TPC Electronics work on cryostat roof & Interface Milestones

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Integration and Installation Workshop

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Outline

- Work on top of the cryostat for the TPC electronics consortium:
  - Installation of the CE crossing tubes and of the spool pieces
  - Installation of the Warm Interface Electronics Crates (WIECs)
  - Installation of power and bias voltage supplies
  - Installation of cables and fibers
  - Testing prior to APA installation
  - APA installation, cable routing through the cryostat penetrations, final tests
  - BNL mockup and further tests at Ash River
- The goal of this talk is in part to gather information of the “what is required on our side” type

CE crossing tubes (i)

- Sometimes at T0+19 months the DSS crossing tubes are installed in parallel with the installation of the insulation and of the internal membrane
- During a previous workshop we had the following discussion for the TPC electronics crossing tubes
  - The cryostat crossing tube is installed
  - The CE crossing tube is inserted inside the cryostat crossing tube
  - The two are aligned and the cryostat crossing tube is welded in place
  - At this point we could
    - Remove the CE crossing tube and re-install it at a later time
    - Put the sealing ring in place and bolt the CE crossing tube to the flange

CE crossing tubes (ii)

- The cryostat crossing tube has its own gas purge line
  - Gas purge lines are put in place at a later time
- We could put a temporary cover on the CE crossing tube, OR
- We could install the CE crosses with two CE and one PDS flanges (use temporary sealing rings, rubber ?)
- At what time are He leak tests performed on the individual cryostat penetrations ?
  - Just at the end (with final sealing rings) ?
- What is the quality control procedure for welds ?
- It would be nice to fully understand the sequence of operations and when the CE personnel is required (even just for supervision) for this sequence of operations

CE crossing tubes (iii)

- It's clear that CE crossing tubes (and spool pieces) are not going to be needed before T0+19 months
- Will target delivery to warehouse facility by T0+13 months

- A question I already asked last year (that went unanswered)
- What kind of QC is required on the spool pieces plus flanges prior to installation ?
  - A final He leak test will be performed after all cables have been routed
  - For ProtoDUNE we performed He leak tests on the CE and PD flanges prior to installation
  - Some QC testing done by vendor of spool pieces (pressure testing, not He leak test)
  - Is this sufficient ? Should we plan on performing He leak test on assembled spool piece plus CE and PD flanges prior to the delivery to SURF ?

CE spool pieces

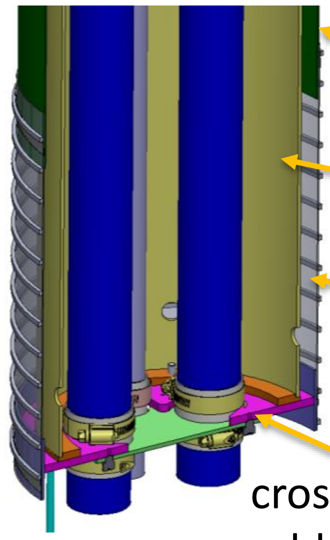
- We are planning to have hookups for gas purge lines on the CE flanges (should also have them on the PD flange)
- This will allow us to decide whether to use them at a later date
- Are we planning to have the corresponding purge lines or should we remove the hookups from the design ?
- Manhong has run CFD simulations with various configurations

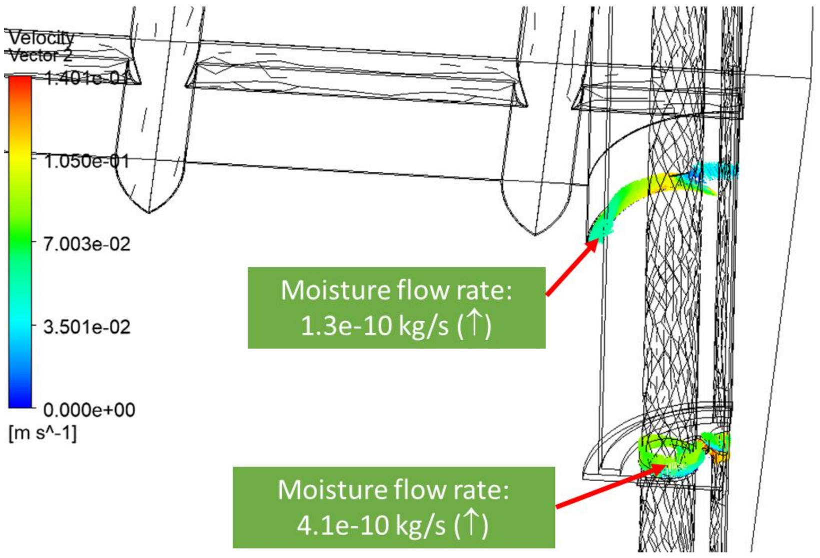
1. Gas purge lines on the CE and PD flanges only
2. Additional gas purge line on the cryostat crossing tube

- (will run configuration with gar purge line only on the cryostat crossing tube, need to add vent holes on the TPC electronics crossing tube)
- (will rerun some simulation with additional material in the crossing tube – steel pipe to house fibers for calibration of PD)

CFD Simulations (i)

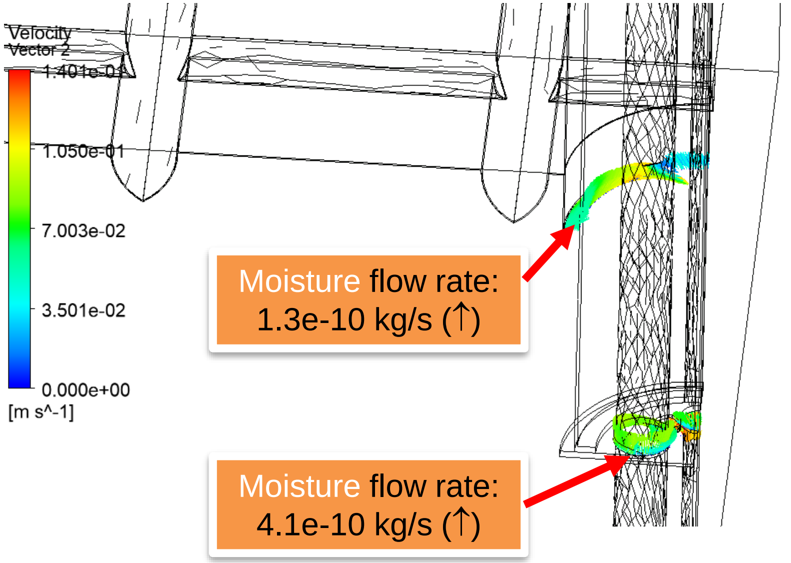
- Study was done to understand whether we need to seal the volume of the TPC electronics cryostat crossing tube
- Mass flow rate of moisture (case 1):
  - Total moisture entering penetration from ullage: 2.2×10^{-9} kg/s
  - Total moisture exiting from vent holes: 3.2×10^{-8} kg/s
  - Largest fraction of moisture comes from outgassing of CE cables in the cryostat penetration
- Net moisture flow always upward

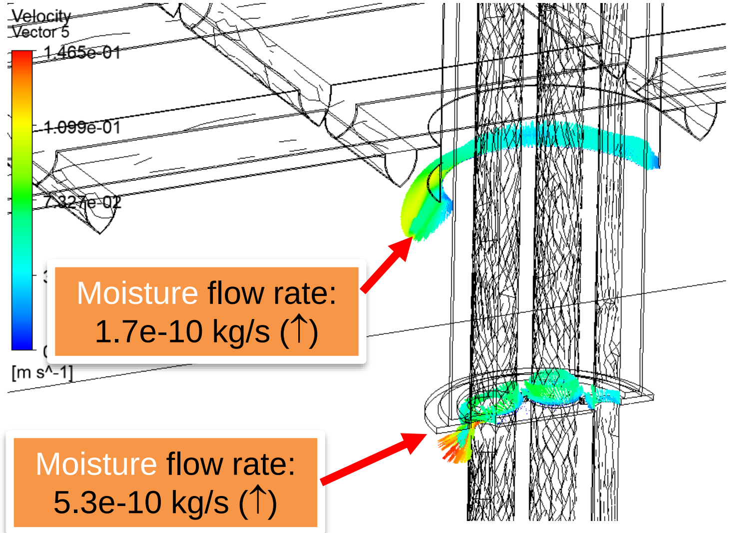




CFD Simulations (ii)

- Mass flow rate of moisture (case 2):
  - Total moisture entering penetration from ullage: 1.4×10^{-9} kg/s
  - Total moisture exiting from vent holes: 1.9×10^{-8} kg/s
- Less outgassing from the cables in the ullage and also in the TPC electronics penetration (-36%)
  - Due to increase of cold gas flow in the volume between the two cryostat penetrations
- Net moisture flow always upward





Other work on top of the cryostat

- Low voltage power supplies
  - 25 Wiener PL506 (one per row of APAs, 6 cables with sense wires going to the 3 cryostat penetrations from each PL506)
- Bias voltage supplies
  - 12 to 25 Wiener MPOD systems with 49-175 modules
    - Number of crates / modules depends on granularity of hardware interlocks
      - More extensive system allows for hardware interlocks at the APA level
      - Smaller system requires turning off an entire row of APAs
  - A total of 658 HV (RG-59 coax) bias voltage cables (between 8 and 12 per APA pair)
- Power supplies for fans and heaters
  - Need to understand granularity (probably 1 of each type per row of detector, 4 cable bundles going to each cryostat penetration)

Other work on top of the cryostat (i)

- Installation of power supplies and laying down cables from power supplies to the cryostat penetrations should not be a lengthy operation (most probably limited by delivery to the cavern and by the availability of JPO technicians for routing cables)
- No plans in place (yet ?) for adding resistive loads at the end of the cables and performing tests
  - Any test will need Slow Control and Detector Safety System in place
- The installation of the power supplies on the detector mezzanine can be scheduled to happen in parallel with the work on the cryostat penetrations or later
  - The second helps with flattening the CE resources
- Cabling requires that all cable trays are in place

Other work on top of the cryostat (ii)

- The responsibility of the TPC electronics consortium for fibers ends at the mini-racks next to the cryostat penetrations
  - For each WIEC we will have a MTP-12 to LC fanout that will be connected on the five WIBs (2 fibers per WIB, 2 spare fibers)
    - There will be a patch panel on the mini-rack where we will connect to an MTP-12 fiber provided by the DAQ group
  - We will also have 1 fiber bringing the clock to the PTC in each WIEC
    - Assume this is an LC to LC connection, and that the DAQ group will install a clock fanout system (to be used by both the PDS and TPC electronics consortium) on the mini-rack
  - We will have 1 (or 2) fibers from each WIB plus 1 (or 2) fibers from the PTC going to a network switch on the mini-rack
  - We are discussing having hardware interlocks inside the PTC, which would require a fiber going to the mini-rack where we will make an optical to electrical conversion and have a cable bringing the information to the Detector Safety System
  - Will also have a fanout for the Gb Ethernet links so that we have only a MTP-12 bundle going to the detector mezzanine for each cryostat penetration

Installation of cables and fibers

- Laying cables / fibers in the cable trays going from the mini-racks to the detector mezzanine should be done by JPO personnel
- I agree that final fiber connections should be done by expert personnel under the supervision of TPC electronics consortium members
  - The only cabling mistake in the CMS pixel detector was done by “fiber experts” ☹
- I think that physicists can plug in SHV connectors (and also the power cables to the PTC and the heaters / fans)
- Given the small number of cables and the planned size of the cable trays, I do not think that we need to cut the cable to length
  - Will fabricate cables of 3 different lengths (near, middle, far) and arrange slack in the cable trays

Installation of WIECs

- WIECs will be installed on the CE flanges ahead of the APA installation inside the cryostat
- We will have a stand to support the WIEC while it is being attached to the CE flange
- At this point we plan to connect cables / fibers and perform communication tests between the DAQ (CCM, SC) and the PTC and WIBs, could also perform data transmission tests
- These activities should be completed prior to beginning of installation of APAs inside the cryostat
  - This however requires that the DAQ (or a part of it) is already in place

Cold boxes

- We will have three extra spool pieces mounted on top of the three cold boxes
- Spool pieces will be accessed from outside the clean room
- The WIECs from the cold boxes will be connected to the power supplies for row 25 of the detector (need extra set of cable trays)

- We will have a permanent set of cables inside the cold boxes going from the CE/PD flanges to patch panels inside the cold box
  - When testing the CE/PD systems on the APAs inside the cold boxes we will connect the readout cables to the patch panels

After the APA installation (i)

- Once the APAs are installed inside the cryostat
  - The flanges will be removed from the spool piece (do we first remove the crates or do we keep them attached ? In both cases we will need a support system for the crates)
  - Cables will be routed through the cryostat penetrations and connected to the flanges
  - Perform fast electrical connectivity test (including talking to the FEMBs)
  - Put the final sealing rings in place
  - Close the flanges, perform additional tests
  - Perform He leak tests
  - Start doing more extensive readout tests

After the APA installation (ii)

- For this operation
  - Small portable tent over the cryostat penetration (air flow plus tent should reduce considerably dust falling into the cryostat)
  - Support for WIECs
  - Harness to pull cable bundles through the cryostat penetration
  - Need to understand exact sequence of cable installation
  - Understanding these operations is one of the goals of mockup being prepared at BNL
    - Other goals: understand cable routing in the cable trays inside the cryostat, need for additional temporary tray during APA movements, understand interference between brackets for FEMBs and cable restraint system

BNL Mockup

- Building mockup of top of APA / DSS / cryostat roof / cryostat penetration to extend scope of studies done so far at Ash River
- Manhong will discuss this in his presentation tomorrow morning

Action items from previous review

1. Can we use slotted conduits for routing the TPC electronics cables through the APA frames (slotted conduits can be installed at the APA factories, facilitate / speed up installation process) ?
    1. Yes, tests performed during the trial installation at Ash River in October 2019

There are no other action items

Other tests at SURF

Some of the electronics on top of the cryostat will sit in air cooled crates

- Assume will use best possible air filters, replace as necessary

The warm interface electronics crate is its own enclosure and will have the best possible air filters

In both cases it would be great to be able to put a rack full of electronics (low voltage power, APA wires bias voltage, others) and a warm interface electronics crates somewhere in the SURF cavern in an area with a dust level close (1 order of magnitude ?) to that expected in the DUNE caverns

- The sooner the better, need to have a way of doing this
- Will help us planning for filter replacement, understand if we need design changes

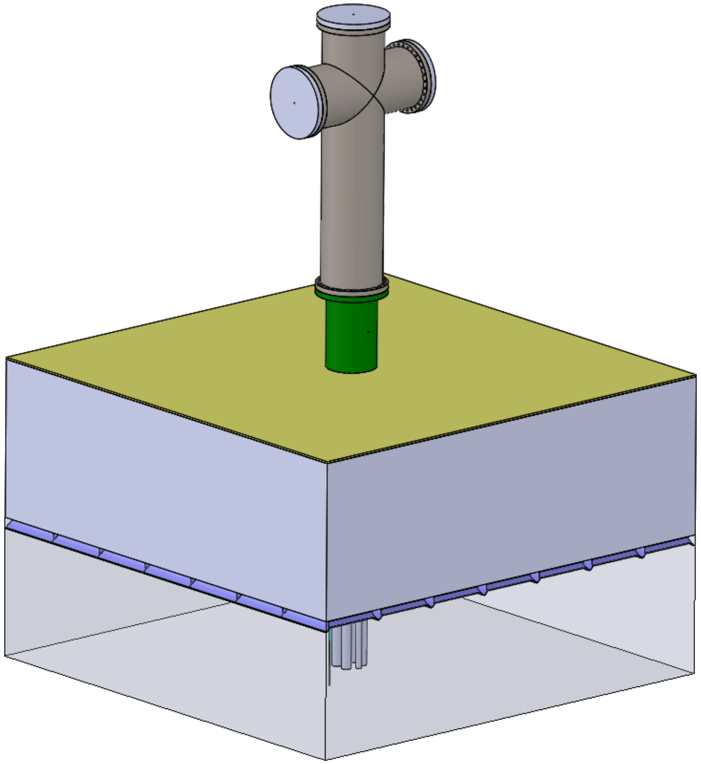
Milestones ?

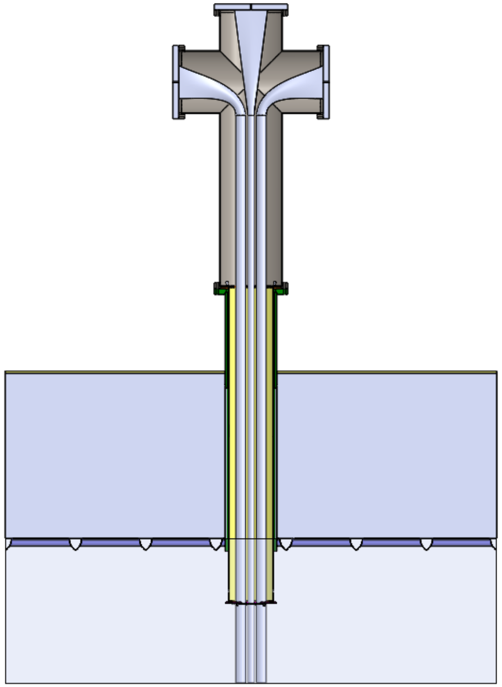
- 10 minutes for discussion
- Aim to have parts delivered to SDWF at least 6 months prior to their need by date at SURF
- Need by date for cryostat penetrations / spool pieces / flanges set by beginning of installation of DSS penetrations
- Need by date for supplies / cables and fibers / WIECs depends on the exact sequence of installation
- Would prefer to do these activities once the cryostat penetrations are complete, to minimize / flatten personnel needs at SURF
- Goal: have all WIECs on top of the cryostat tested prior to the beginning of the installation of the APAs inside the cryostat

Backup

- Slides describing CFD calculations by Manhong Zhao (BNL)

DUNE Signal Penetration CFD Study

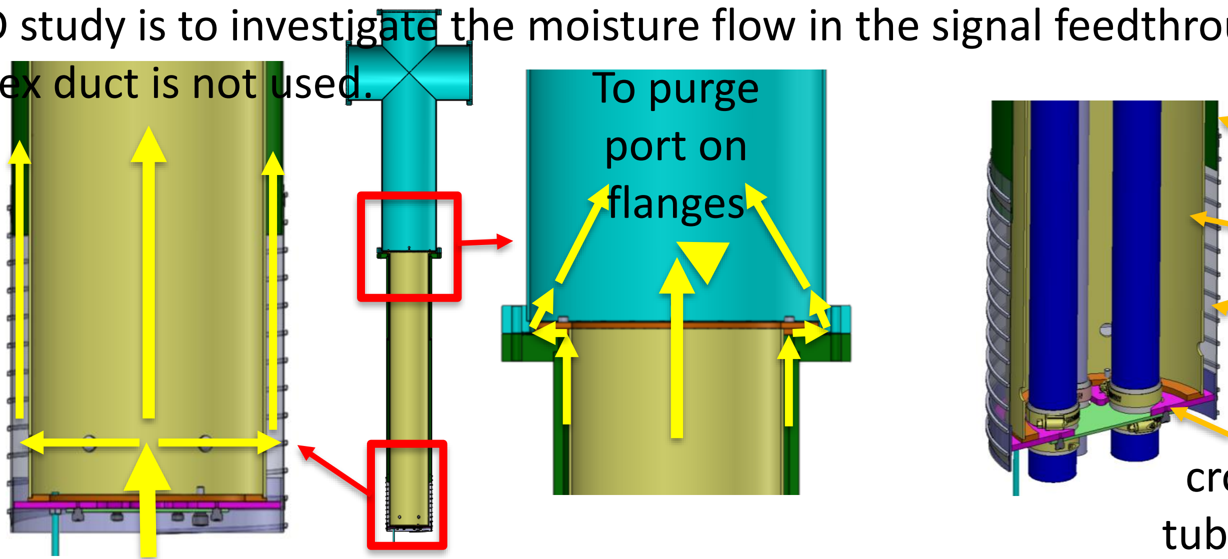




Introduction

A Teflon flex duct was added to the signal feedthrough design to cover the gap between the CERN crossing tube and the CECT (CE crossing tube). The purpose of the Teflon duct is to prevent contamination (moisture) flowing back to the Argon ullage.

This CFD study is to investigate the moisture flow in the signal feedthrough when this Teflon flex duct is not used.



Simplifications and assumptions

1. The geometry model consists of one signal feedthrough and a section of cryostat and ullage of size 2.38m x 2.38m.

2. A vent hole of ¼” in diameter is located at the center of each PD/CE flange. An additional vent hole of ¼” in diameter is located at the CERN crossing tube. Gas flow rate through each vent hole is equal.

3. Two CFD models are simulated.
   1. Model A: When the additional vent hole at the CERN crossing tube is NOT used, the CFD model can be reduced to a quarter size taking advantage of symmetry.
   2. Model B: When the additional vent hole at the CERN crossing tube is used, the CFD model can only be reduced to a half size taking advantage of symmetry.

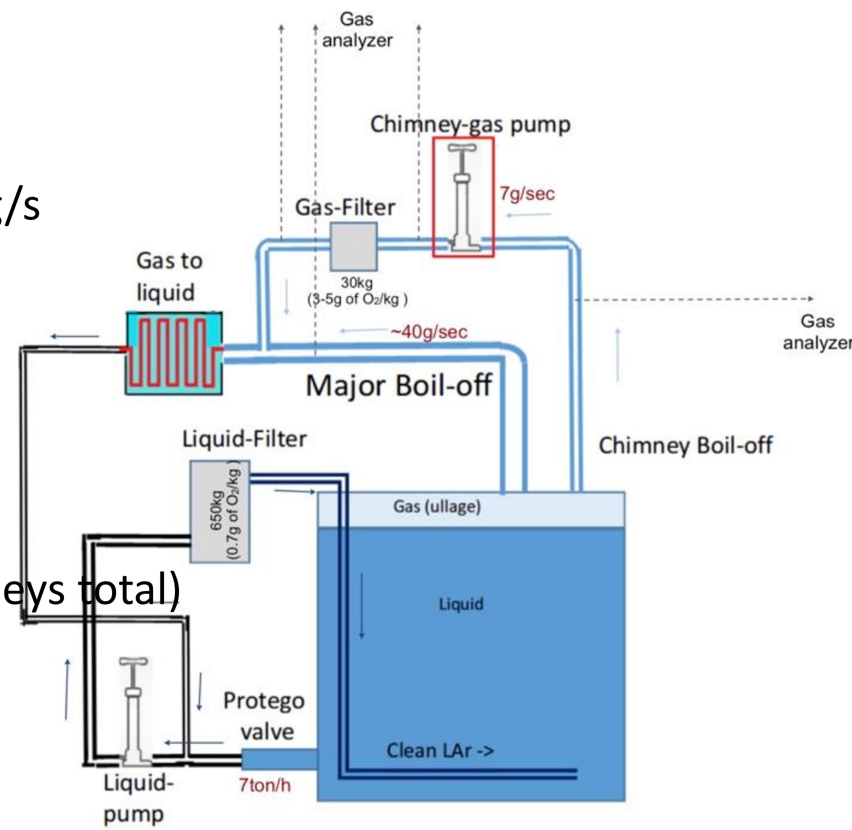
4. Liquid Argon in DUNE cryostat evaporates at the same rate per area as the evaporation rate measured in ProtoDUNE cryostat.

ProtoDUNE recirculation/purification system

Total evaporation rate in protoDUNE SP is ~ 47 g/s

Average boil-off at liquid surface per area
47 g/s / (8.548m x 8.548m) = 0.643 g/s/m^2

Mass flow rate per chimney (Assumed 30 chimneys total)
7 g/s / 30 = 0.2333 g/s (per chimney)

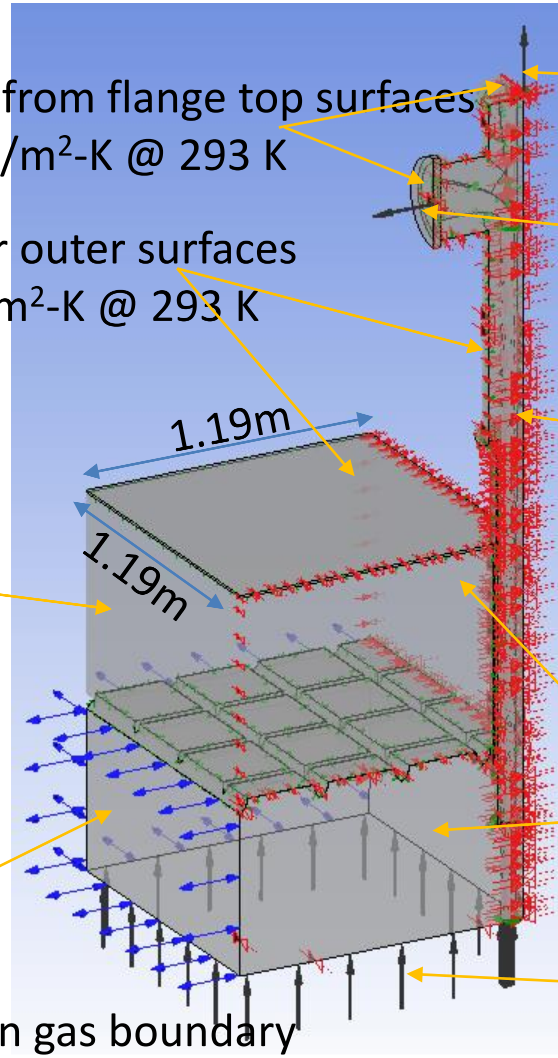


CFD model A

Additional vent hole not used

Heat from flange top surfaces
50 W/m^2-K @ 293 K

Other outer surfaces
6 W/m^2-K @ 293 K



Mass flow rate at Outlet 1:
0.2333g/s / 3 / 4 = 0.0194 g/sec

Mass flow rate at Outlet 2:
0.2333g/s / 3 / 2 = 0.0389 g/sec

Moisture diffusion from cables to Argon

Symmetry condition utilized to reduce the model to a ¼ model.

50 mbar pressure in Argon ullage

Mass flow rate at Inlet:
0.643g/sec/m2 * (1.19m * 1.19m) = 0.91 g/sec

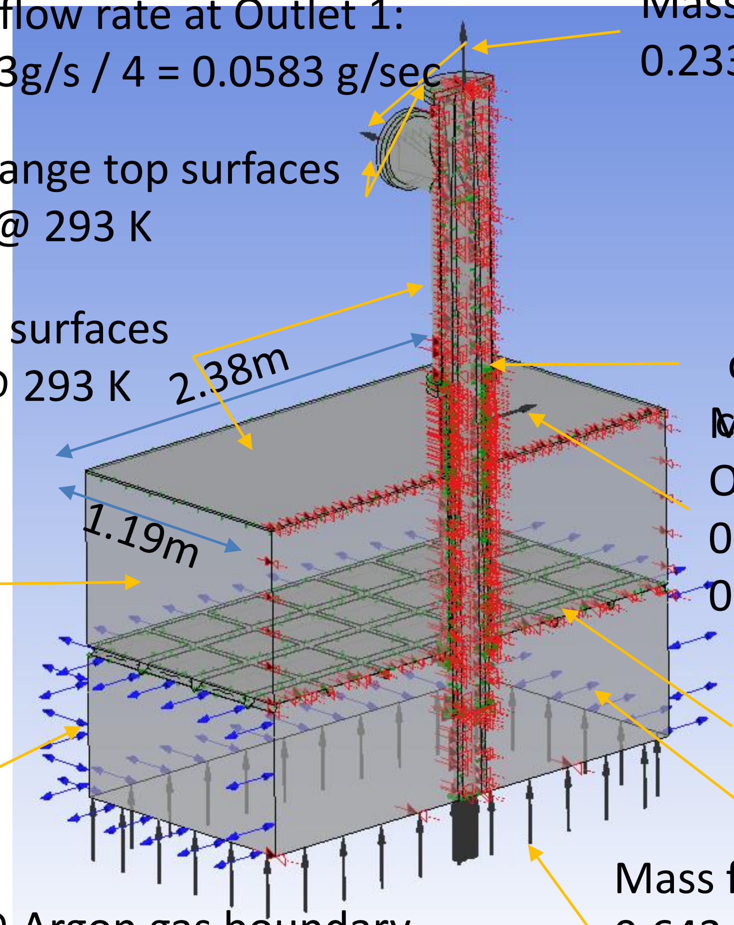
Thermal Conductivity of Insulation							
Temp (°C)	40	20	-20	-40	-80	-120	-160
TC (W/m.K)	0.028	0.026	0.025	0.025	0.024	0.019	0.015

Ullage Opening boundary condition

87.3K @ Argon gas boundary

CFD model B

Additional vent hole is used



Mass flow rate at Outlet 1:
0.2333g/s / 4 = 0.0583 g/sec

Mass flow rate at Outlet 2
0.2333g/s / 4 / 2 = 0.0292

Heat from flange top surfaces
50 W/m^2-K @ 293 K

Other outer surfaces
6 W/m^2-K @ 293 K

Moisture diffusion from Cable to Argon

Mass flow rate at Outlet 3:
0.2333g/s/4/2 = 0.0292 g/sec

Symmetry condition utilized to reduce the model to a ½ model

50 mbar pressure in Argon ullage

Thermal Conductivity of Insulation							
Temp (°C)	40	20	-20	-40	-80	-120	-160
TC (W/m.K)	0.028	0.026	0.025	0.025	0.024	0.019	0.015

Ullage Opening boundary condition

87.3K @ Argon gas boundary

Mass flow rate at inlet:
0.643g/sec/m2 * (2.38m *
= 1.82 g/sec

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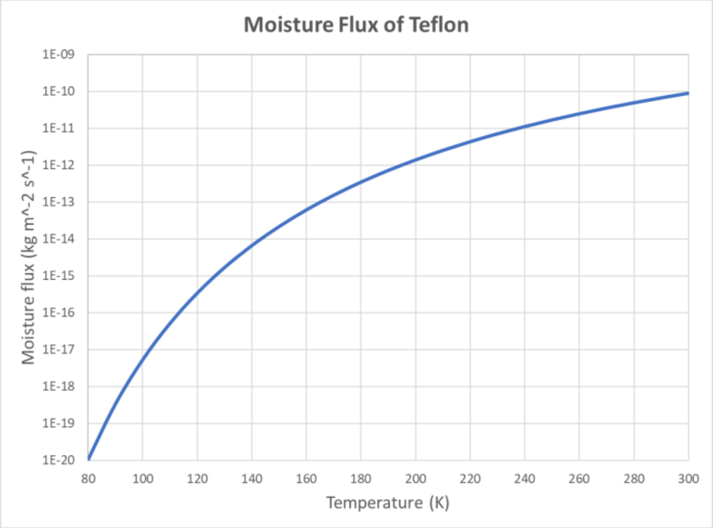
Moisture release of Teflon wire insulation

Surface mass flux

$$H2O_{SurfaceFlux}(t_{ins}, Temp, t) := \left| \left(\phi_{waterMax} \cdot \sqrt{\frac{D_o \cdot e^{\frac{-U}{k_b \cdot Temp}}}{\pi \cdot t}} \right) \text{ if } t \le \frac{(t_{ins})^2}{2\pi \cdot D_o \cdot e^{\frac{-U}{k_b \cdot (Temp)}}} \right.$$

Where:

- "$H2O_{SurfaceFlux}$" - is a function of thickness, temperature, and time
- "t" - is time after placed in dry atmosphere, starting fully saturated in (seconds)
- "Temp" - is Teflon temperature in (Kelvin)
- "U" - is the activation energy which is estimated at (0.43eV)
- "k_b"- is the Boltzmann constant ($1.381*10^{-23}$ $m^2*kg/K*s^2$)
- "$\varphi_{waterMax}$" is the saturated concentration of water in Teflon (216 grams/m^3)
- "t_{ins}" is the thickness of the material, drying on one side, other side adiabadic
- "D_{12}(Temp) " is the temperature dependant diffusion coefficient
- "D_o" is estimated at (0.73694 cm^2/sec) for Teflon



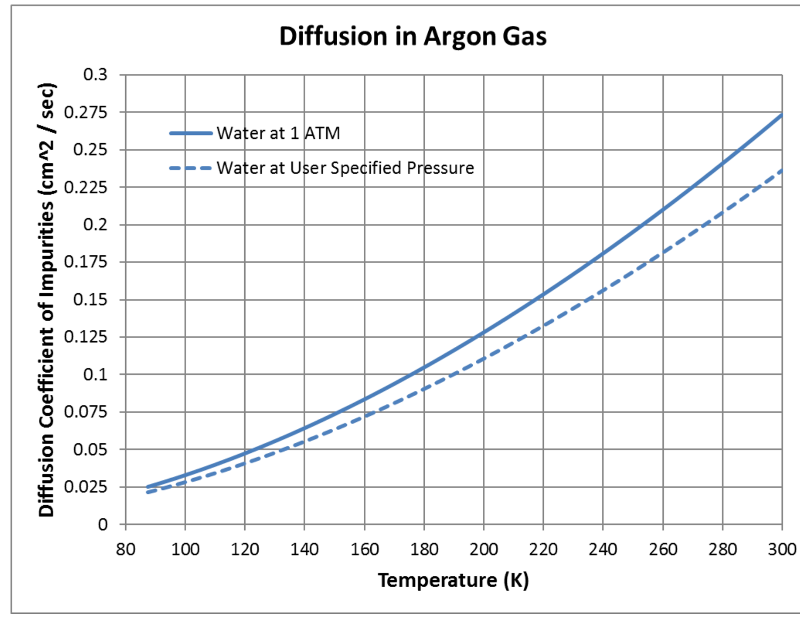
Assume cables are placed in dry atmosphere for 100 days,

H2OFlux = 0.216*sqrt(2.715e-12*exp(-4988[K]/T)) [kg m^-2 s^-1]

Reference: Mass Transport of Water in Teflon Down to Cryogenic Temperatures; a Transient Numerical Analysis, Erik Voirin

Diffusion coefficient of moisture in Argon gas

$$\text{Diffusion}_{12}(T) = \frac{1.86 \cdot 10^{-3} \cdot T^{\frac{3}{2}} \cdot \sqrt{\dfrac{\frac{kg}{kmol}}{M_1} + \dfrac{\frac{kg}{kmol}}{M_2}}}{\dfrac{P}{atm} \cdot \left[\dfrac{1}{2}(\sigma_1 + \sigma_2)\right]^2 \cdot \dfrac{\left[2.6693 \cdot 10^{-6} \cdot \left(\dfrac{M_{Ar}}{\frac{kg}{kmol}} \cdot T\right)^{\frac{1}{2}}\right]}{\dfrac{\mu_{Ar}(T)}{Pa \cdot s} \cdot \left(\dfrac{\sigma_{Ar}}{Angstrom}\right)^2}}$$



H2ODiff = 0.275 [cm^2 s^-1] * (T/300[K])^1.9*(1 [atm] /(1.04935 [atm] + Pressure))

Reference: Diffusion Coefficients of Water and Oxygen in Argon, Erik Voirin

CFD Results (A): moisture flow rate

<u>Mass flow rate of moisture</u>

Gap at cable clamping plate:
4.1×10^{-10} kg/s

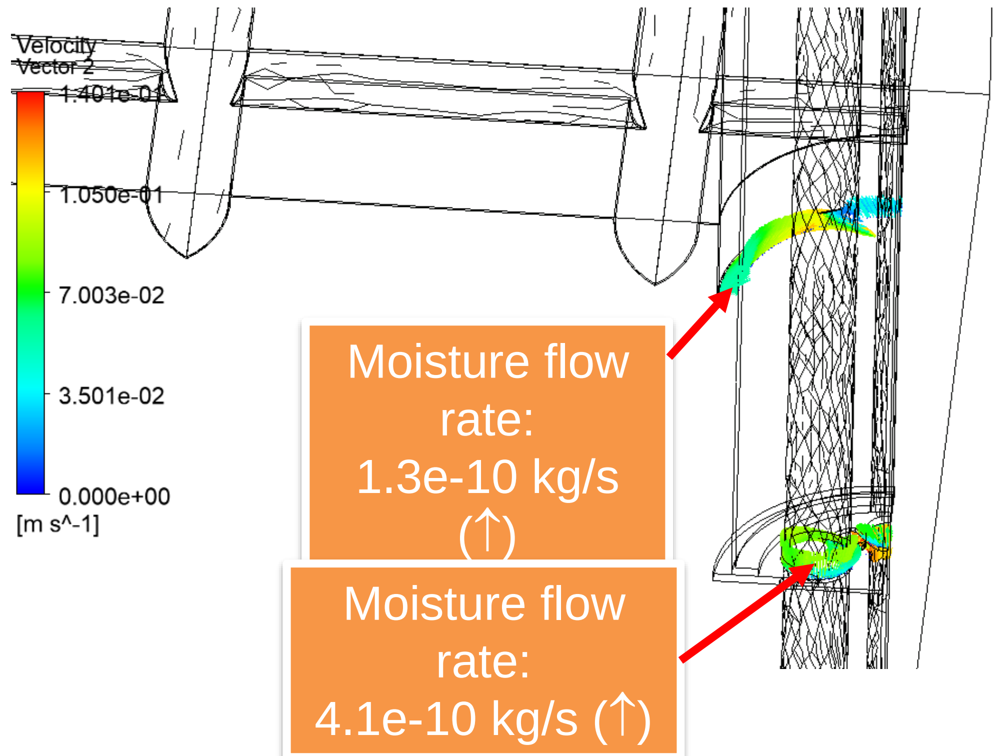
Gap between CERN crossing tube and CECT:
1.3×10^{-10} kg/s

Total moisture enters to penetration from ullage:
2.2×10^{-9} kg/s (per penetration)

Vent hole at CE flange:
5.4×10^{-9} kg/s

Vent hole at PD flange:
2.7×10^{-9} kg/s

Total moisture exits from vent holes:
3.2×10^{-8} kg/s (per penetration)



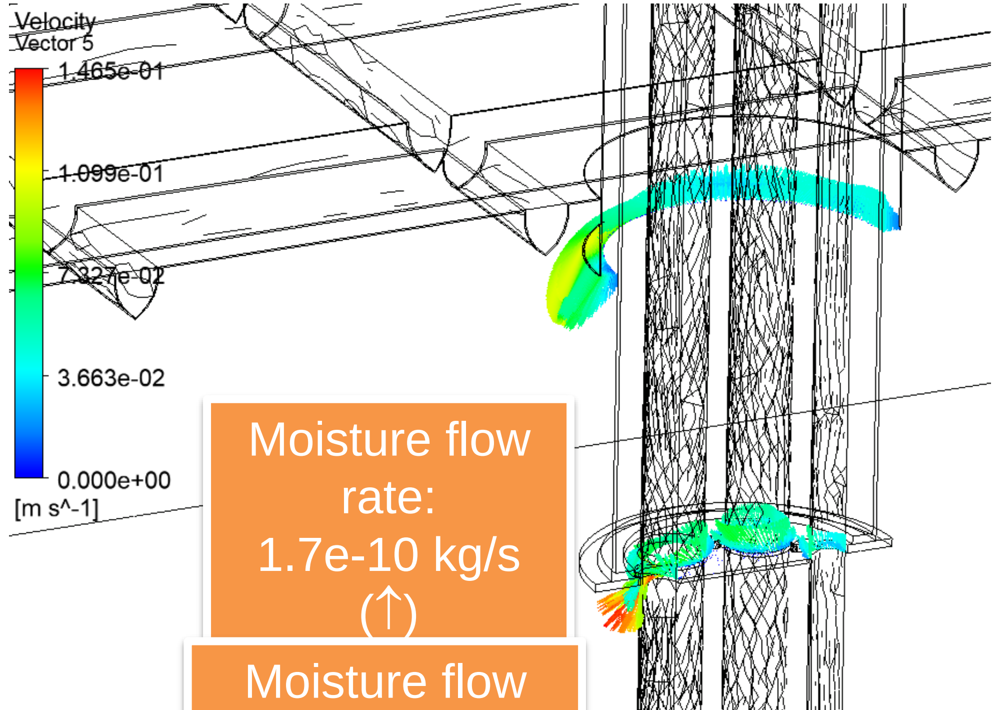
The directions of net moisture flow at both the gap at cable clamping plate and the gap between CERN crossing tube and CECT are upward into the feedthrough.

CFD Results (B): moisture flow rate

<u>Mass flow rate of moisture</u>

Gap at cable clamping plate:
5.3×10^{-10} kg/s
Gap between CERN crossing tube and CECT:
1.7×10^{-10} kg/s
Total moisture enters to penetration from ullage:
1.4×10^{-9} kg/s (per penetration)

Vent hole at CE flange:
5.3×10^{-9} kg/s
Vent hole at PD flange:
2.6×10^{-9} kg/s
Vent hole at Crossing Tube:
1.5×10^{-9} kg/s
Total moisture exits from vent holes:
1.9×10^{-8} kg/s (per penetration)



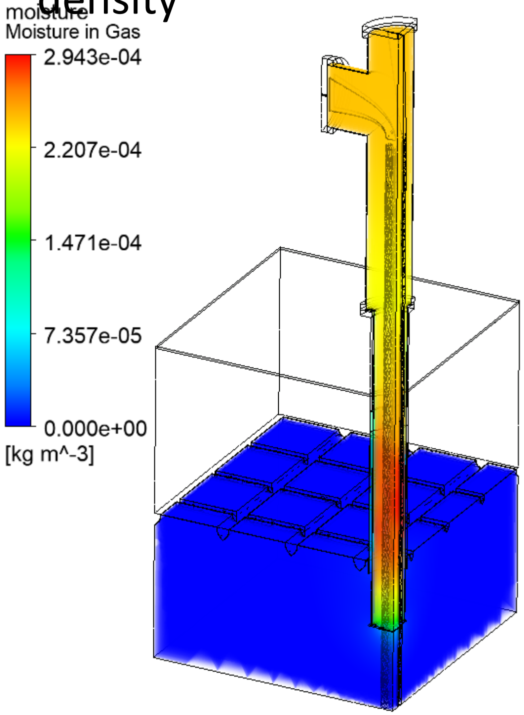
Moisture flow rate:
1.7e-10 kg/s (↑)

Moisture flow rate:
5.3e-10 kg/s (↑)

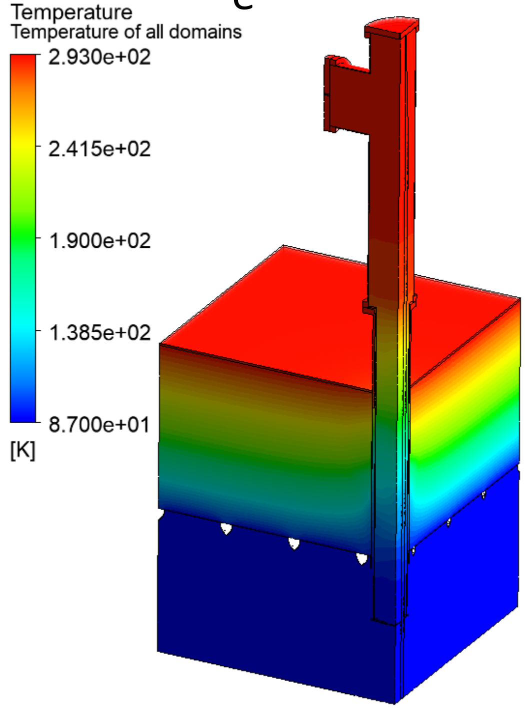
The directions of net moisture flow at both the g[…] plate and the gap between CERN crossing tube and CECT are upward into the feedthrough.

CFD Results (A)

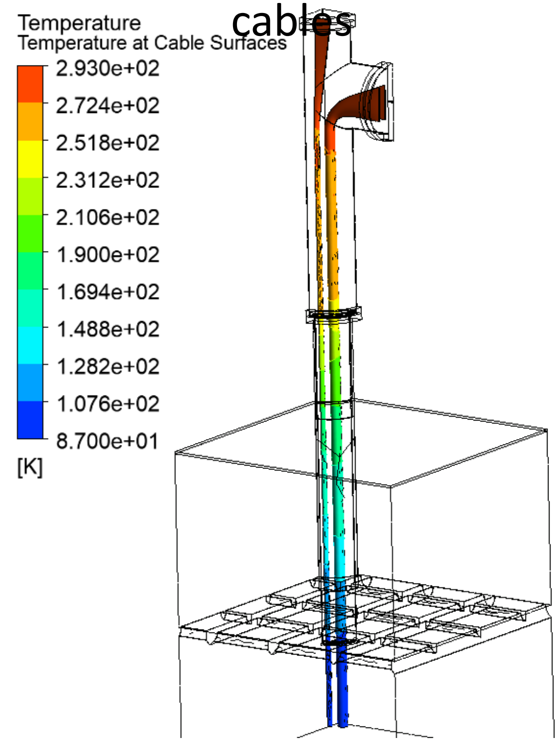
Moisture density



Temperature



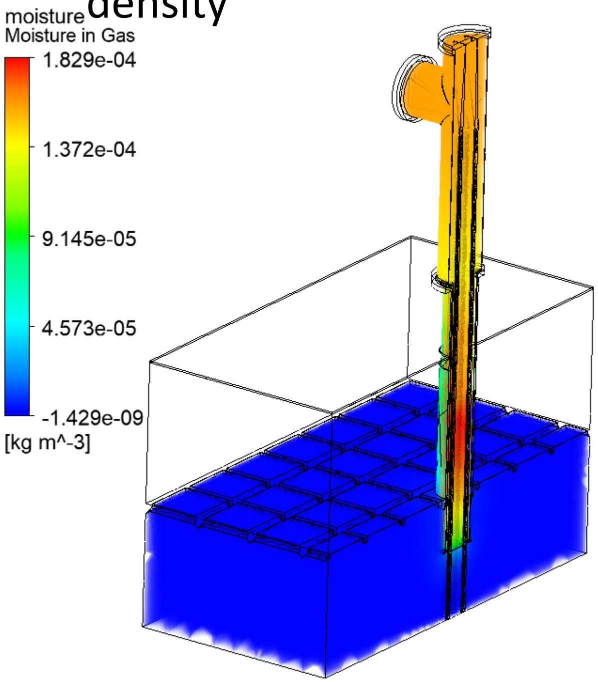
Temperature of cables



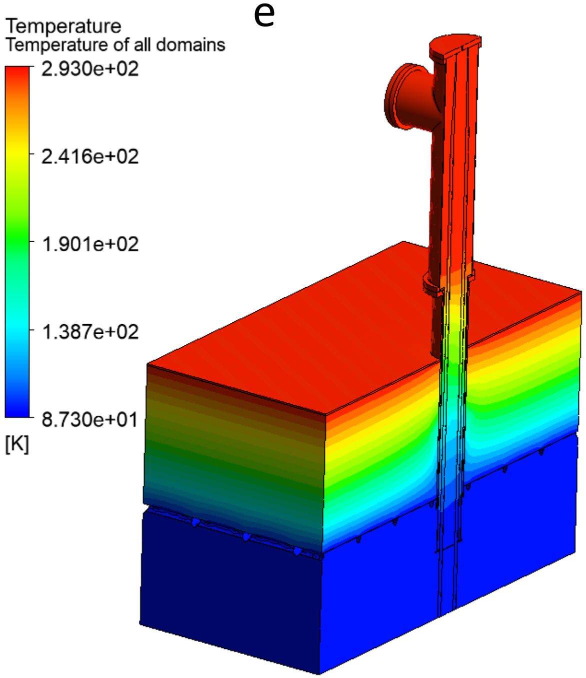
Average moisture density near cable surfaces 0.00022 [kg m^-3]

CFD Results (B)

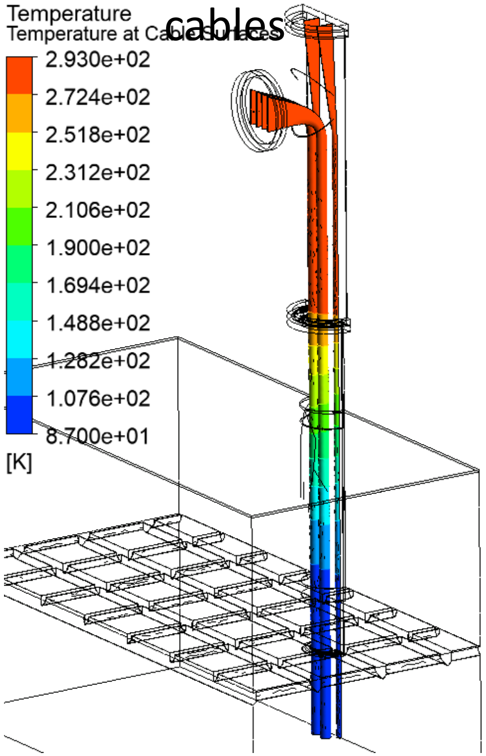
Moisture density



Temperature



Temperature of cables



Average moisture density near cable surfaces 0.00014 [kg m^-3]

Summary

<u>Mass flow rate of moisture</u>

Model A: additional vent hole is NOT used

Total moisture enters to penetration from ullage:

2.2×10^{-9} kg/s (per penetration)

Total moisture exits from vent holes:

3.2×10^{-8} kg/s (per penetration)

Model B: additional vent hole is used

Total moisture enters to penetration from ullage:

1.4×10^{-9} kg/s (per penetration)

Total moisture exits from vent holes:

1.9×10^{-8} kg/s (per penetration)

The directions of net moisture flow at both the gap at cable clamping plate and the gap between CERN crossing tube and CECT are upward into the feedthrough.

Therefore, the gap between CERN crossing tube and CECT can be left