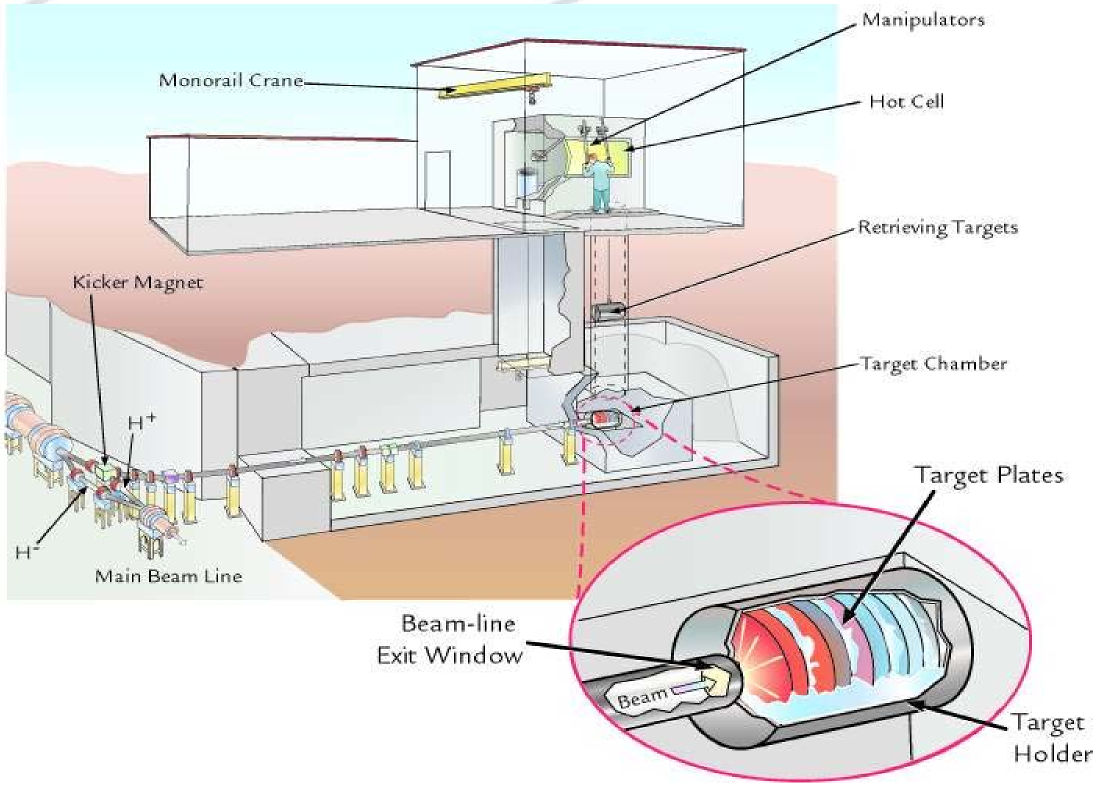
- Isotope Production Facility
- Cutting of Window and Dimensional Measurements
- Calculation of Dose and Irradiation Temperature
- Shear Punch Testing
  - Trepanning of Specimens
  - Dose/Irradiation Temperature vs. Location
  - Shear Punch Testing and Data
- TEM Analysis
- Comparison to previous test results
- Summary

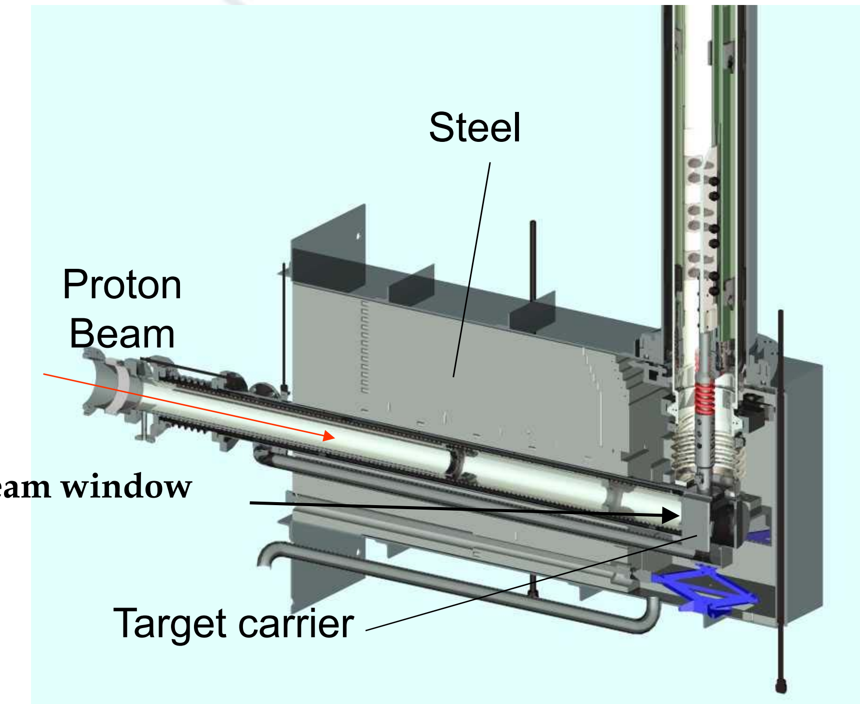
Isotope Production Facility - LANSCE



H+ is produced at the source injector, accelerated through DTL, diverted to IPF at the TR region through magnets, and ended on targets inside a heavily shielded target irradiation chamber .

Isotope Production Facility and Beam Window

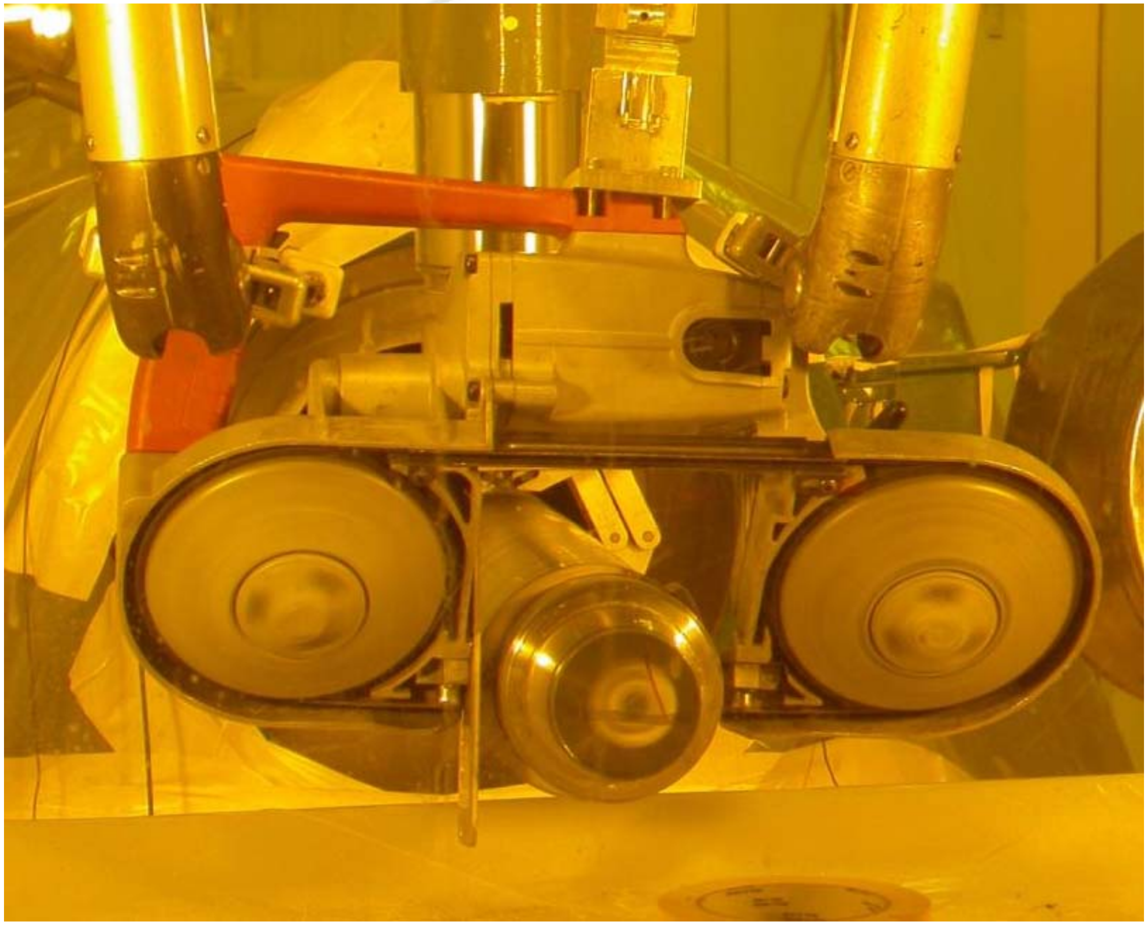




The proton beam is delivered via a vacuum beam pipe. Inconel 718 beam window isolates the beam pipe (under vacuum) and the target irradiation chamber (15 psig of cooling water).

Present design limit for window is 5 years and would like to increase that limit through analyzing properties after 5 years of operation.

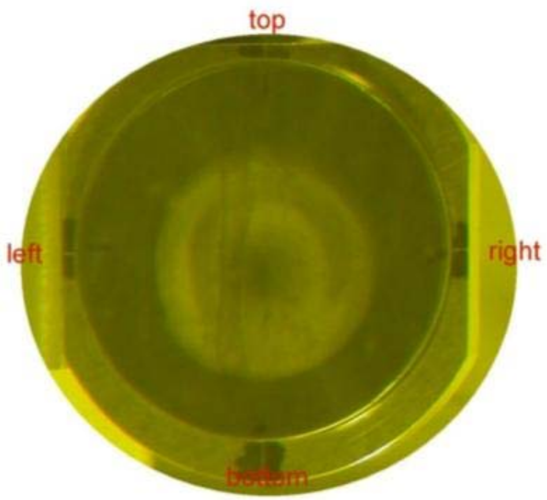
Cutting off the Window

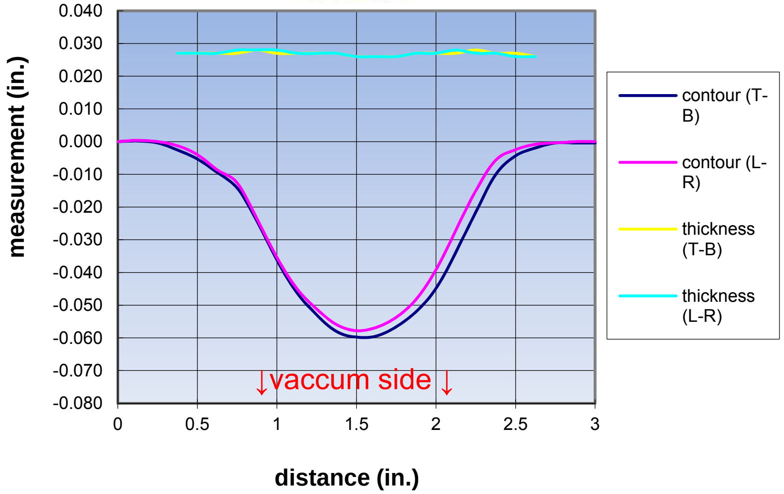


Window was cut from beam tube remotely in the corridor of the CMR Wing 9 hot cells

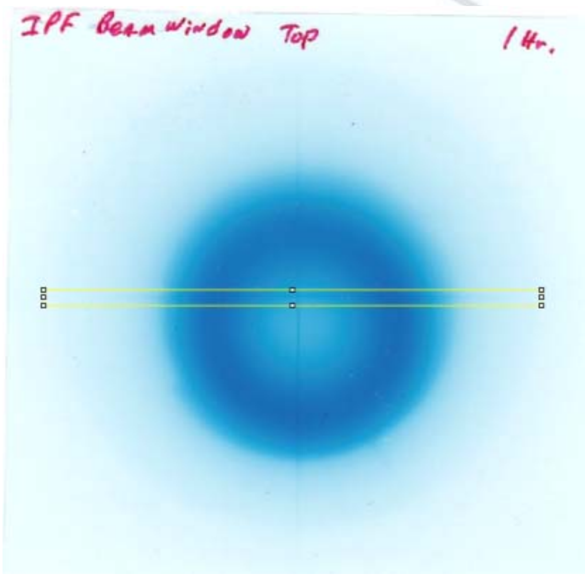
Then, the window was placed into an individual hot cell for analysis and sample preparation.

Dimensional and Dose Measurements on Window

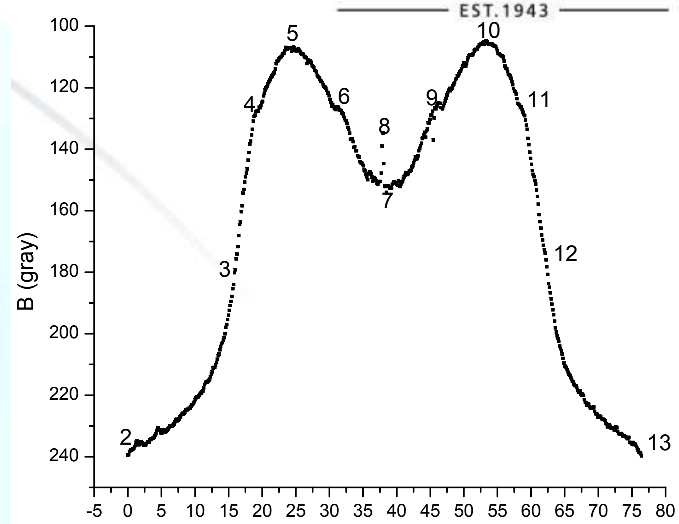


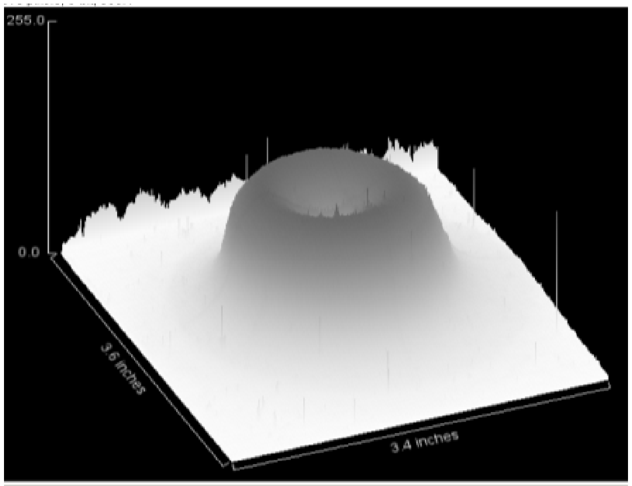


Beam window deformed 1.5mm into the vacuum side.



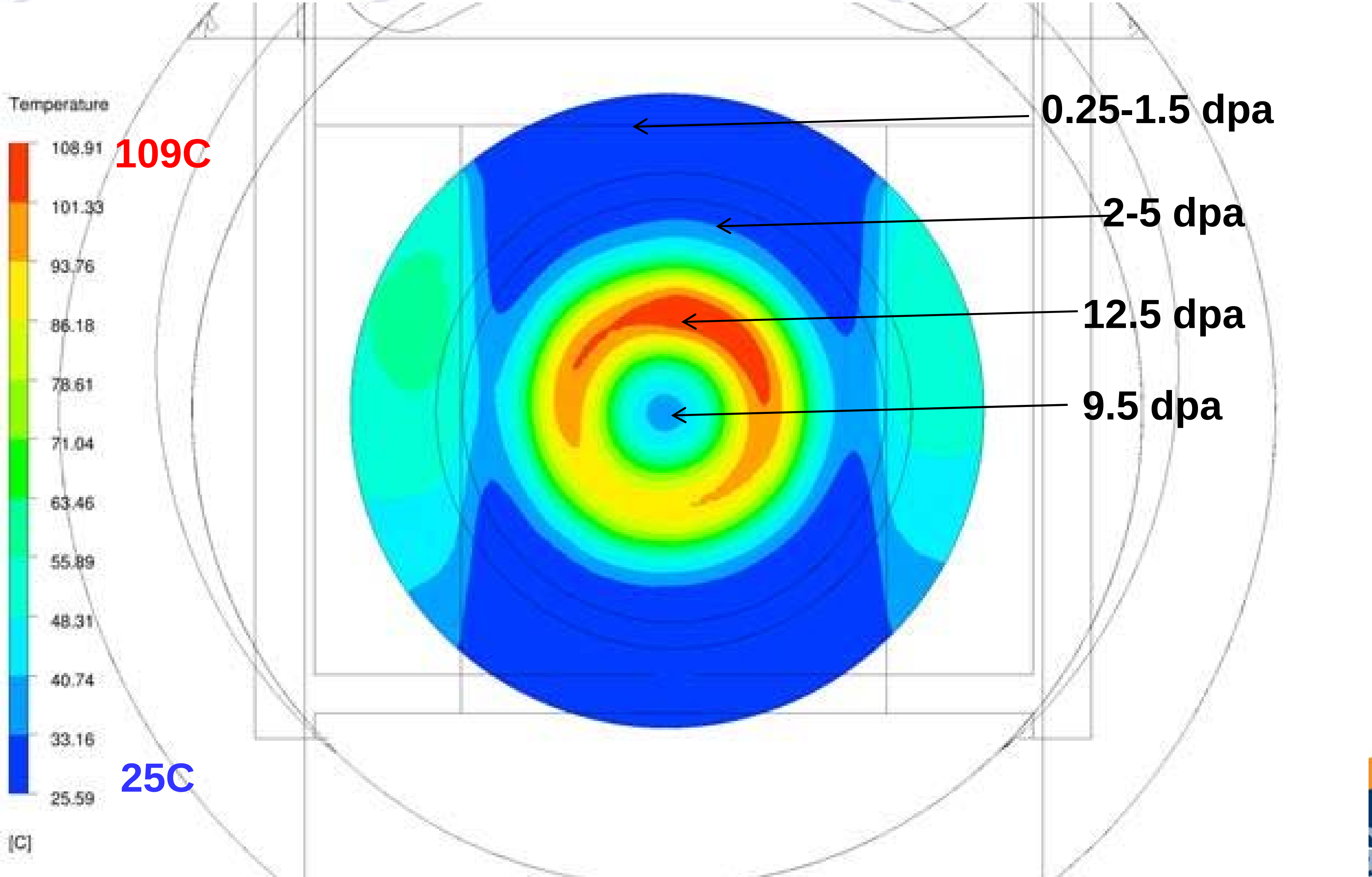
GAFCHROMIC HD-810 dosimetry film was used to measure the absorbed dose of high energy photons from the activated beam window.



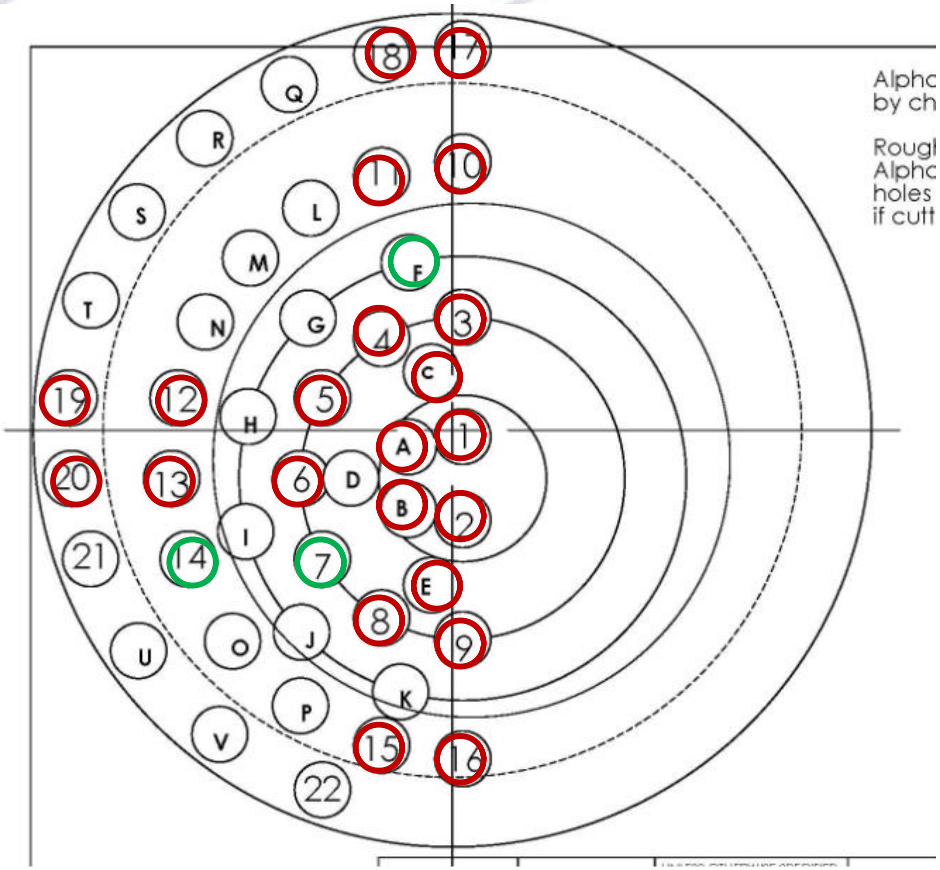


Rastered beam profile shows a Gaussian distribution and the highest dose region corresponds to the darkest blue region on the Gafchromic film.

Temperature and Dose Map



Cutting and Shear Punch Testing Plan



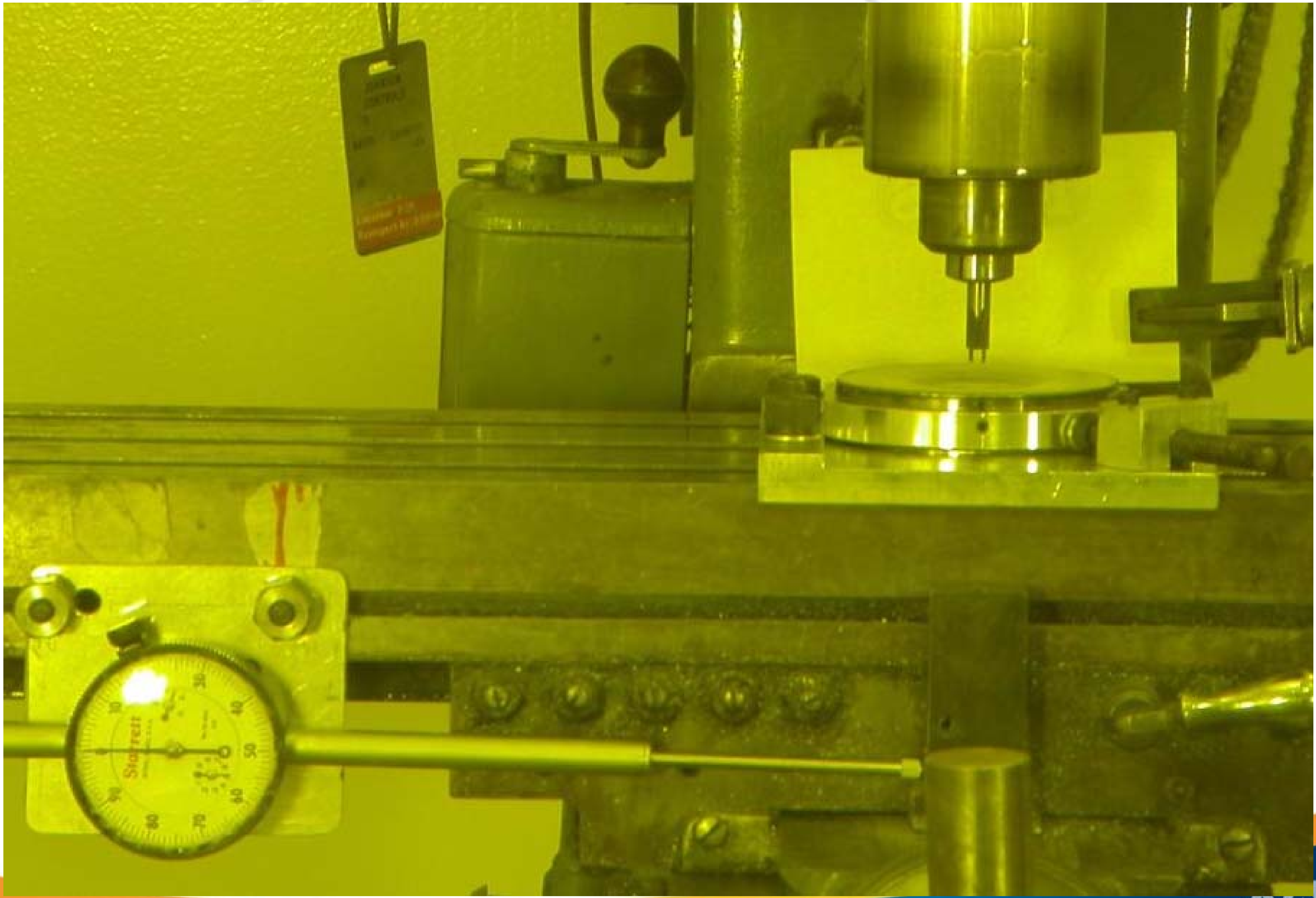
Samples Tested

Samples Cut but Untested

Black Circles were not cut

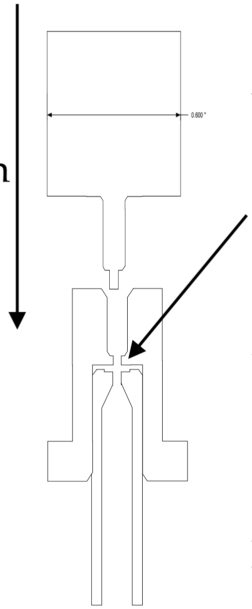
- Beam profile was superimposed on the window to determine the cutting plan as a function of radiation dose (dpa).
- 3-mm OD samples were cut with a Mill machine. A total of 3 cutting bits were spent to cut out 20 numerical samples (1-20) and 5 alphabetical samples (A, B, C, E, and F).
- Cut-out samples were polished and thinned from on both sides to 0.254 mm thickness.
- The shear punch testing for the following samples were completed as a function of radiation dose (dpa):
  - 2 controls samples of unirradiated Inconel 718
  - 1-6, 8, 9, 10-13, 15-16, 17-18, 19-20, A-C, and E

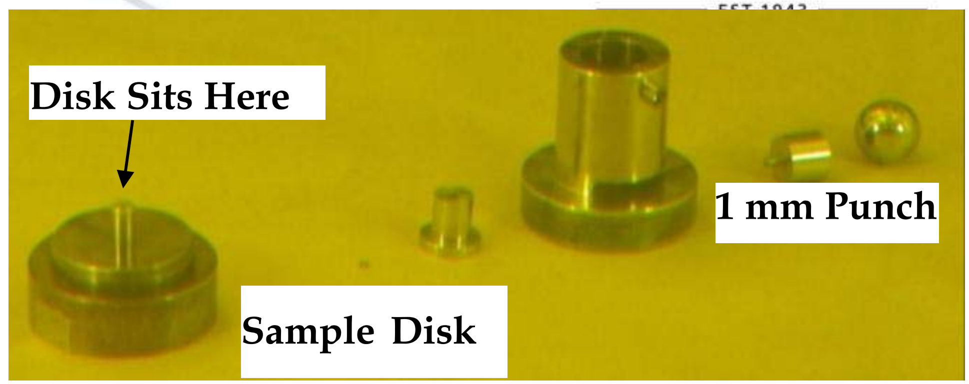
Trepanning 3 mm Diameter Samples from Window



Shear Punch Testing Equipment at CMR Hot Cell

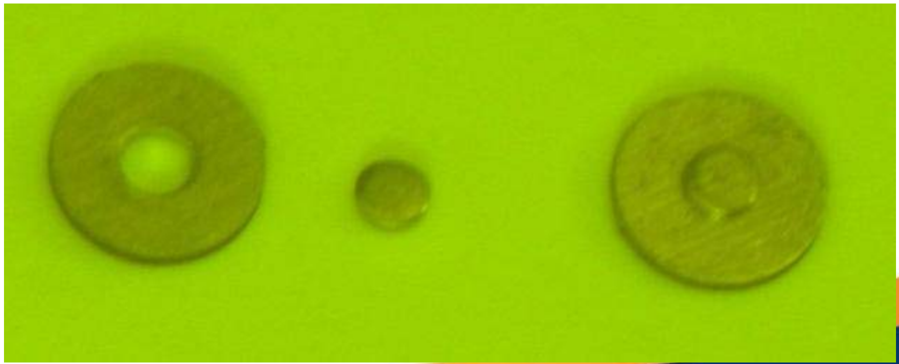
Shear Punch Set-up





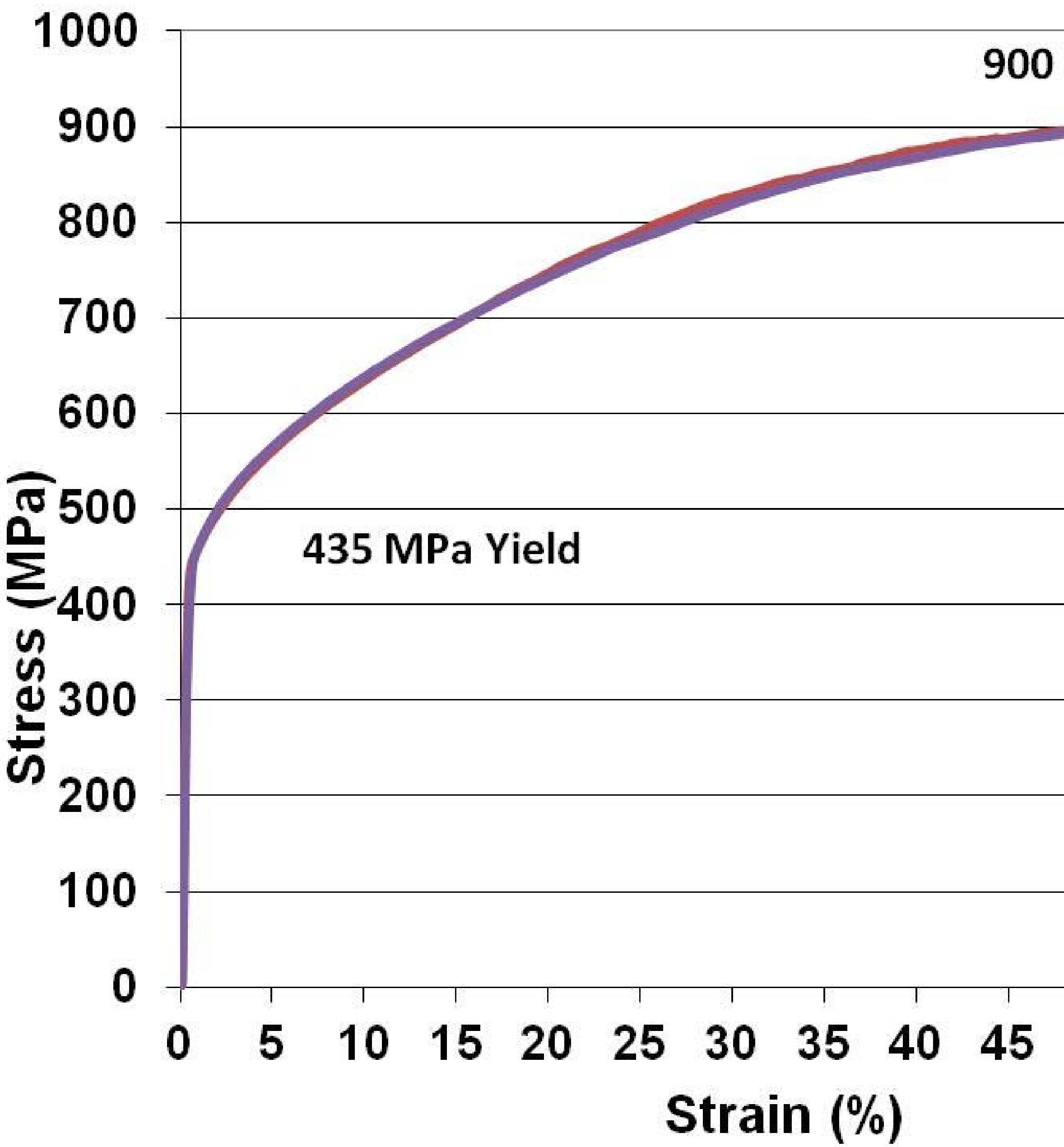
- Performed 25 shear punch tests on 3 mm diameter specimens.
- Tested at initial strain rate of 5 x 10-4/s.
- Tested at in ultra high purity argon.

Loading sequence



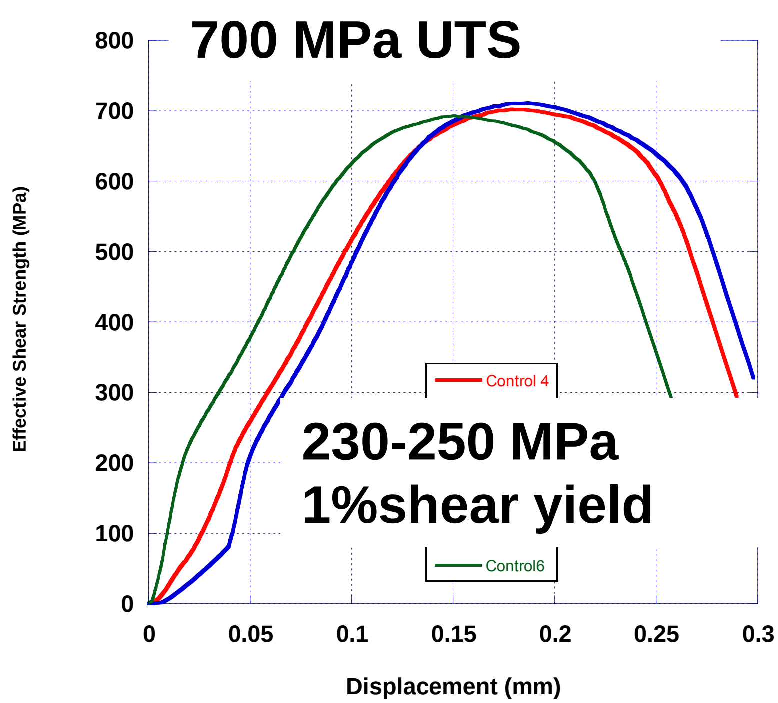
Typical shear punch specimen

Control Material Tensile Tests vs Shear Punch

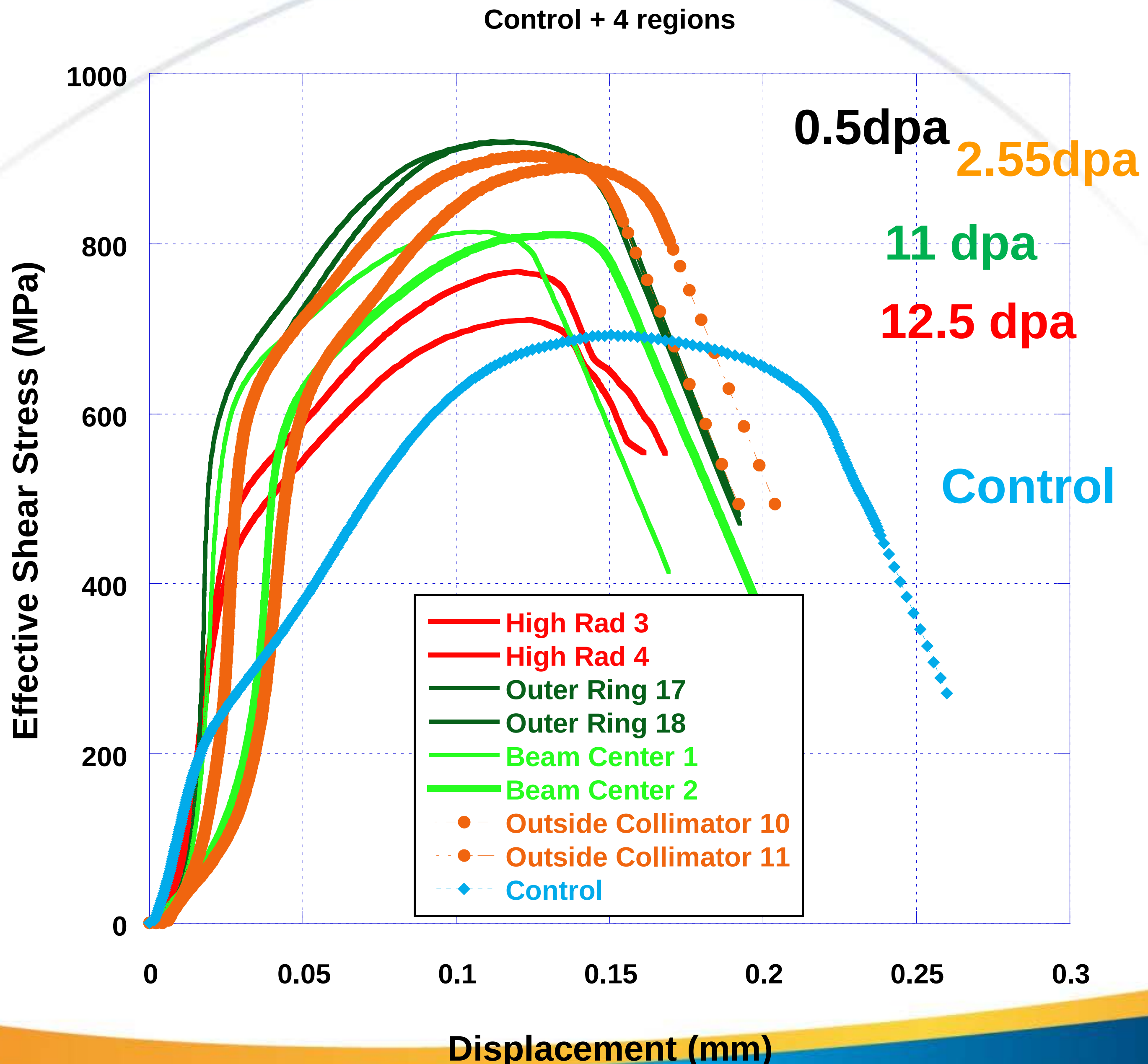


- UTS correlation - 1.28
- Yield Correlation- 1.77
- Lit values 1.4, 1.73

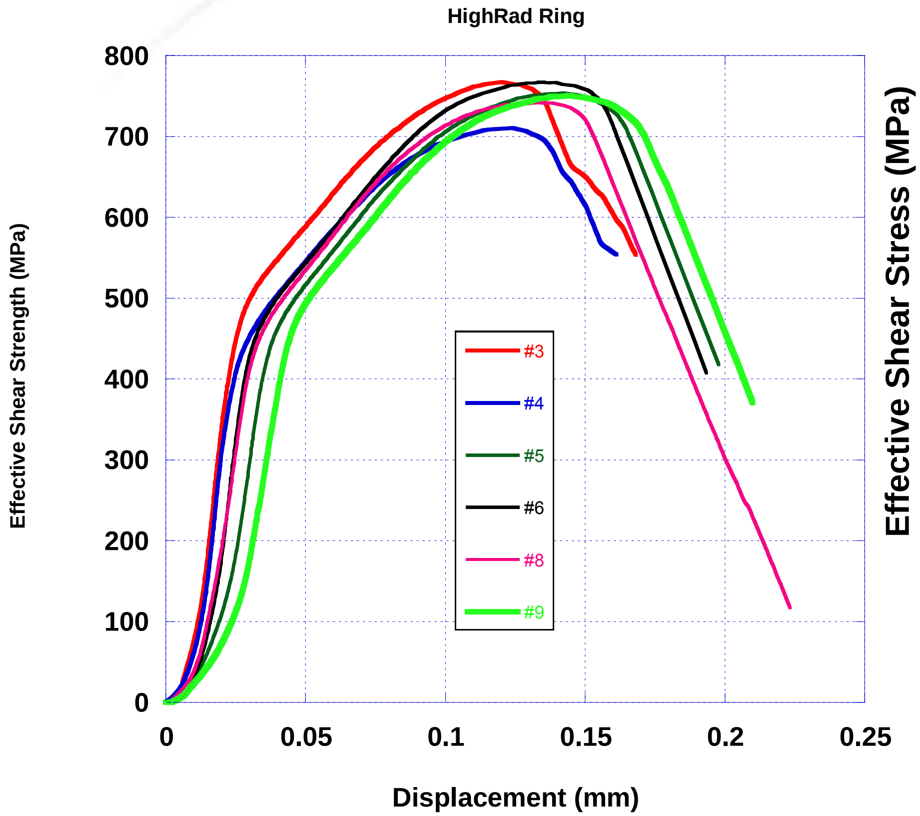
Toloczko&Kurtz

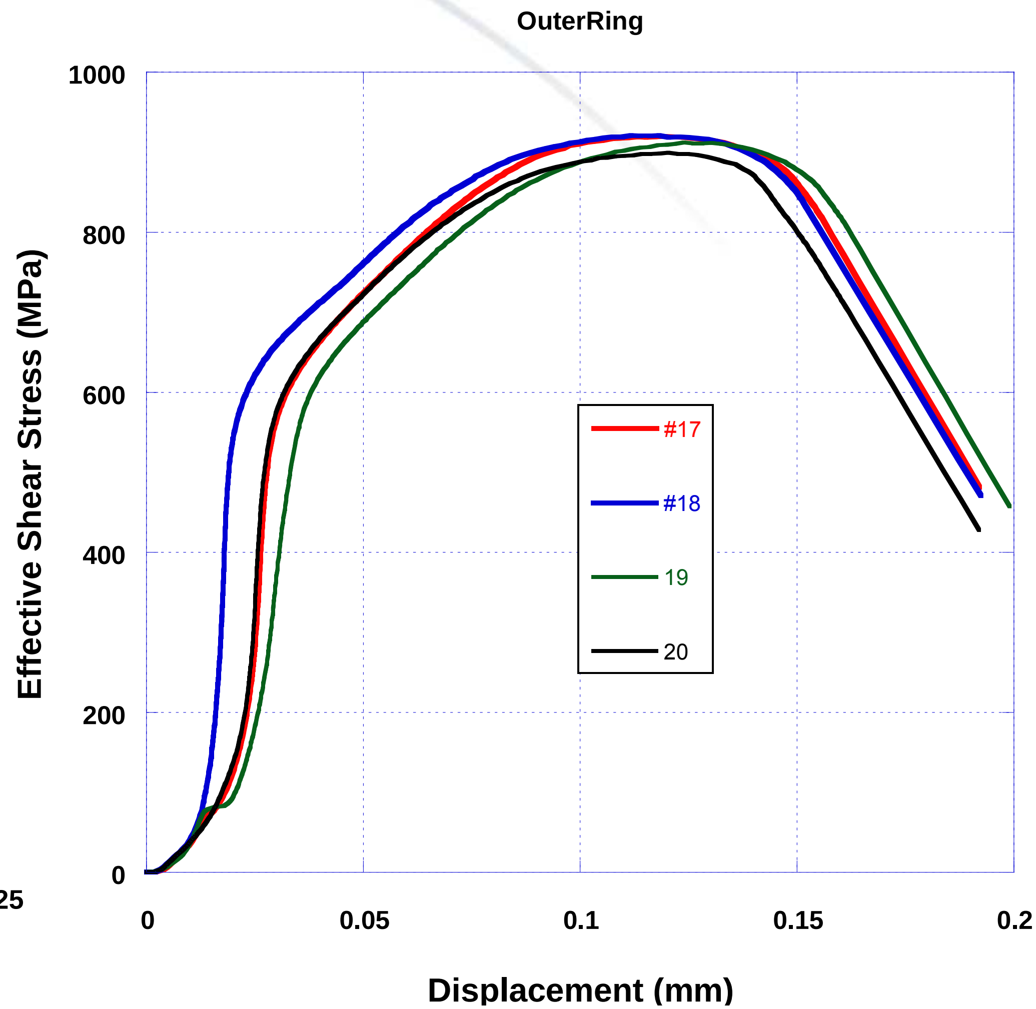


Shear Punch, Outer to Inner



Comparison of Shear Stress/displacement Curves





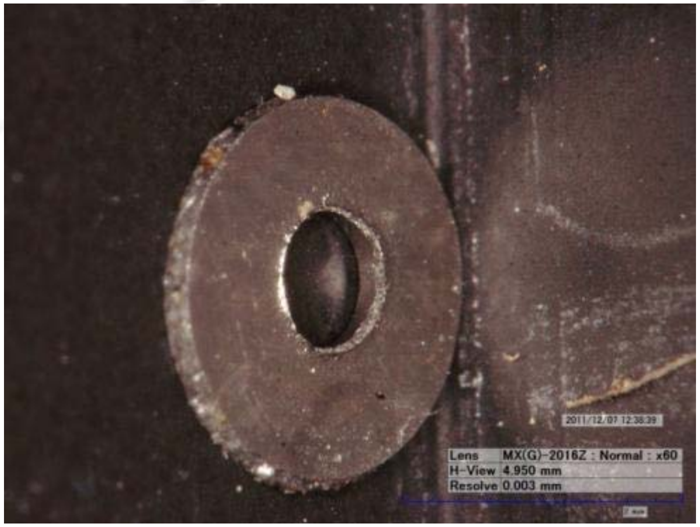
Dose = 12.5 dpa

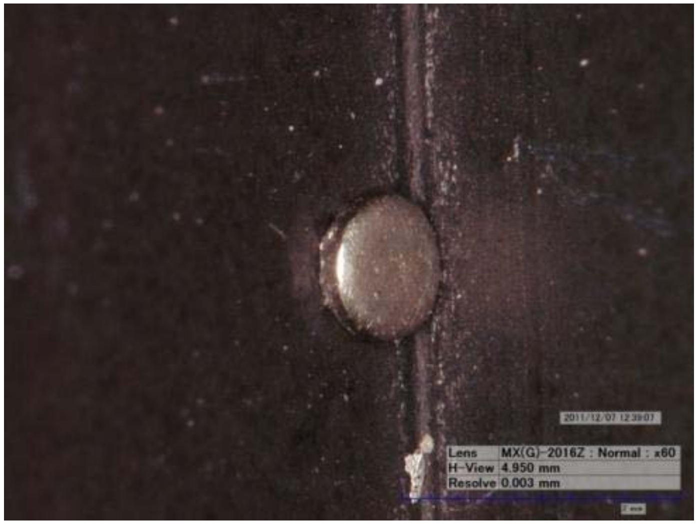
Tirr= 109C

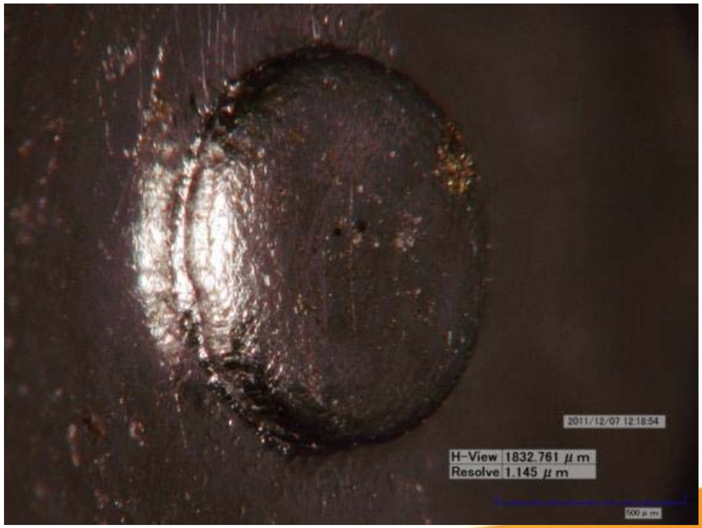
Dose = 0.5 dpa

Tirr=50C

Optical Images of Exit side of Shear Punch Specimens



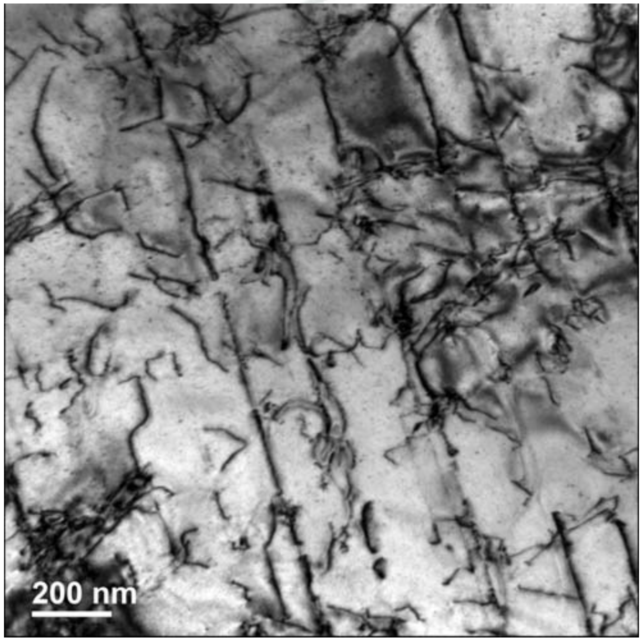


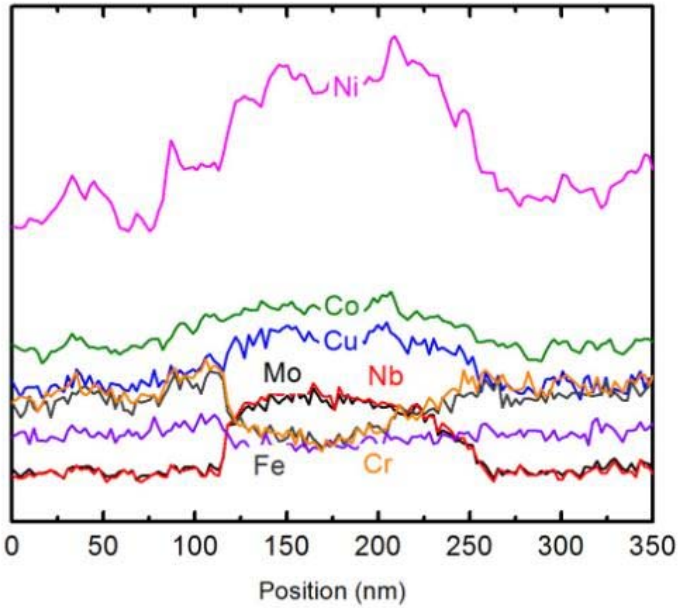


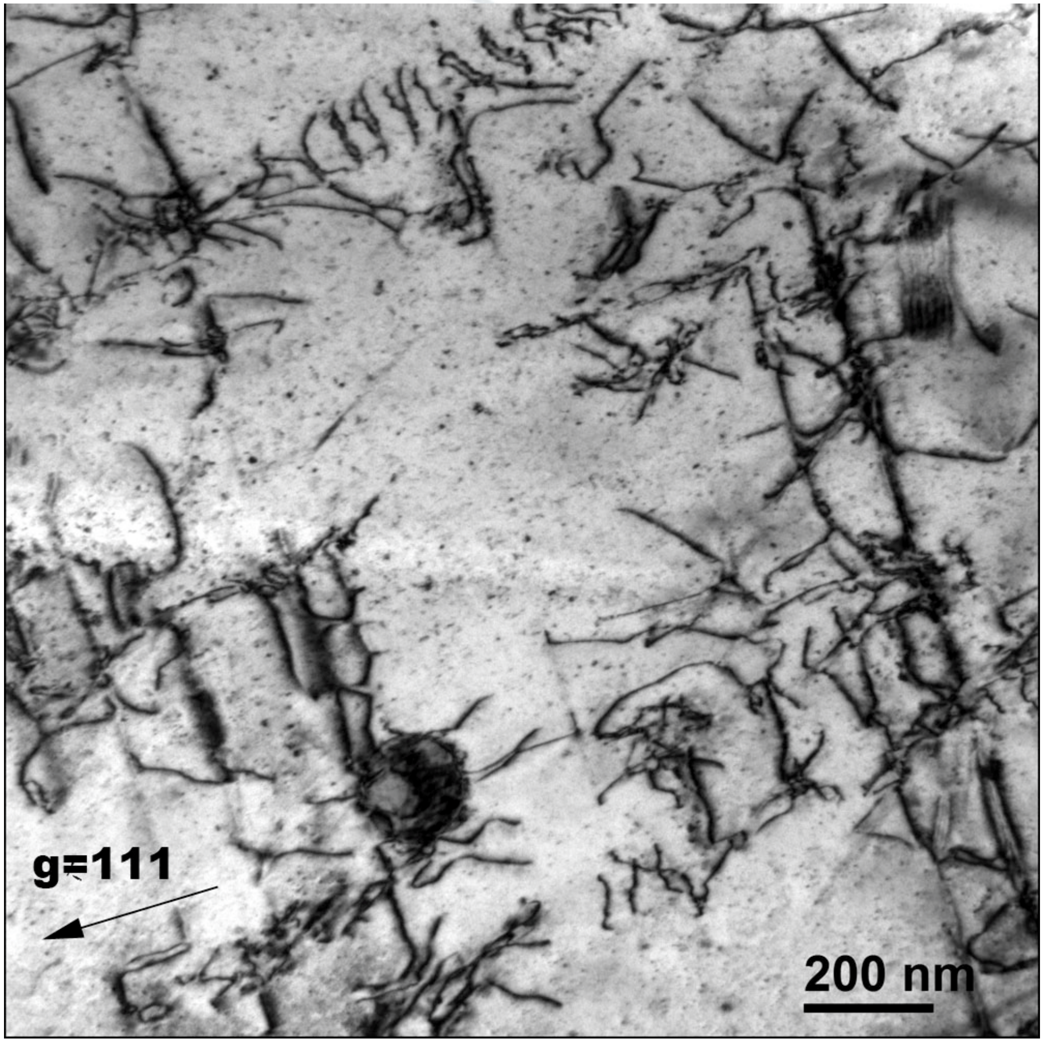
Control Material

Dose = 12.5 dpa

Inconel 718 Solution Annealed-unirradiated

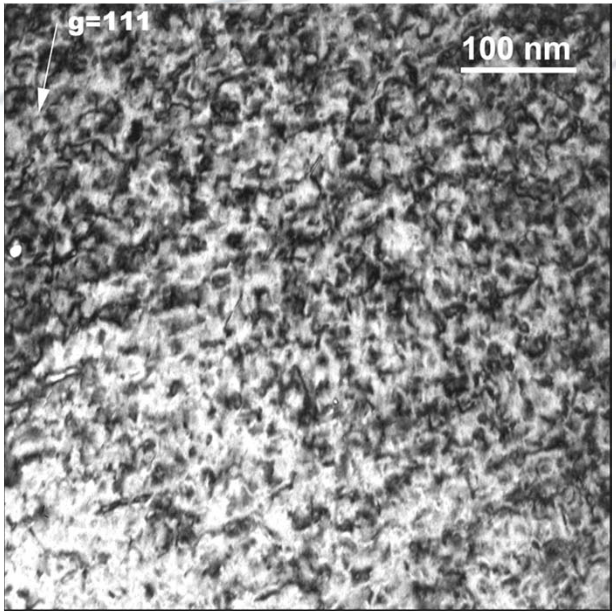


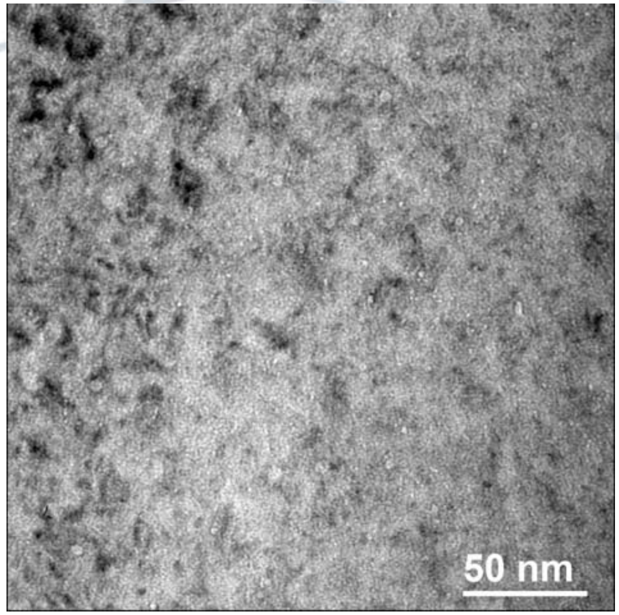


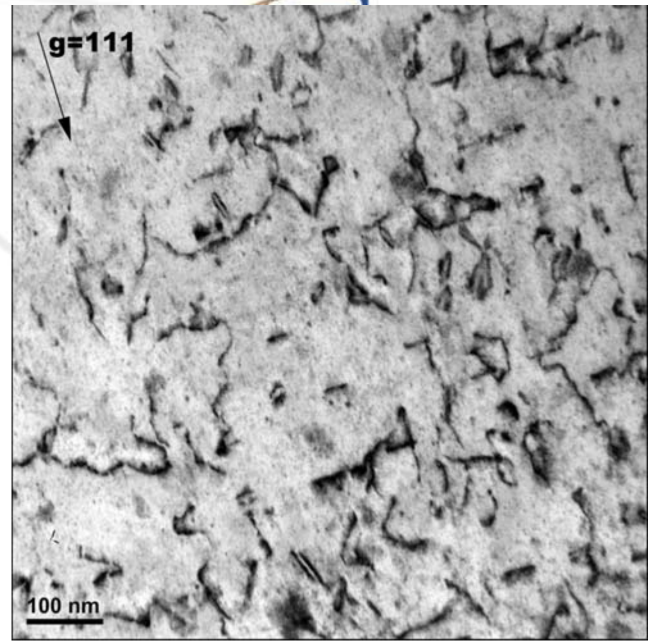


- Bright field TEM images showing dislocations and some precipitates

TEM Analysis of Irradiated Alloy 718 Samples

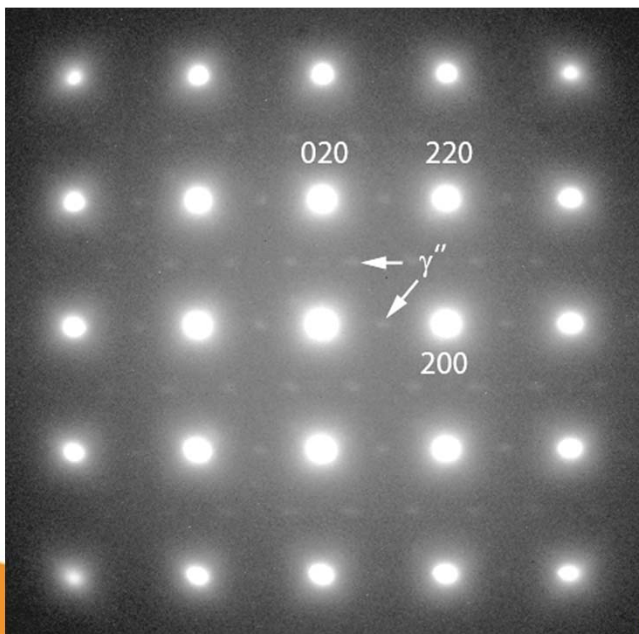


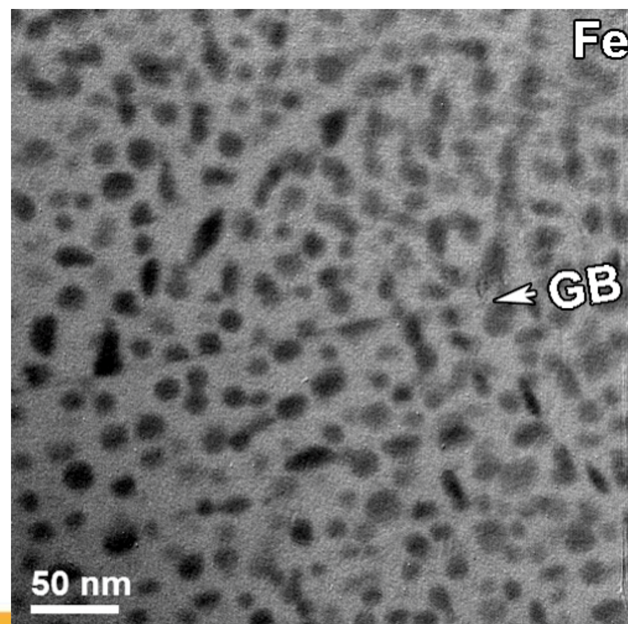


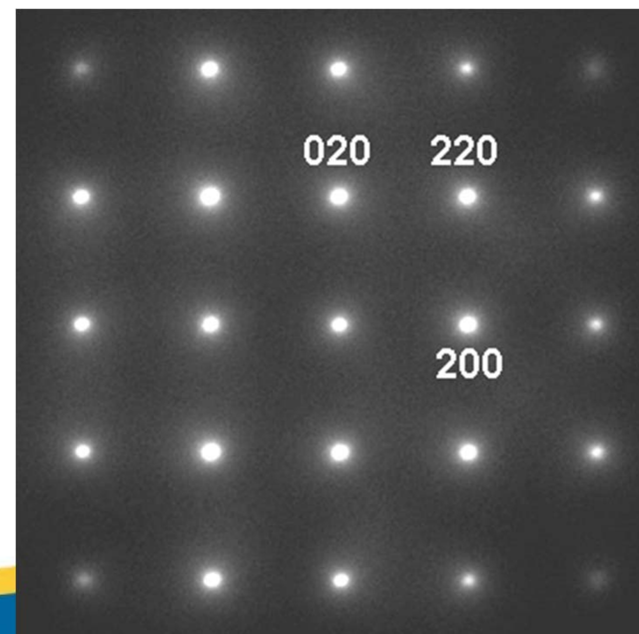


0.5 dpa at 50°C

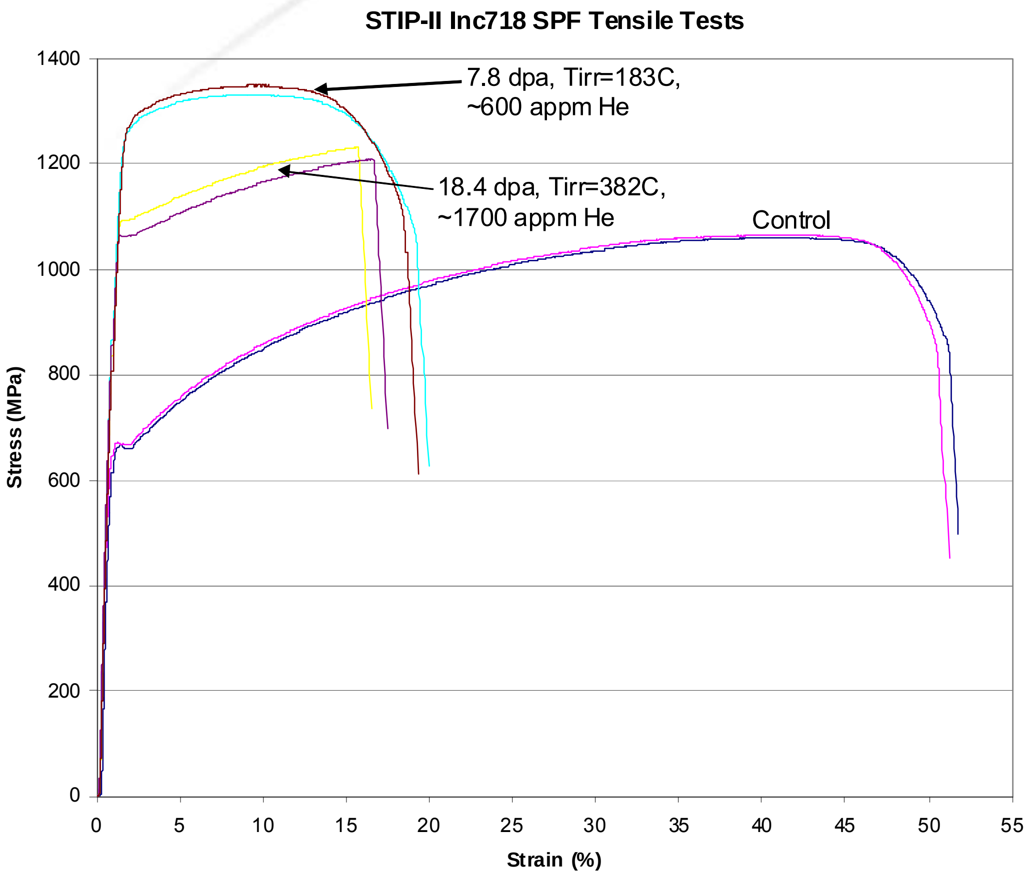
12.5 dpa at 109°C

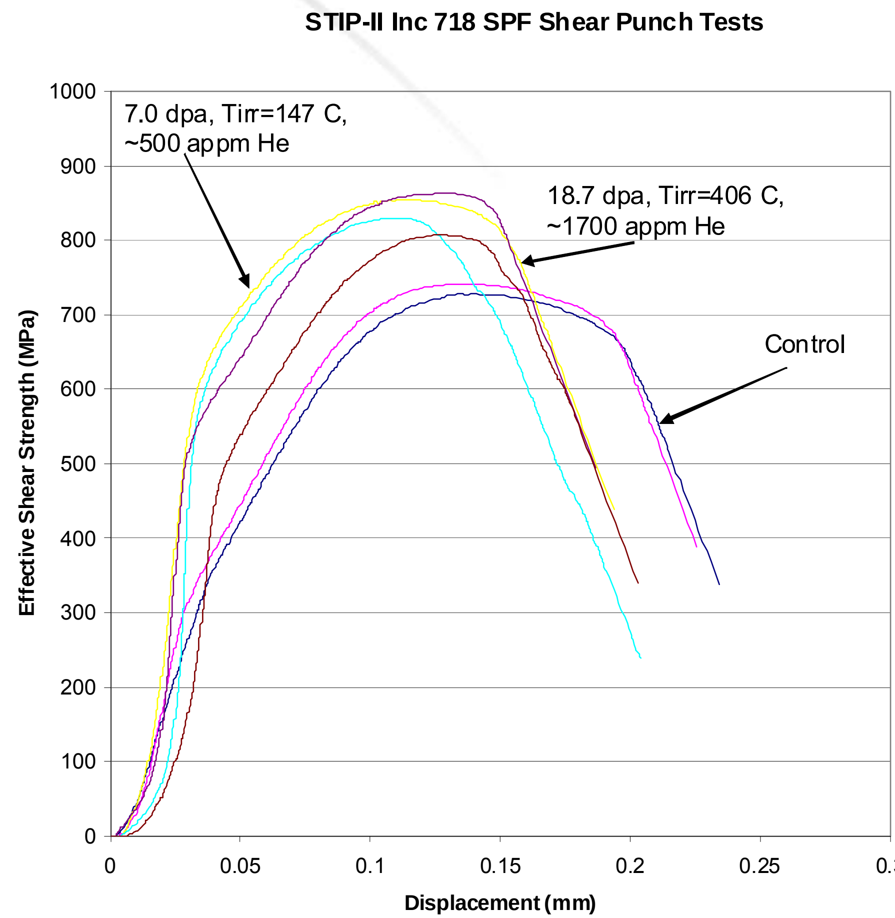






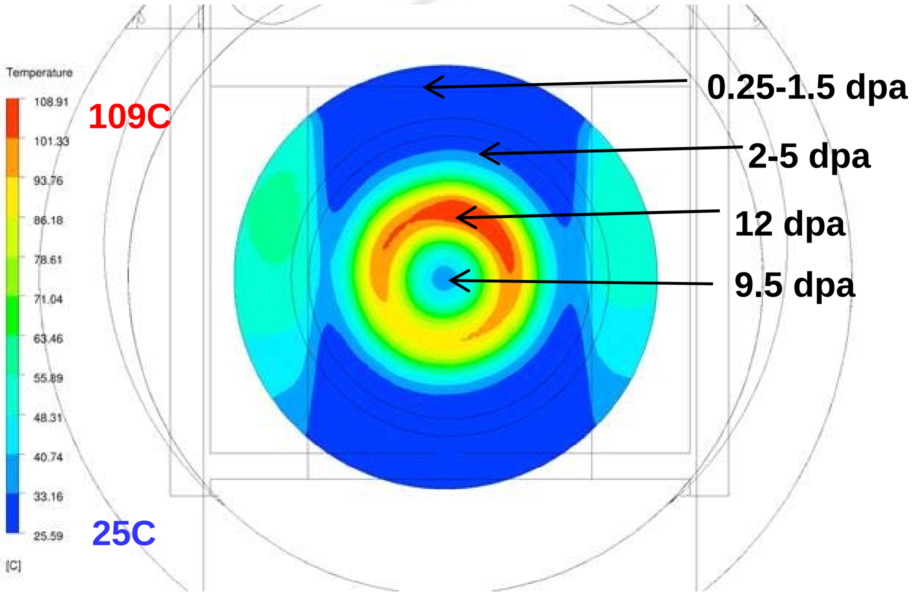
Previous Results on Proton Irradiated Annealed 718 SPF

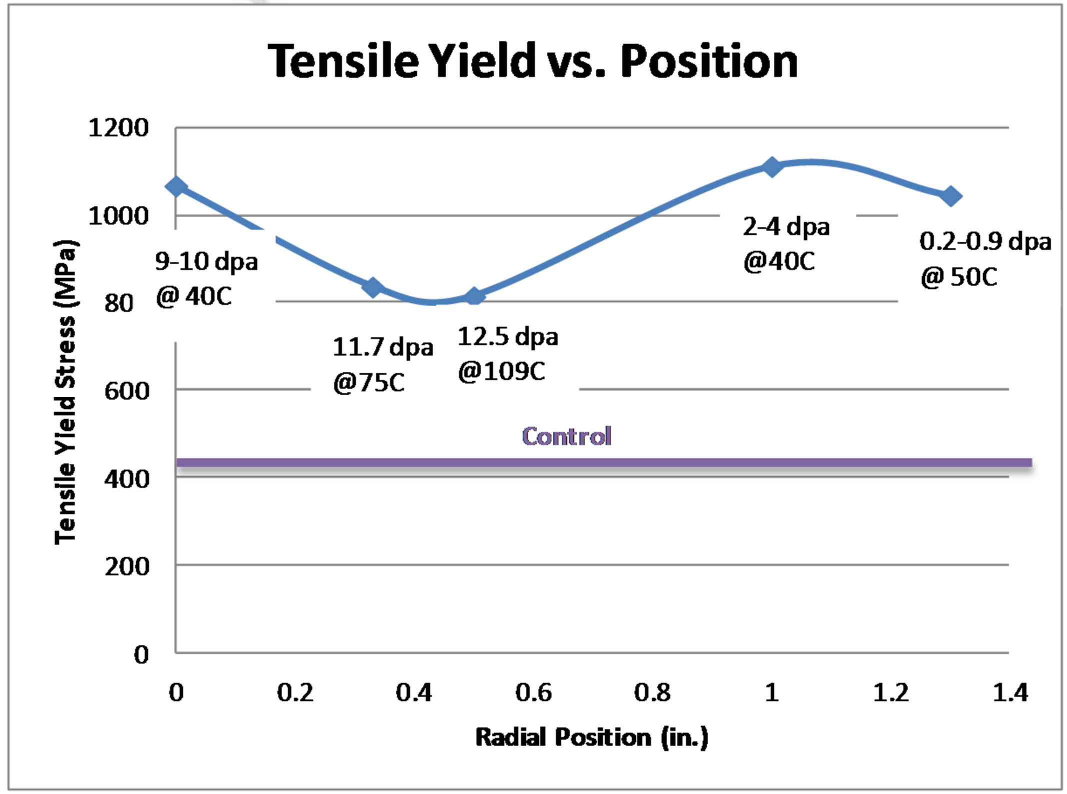




- Inconel 718 SPF samples irradiated in STIP-II
- Samples show good retention of ductility even with much higher helium levels

Summary of Tensile Results



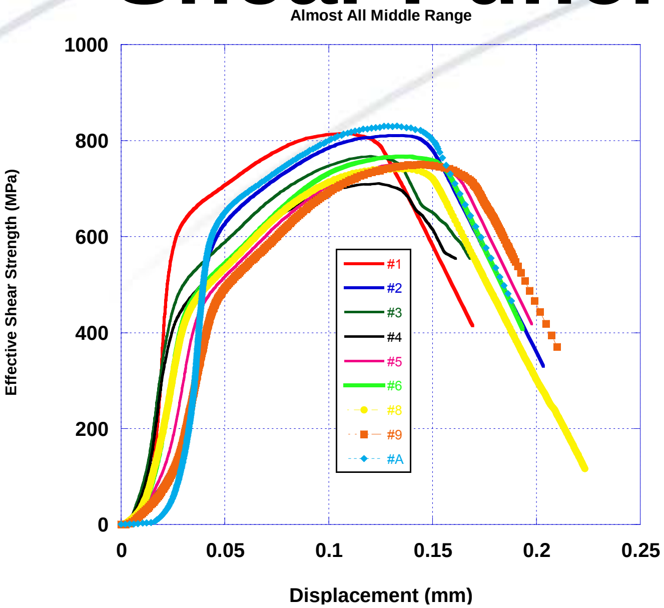


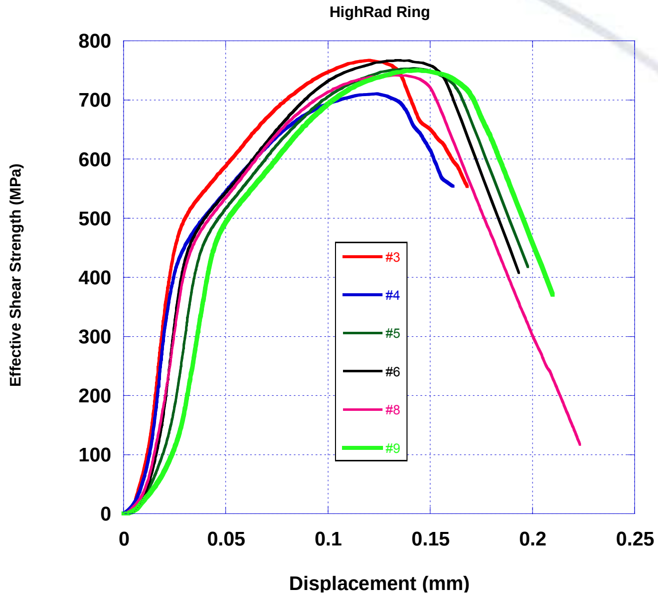
- All samples display ductility in both yield vs UTS and optically.
- Samples taken in outer ring and outside collimator have a higher yield and UTS than control or high radiation dose samples.
- Increased hardening appears to be a combination of increased defect density, bubble density and second phase precipitation
- From these results we are confident to push lifetime out to ~17 dpa
- Further analysis required to understand bubble formation in low dose samples.

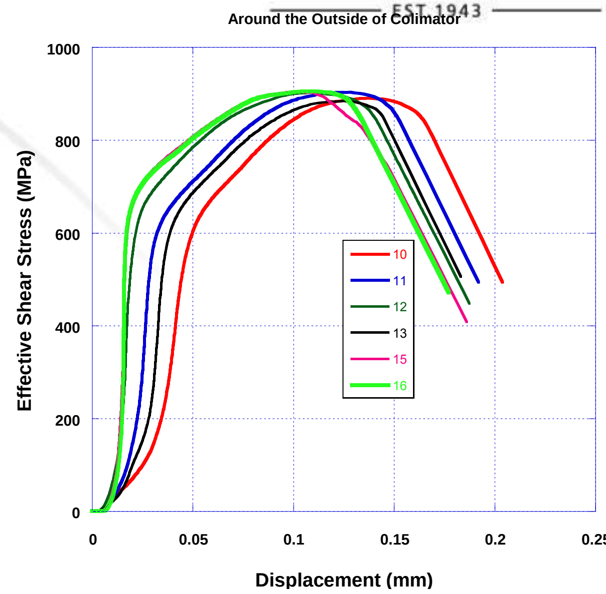
Comparison to previous tensile results

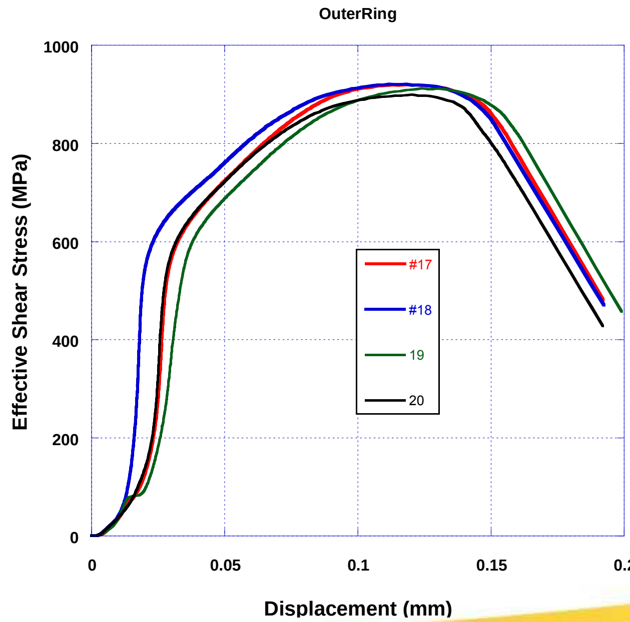
- Farrell et al. (03) shows increase from 350 MPa to 900 MPa for irradiation at 50-100C for a dose of 1.2 dpa
- STIP-II shows increase from 600 to 1200 MPa at 183C and 600 to 1100 MPa at 382C to doses of 7.8 and 18 dpa respectively
- IPF data shows increase from 450 to 1100 MPa at 9 dpa and 850 MPa at 11-12 dpa. Also an increase to 1100 MPa is observed at 2-4 dpa.

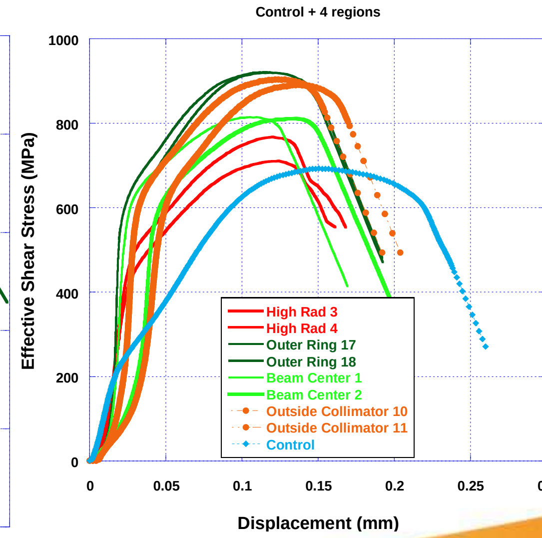
Shear Punch Results

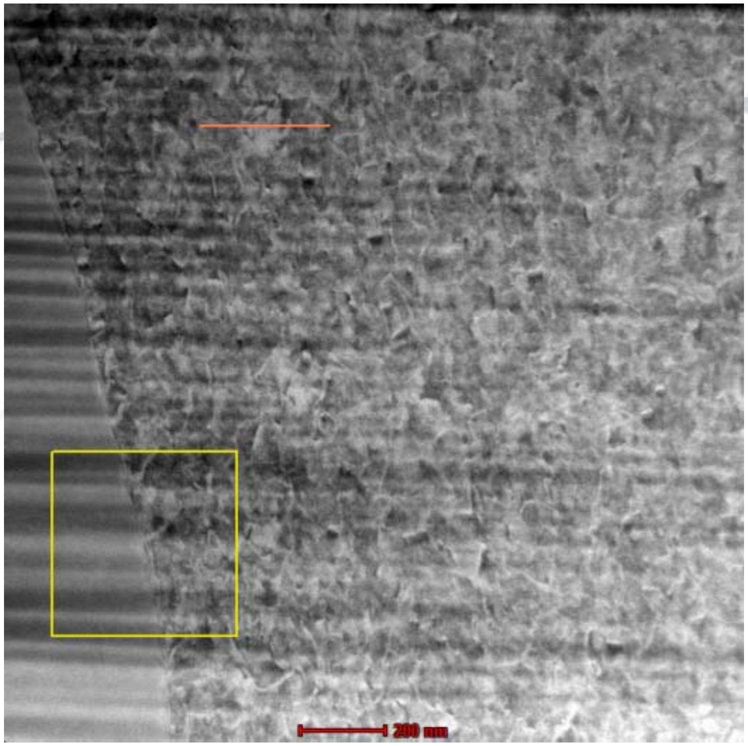


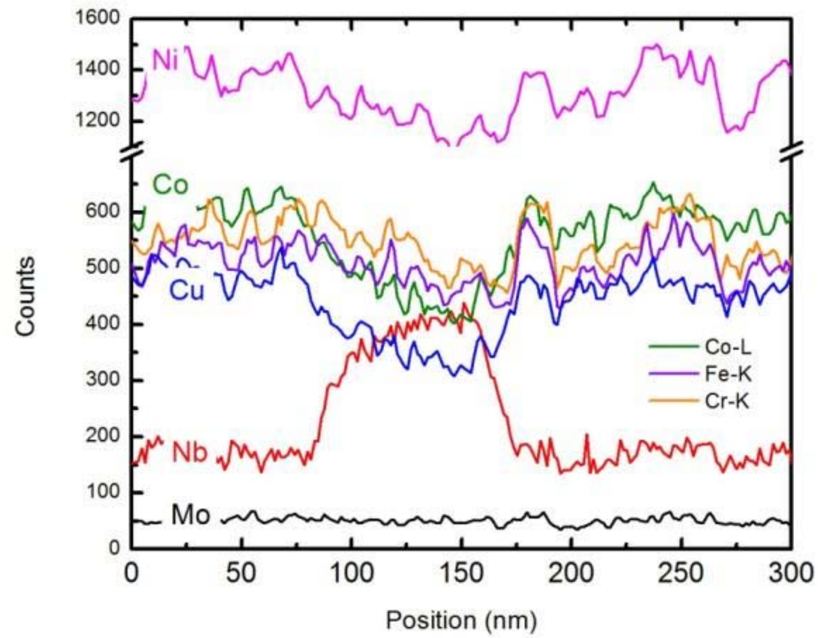


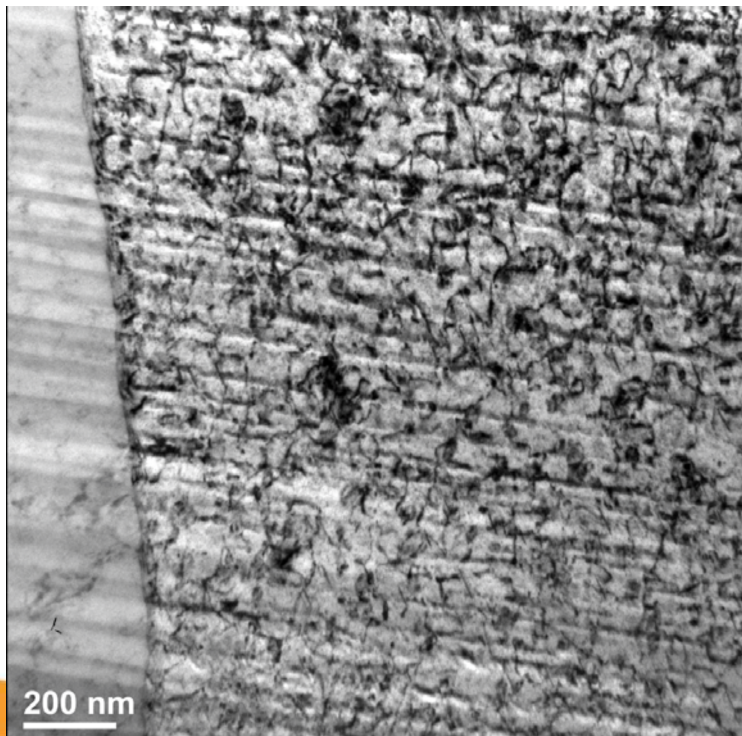


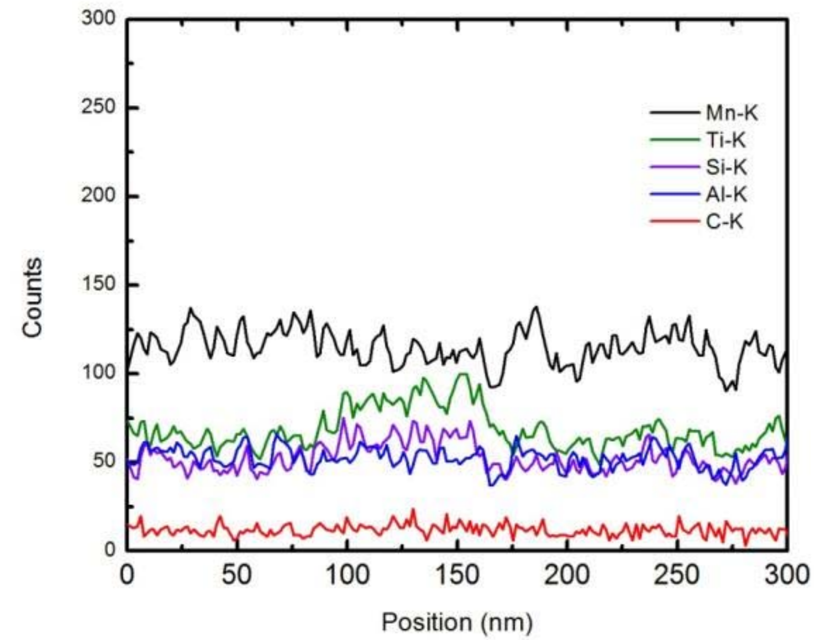






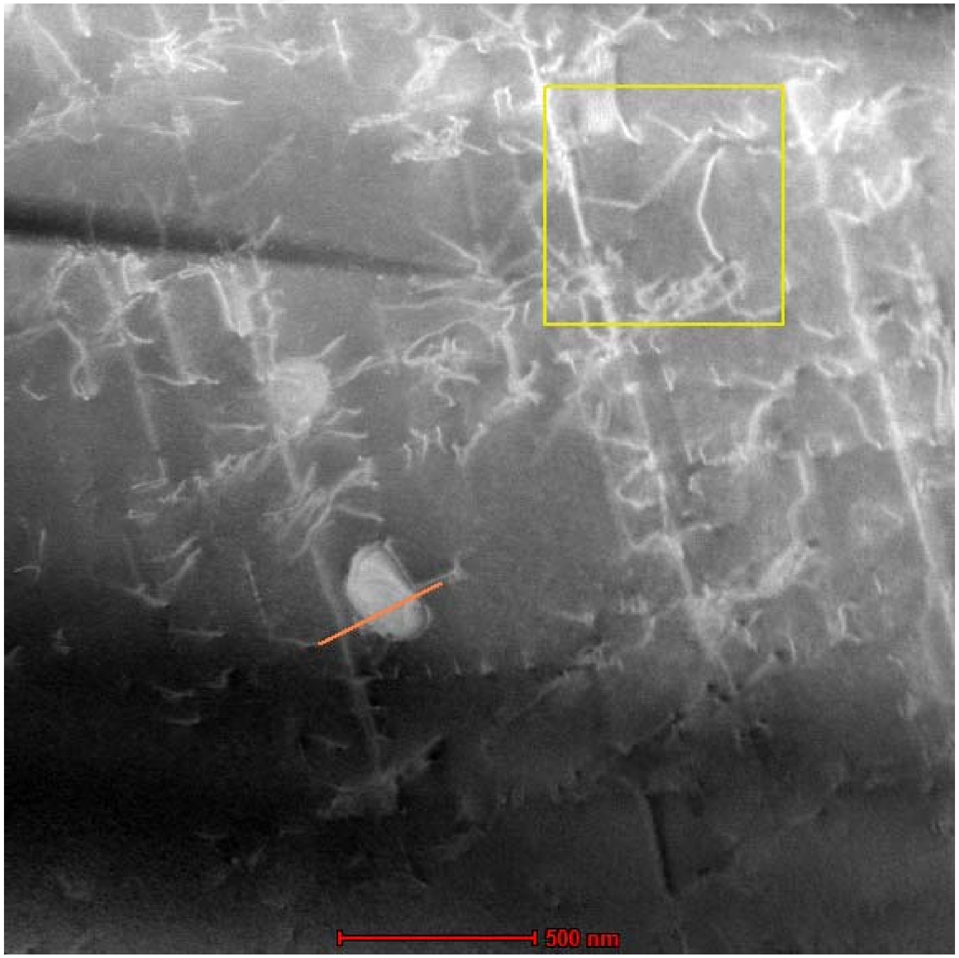


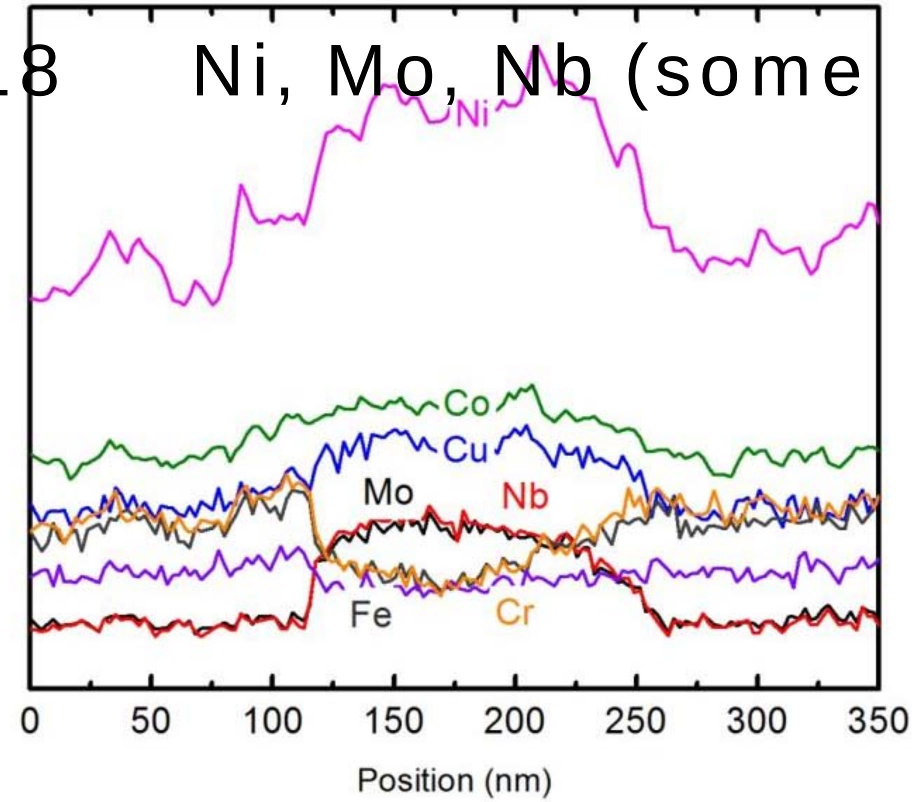


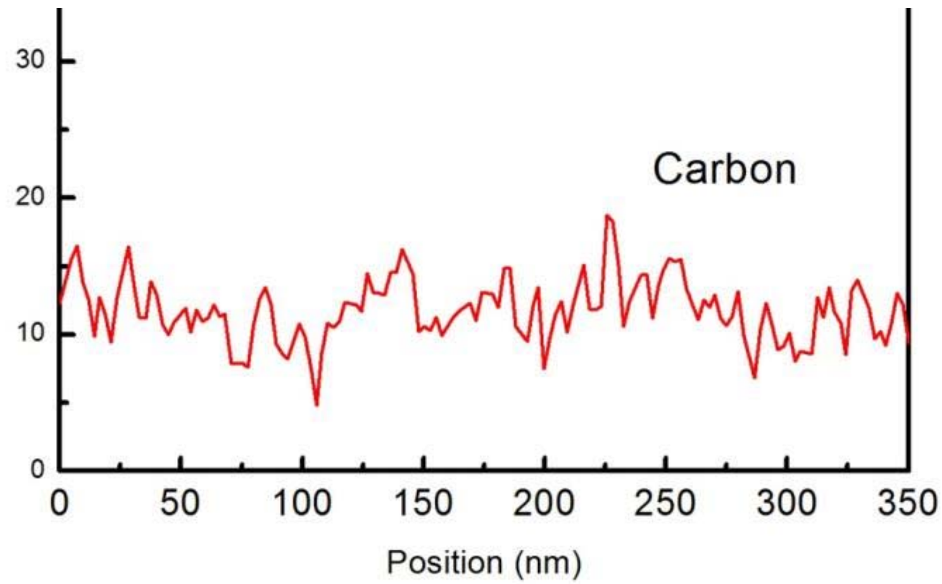


- **Dark and bright field TEM images showing smaller precipitates and dislocations.**

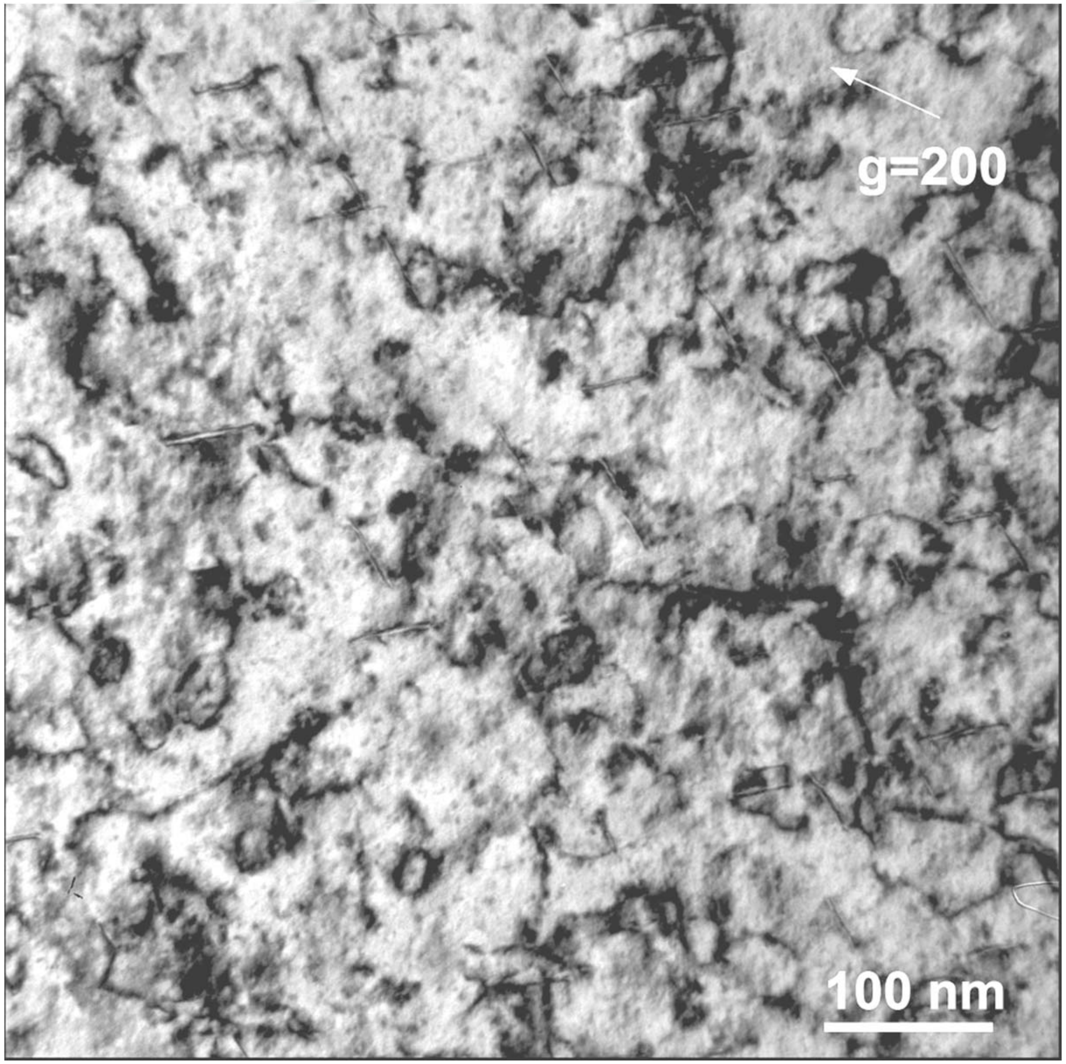
Unirradiated Inconel 718 Ni, Mo, Nb (some Co, Cu) rich precipitate







Inconel 718 #5 ~14 dpa @109°C



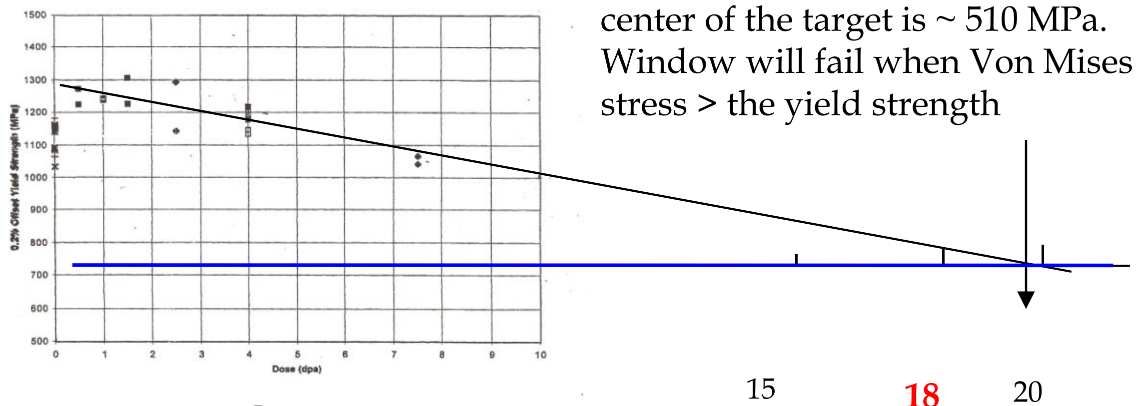
Irradiation Damage and Replacement

Los Alamos NATIONAL LABORATORY EST.1943

- Beam transmission through the window incurs heating causing thermal stress.
- Beam irradiates the window causing mechanical properties to change.
- Beam window design criteria is 20 dpa (displacement per atom). Beam window reached the end of its life.
- Estimate dose rate is 100 R/hr at contact without shielding and highly contaminated.
- We replaced window in March 2010, stored at Area A and shipped to CMR in November 2010.

Calculated Von Mises stress under pressure and thermal load at the center of the target is ~ 510 MPa. Window will fail when Von Mises stress > the yield strength

718 Yield



Fi **Dose, dpa** mix

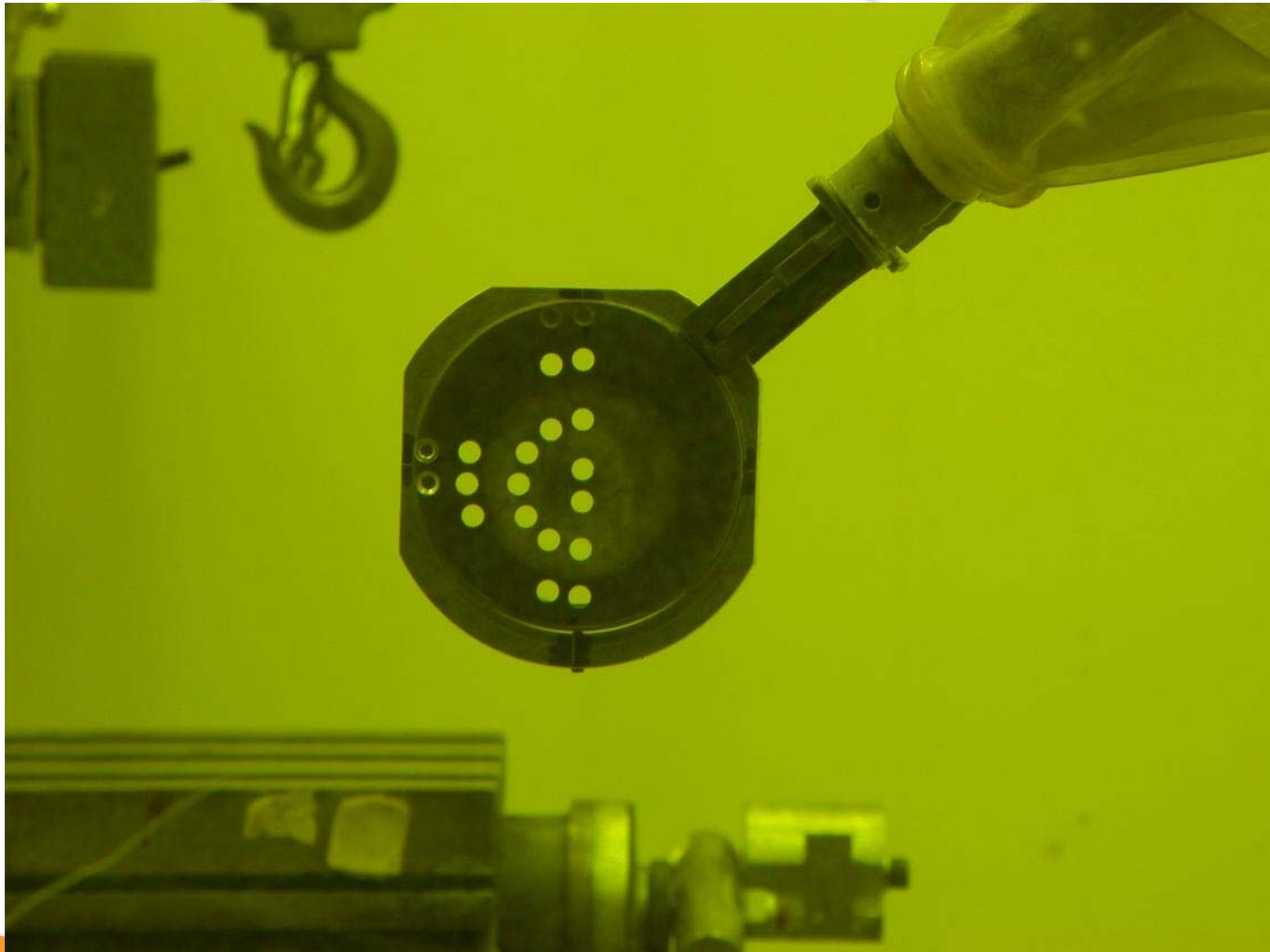
End of run cycle 2009

Image of Beam Window Surface

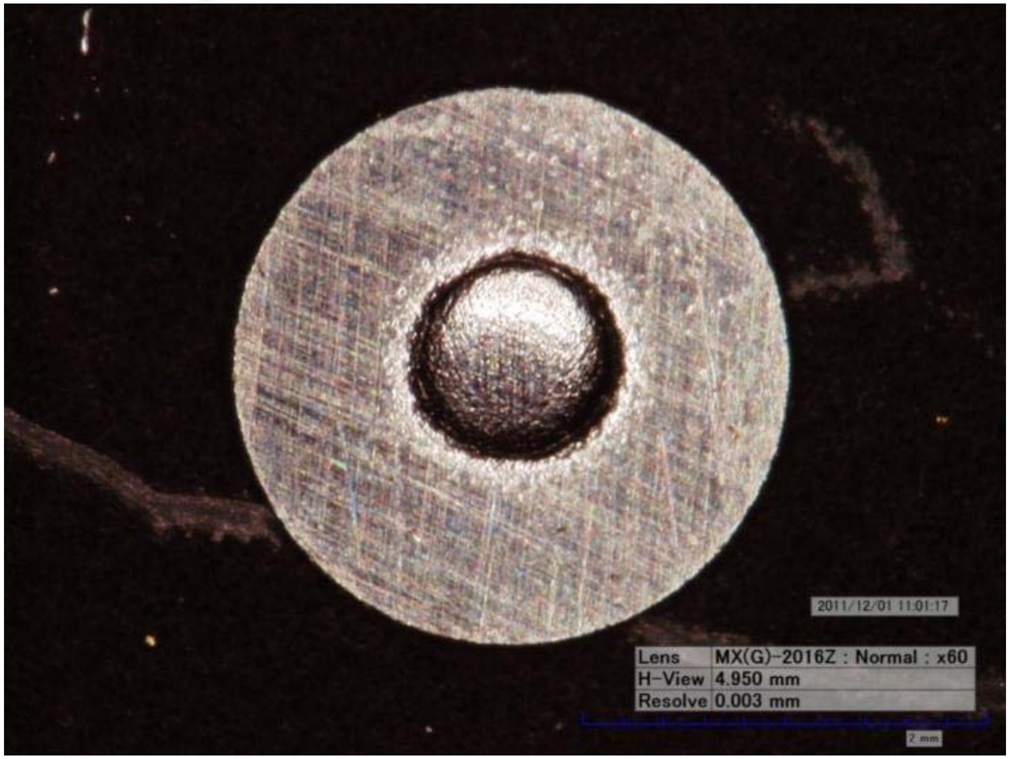
Outline of beam collimator is evident on beam window

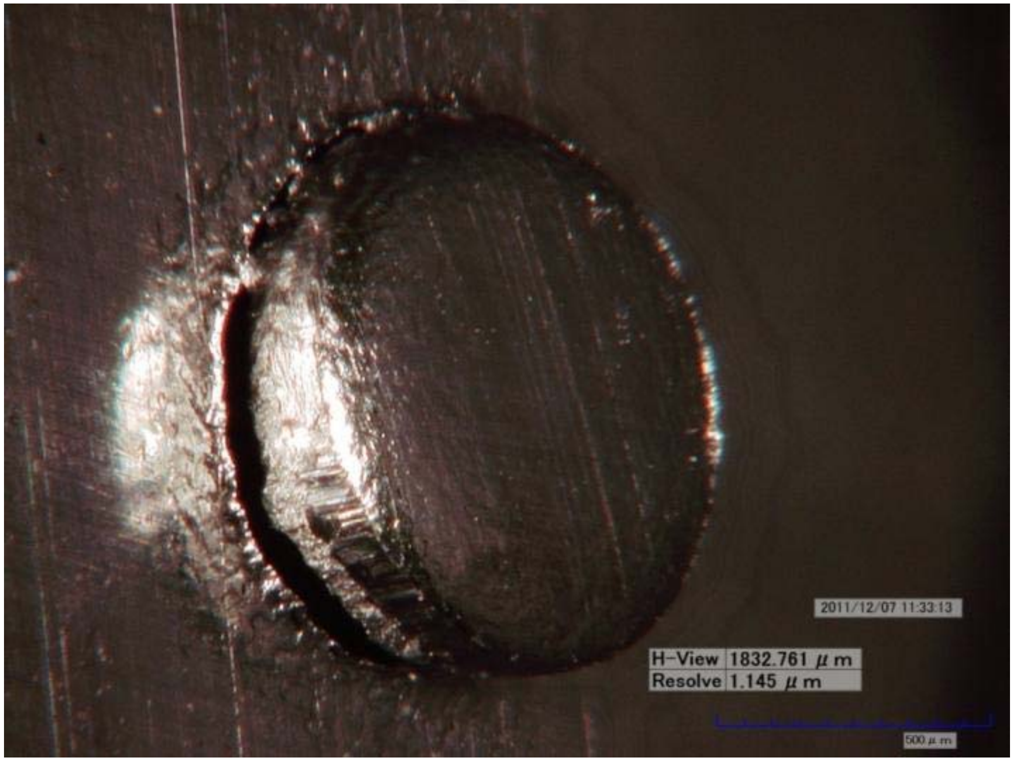
Approximate dimensions are 10 cm diameter x 0.5 mm thick.

Machined Window

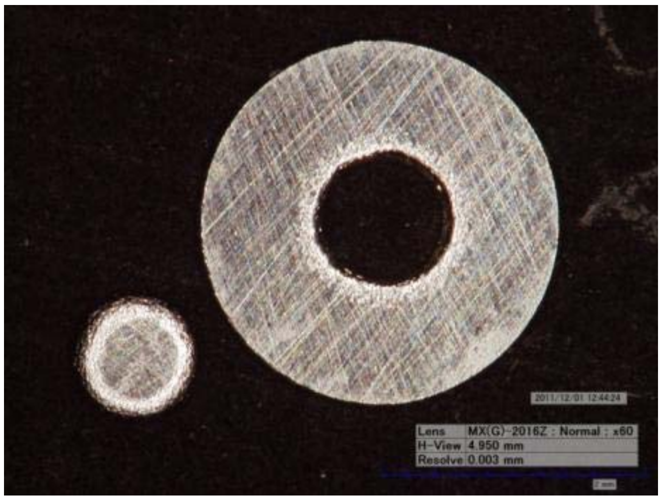


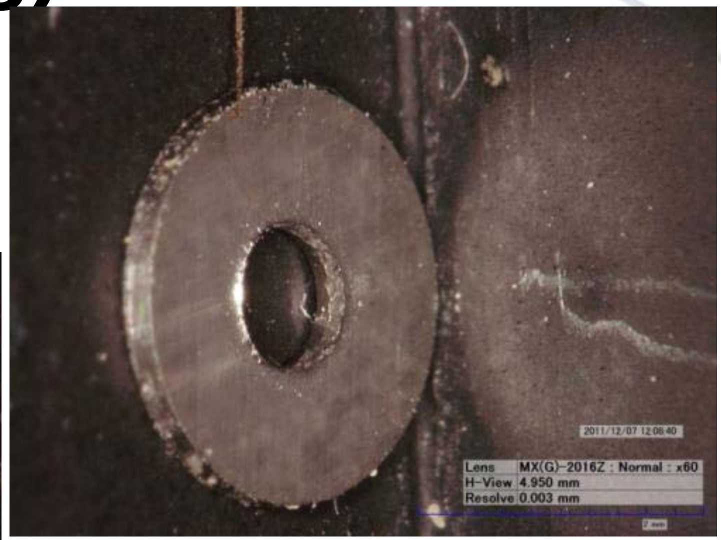
Optical Images of Control Sample #6 (Unirradiated)

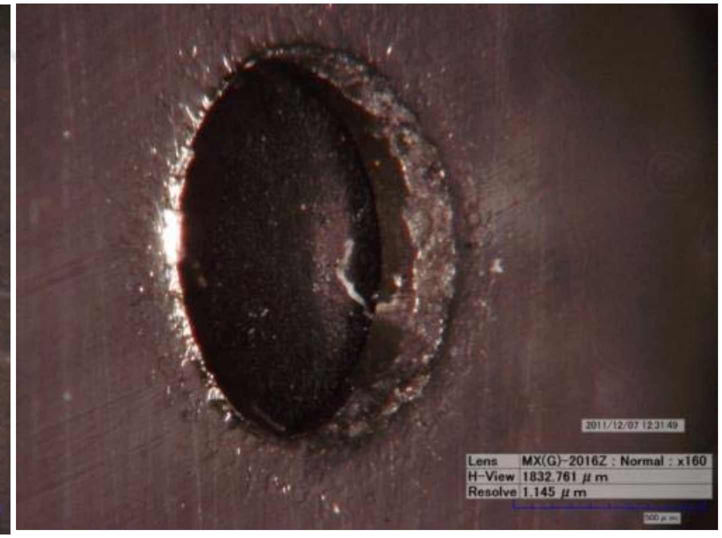


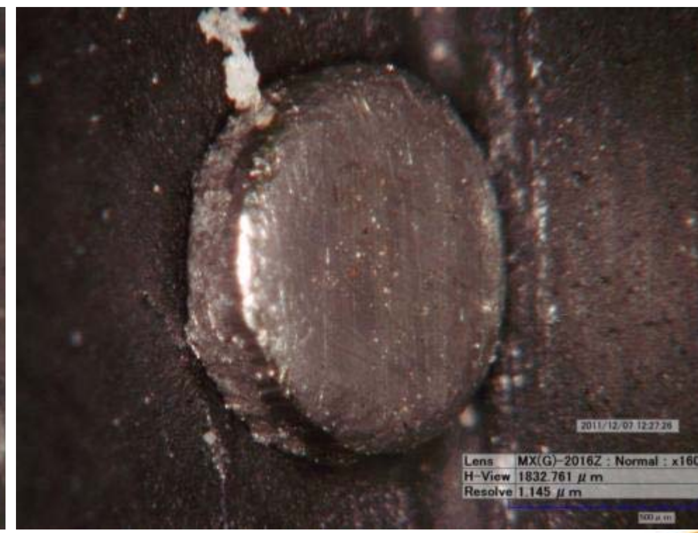


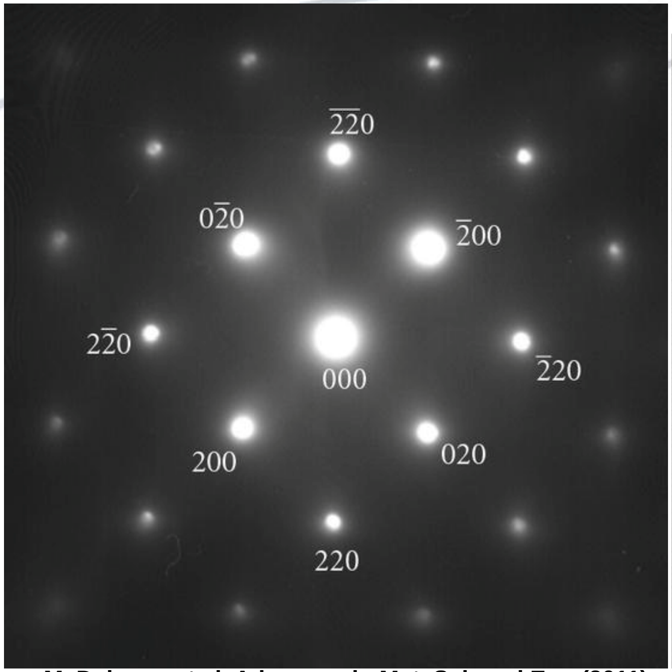
Optical Images of Sample # 8 (High Radiation Ring)





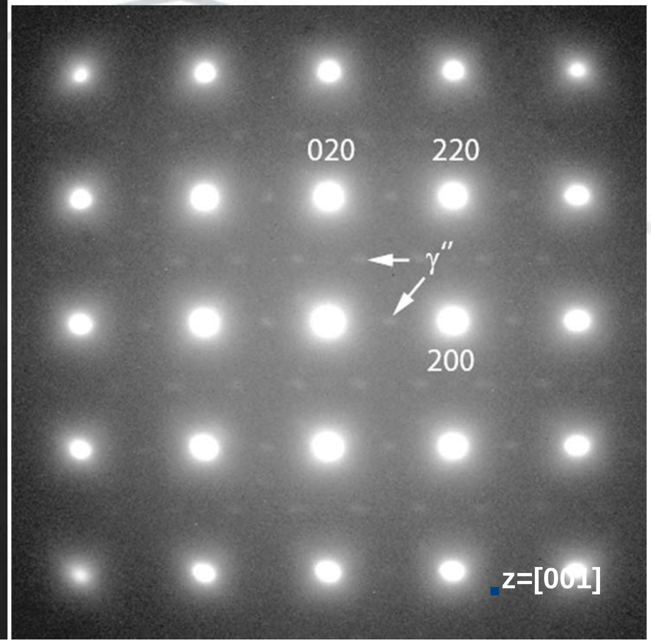




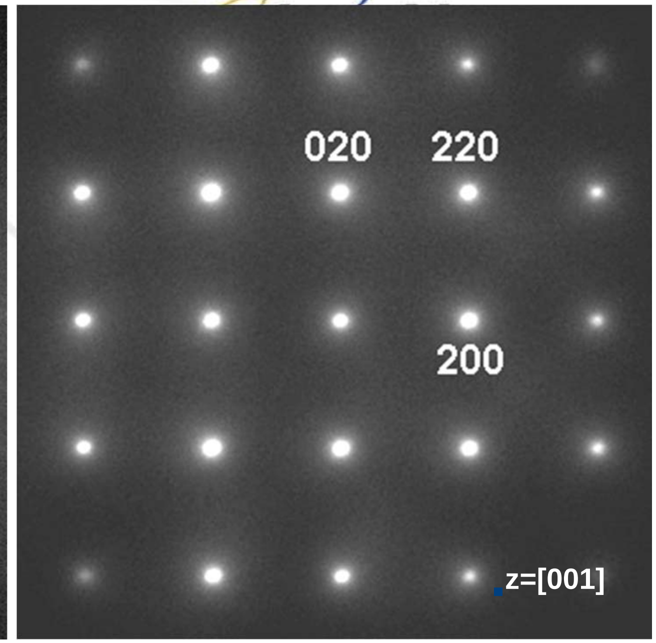


Reference: M. Dehmas et al. Advances in Mat. Sci. and Eng (2011)

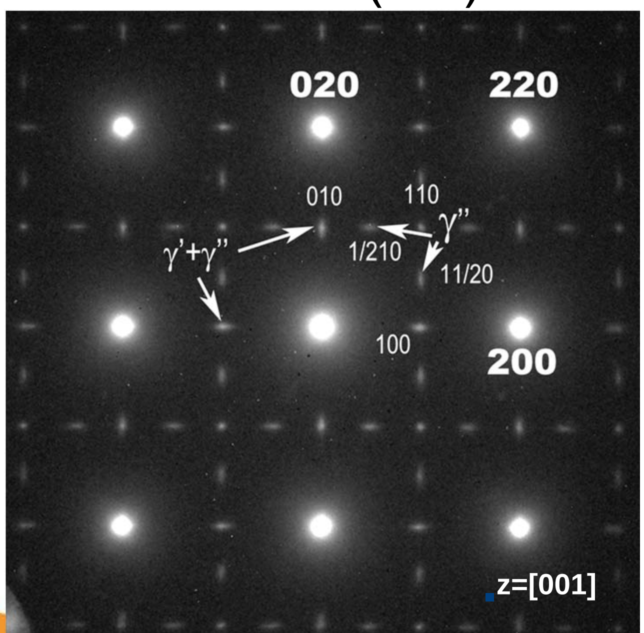
Unirradiated (SA)



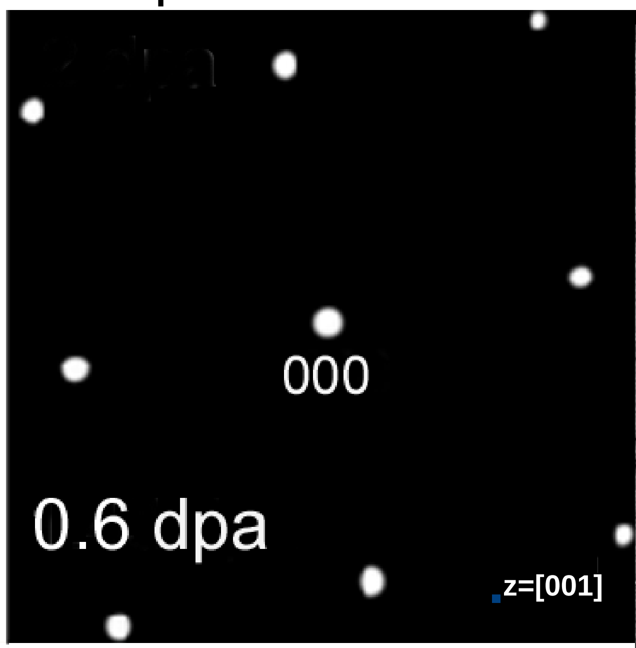
0.5 dpa at 50°C



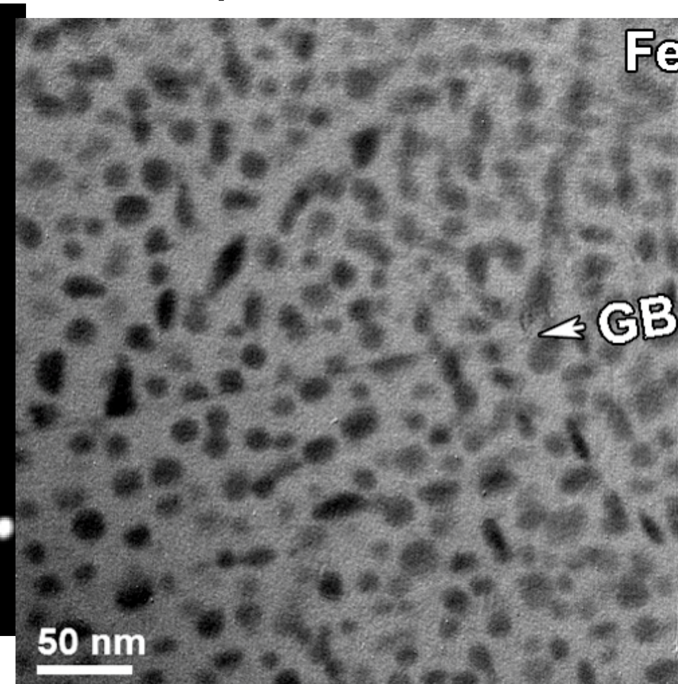
12.5 dpa at 109°C



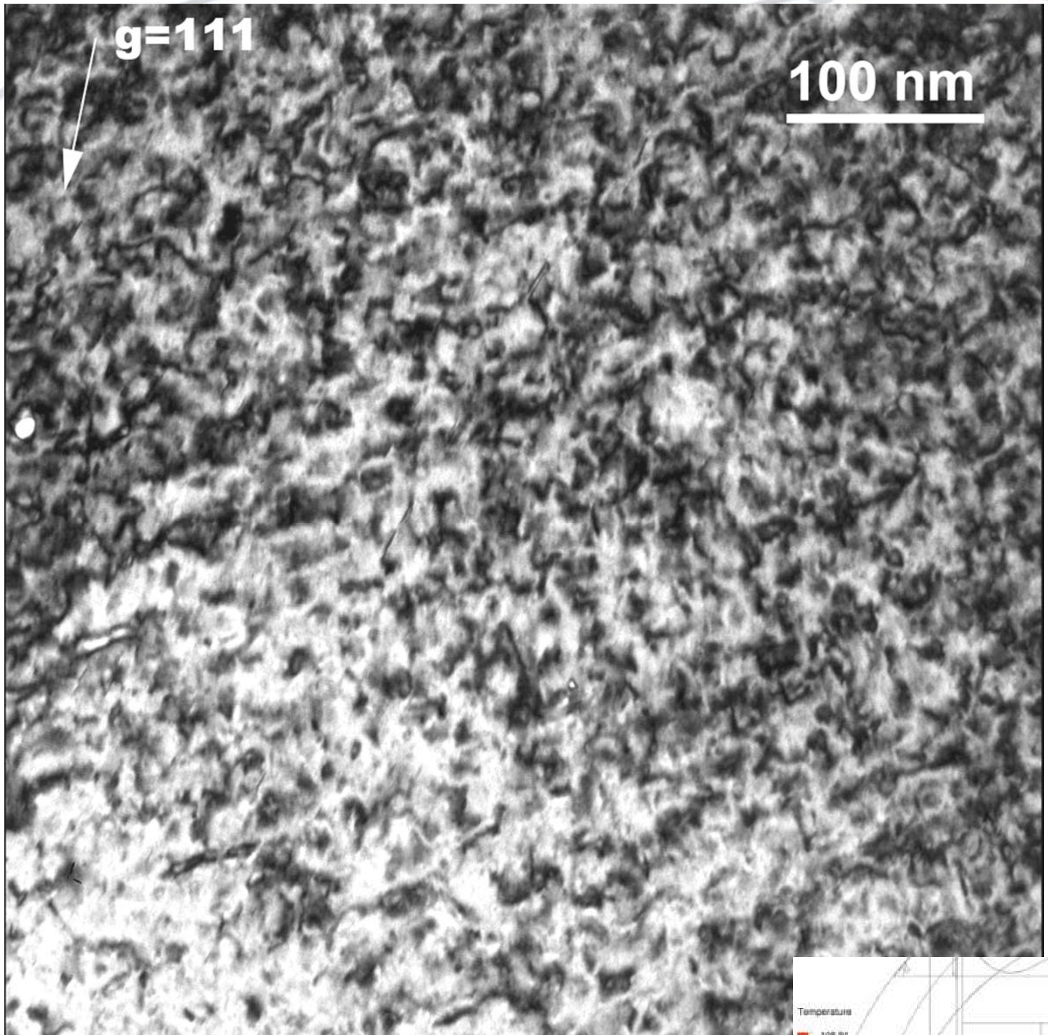
Unirradiated-PH

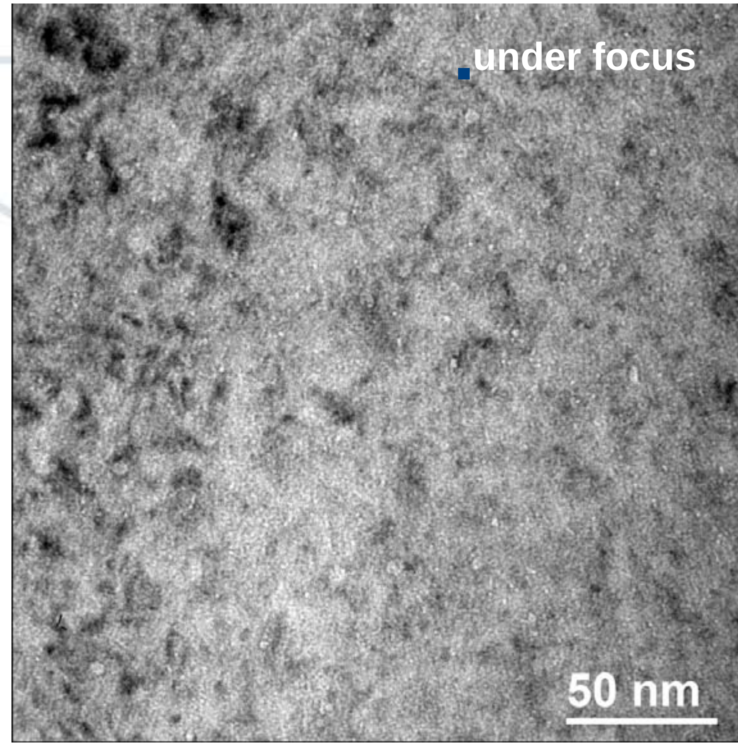


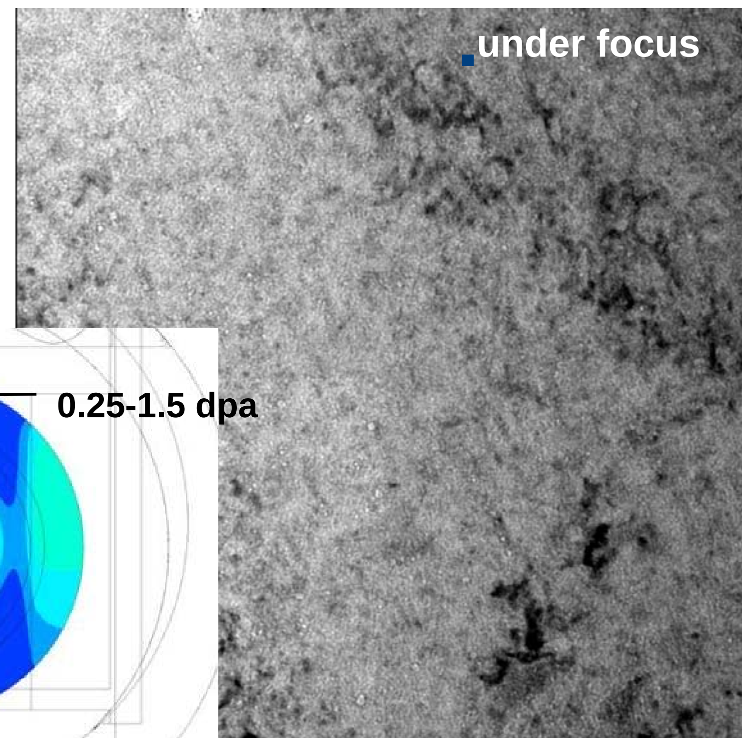
0.5 dpa at 30-60˚C



Inconel 718 #19 ~ 0.5 dpa @50°C



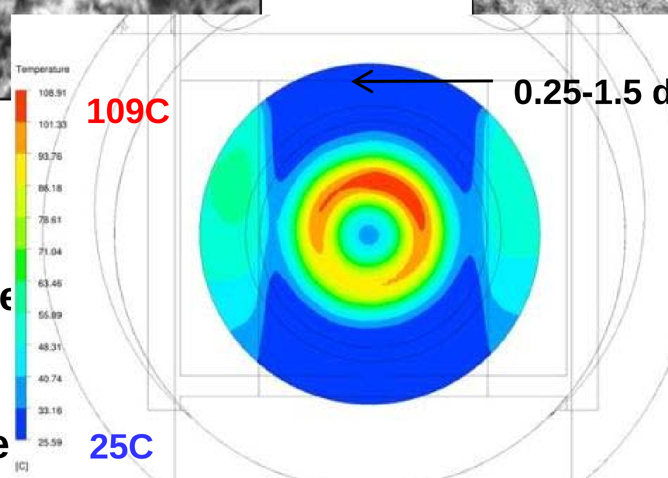




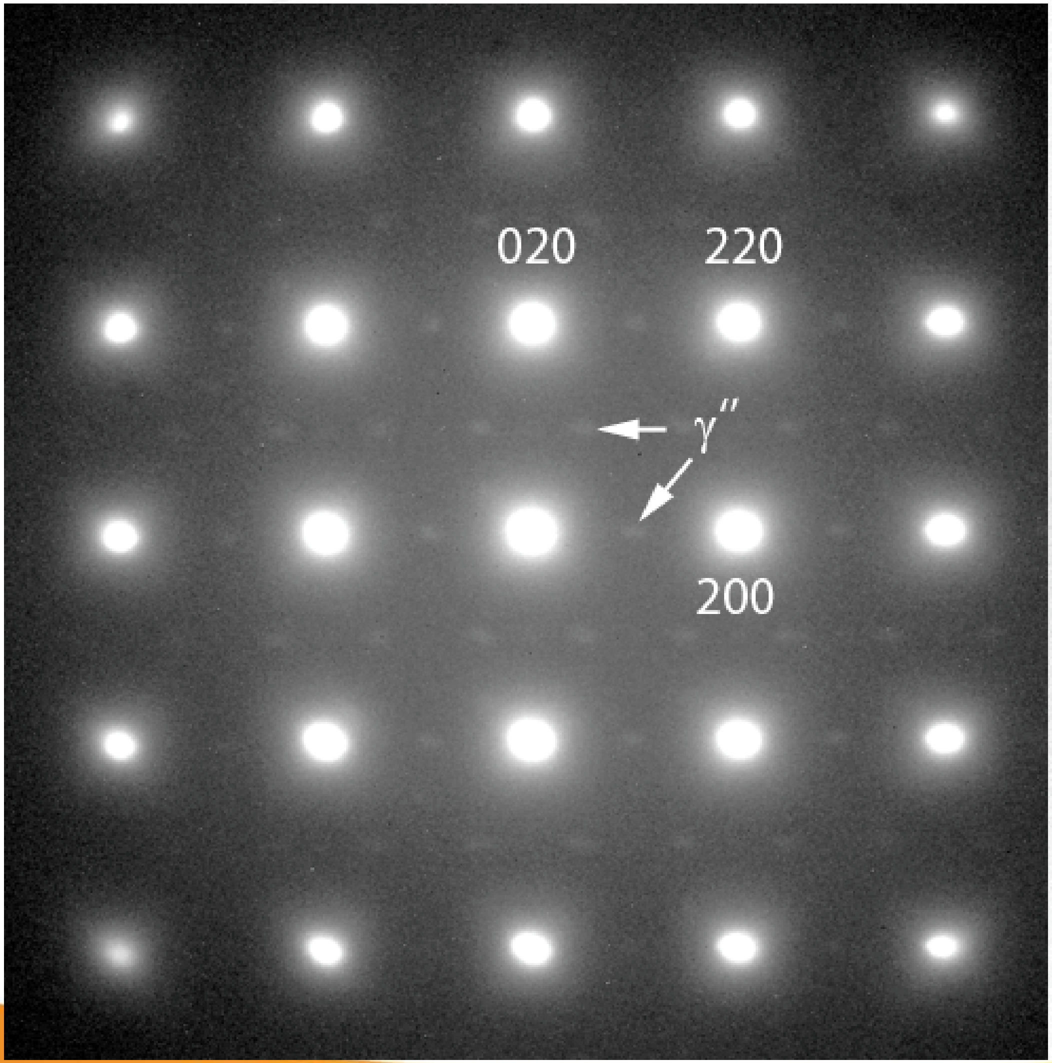
- **Bright field TEM images showing dislocation loops.**

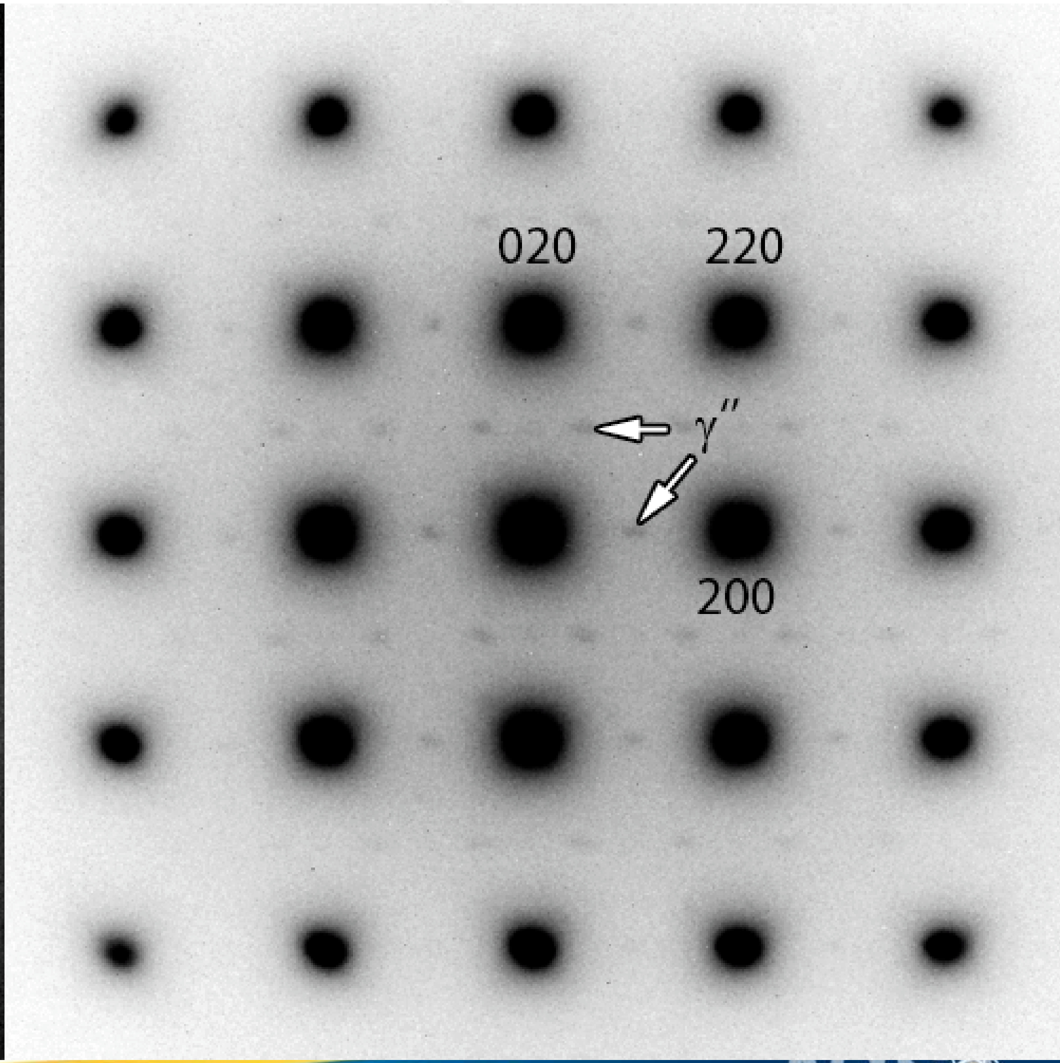
- **Under-focus TEM images on the right are showing a high**

- **Density of bubbles/voids that are on the order of 5-10nm**

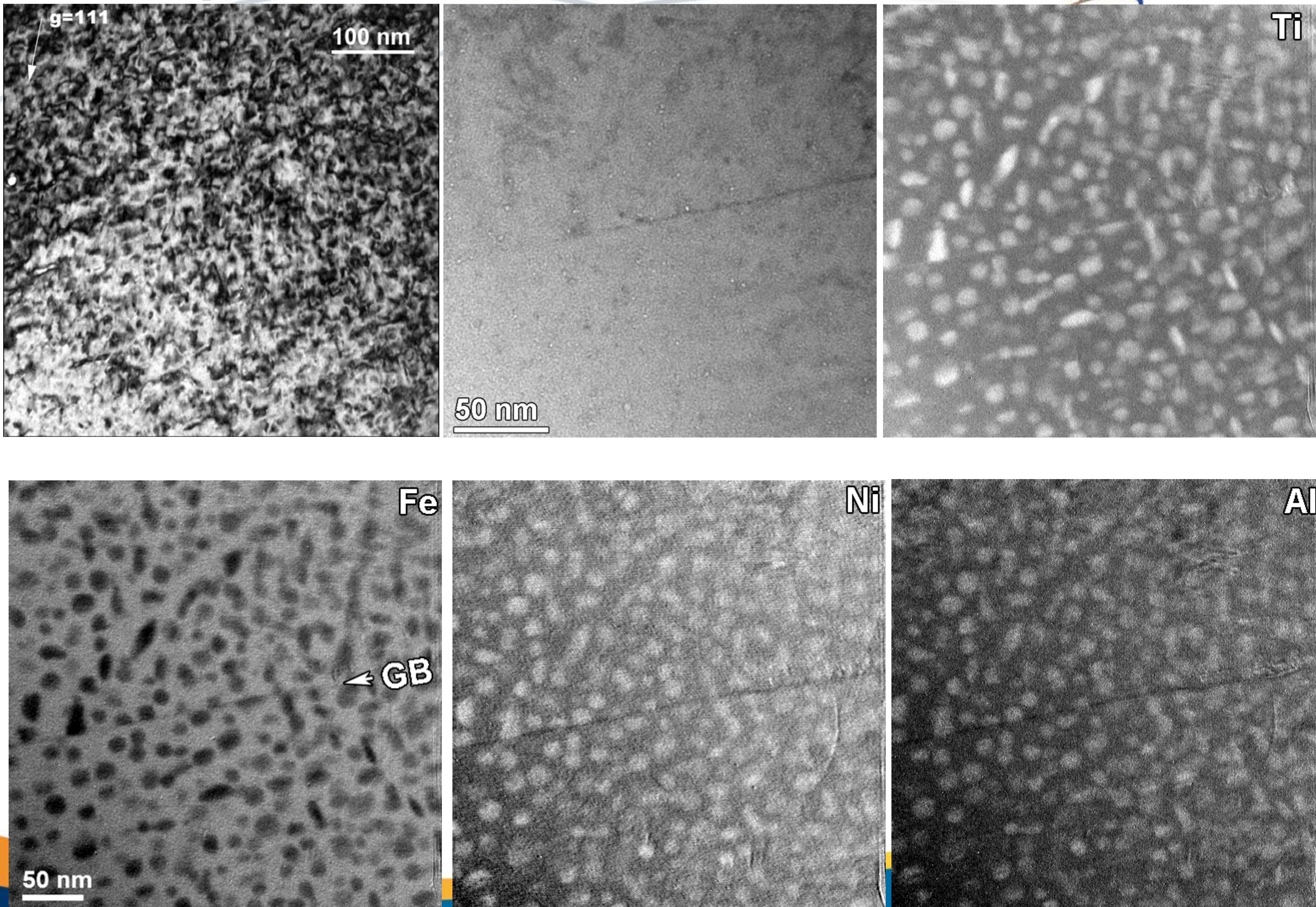


Inconel 718 #19 ~ 0.5 dpa @50°C γ“ precipitates

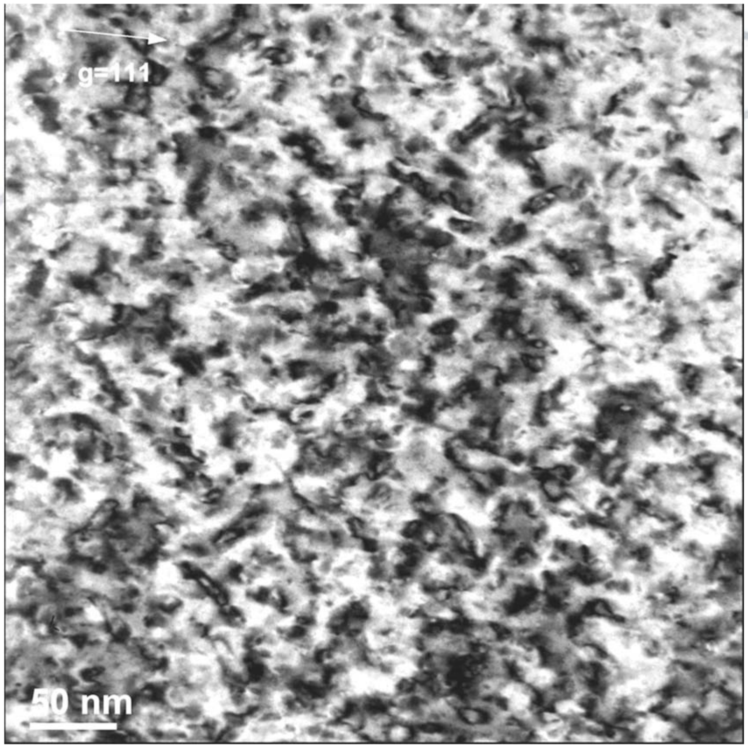


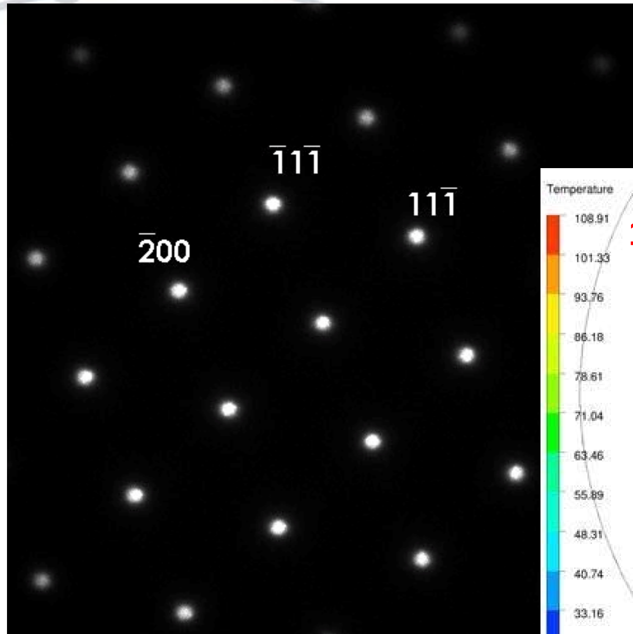


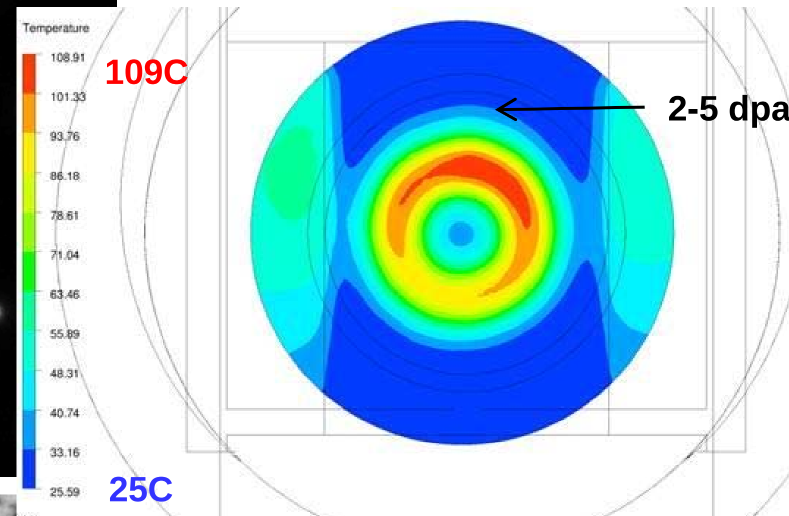
0.5 dpa 50°C

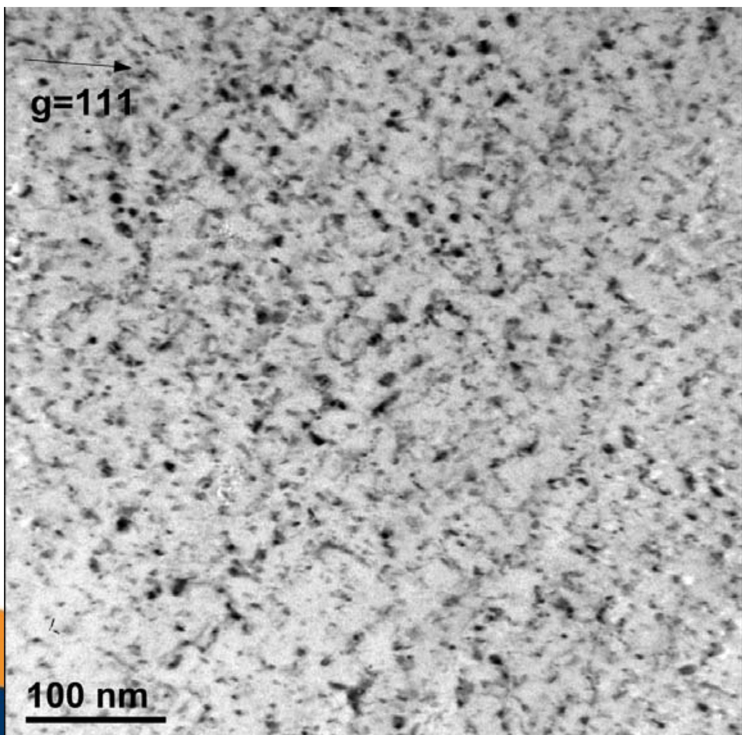


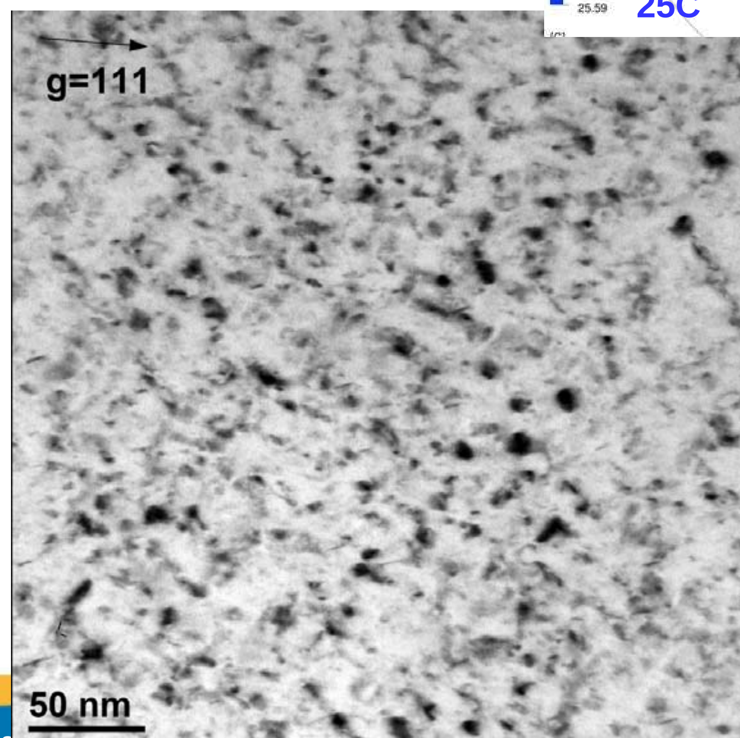
Inconel 718 #16~ 2.5 dpa @ ~40°C



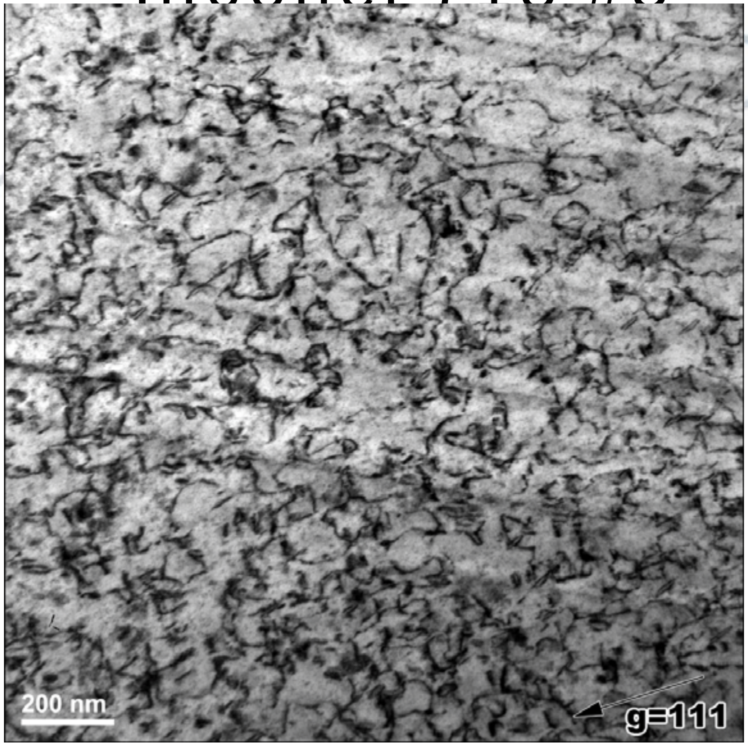


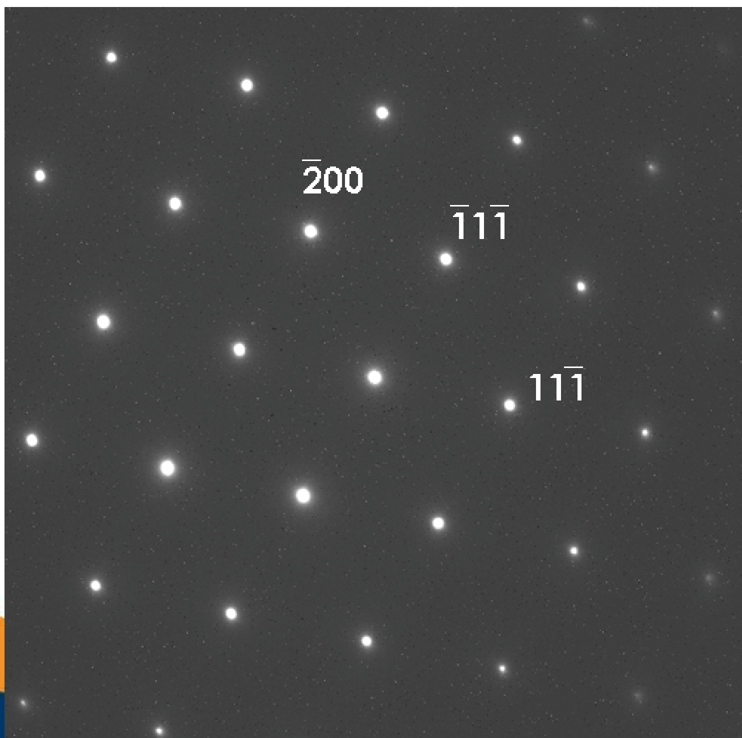


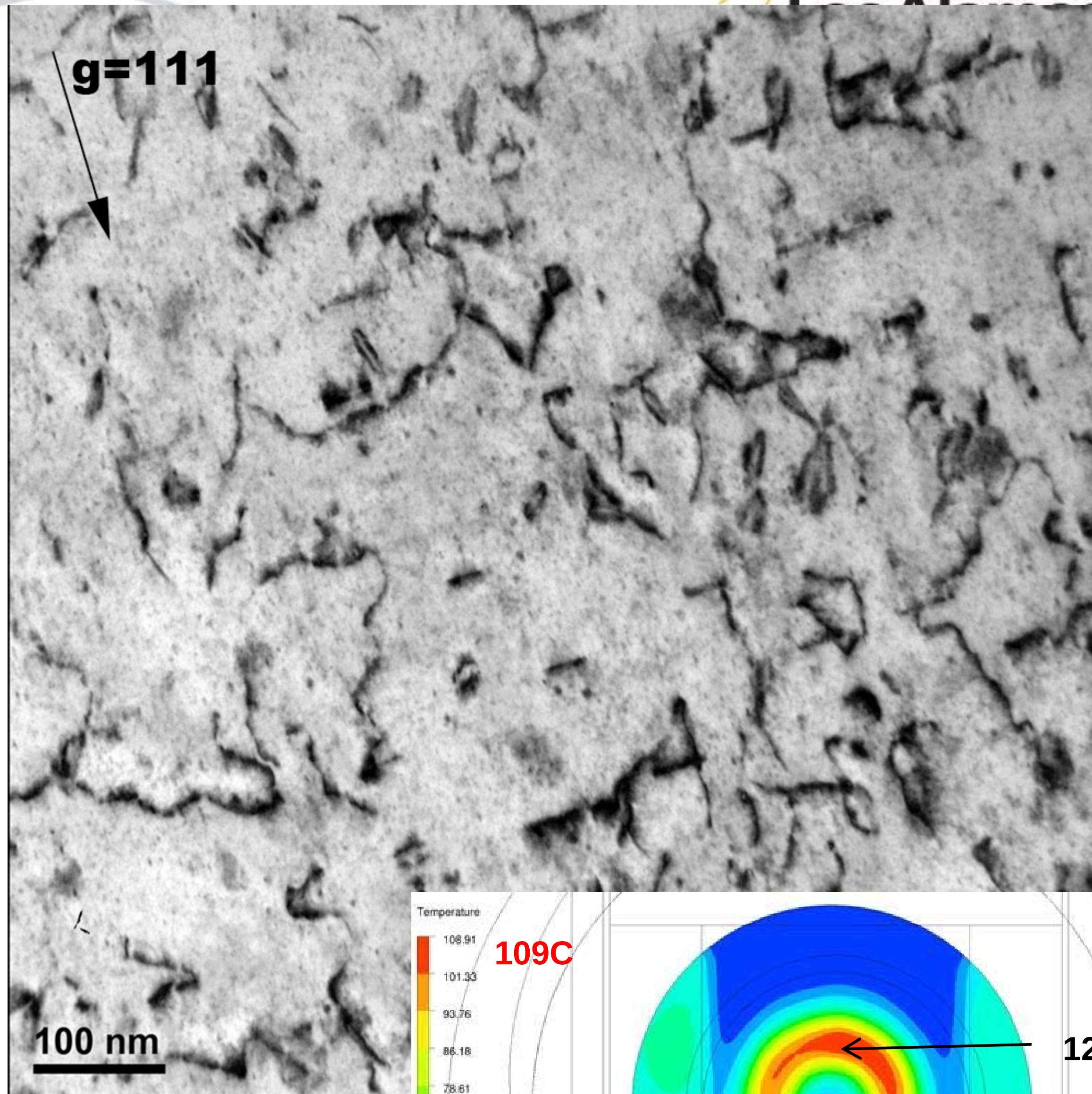


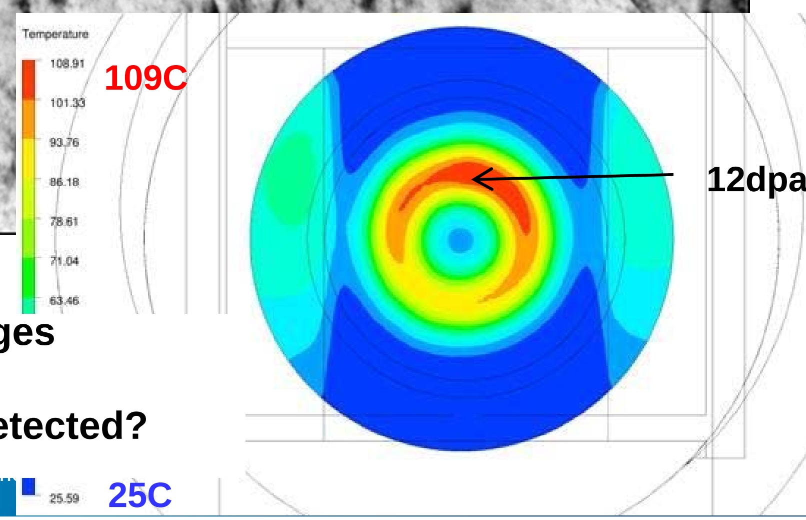


Inconel 718 #5 ~12 dpa @109°C



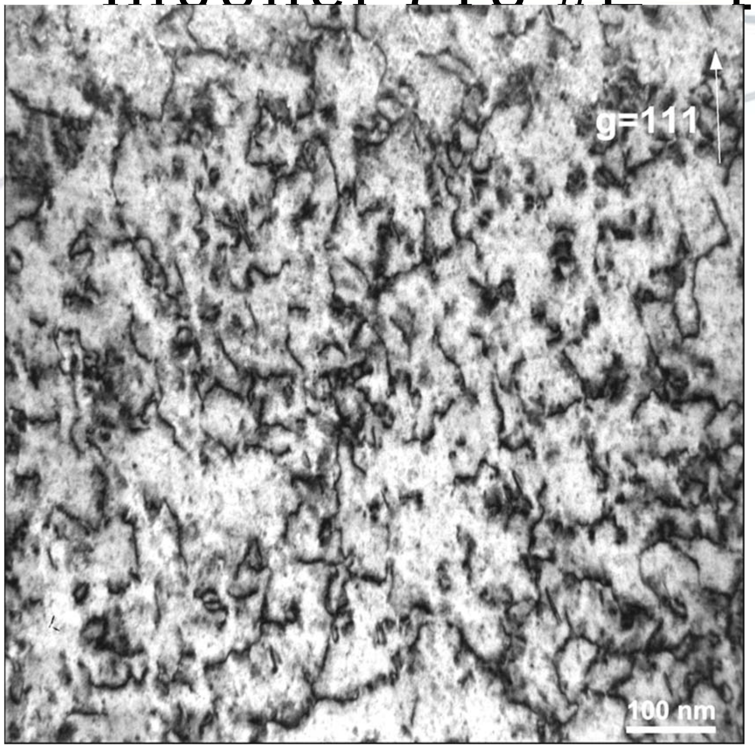


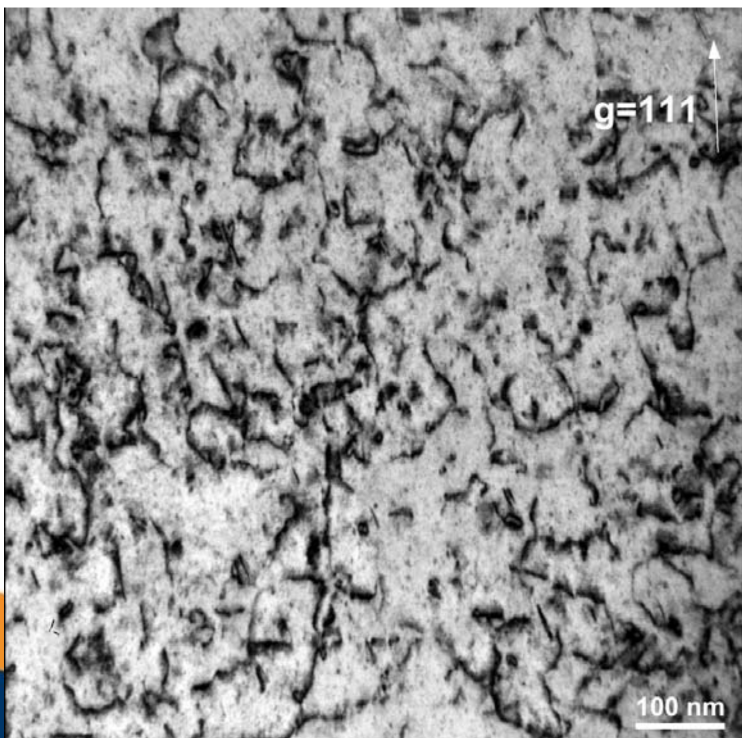


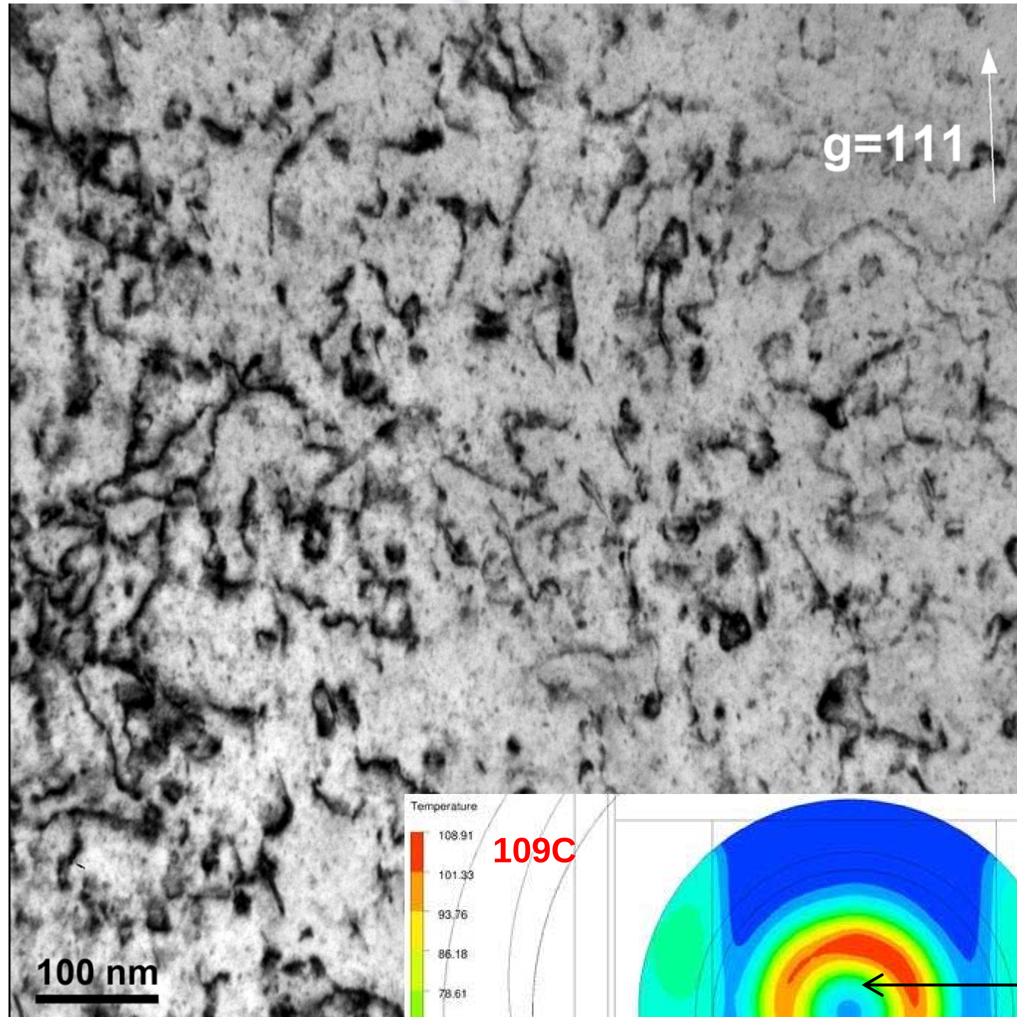


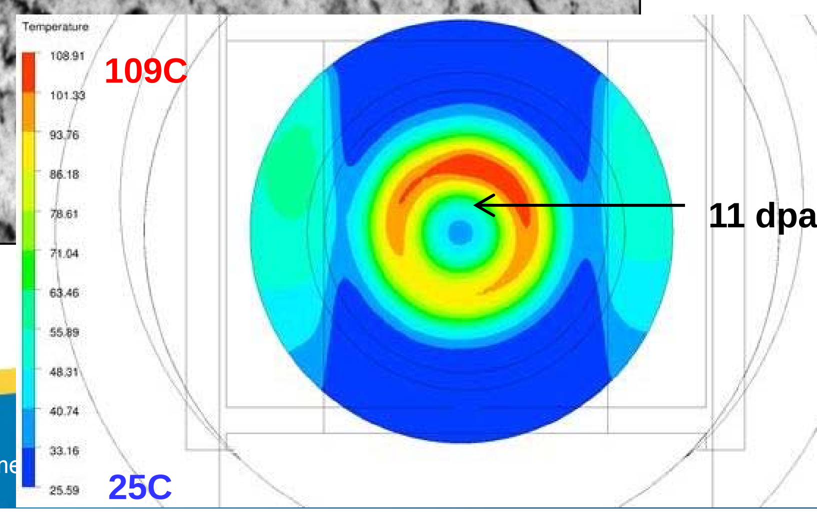
- **Bright field TEM images showing dislocations, precipitates are not detected?**

Inconel 718 #E ~11 dpa @~75°C

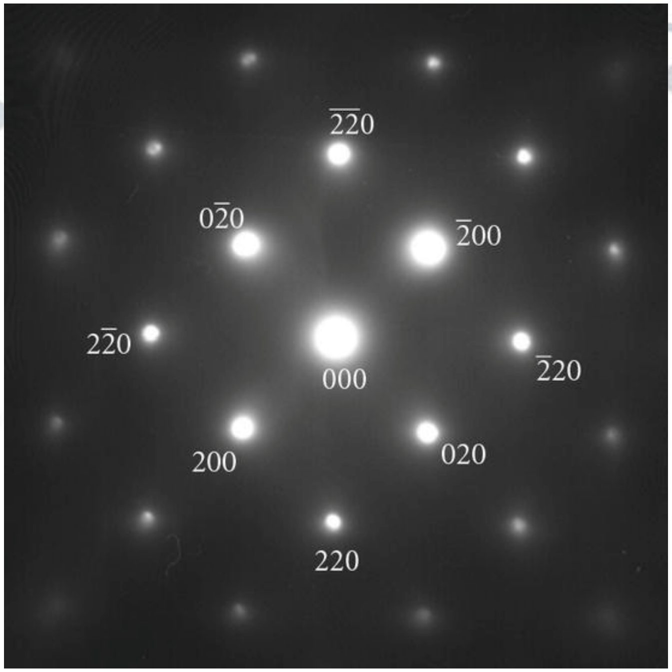




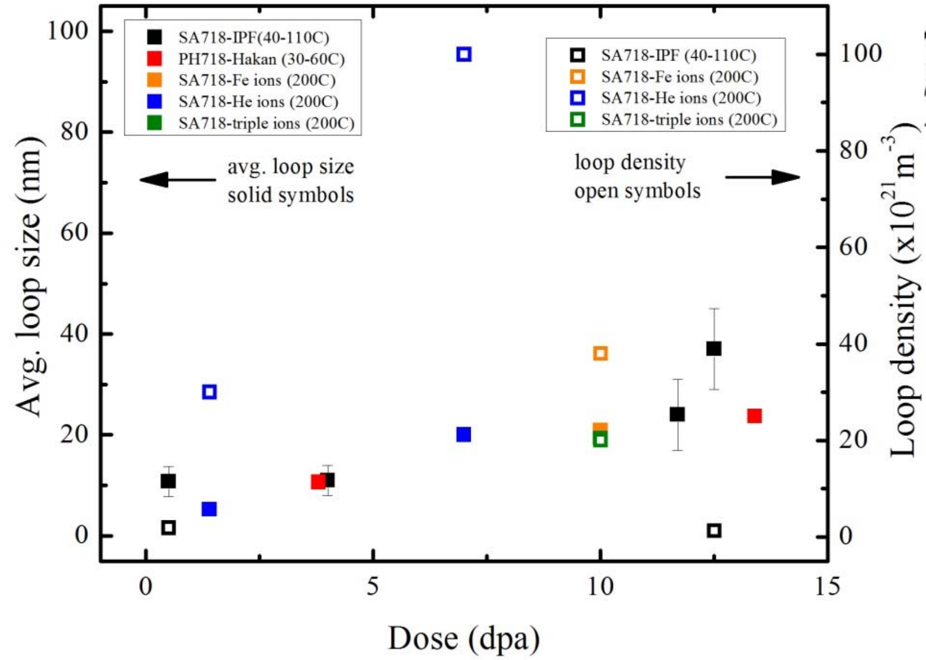


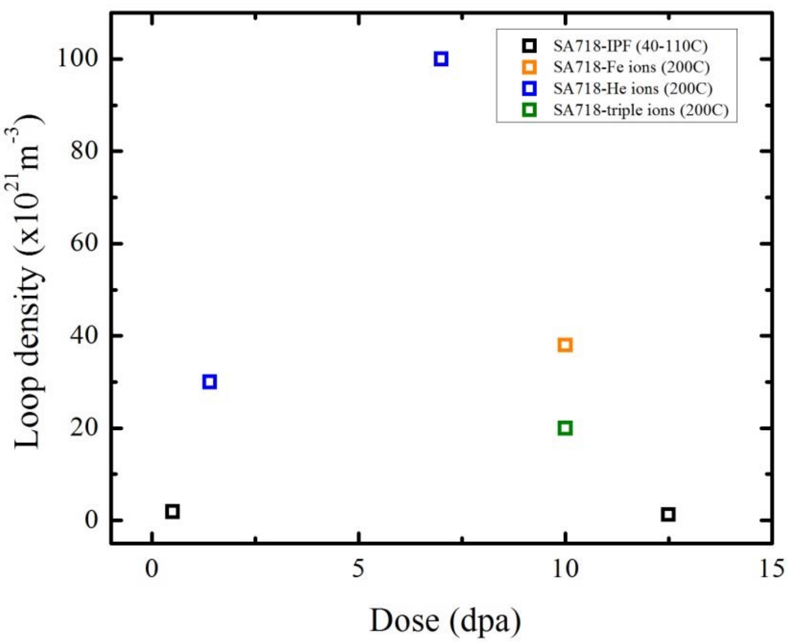


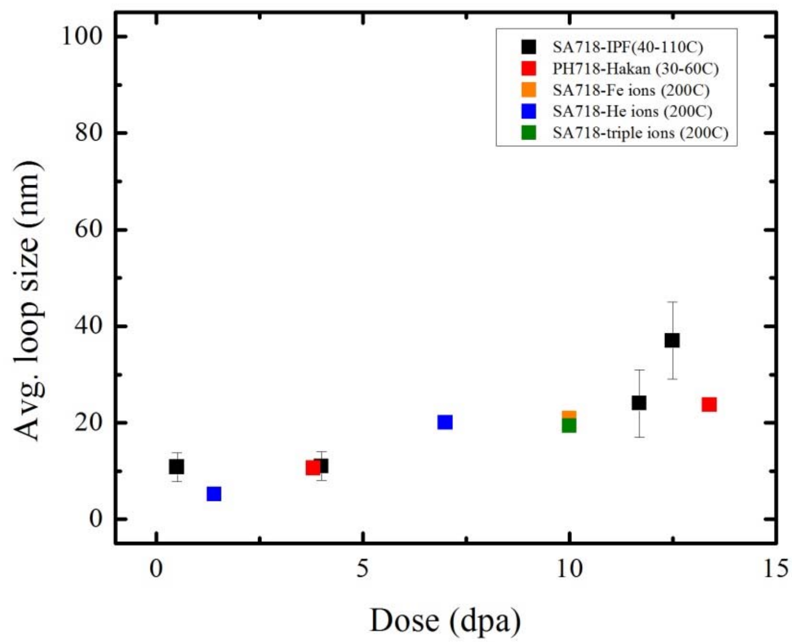
Loop size and density



Reference: M. Dehmas et al. Advances in Mat. Sci. and Eng (2011)







Loop density

Loop size