In-situ Surface Contamination Removal and Cool-down Process of the DEAP-3600 Experiment

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DEAP-3600 Collaboration

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Particle Physics Rutherford Appleton Laboratory

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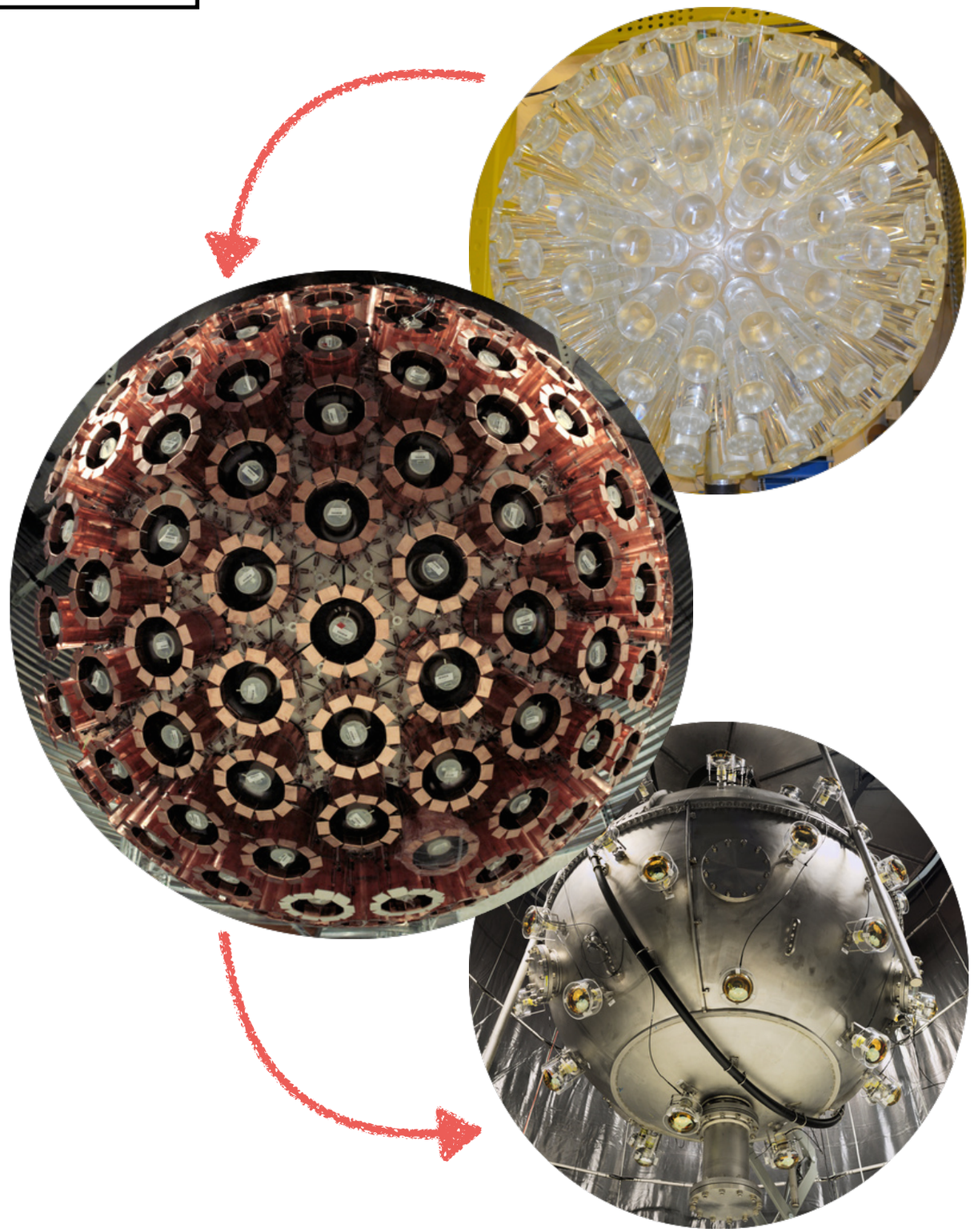
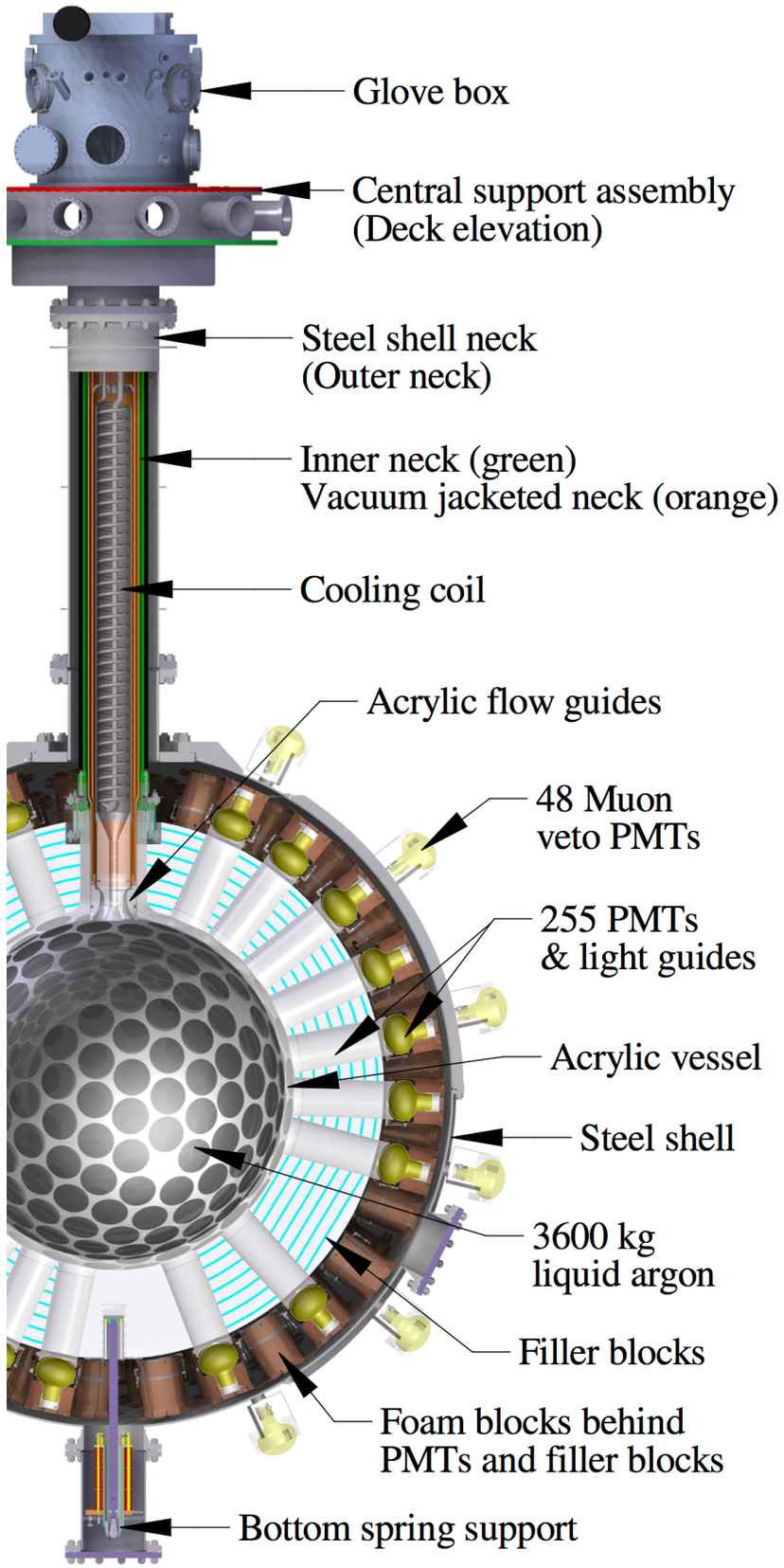
Outlook

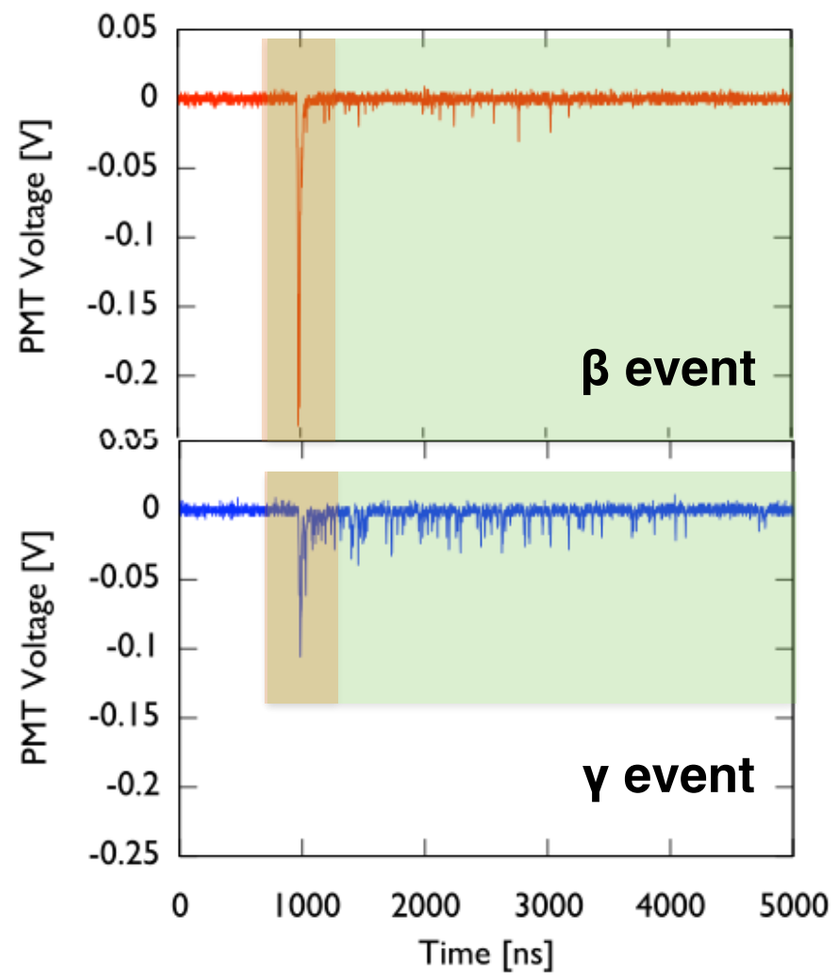
- Introduction
- The Resurfacer
  - Motivation
  - Design
  - Operation
- Cool-Down Process
  - Challenges
  - Hardware
- Conclusions

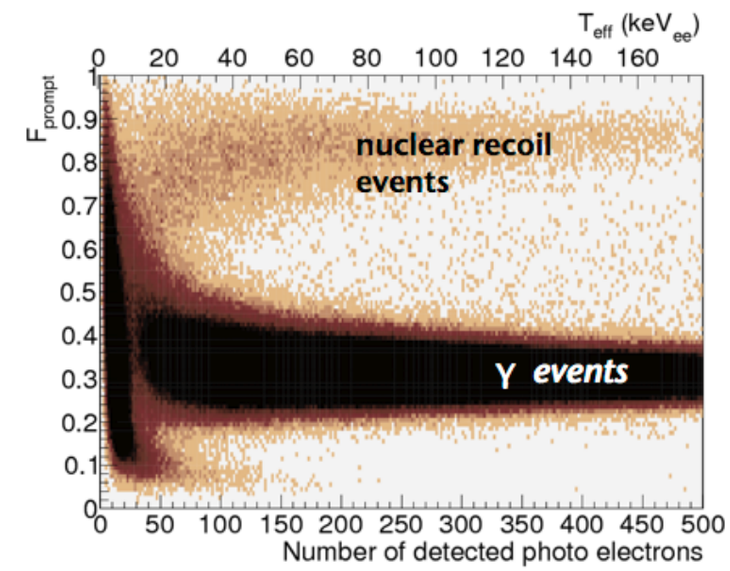


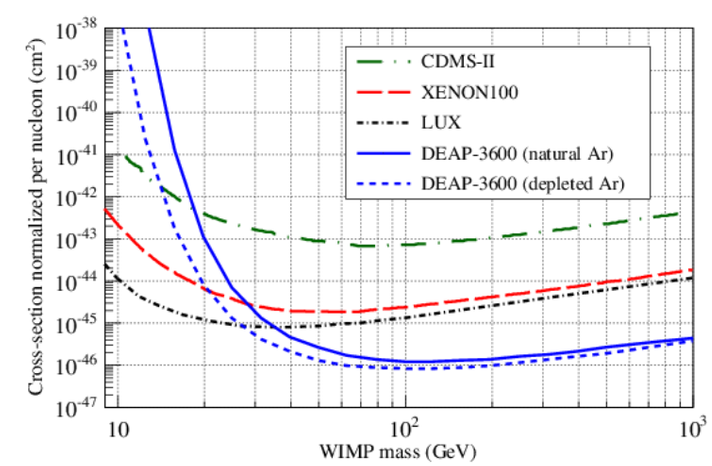


Introduction

- First ton scale Dark Matter detector to complete construction.
- Single Phase LAr, target contained within an acrylic vessel (AV).
- 255 Hamamatsu R5912 HQE PMTs 8".
- Acrylic light-guides (LG) and Filler Blocks (FB) provide neutron shielding.
- Inner detector sealed inside a Stainless Steel vessel, which is mounted with 48 veto tubes.
- 402 m² Ultra-pure Water (UPW) shielding tank.
- Pulse-Shape Discriminator (PSD), strongest weapon.
- Sensitivity of 10^{-46} cm² (SI) for 100 GeV WIMP.







The Resurfacer : Motivation

The acrylic used for the AV was carefully fabricated in a low Rn environment, with a control to $<10^{-20}$ g/g ^{210}Pb from Rn exposure.

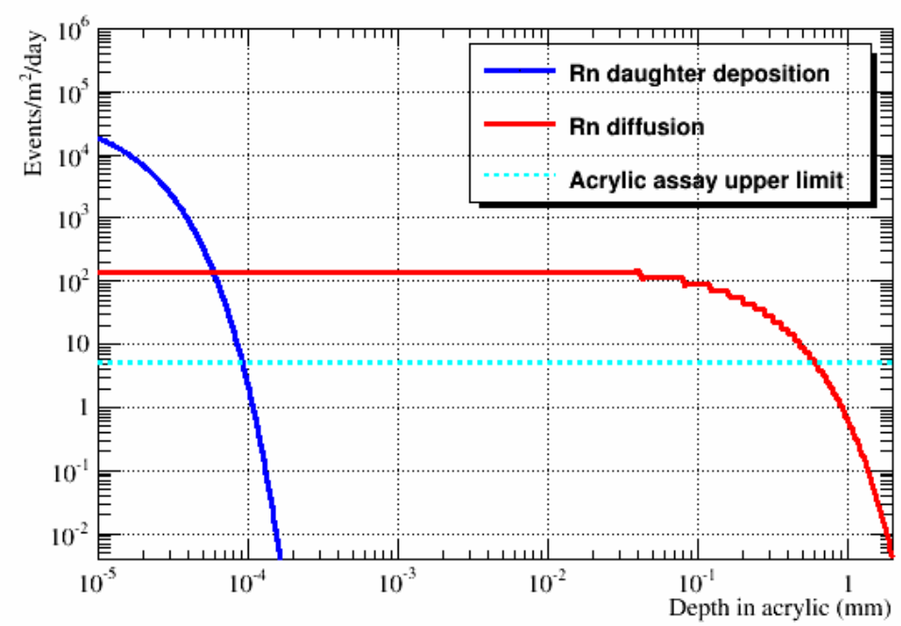
Some installation tasks had the inner AV exposed to air (131.0±6.7 Bq/m^3).

Rn daughter deposition (d)

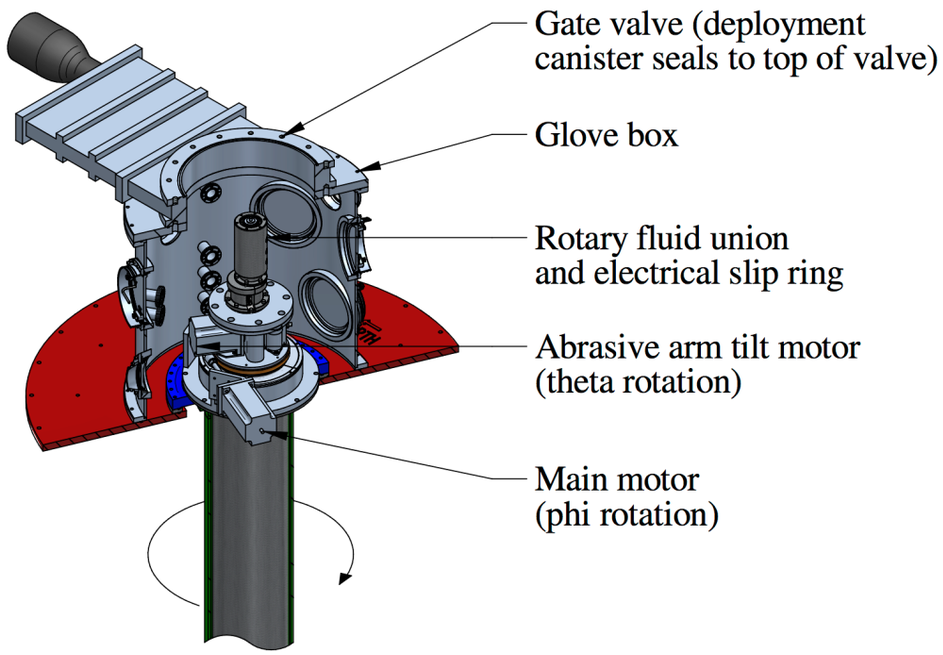
$$d = \epsilon S C$$

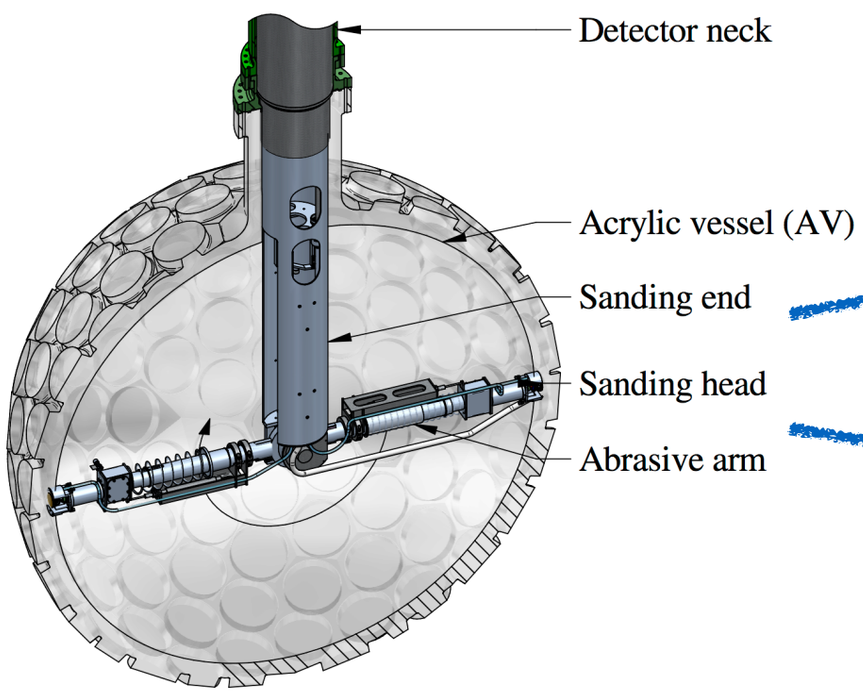
Rn diffusion (F)

$$F = -D\frac{\partial C}{\partial x}$$



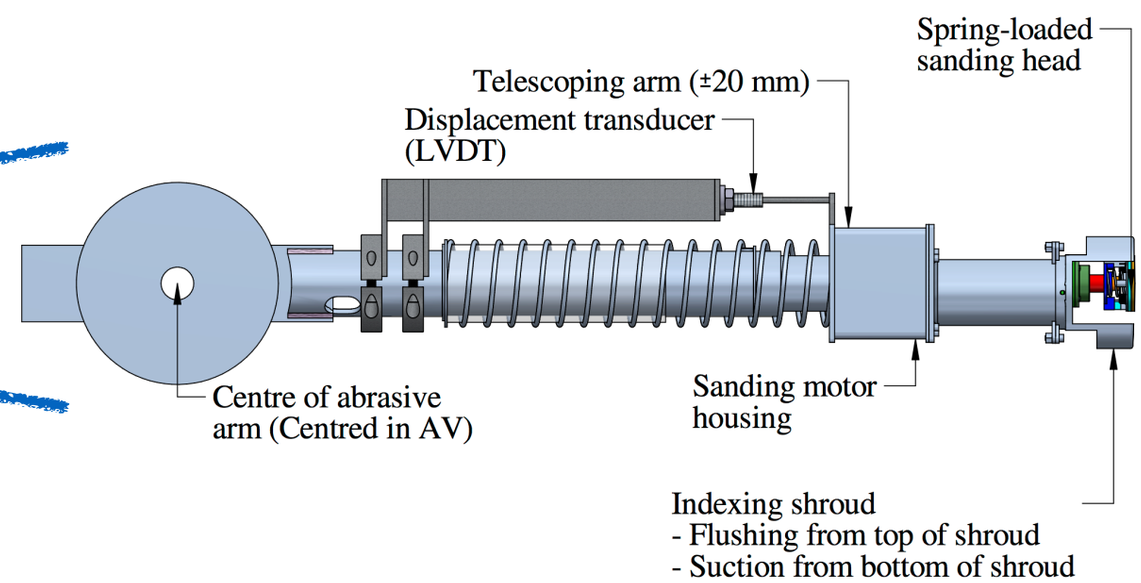
The Resurfacer : Design





Key Features :

- Sanding arms specifically designed to maintained constant pressure on the acrylic surface.
- Sanding arms were mounted with LVDT displacement transducers to carefully measure the removal rate.
- Full system dedicated to deliver and extract ultra-purified water (UPW) to the sanding heads.
- Rotating coupling at top allows transmission of fluids and electrical connections while maintaining vacuum rated seal.
- All electrical connections and motors were water resistant.
- Rn emanation test was performed on all components used for this custom made robot.
- Sanding efficiencies methodically measured with a series of ex-situ tests for each individual sanding arm.
- Insertion/extraction via deployment system.



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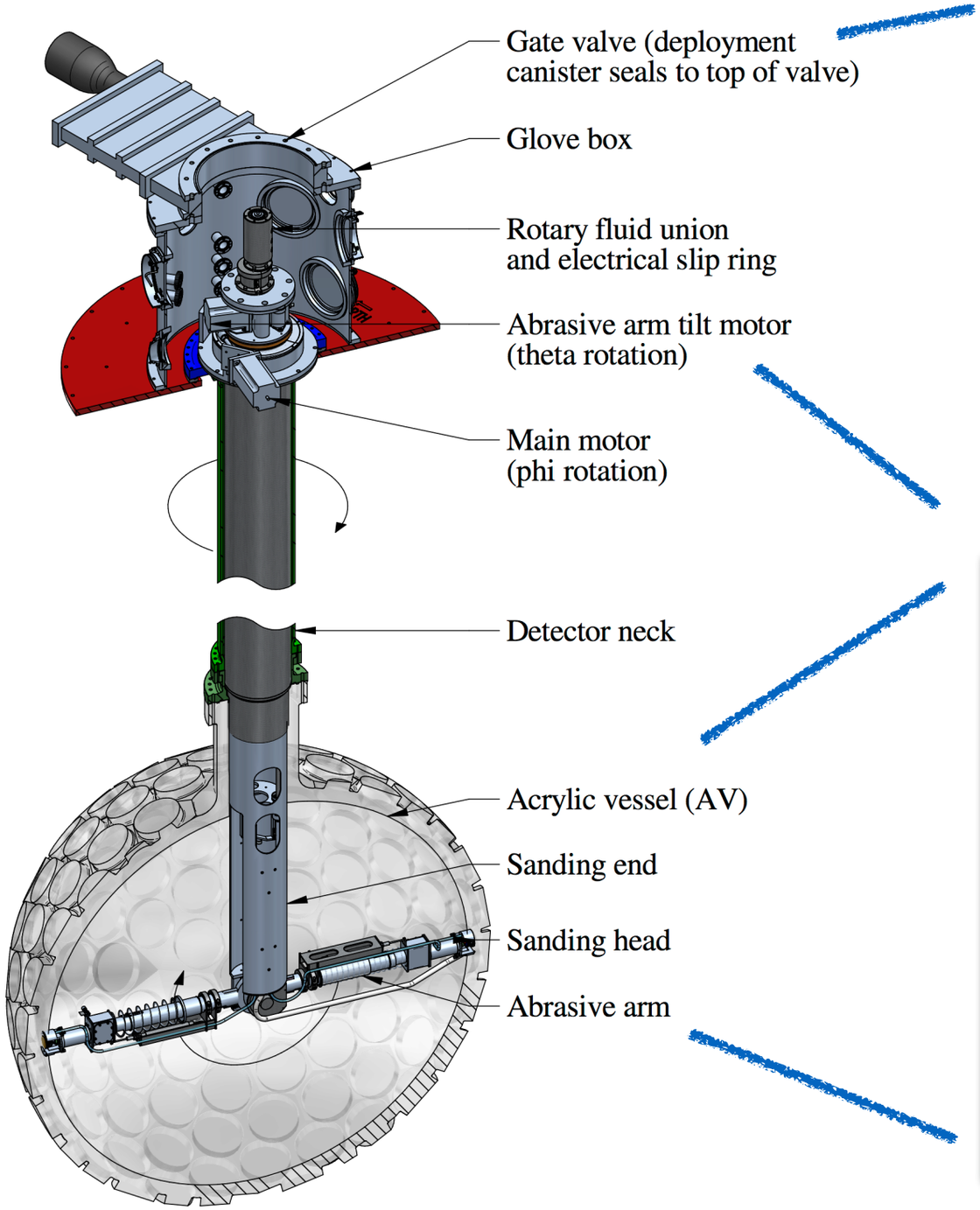
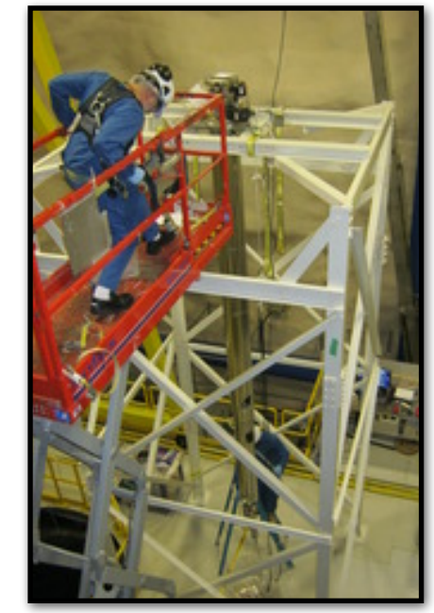
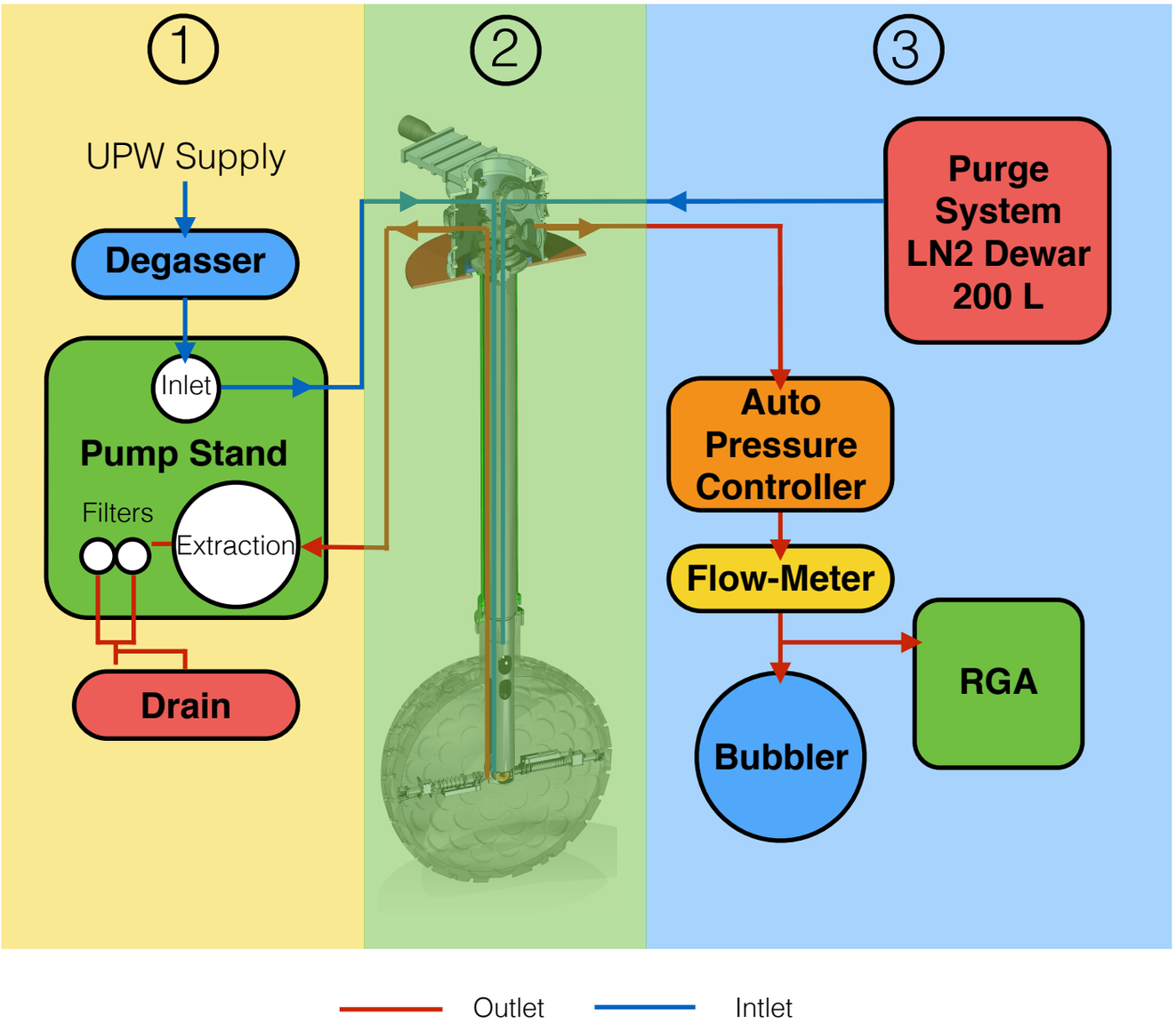




The Resurfacer : Operation

Operational Diagram

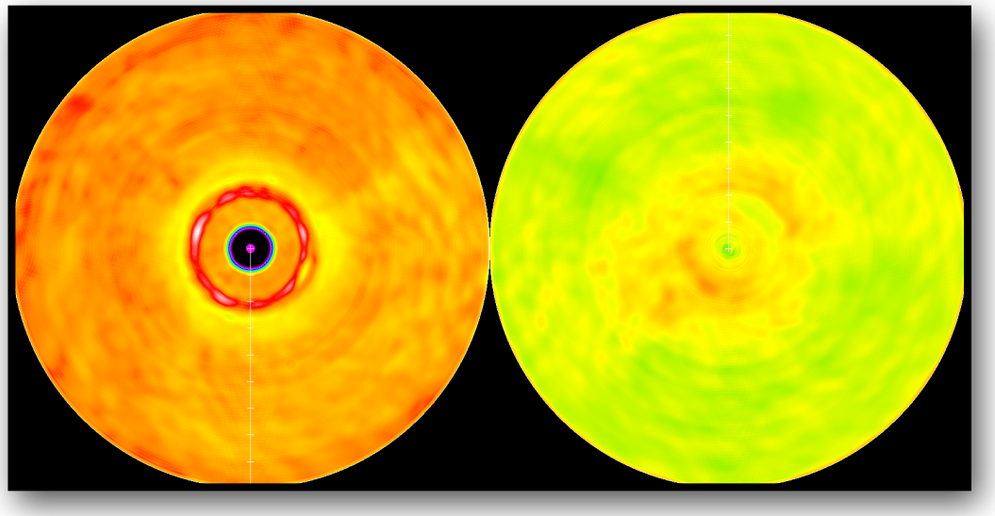


Resurfacer System:

1. Fluids Section: *A series of pumps deliver and extract degassed UPW to and from the AV. Extracted UPW goes through filters that collect the removed acrylic.*
2. Mechanical Section: *Includes the rotating coupling connection at top that allows to maintain fluids and electrical connections while keeping vacuum seal.*
3. Purge Gas Section: *AV is kept at 3 psig positive pressure with ultra-purified N2 gas (0.039 mBq/m3).*

Operation:

- Successfully ran the Resurfacer for over 200 hours.
- Removed 500 microns of acrylic from the most inner surface of the AV.
- Inner AV surface contaminations reduced by a factor of 2000.
- AV was never exposed to lab air during and after operation.



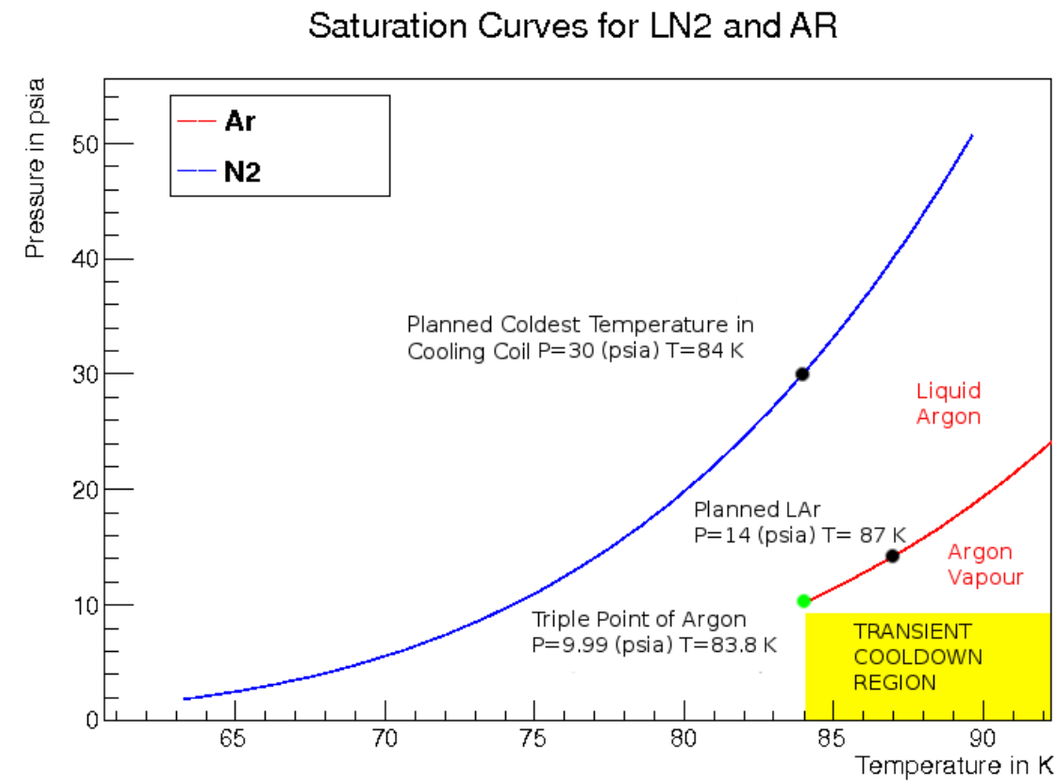
Spherical representation of the LVDT position transducer readout. Right is the AV north hemisphere, Left is the AV south hemisphere

Cool-Down Process : Challenges

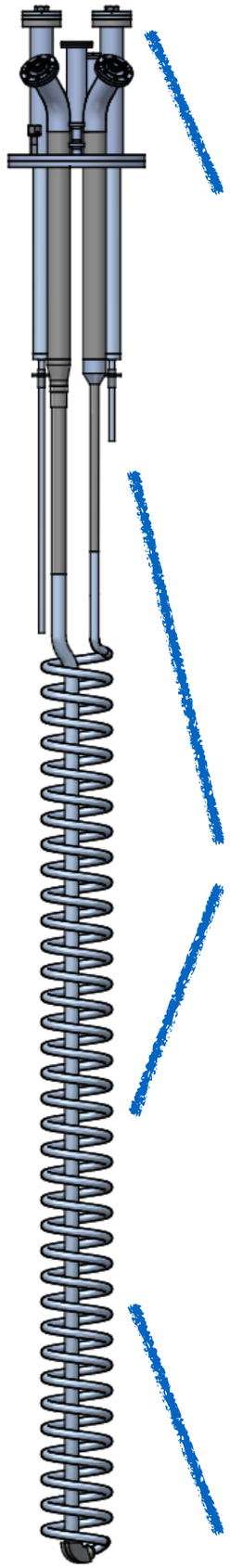
Goal - From AV at room temperature and in a vacuum state, to AV filled with LAr at 87 °K.

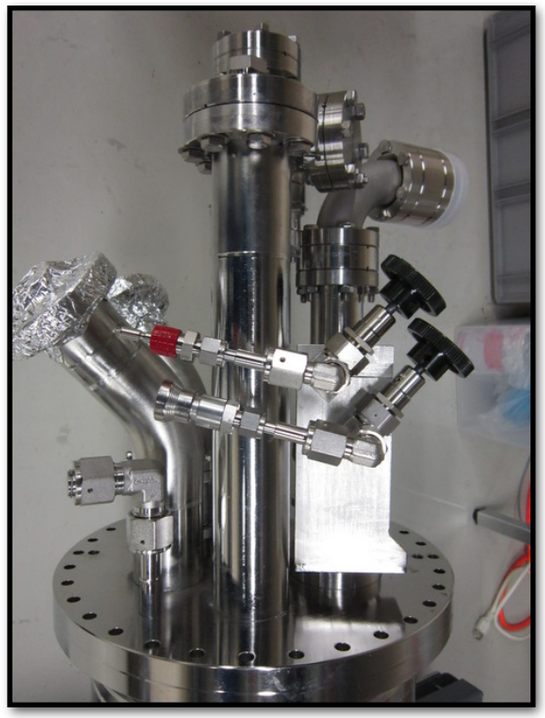
Challenges - The cool-down rate needs to be set so that it would: reduce thermal inducted stress from local and time variations in temperatures within the acrylic and avoid Argon freezing.

- The detector will be cooled at low pressure (10 psia), via small pressure increments (0.1 psig) to ensure safety. Reduce stress on the acrylic and optimize uniformity.
- With a cooling power that will never exceed 1 KW, the cool-down process is projected to be completed within 2 weeks.
- Heat transfer in the process was carefully studied and characterized (including MC model). Three main contributions:
    1. Heat Transfer between cooling hardware and the Ar gas.
    2. Heat transfer between the AV surface and the Ar gas.
    3. Heat transfer through the acrylic.



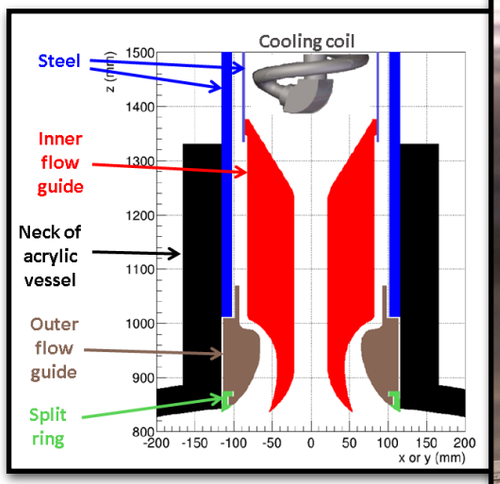
Cool-Down Process : Hardware

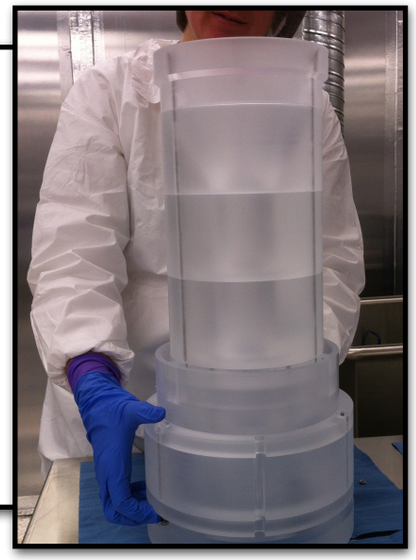


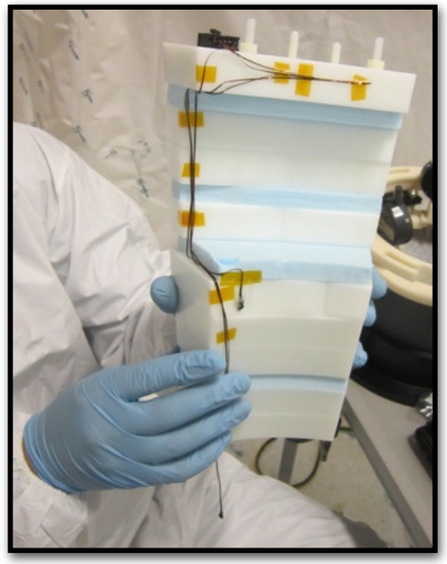


Hardware :

- 300 W Cooling-coil. The Coil will be filled/cycled with LN2 (87 K).
- Cooling-coil + process system were fully tested in May 2014. Tests showed that we can achieve the required cooling target.
- Specifically designed acrylic flow-guides mounted at the bottom of the coil to guide the Argon into the AV.
- Multiple temperatures sensors spread across the detector, placed at different radial distances along LGs.



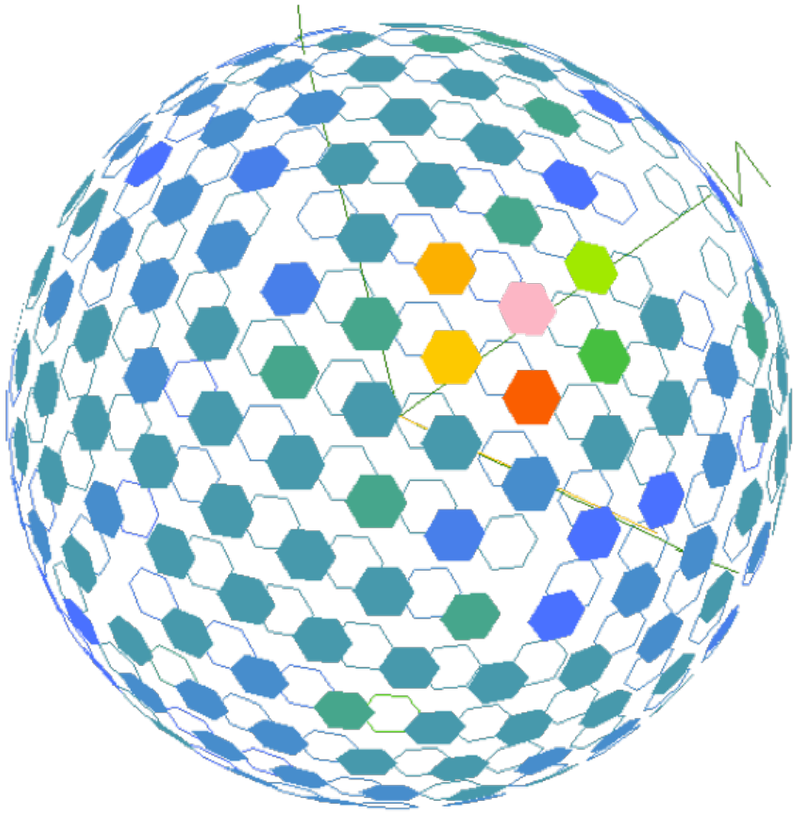




Conclusions

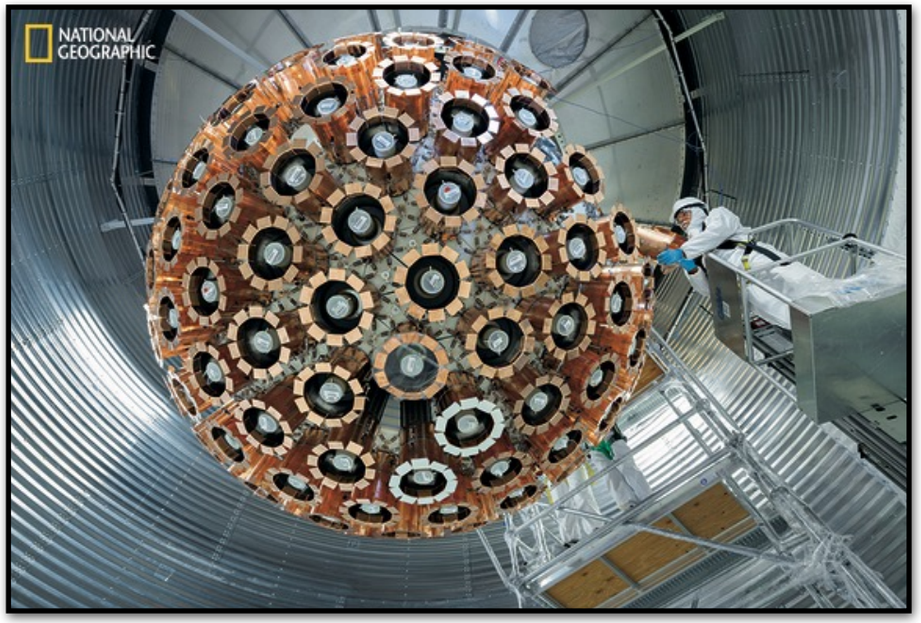
DEAP-3600:

- Construction completed.
- DAQ and Process System commissioned.
- Advanced PMTs characterization.
- Performed optical calibration with multiple sources (optical-fibre injections, Laserball).



Resurfacer:

- Successfully ran the resurfacer (full system) for over 200 hours.
- Removed acrylic calculated with multiple measurements. Estimated 500 microns removed.
- Inner AV Surface contaminations reduced by a factor of 2000.



Cool-down Process:

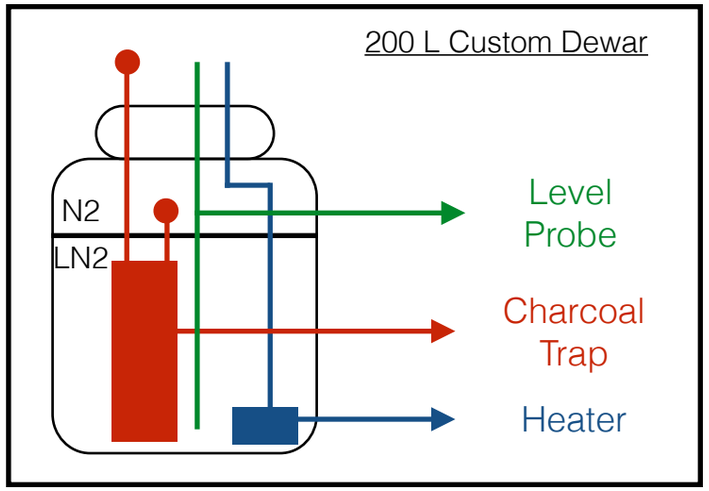
- Methodically studied all possible failure modes.
- Full cooling system commissioned, test run indicates that the cooling system can achieve required cooling power.
- Cool-down process expected to be completed within 2 weeks.

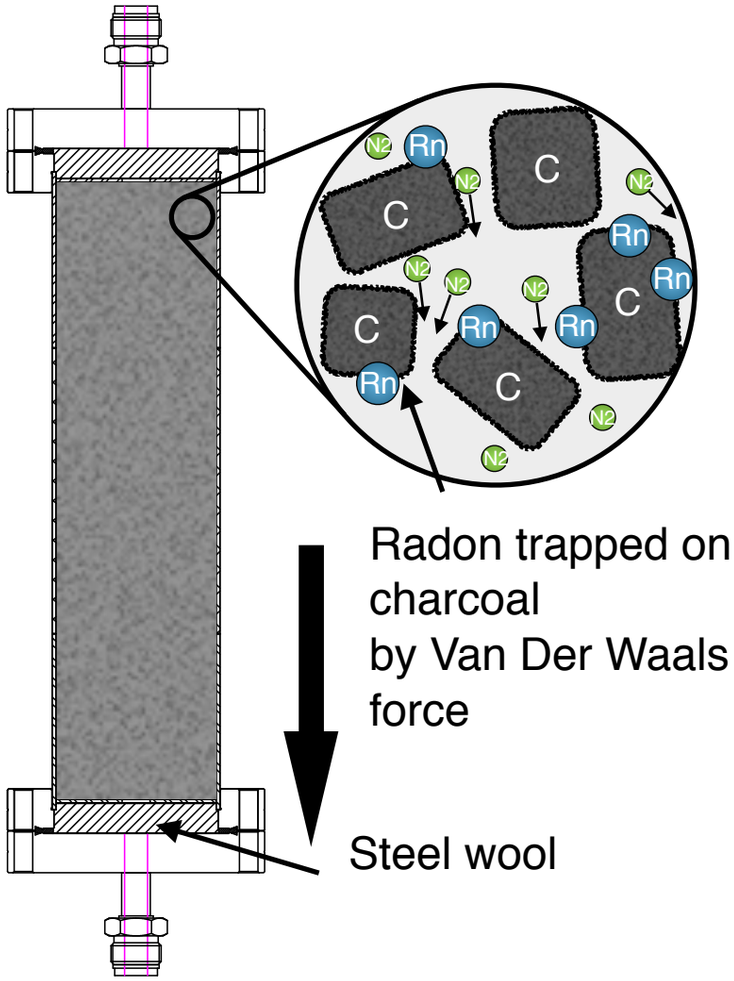
Back-Up

The Resurfacer : Purge Gas System

- Purifies boil off nitrogen with a 50g activated charcoal trap.
- Designed so that the internal dewar pressure creates flow through the Rn trap.
- U.L. of 1 mBq of 222Rn inside the AV.
- Generates 0.039 mBq/m3 of Purge Ultra-Purified N2 Gas.
- Purge maintained at a flow of 9 L/m, to balance the in/out of UPW.
- Pressure maintained with a (MKS-640) auto pressure control valve (3 psig).
- Not just for the AV, but used to ensure cleanliness in all other active volumes.

http://www.sciencedirect.com/science/article/pii/S0168900204023356

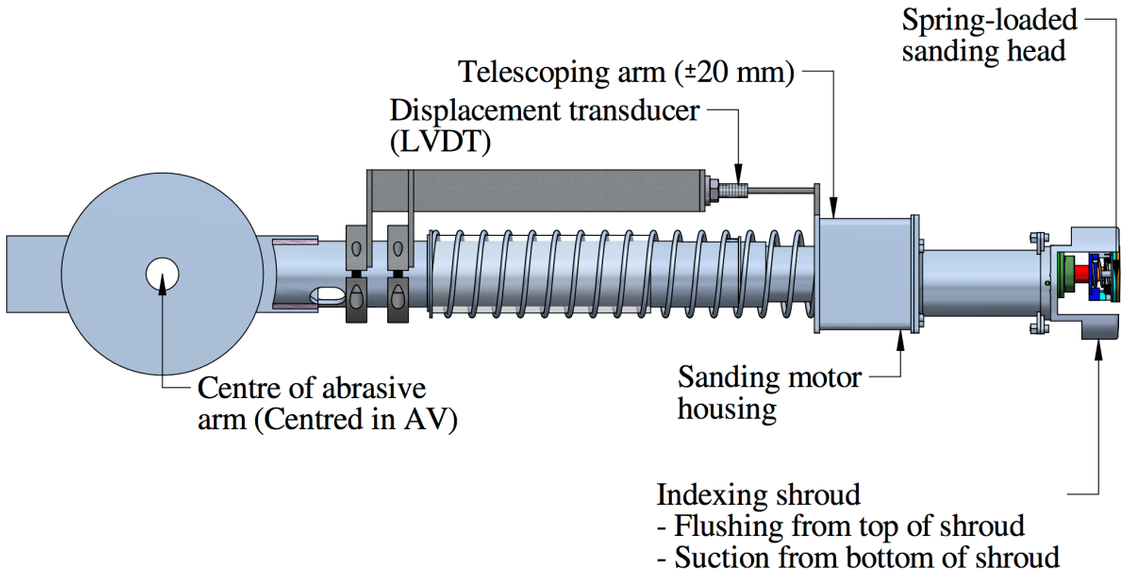




The Resurfacer : Sanding Arms Efficiency

Efficiency Studies :

- Measured ex-situ in test set-ups both at Queen's University and at SNOLAB.
- Sanding efficiency measured for each individual arm (North and South).
- Used 3 different methods: measured the sanded acrylic from holes located on the acrylic test plates, measured motor performance on a stand-alone set-up, and measured the collected removed acrylic with a series of filters.
- North sanding efficiency - 8.3 g/hr.
- South sanding efficiency - 9.3 g/hr.



Cool-Down Process : Heat Transfer

Heat Transfer between cooling hardware and injected Argon gas.

$$Q_{coil} \propto \frac{k_{Ar}^{0.75} P^{0.5} (\Delta T)^{1.25}}{\mu^{0.25} T^{0.75}}$$

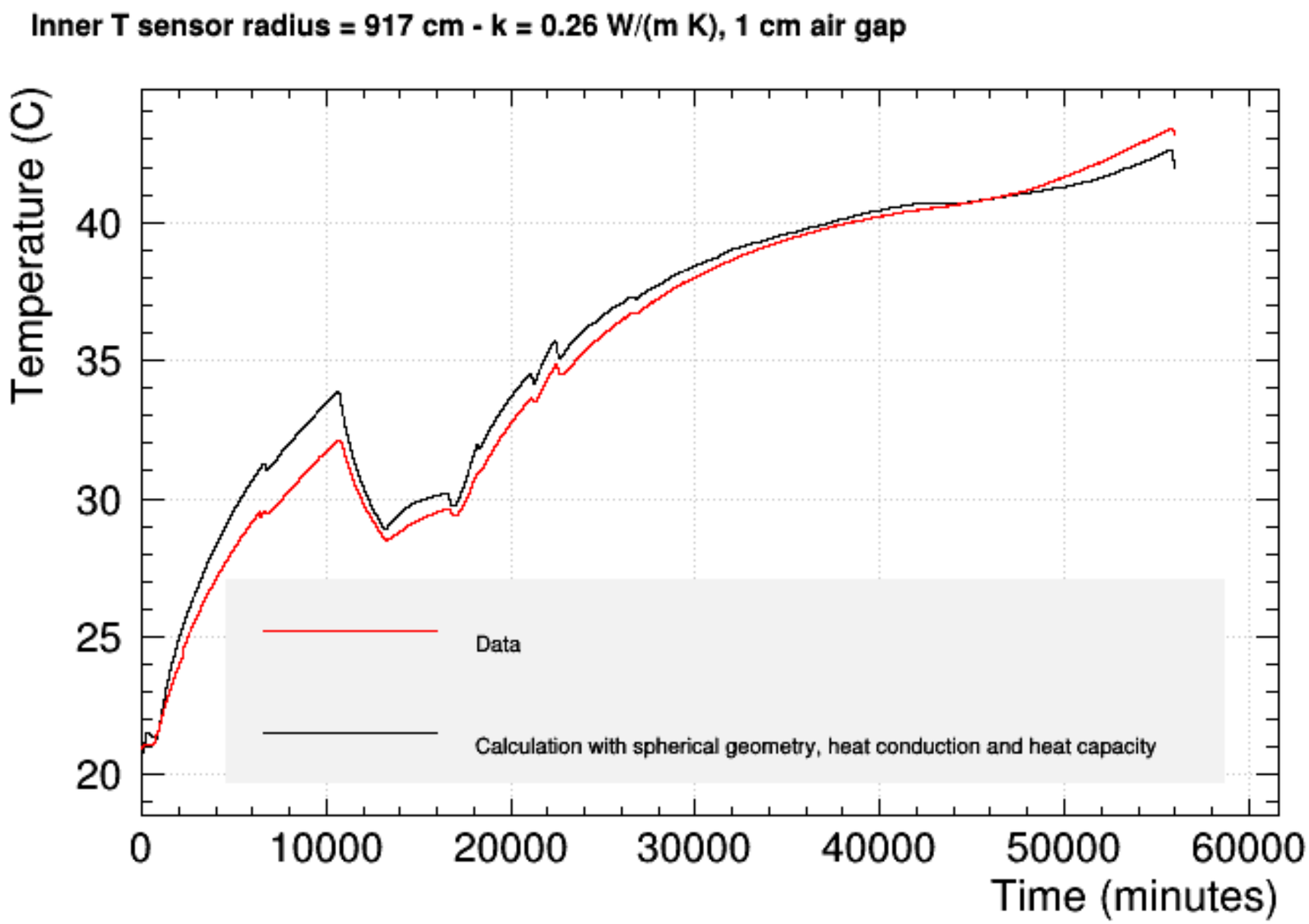
Heat Transfer between AV surface and the injected Argon Gas.

$$Q_{ac} = 5.38 k_{Ar} (2 + 43.5 (\frac{P^2 \Delta T}{T_{Ar}^3 k_{Ar} \mu})^{0.25} \Delta T$$

Heat Transfer through the acrylic.

$$Q_{solid} = 4\pi k_{ac} r_1 r_2 (\frac{T_1 - T_2}{r_1 - r_2})$$

Cool-Down Process : MC Model



Tested the MC model with the temperatures sensors data from the blackout of the AV.