Survey of Metal Contamination in DIII-D Plasma Facing Tiles with Beta Backscattering and XRF

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GENERAL ATOMICS

Unusually high levels of metal impurities impeded high performance operation on DIII-D in 2011

- Vessel inspection found damaged components as potential sources of metal impurities.
- Portable Beta-Backscattering and X-ray Fluorescence instruments were used to look for metal impurities in the graphite plasma facing surfaces
- In-vessel sanding and ex-vessel grit blasting of contaminated tiles were done to remove metal impurities.

Several potential sources of metal impurities were identified during 2011 campaign

Timeline of events:

2011:

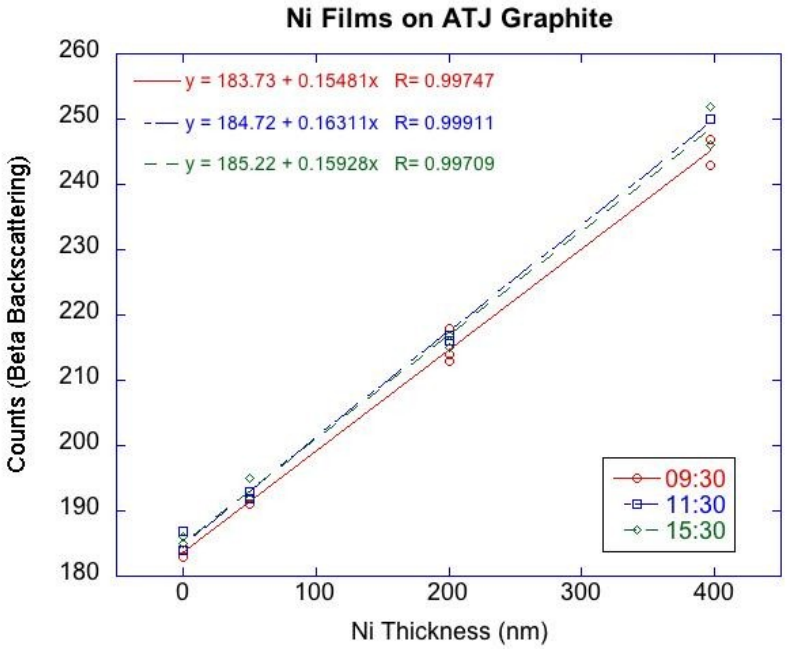
- **8/12 – Runaway electron/probe accident, impurities increasing later**
- **9/23 – Neutral Beam drift duct weld leak**
- **9/30 – Vent inspection finds splatter, NB drift duct melting**
- **10/19 – Boronize, keep operating short-term**
- **10/21 – Midplane probe damage discovered**
- **12/16 – Long vent, impurity survey, and tile cleaning**

2012:

- **4/16 – Plasma Startup**
- **4/19 – Start RF Antenna conditioning, impurity problems begin**
- **5/2 – 0-Degree FW Antenna arcing observed with camera, correlated with prompt increase in impurity levels.**
- **5/29 – Vent, survey, limited tile sanding on lower centerpost tiles**
- **6/4 – USN Radiated power down to 30% from April startup**
- **6/5 – LSN low power accumulating impurities in outer shelf only, otherwise impurities are low**
- **6/9 – Boronize**
- **Current status – Vessel impurities are low**

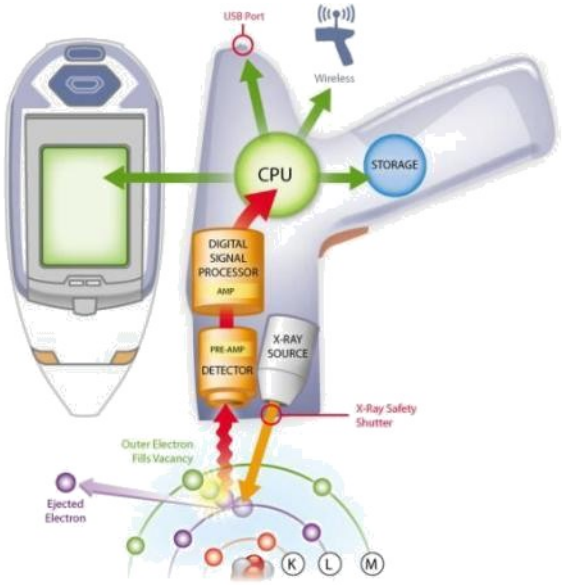
Beta backscattering: Overview of survey instrumentation

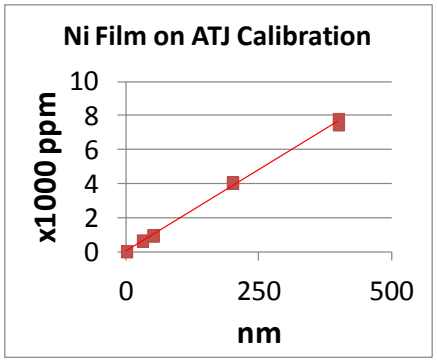
- **Radioactive beta source: Pm-147, 13.1 µCi**
- **Max beta energy 224 keV, average 62 keV**
- **Depth sensitivity limit ~ 30µm**
- **Measured count rates 50-200 cpm**
  - In-vessel background level ~50 cpm
- **Detects high-Z thin films on low-Z substrate**
- **Calibrated for equivalent Ni film thickness**

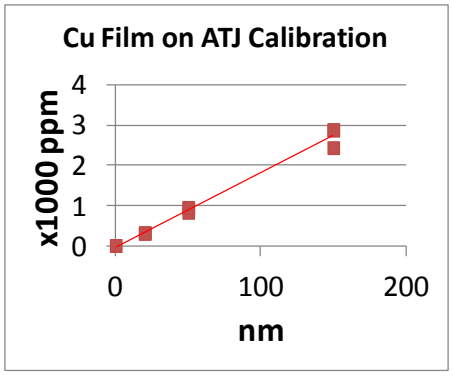


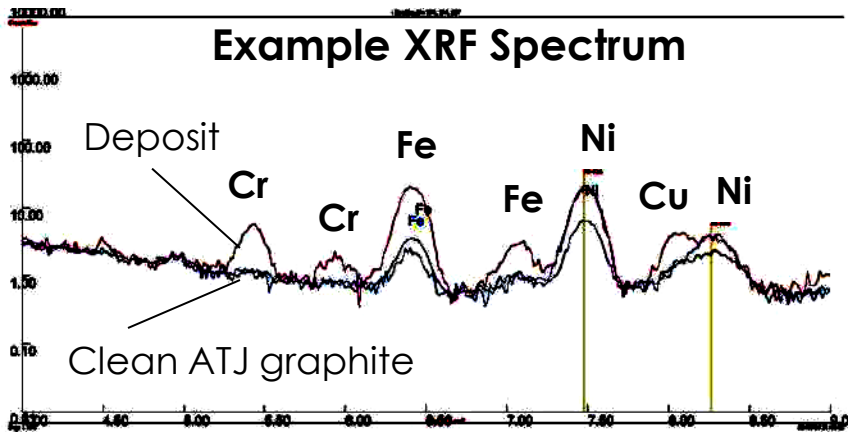
Handheld X-Ray Fluorescence (XRF): Overview of survey instrumentation

- **Model: Thermo-Niton XL2 GOLDD™**
- **45keV/8keV probing beam energy**
- **1.5-30keV energy sensing range**
- **Depth sensitivity limit: ~ 0.8-5mm**
  - Depends on element
  - Sensitive to bulk impurities in graphite
- **Element sensing range: Al – U**
  - Not sensitive to lighter elements
  - Calibrated for **Cu** and **Ni** thin film deposit on ATJ graphite



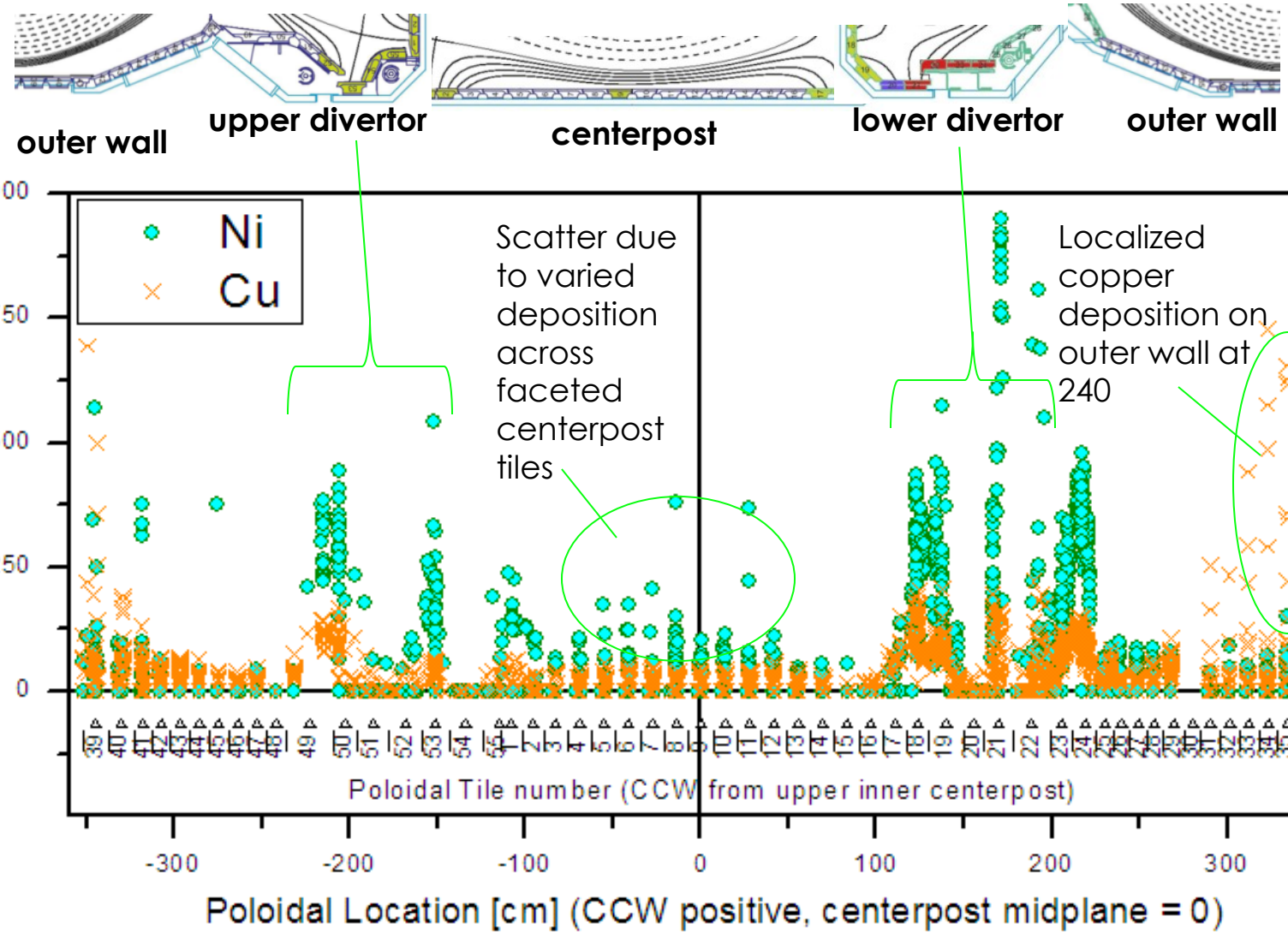






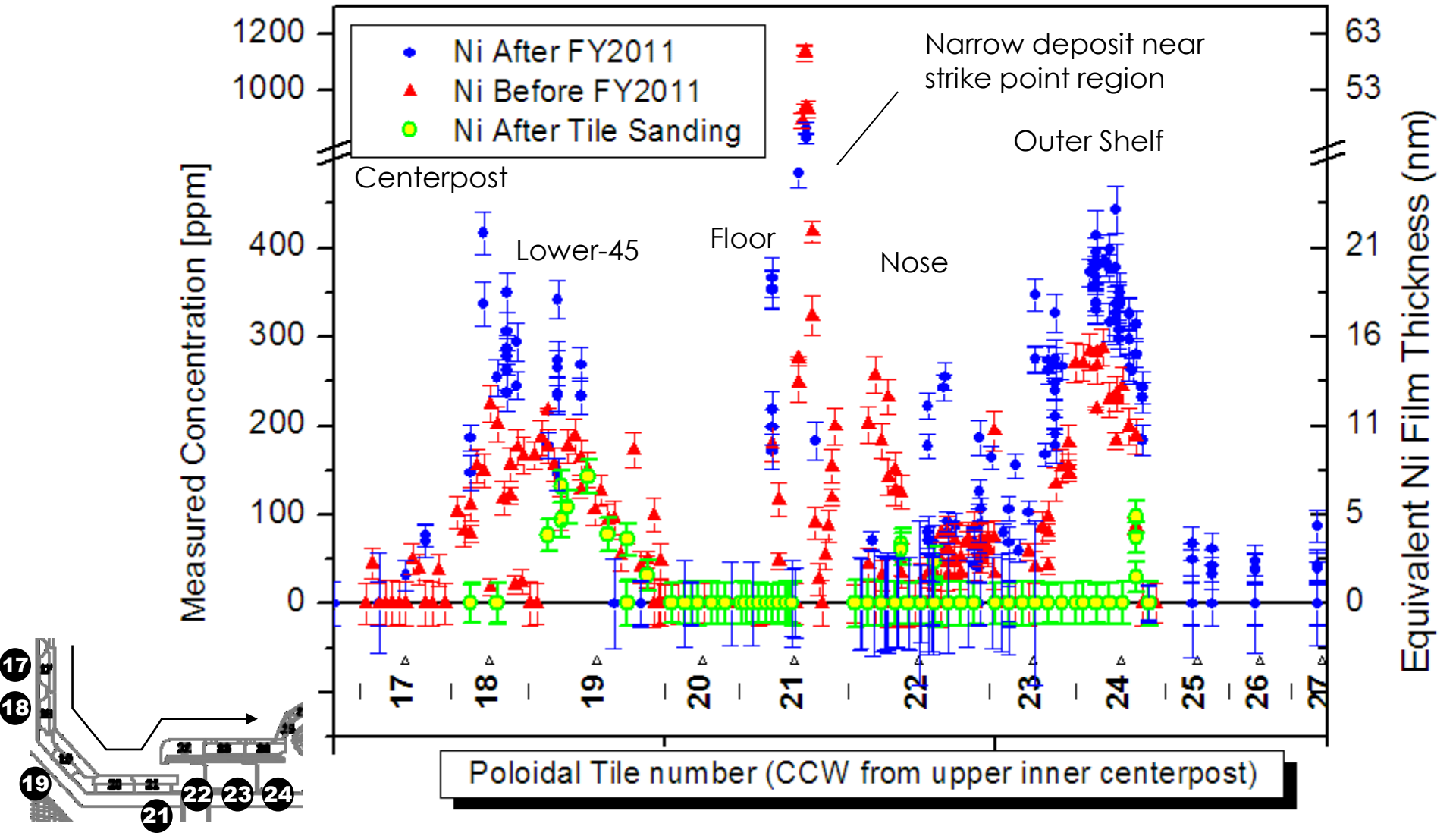
Poloidal distribution shows metal deposition is largely localized near divertor regions

Poloidal distribution of Cu and Ni, showing data from many toroidal locations between 130-300 degrees



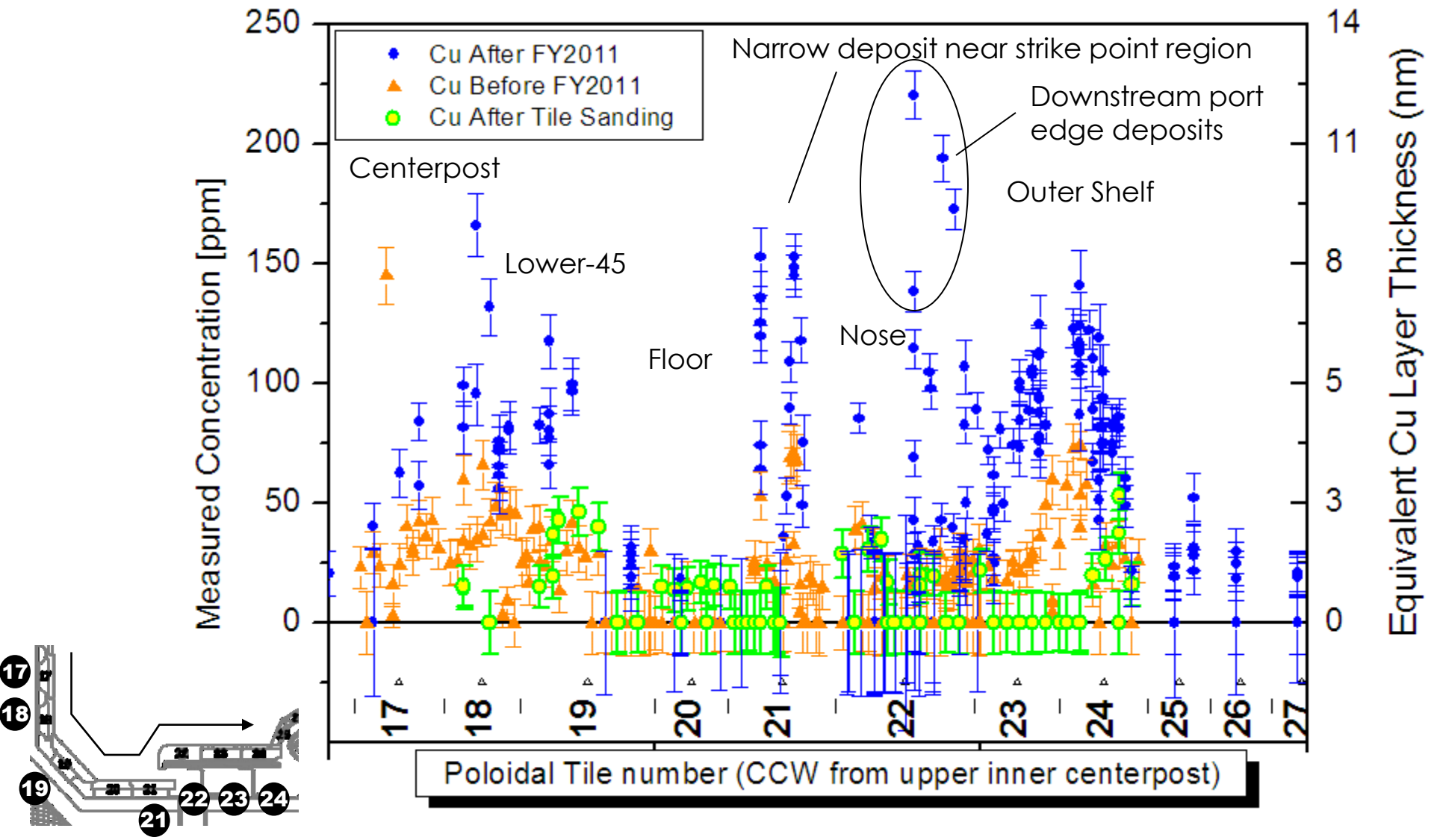
Lower Divertor Detail – Nickel

XRF survey results – 130 to 175 degrees poloidal



Lower Divertor Detail – Copper

XRF survey results – 130 to 175 degrees poloidal

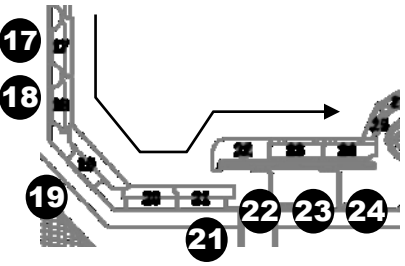


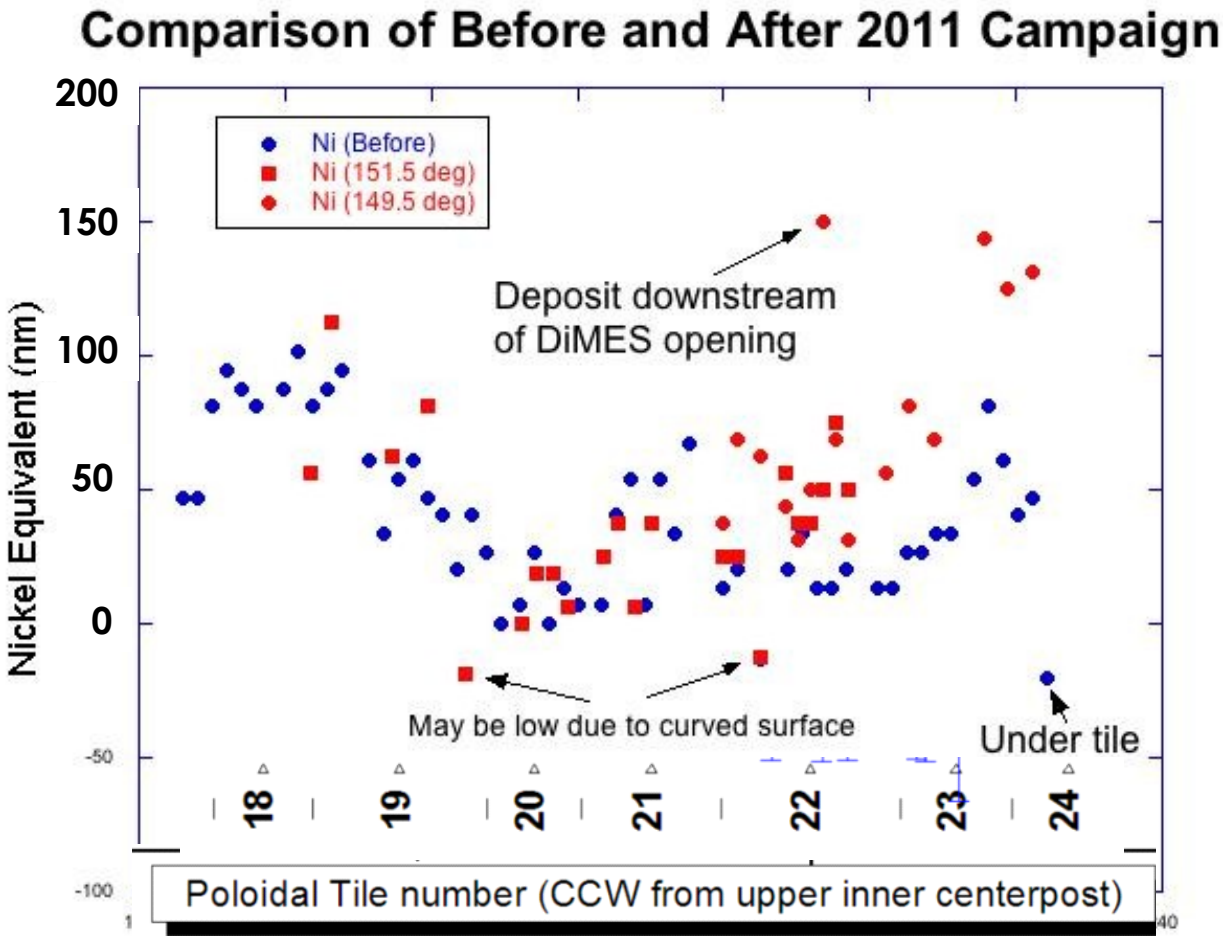
Metals Poloidal Distribution – 2010 and 2011 Lower Divertor Beta Backscattering Results

Equivalent to pure nickel film between 50-150nm thick

BB is not element-specific

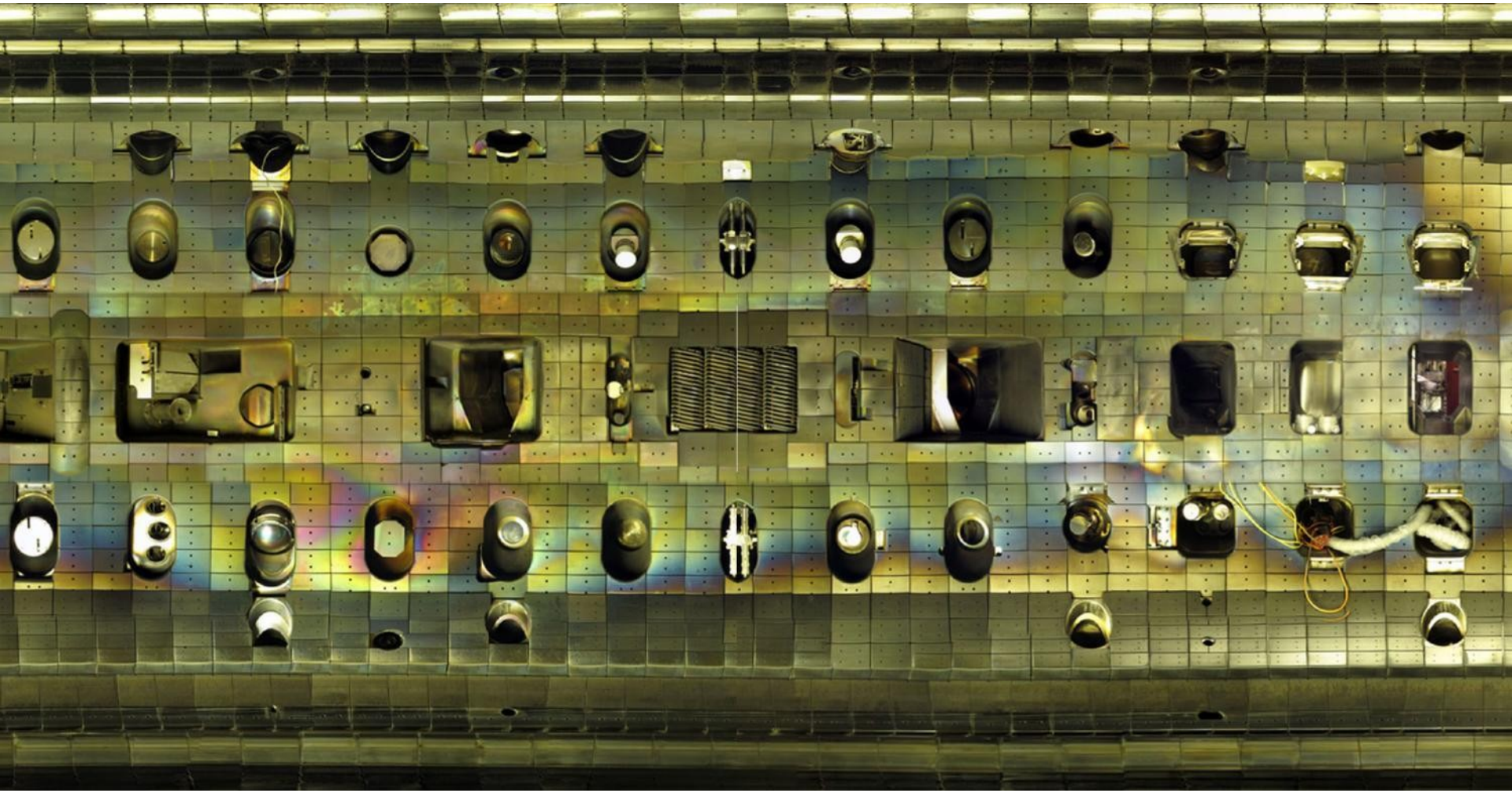
Film thickness 4x higher than XRF estimates for Cu and Ni, partly due to presence of Fe, Cr, and other metals



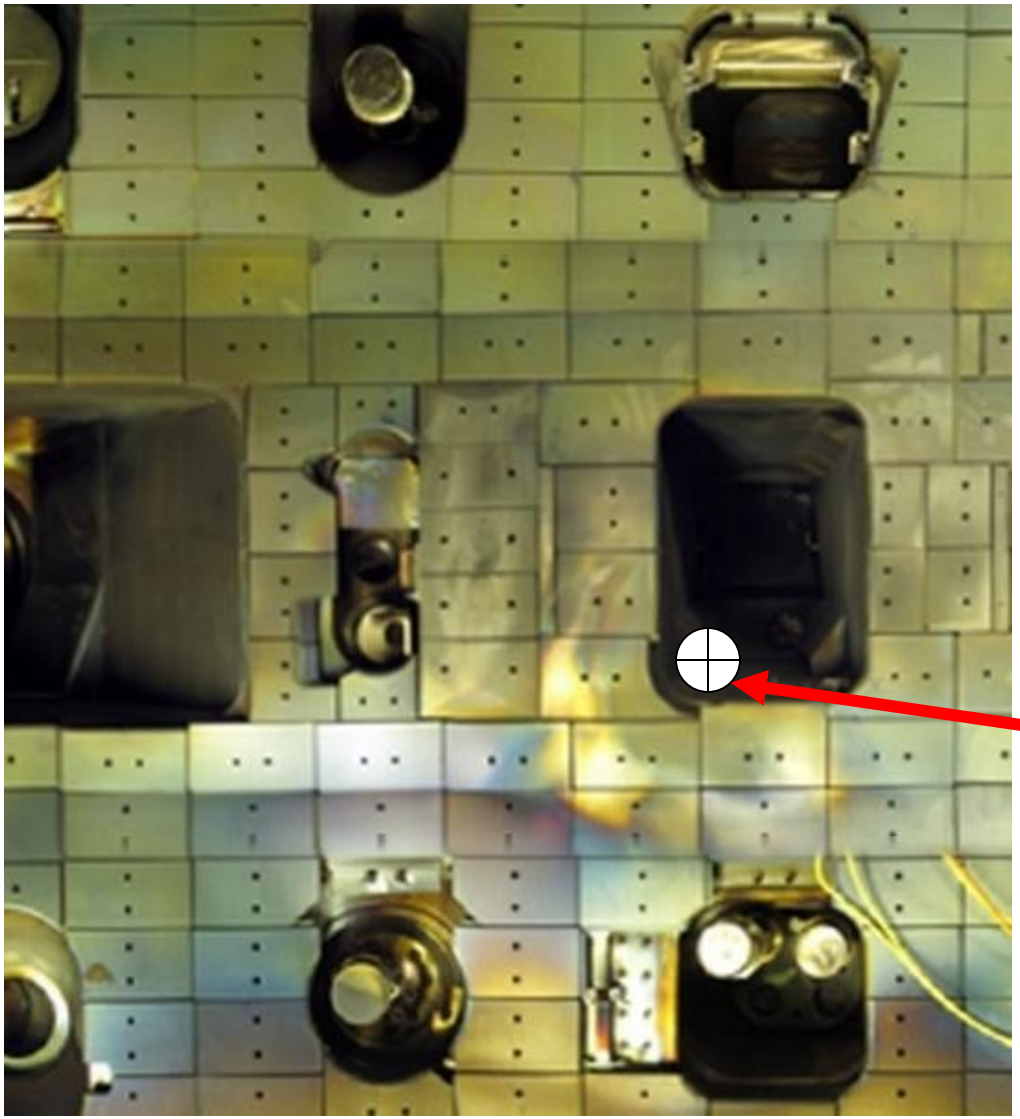


2-D vessel outer wall and divertor area surveyed by XRF from 90 to 270 degrees

Panoramic view of outer wall, upper and lower divertors



Dec 2011 vessel inspection found bright-colored region near 240-degree outer wall midplane

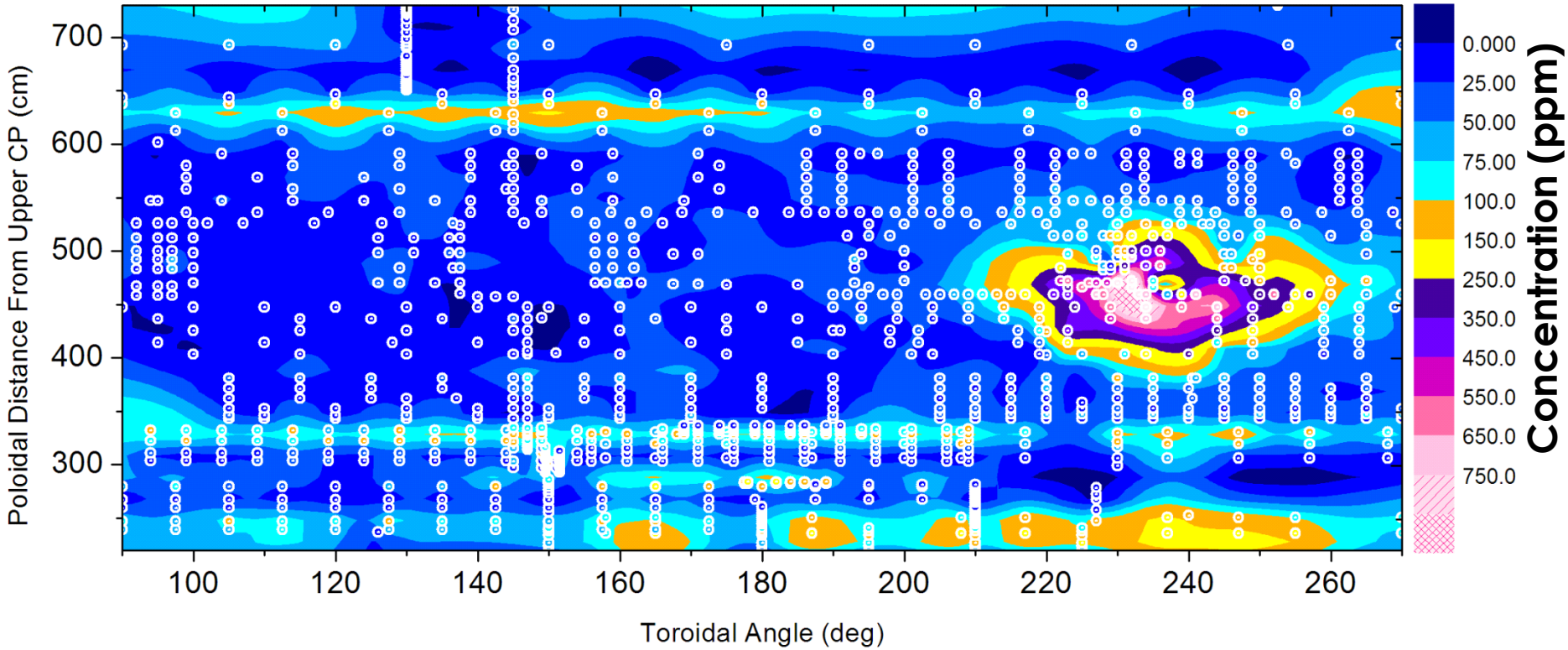


XRF analysis verified presence of copper in colored region.

Source of copper vapor deposit *and* nickel splatter was later found to be from a reciprocating midplane probe that was damaged by runaway electron beam.

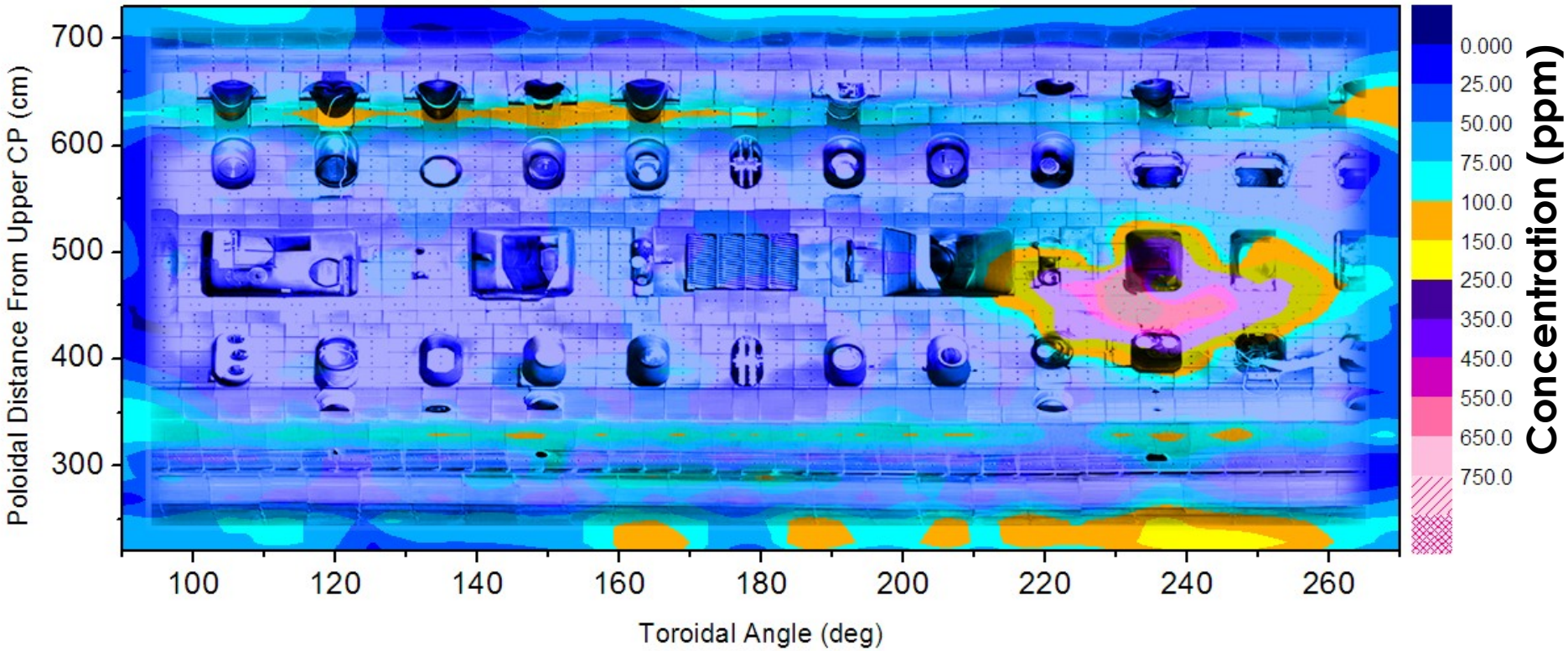
Damaged midplane probe head

Copper survey of outer wall and divertor area from 90 to 270 degrees



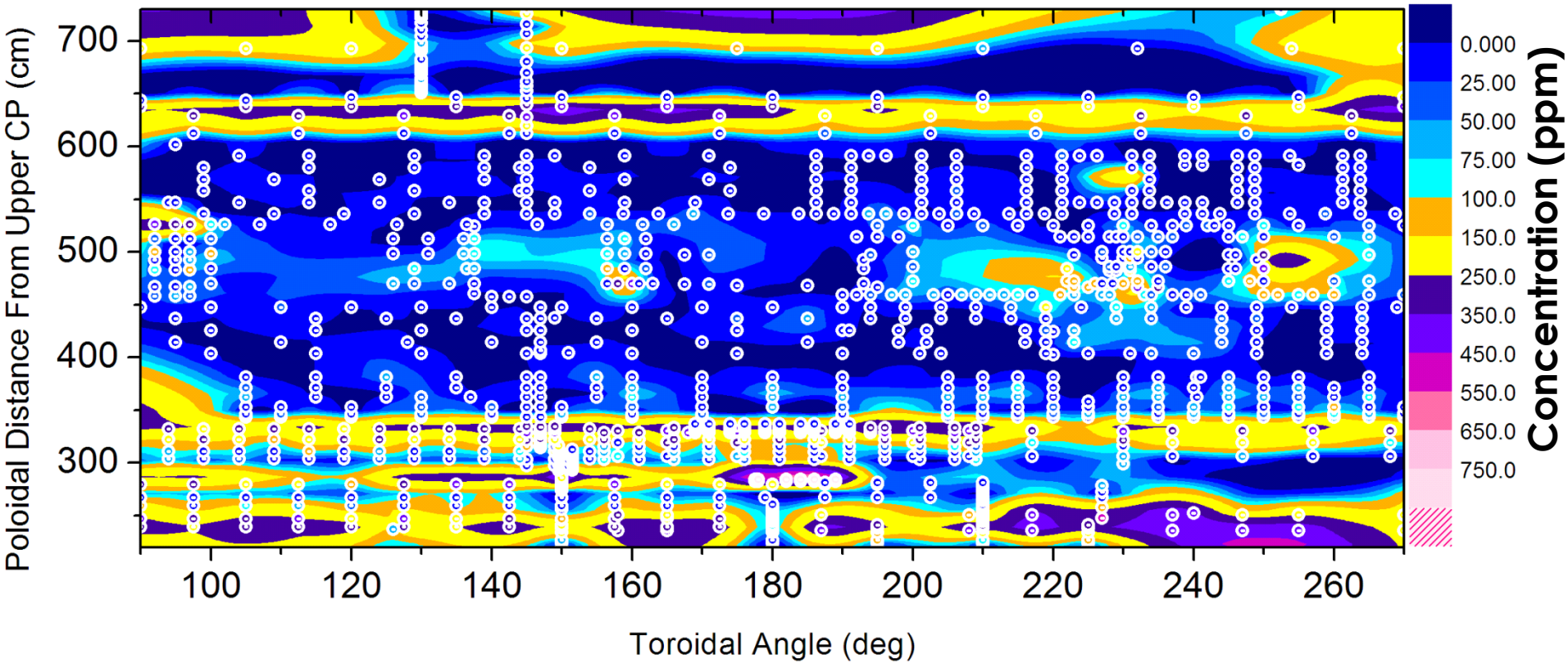
Main copper deposit near 240-degrees due to midplane probe damage
Upper and lower outer shelf, and upper and lower centerpost are toroidally symmetric deposit regions

Copper survey of outer wall and divertor area from 90 to 270 degrees



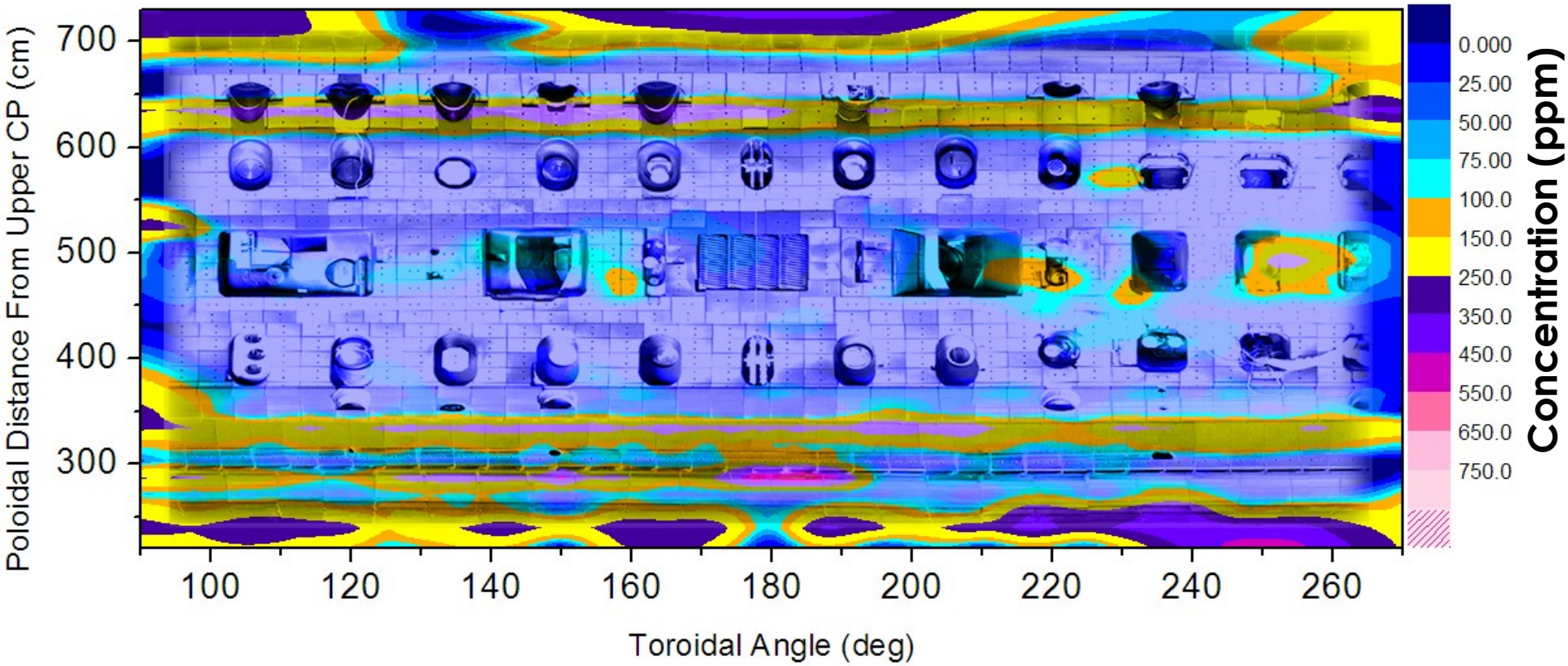
Main copper deposit near 240-degrees due to midplane probe damage
Upper and lower outer shelf, and upper and lower centerpost are toroidally symmetric deposit regions

Nickel survey of outer wall and divertor area from 90 to 270 degrees



Main nickel deposit are in upper and lower divertor, shelf, and centerpost regions.
Some scattered areas in the outer wall show above background.
Toroidal bumper limiters only slightly above background.

Nickel survey of outer wall and divertor area from 90 to 270 degrees



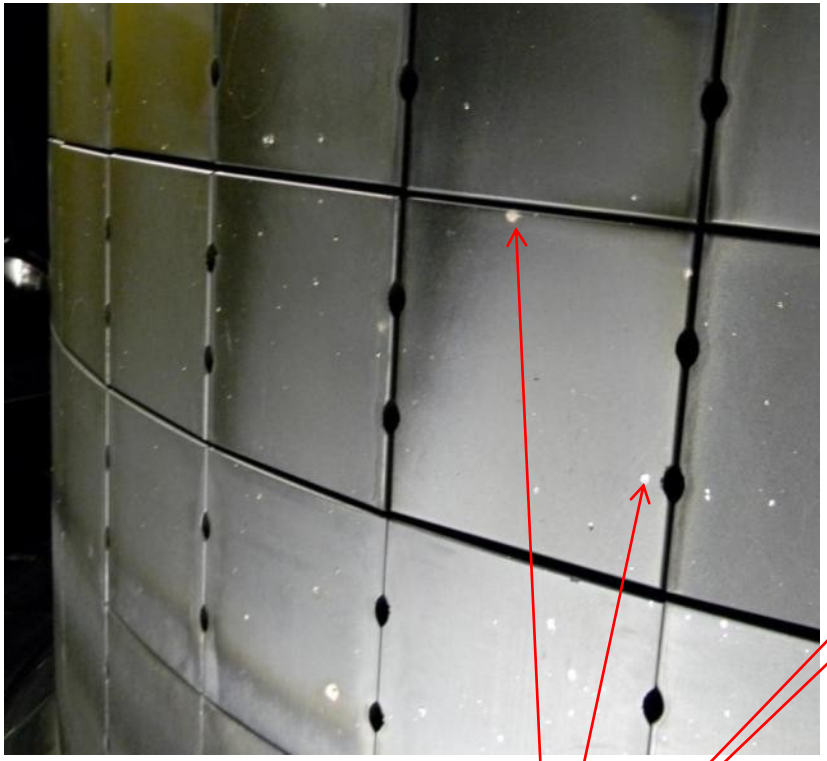
Main nickel deposit are in upper and lower divertor, shelf, and centerpost regions.
Some scattered areas in the outer wall show above background.
Toroidal bumper limiters only slightly above background.

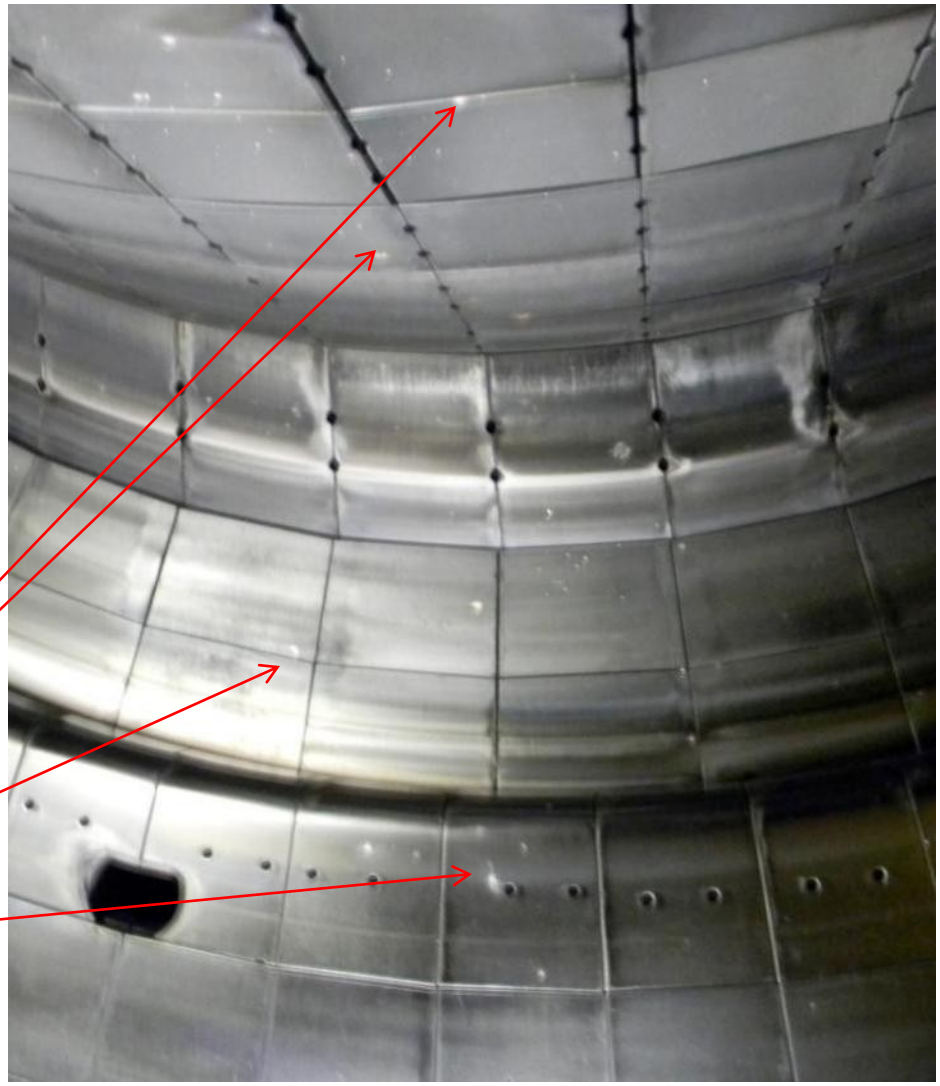
Conclusions

- Portable XRF and Beta Backscattering are complimentary tools for in-vessel surface analysis
- Multiple sources contributed to vessel wall impurity increase, but cause of plasma impurity increase is still being investigated.
- Impurities concentrate in upper and lower divertor regions, forming consistent deposition pattern seen previously
- Leading edges that receive higher particle flux also show higher levels of metal deposits.
- After tile sanding, 2012 Startup plasmas showed no significant increase in dust levels over previous years, and impurity levels decreased.

Supplementary slides

Sept 2011 Vessel Inspection Found Metal Splatter on Centerpost between 220-250 degrees

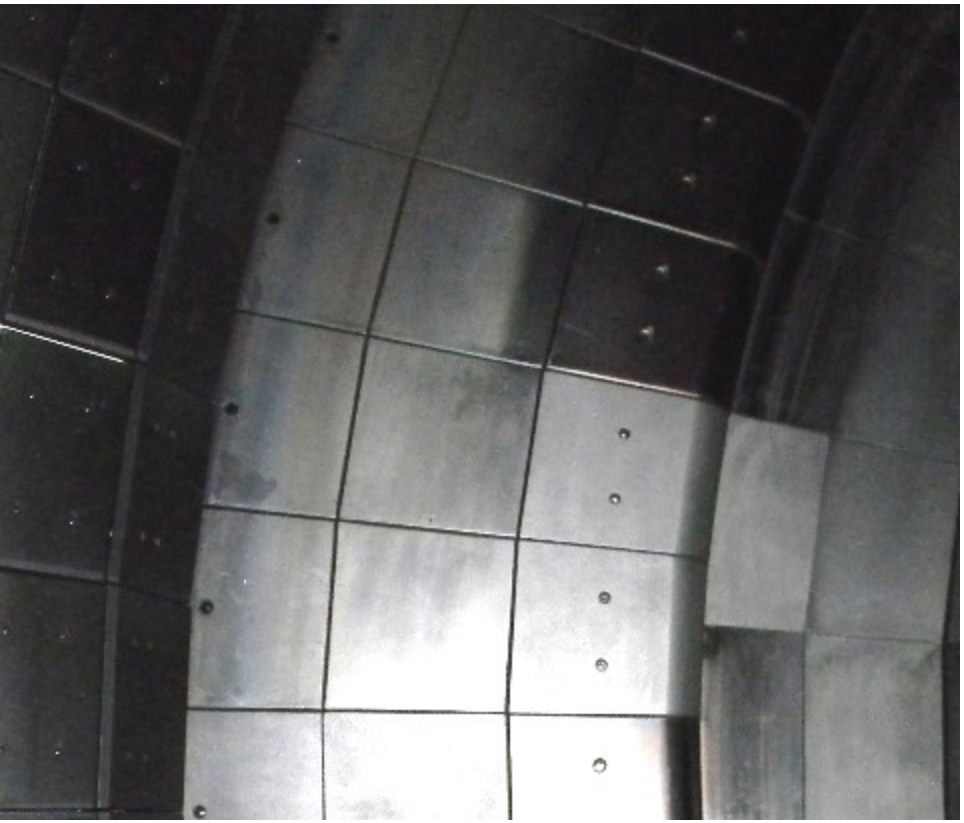




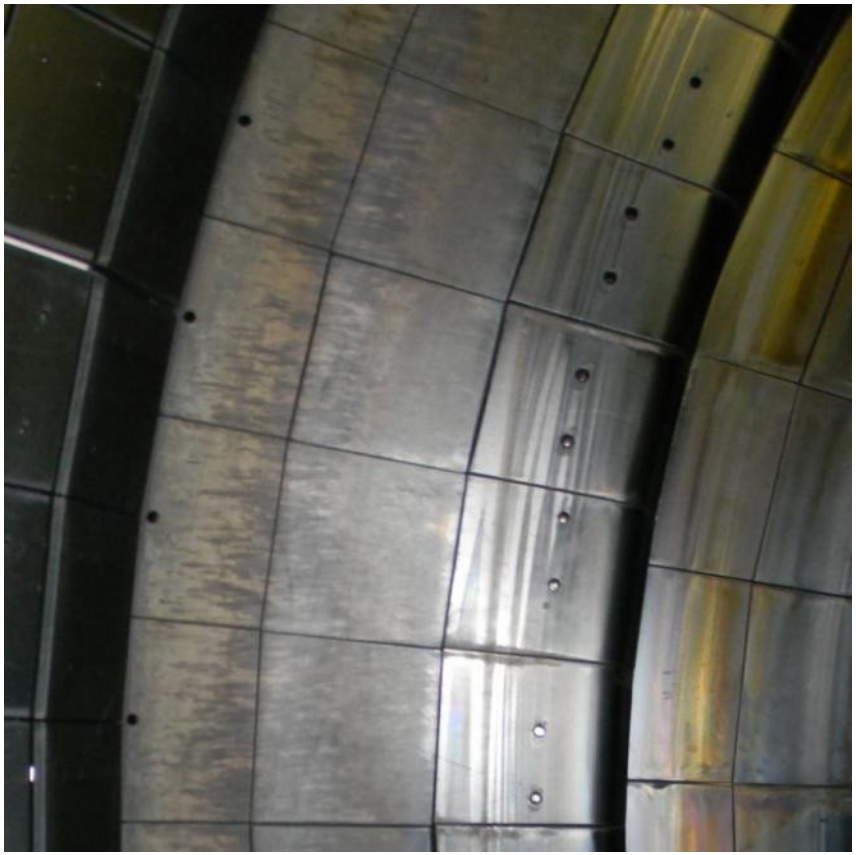
Inconel fragments removed with a simple scraping tool

Lower divertor had unusual striping, discoloration, and pronounced arc track erosion on outer shelf

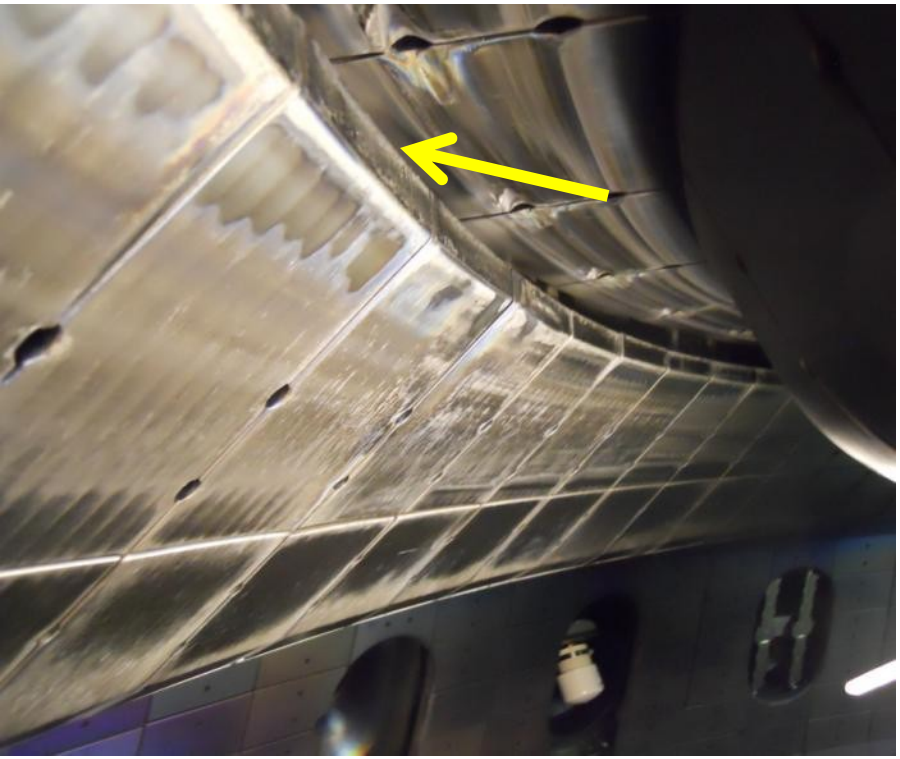
2010

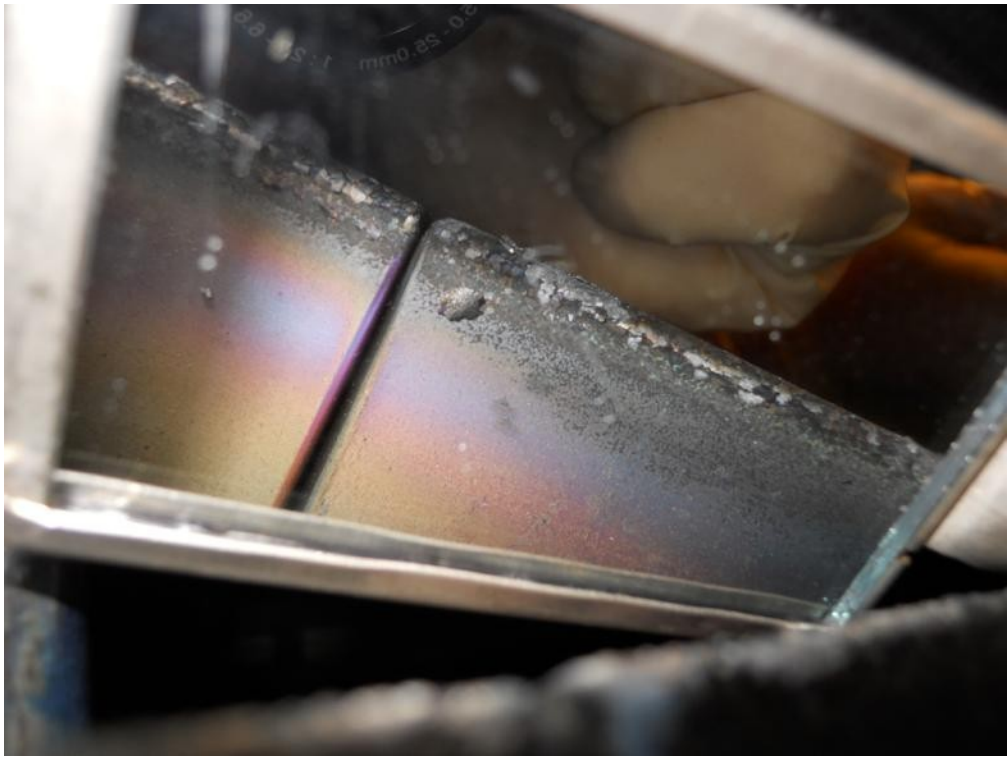


2011



Upper divertor has massive erosion at bolt hole edges, as well as flaky deposits

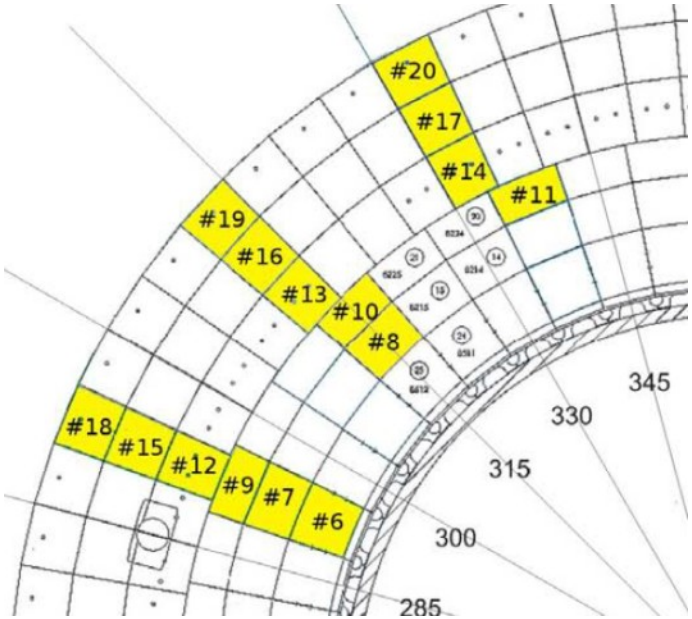


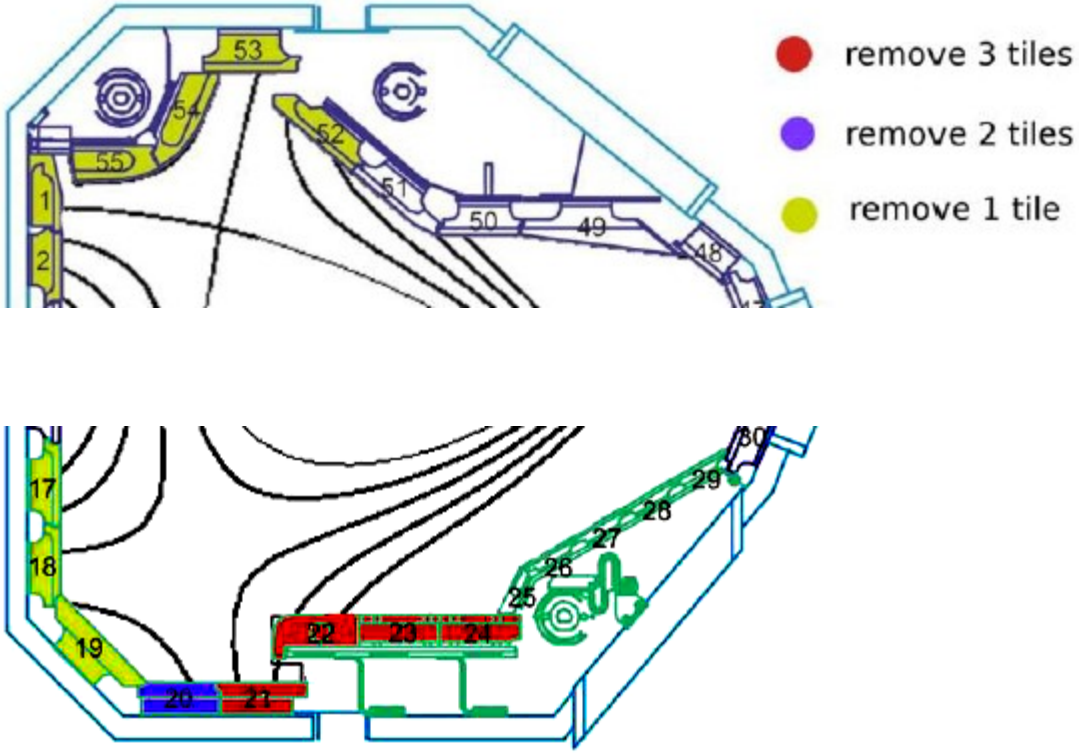


Deposits exfoliating in large flakes, resting gently on upper surface of baffle tile.

A limited set of tiles removed after 2010 campaign were available to measure for comparison

- Upper and lower divertor tiles located at 300-315 degrees toroidal
- Installed in 2006, Removed May 2010
- Provides a comparison of wall conditions before FY2011 campaign

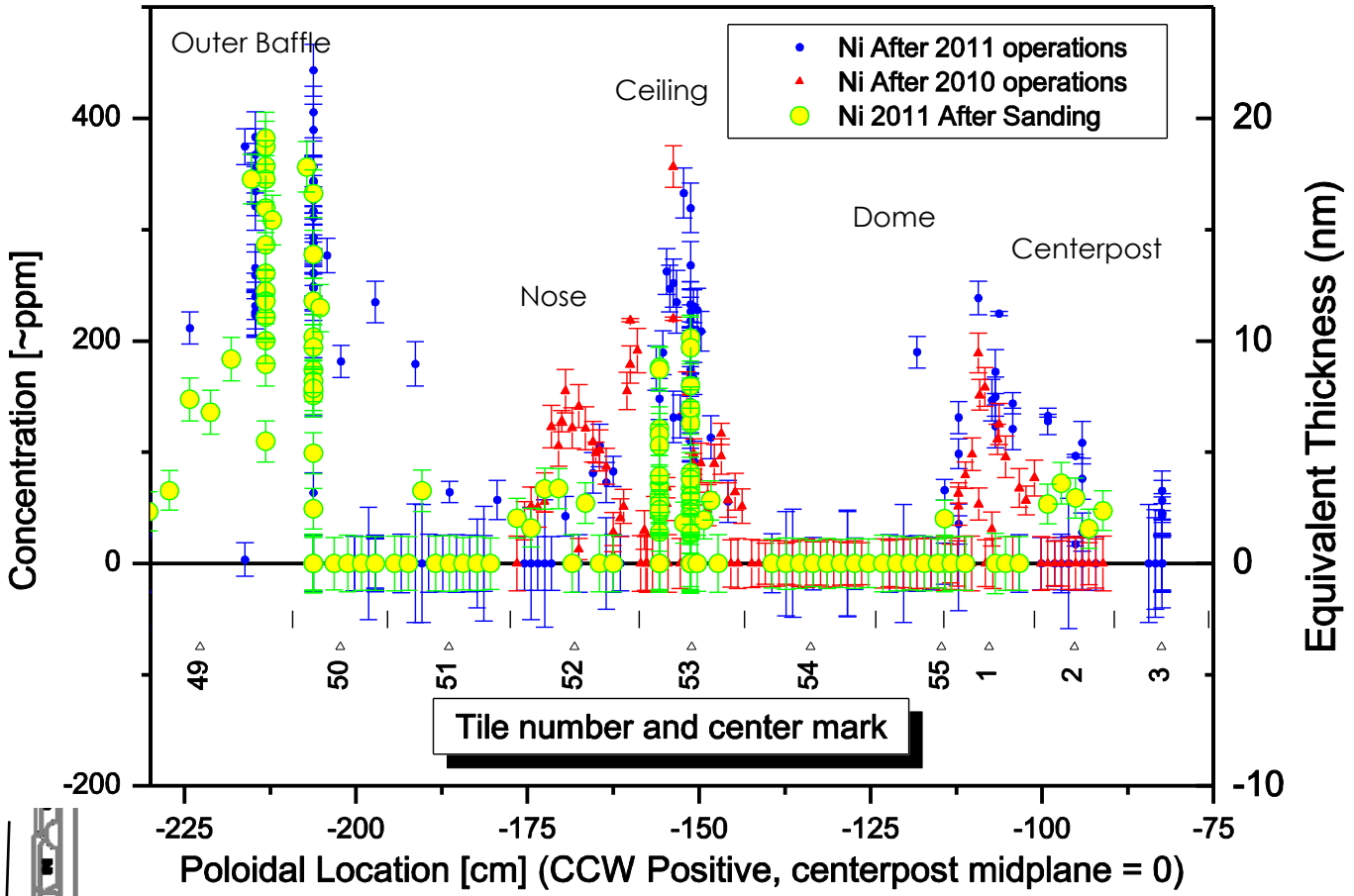


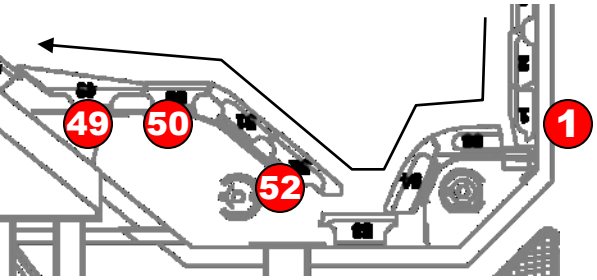


Contaminated tiles were cleaned by in-vessel and ex-vessel abrasives

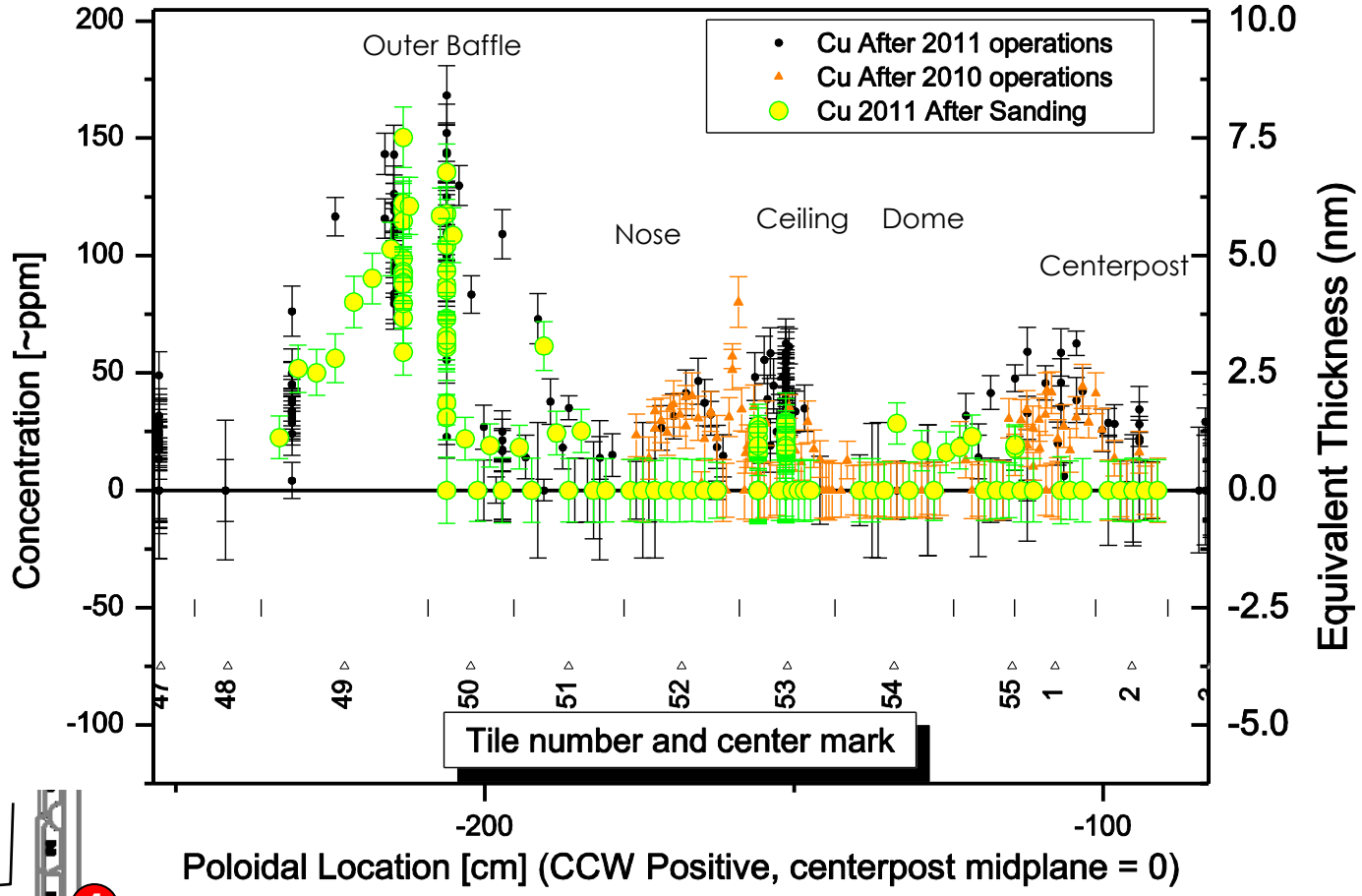
- Tiles were hand-sanded using a vacuum attached sanding block and frequently changed, heavily perforated SiC 150-grit paper
- All recessed ports taped up to prevent dusting up of windows and diagnostics.
- Personnel used Purified Air Powered Respirators with full face hoods and HEPA filtered air intake.
- Dust production was minimal and well managed.

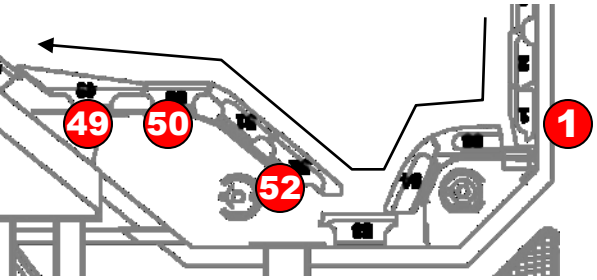
Upper Divertor Detail - Nickel



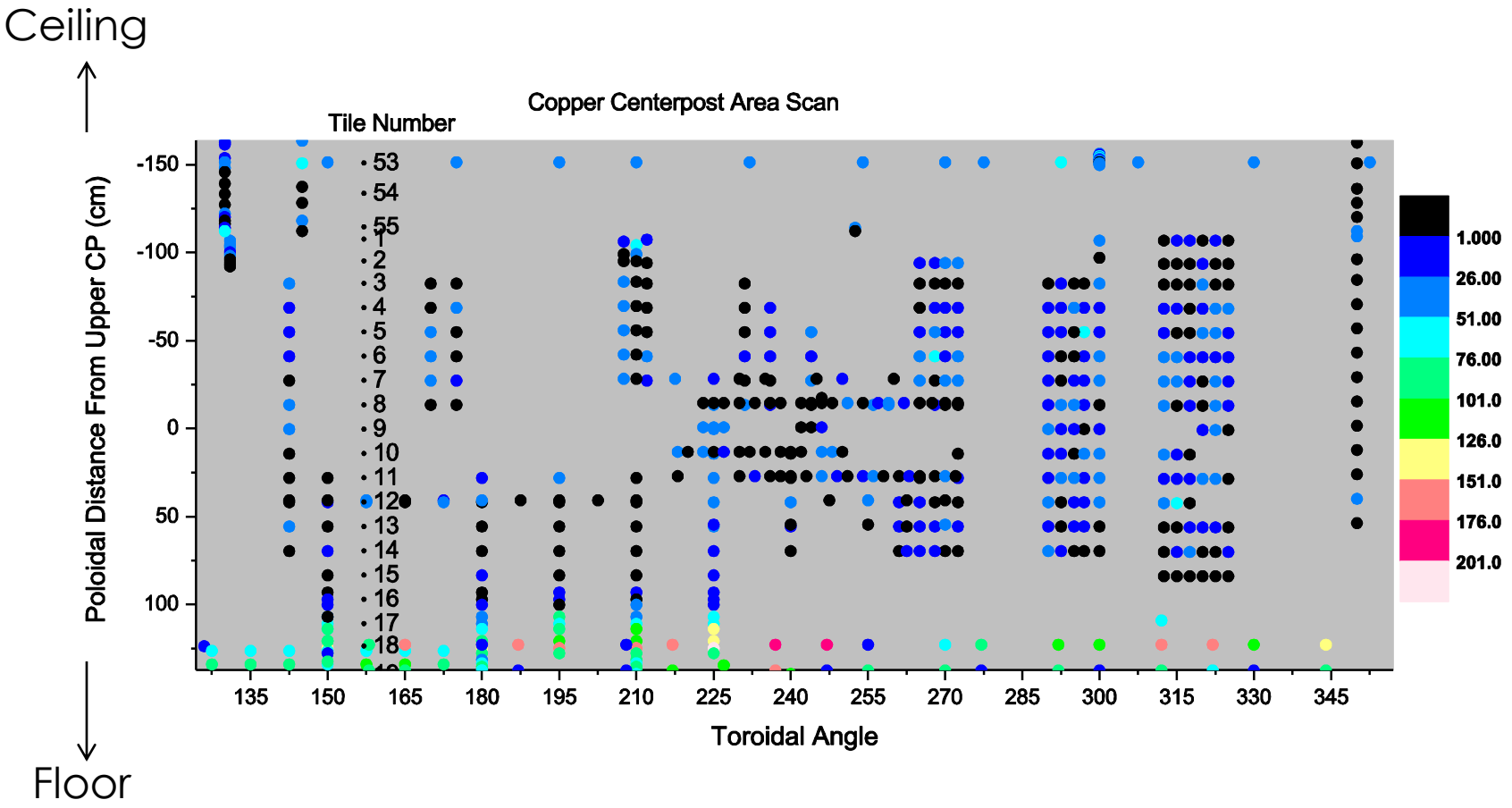


Upper Divertor Detail - Copper



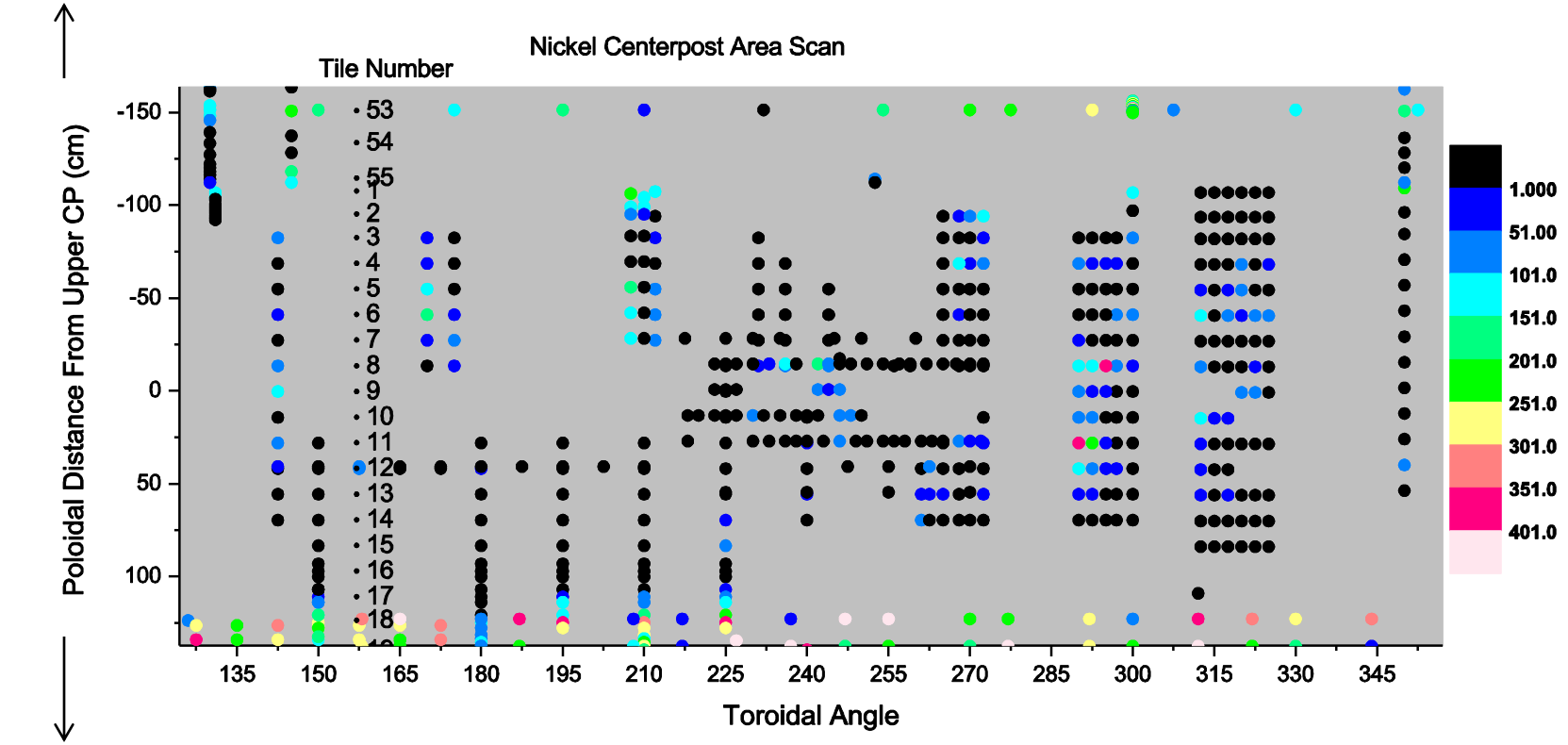


Copper Survey of Centerpost



Nickel Survey of Centerpost

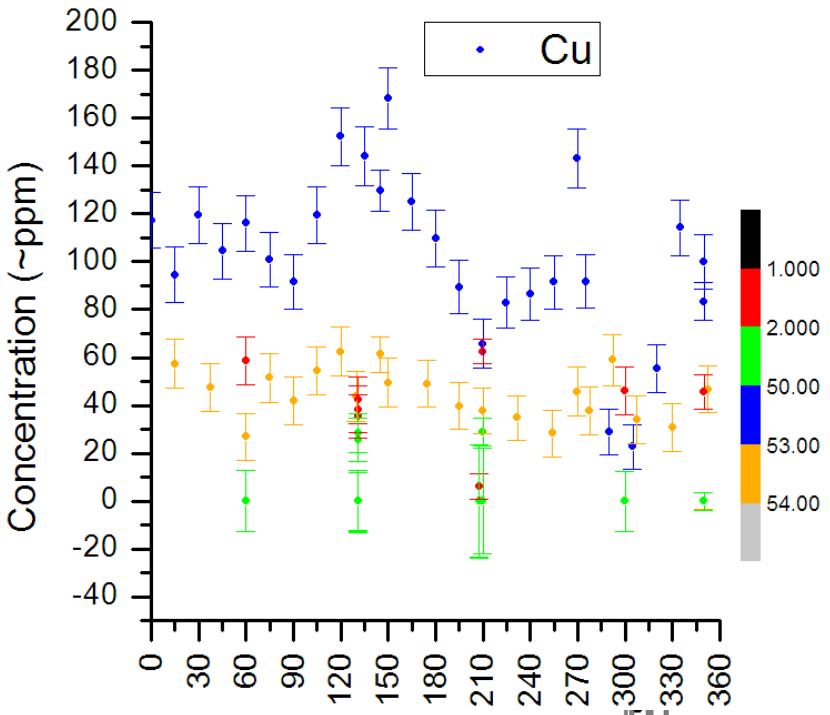
Ceiling

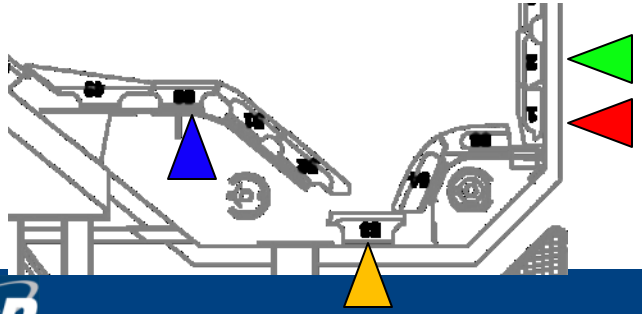


Floor

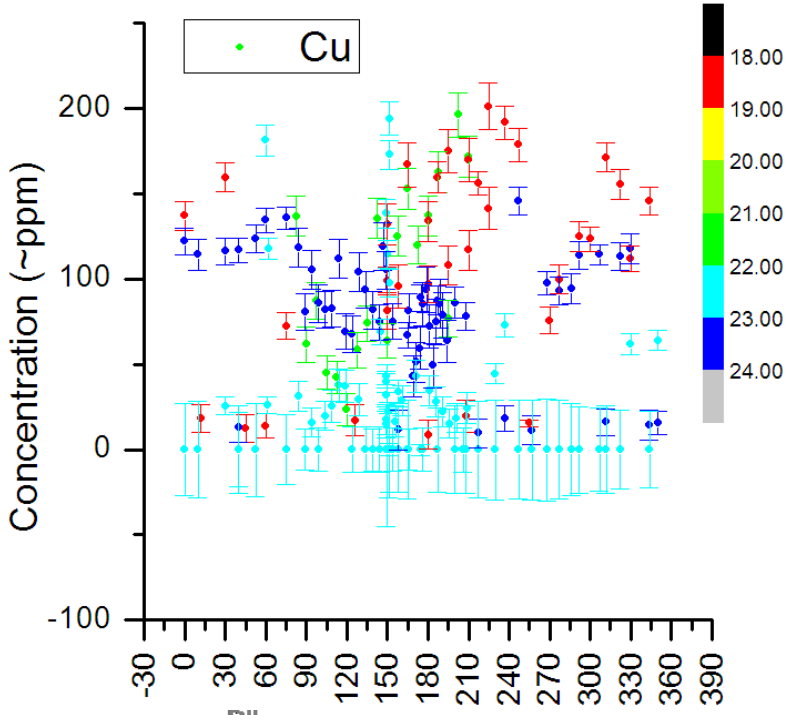
Copper distributed toroidally with minor local variations present and varying poloidally

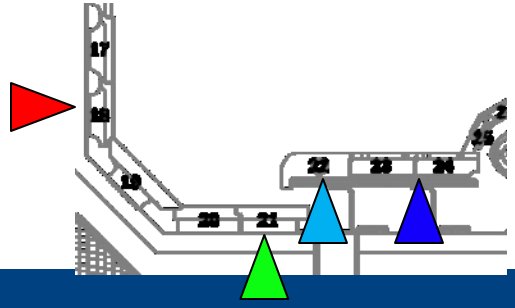
Upper Divertor





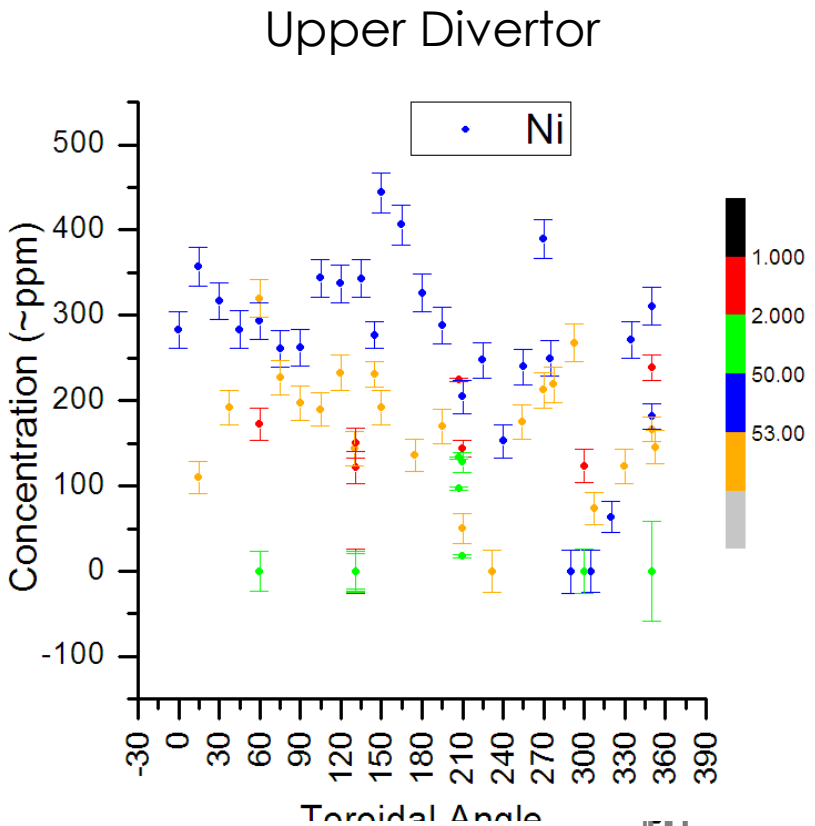
Lower Divertor

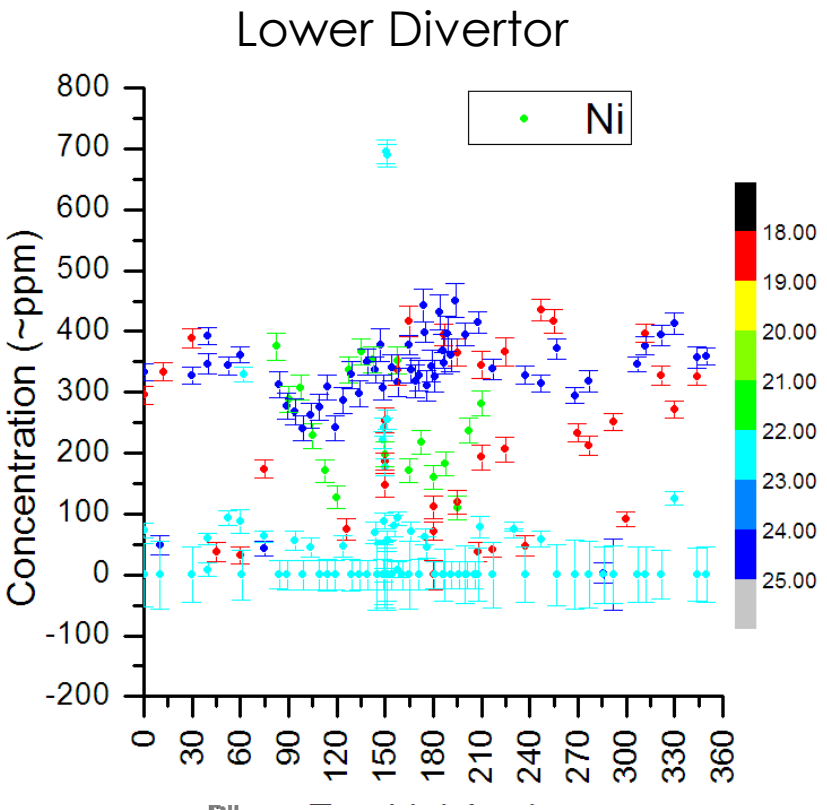


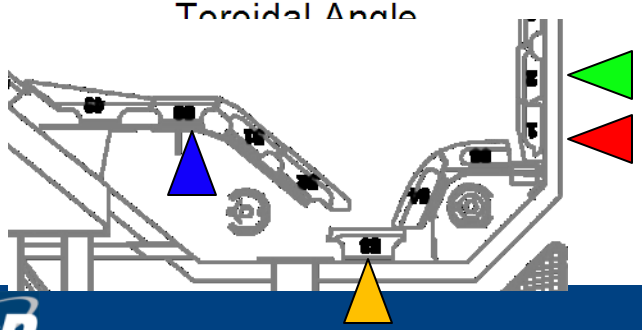


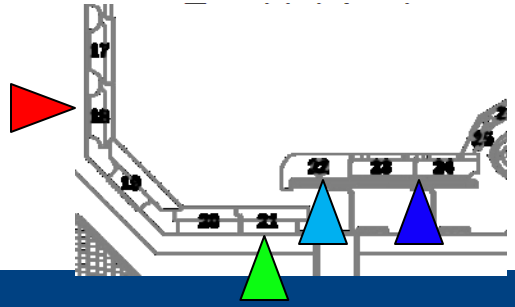
color-coded poloidal locations indicated

Nickel distributed toroidally with minor local variations present, different than copper









color-coded poloidal locations indicated

Toroidal distribution measured by beta backscattering is comparable

Measurements taken around outer lower shelf, on Tile 24.

Additional scatter in the data can be due to measurements on and off arc erosion tracks.