VACUUM PUMPING CROSSES AND KEYHOLE VACUUM CHAMBERS FOR THE APS-UPGRADE STORAGE RING VACUUM SYSTEM

Advanced Photon Source Upgrade, Argonne National Laboratory, Lemont, IL

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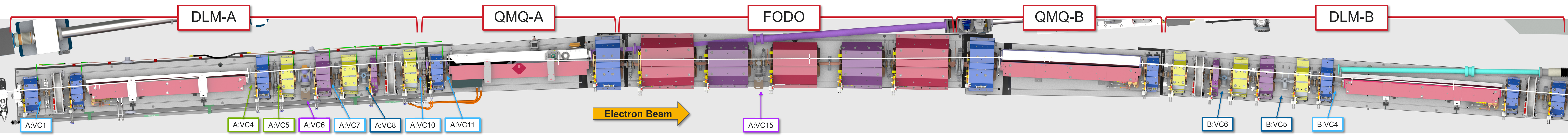
Austin McElderry, Brian Billett, Jason Carter, Oliver Mulvany

Standard APS-U Sector



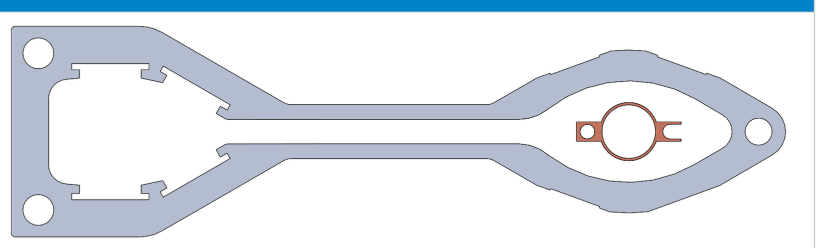
*Courtesy of Josh Downey

NEG-Coated Aluminum Chambers | NEG-Coated Aluminum Pumping Crosses | SST Keyhole Chambers | SST Specialty Pumping Crosses

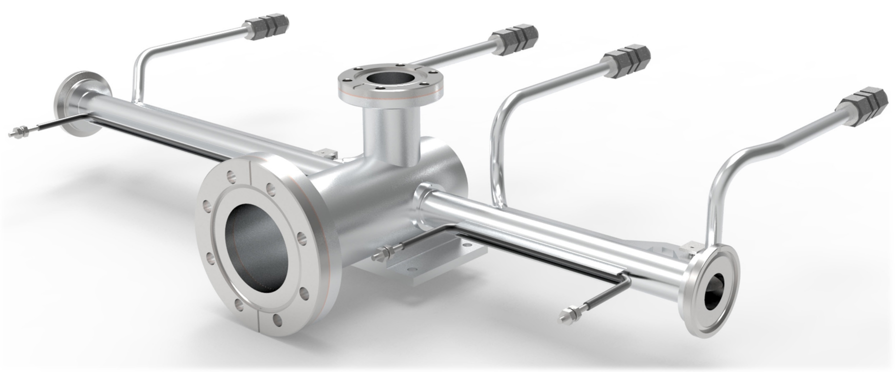
OVERVIEW

Advanced Photon Source Upgrade

- 6 GeV, 200 mA, 1.1 km circumference, optimized for brightness > 4 keV
- Change in scale from existing APS produced numerous engineering challenges



Existing 300 mm wide APS storage ring chamber compared to new APS-U chamber



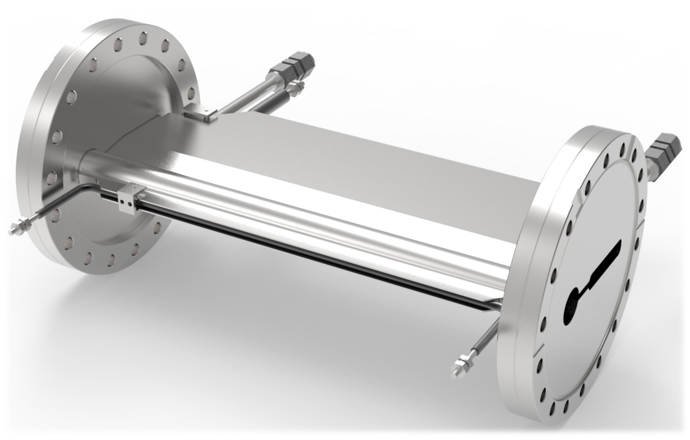
Aluminum pumping cross

Aluminum NEG-Coated Vacuum Chambers & Crosses

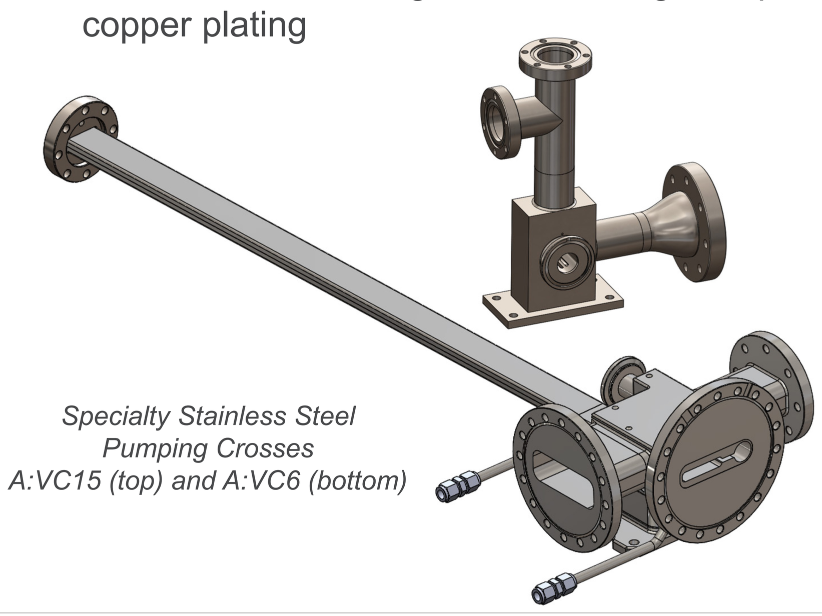
- Five chambers and three crosses per sector (320 total)
- Ø22 mm aperture, vary in length 289 mm – 792 mm
- Inline photon absorber built into the downstream flanges capable of small synchrotron heat loads (~40 W)
- Non-evaporative getter (NEG) coating for pumping in conductance limited system
- Inboard connection to the ion pump

Stainless Steel Keyhole Vacuum Chambers

- Two chambers per sector (80 total)
- Ø22 mm aperture with photon extraction antechamber, 300 mm – 350 mm long
- 316LN SST for strength and low magnetic permeability and internal copper plating



Stainless Steel Keyhole Chamber



Specialty Stainless Steel Pumping Crosses A:VC15 (top) and A:VC6 (bottom)

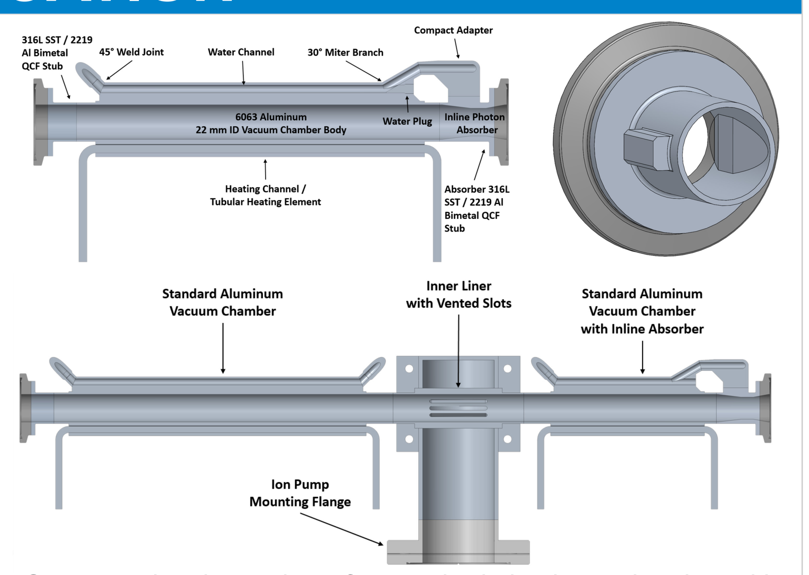
Specialty Stainless Steel Pumping Crosses

- Two chambers per sector (80 total)
- 316LN SST for strength and low magnetic permeability
- Internal copper plating within the Ø22 mm aperture
- Inboard connection to the ion pump
- A:VC15 connects to a turbo pump on top
- A:VC6 houses an outboard crotch absorber and contains a welded-on photon extraction tube

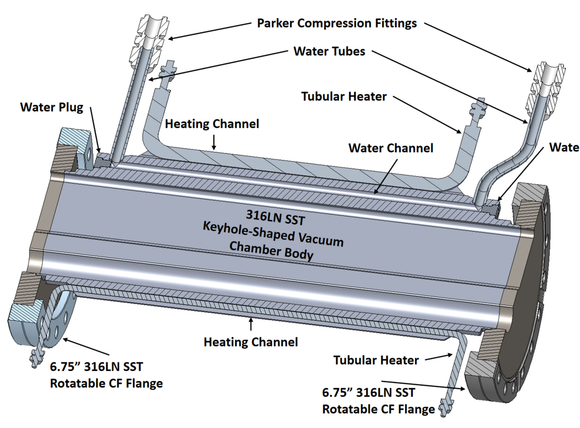
FINAL DESIGN & FABRICATION

Aluminum NEG-Coated Vacuum Chambers & Crosses

- Chamber body produced by three-cavity 6063 Al extrusion
- Ø22 mm cavity for electron beam, Ø5 mm cavities for outboard cooling and inboard tubular heaters for in-situ bakeout
- 316L SST/2219 Al bimetal Quick Conflat (QCF) flanges common across the APS-U storage ring
- Inline photon absorber sink EDM within the downstream flanges
- Prototyping and samples assisted in the development of the compact water-cooling scheme to the absorber
- Vendor weld samples indicated that the saddle weld joint between venting tube and cross body was not fully penetrated and risked NEG-coating quality
- Saddle joint changed to butt-weld joint similar to the A:VC15 design with better success



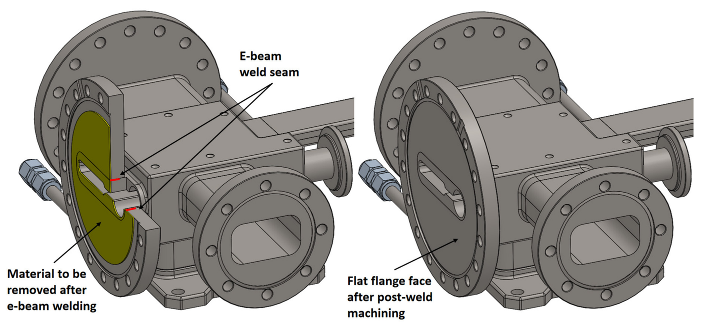
Cross-sectional overview of a standard aluminum chamber with inline absorber (top left), bimetal flange showing the inline photon absorber (top right), cross-sectional overview of an aluminum pumping cross (bottom)



Cross-sectional overview of a SST keyhole vacuum chamber

Stainless Steel Keyhole Vacuum Chambers

- Original final design required the chamber body to be wire EDM with the flanges brazed-on
- Production design incorporated vendor proposed e-beam welding perpendicular to the flange face; chamber body is milled from outside instead
- Interior is electroplated with copper
- Design features two heaters for better bakeout temperatures and passive water cooling

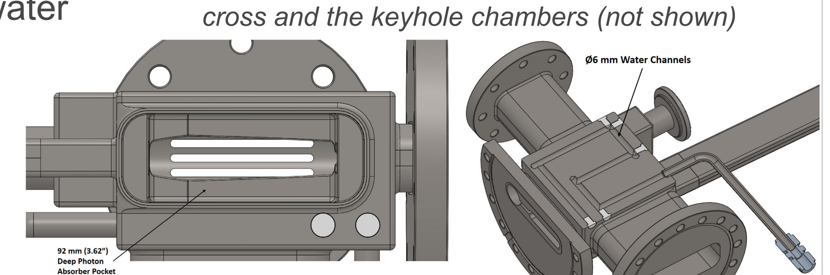


Explanation of the flange e-beam weld for the A:VC6 cross and the keyhole chambers (not shown)

Specialty Stainless Steel Pumping Crosses

A:VC6

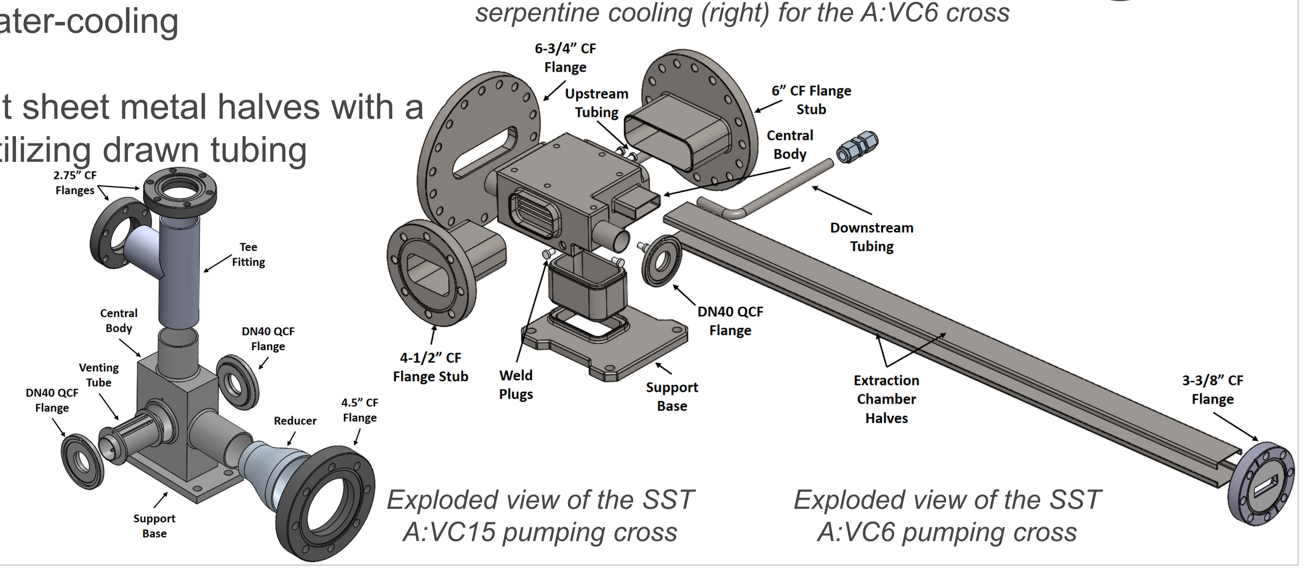
- Complex cross that houses a crotch absorber and ion pump
- Transitions the photon beam from the keyhole aperture to the extraction chambers towards front ends
- Main cross body requires plunge EDM to create absorber pocket and milling for the pumping slots and underside water-cooling
- Keyhole-side flange is e-beam welded
- Extraction tube originally consisted of two bent sheet metal halves with a longitudinal e-beam weld; vendor is instead utilizing drawn tubing
- Interior is electroplated with copper



Deep pocket for discrete crotch absorber (left) and serpentine cooling (right) for the A:VC6 cross

A:VC15

- Simpler SST cross similar in geometry as aluminum cross production design
- Venting tube is e-beam welded to achieve full penetration weld seams
- Interior is electroplated with copper

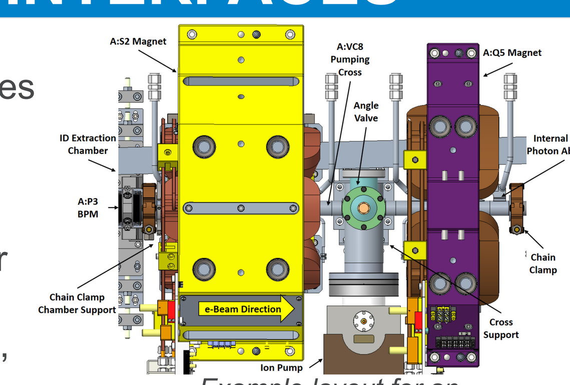


Exploded view of the SST A:VC15 pumping cross *Exploded view of the SST A:VC6 pumping cross*

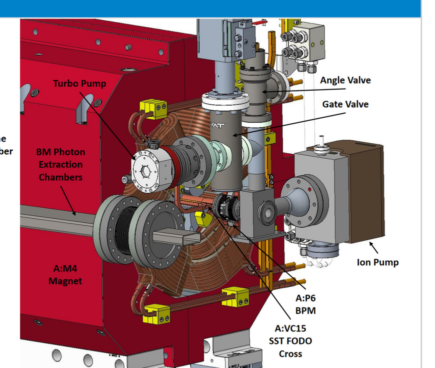
INTERFACES

Interfaces

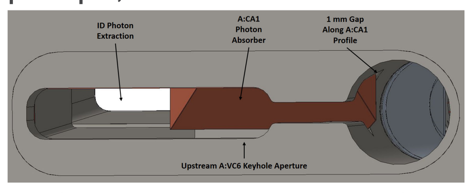
- Magnets: sextupole and quadrupoles for the specified chambers
- Water-cooling system
- Electrical bakeout system
- Other vacuum components: copper and Inconel chambers, discrete photon absorbers, BPMs, supports, pumps, etc.



Example layout for an aluminum pumping cross



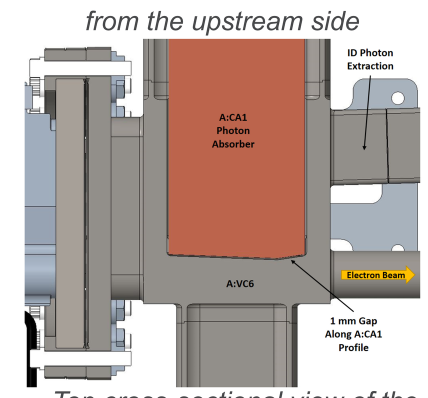
Layout for the A:VC15 SST pumping cross



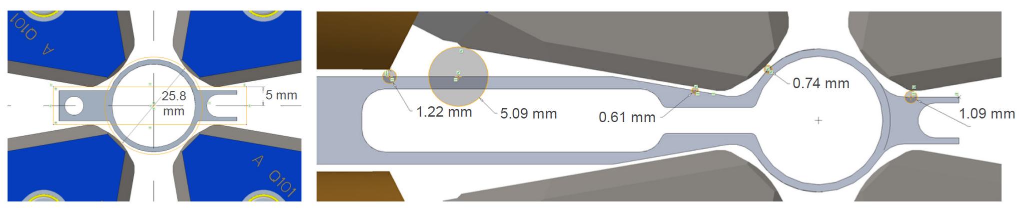
View of the absorber within the A:VC6 cross from the upstream side

Challenges

- Magnet bore gaps <1 mm in most instances
- In-situ electrical bakeout necessary due to limited accessibility
- Compact water routing weaving through magnets and neighboring components
- Consideration for impedance, arcing, and machining tolerance for the A:VC6 absorber pocket

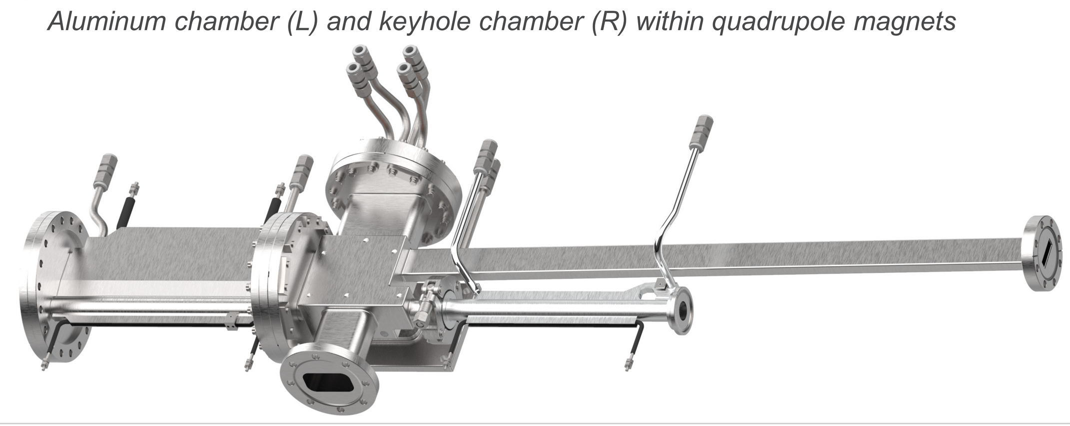


Top cross-sectional view of the discrete photon crotch absorber within the A:VC6 cross body

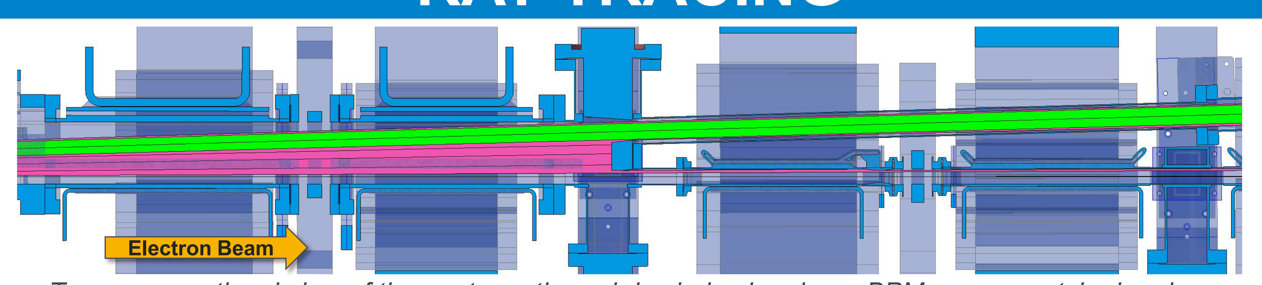


Aluminum chamber (L) and keyhole chamber (R) within quadrupole magnets

String of components: A:VC5 keyhole chamber (L), A:VC6 cross + absorber (M), A:VC7 aluminum chamber (R)

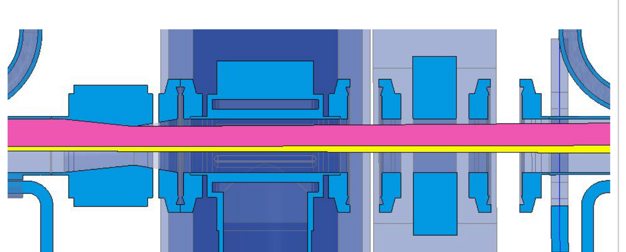


RAY TRACING

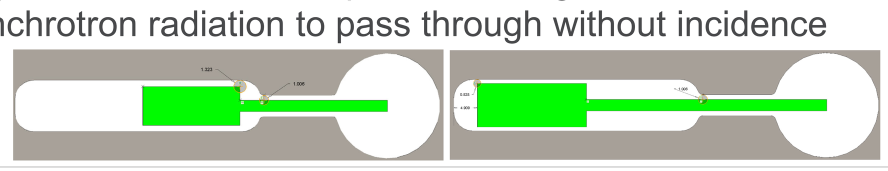


Top cross-sectional view of the ray trace through keyhole chambers, BPM, cross+crotch absorber, aluminum chambers, and photon extraction chambers

- 3D ray tracing layout integrated into a CAD skeleton model system
- Allowed for efficient adjustments to heat load footprints and shadowing
- Heat loads verified with SynRad and analytical calculations
- 0 – 160 W/m heat densities for aluminum chambers
- 98 W (8.1 W/mm^2 heat flux) maximum heat load incorporating missteering for aluminum pumping cross
- Keyhole and extraction apertures designed to allow synchrotron radiation to pass through without incidence



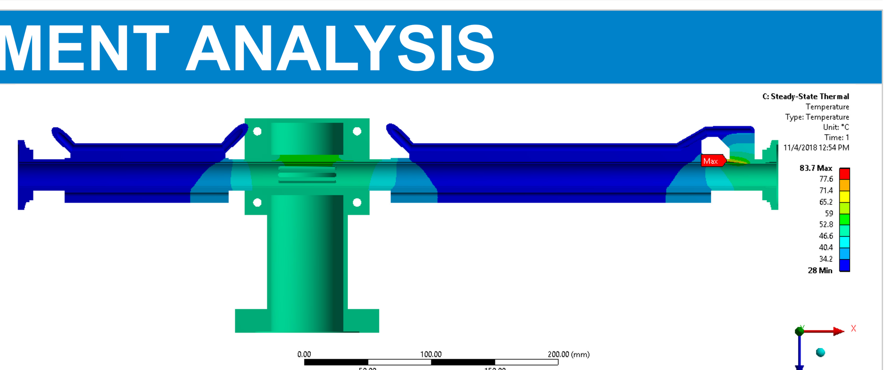
Top cross-sectional view of the ray trace through a copper chamber, cross, and BPM demonstrating shadowing from an inline absorber



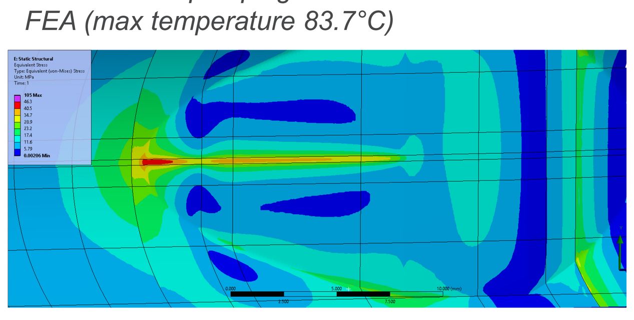
Upstream (left) & downstream (right) beam envelopes for the two keyhole chambers

FINITE ELEMENT ANALYSIS

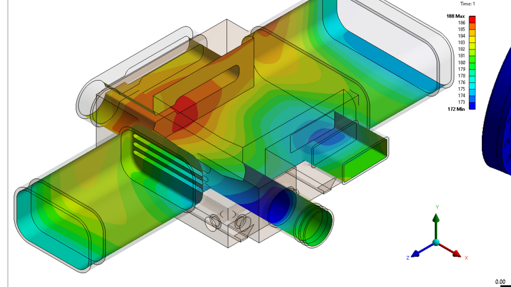
- Designs analyzed during operating conditions, bakeout, and buckling
- Models were partitioned for mesh quality control along the beam heat load application site and thin chamber walls
- Synchrotron radiation heat flux imported to the application site
- Turbulent water-cooling heat transfer coefficient applied to channels
- Atmospheric pressure, water pressure, and constraints also applied
- Sliver models used for simple buckling evaluation for keyhole chambers and rectangular extraction tubes



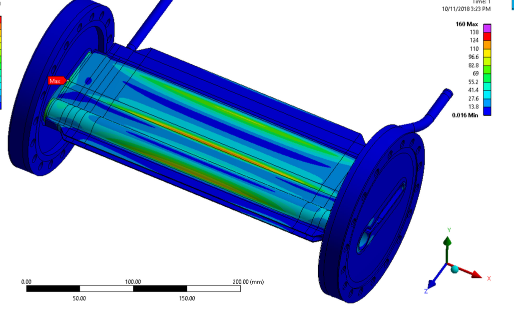
Temperature results of the Al pumping cross thermal-structural FEA (max temperature 83.7°C)



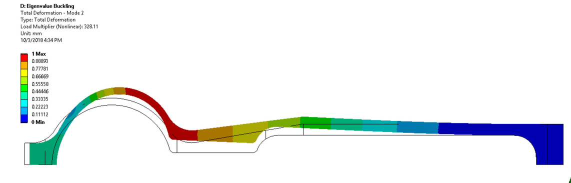
Von-Mises stress results of the Al inline absorber thermal-structural FEA (max stress 46.3 MPa)



Temperature results from A:VC6 cross bakeout analysis (max 188°C, min 172°C)



Von-Mises stress results of the keyhole structural FEA (max stress 135 MPa)



Results of the keyhole buckling analysis; critical load is 328 atm

CONCLUSION

The APS-U is confident with the expected performance of the components presented in this paper. All components have been extensively designed, analyzed, and reviewed. At the time of this publication, most first article chambers have arrived at the APS with the production batches expected through 2022.

U.S. DEPARTMENT OF ENERGY

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