Investigation of Thermal Equilibrium Around an Accidental Event And Impact on Possibly Enclosed Surrounding Environment

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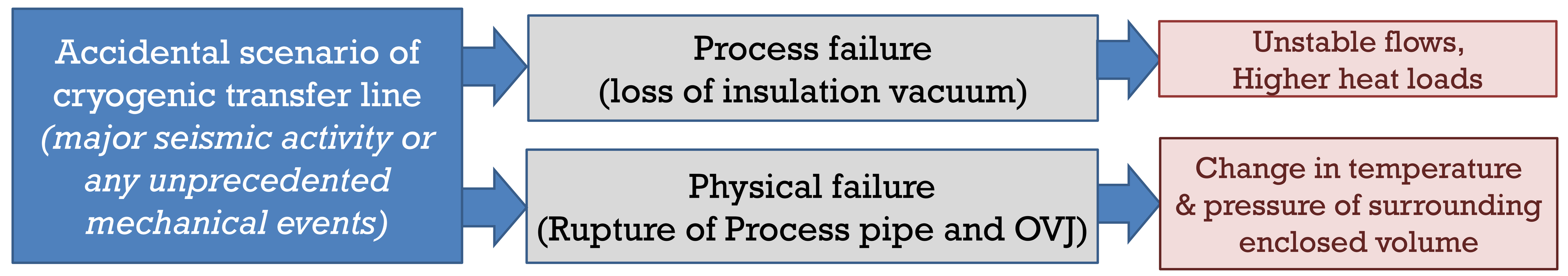
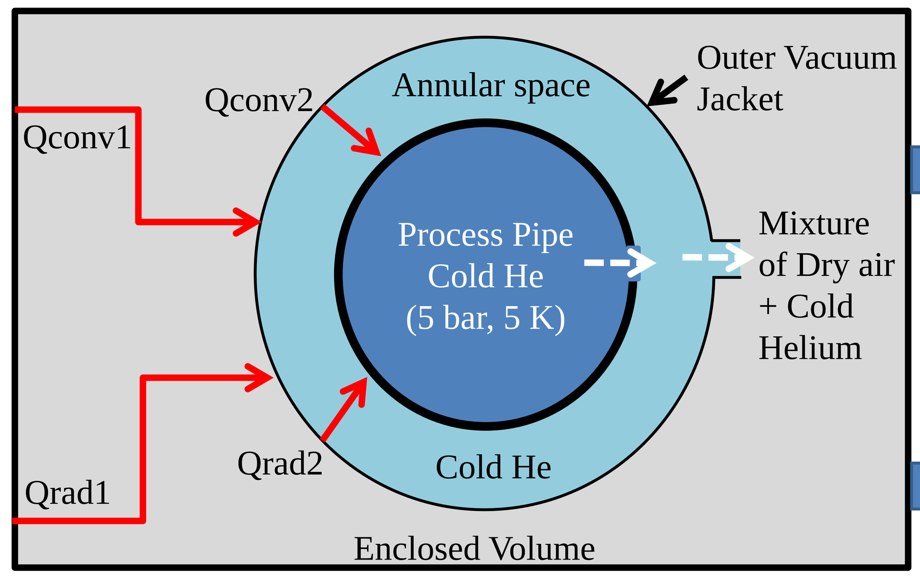
Problem Definition

- High helium inventory is normally expected in Cryogenic Transfer Lines (CTL) during operation of fusion machine.
- In an accidental scenario, the possibility of cold helium release is evident due to complete breakage of process pipe and Outer Vacuum Jacket (OVJ)
- The present study aims to estimate the lowest possible temperature and change in pressure in the surrounding environment due to the possible accidental scenario, especially in a closed volume.



Assumptions and Modelling

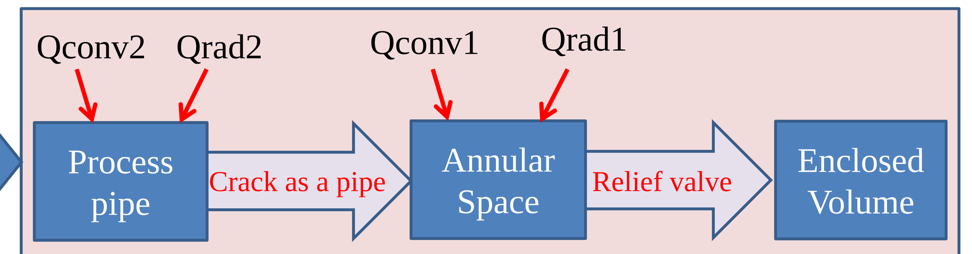
- Smooth crack having equivalent circular cross section of 10 mm diameter across the thickness of process pipe
- Discharge area of rupture disc on OVJ is ~ 507 sq.mm
- Enclosed Volume (EV) is occupied with stagnant dry air at 300 K and 1 bar(a).
- EV is fairly tight for helium, air or mixture of helium with air (worst case scenario) for exhaust
- Heat transfer through conduction mode has been neglected
- The concrete wall of EV has been considered at 300K
- Uniform thermal mixing has been assumed
- Stratification of the flows is not considered, as vertical column of stagnant dry air is considered in EV [2]



$$T_{mix.} = \frac{(m.c_p.T)_{air} + (m.c_p.T)_{helium} + Q_T}{(m.c_p)_{mix.}}$$

$$x_{air} = \frac{(m)_{air}}{(m)_{air} + (m)_{helium}} \qquad Q_T = Q_{conv.} + Q_{rad.}$$

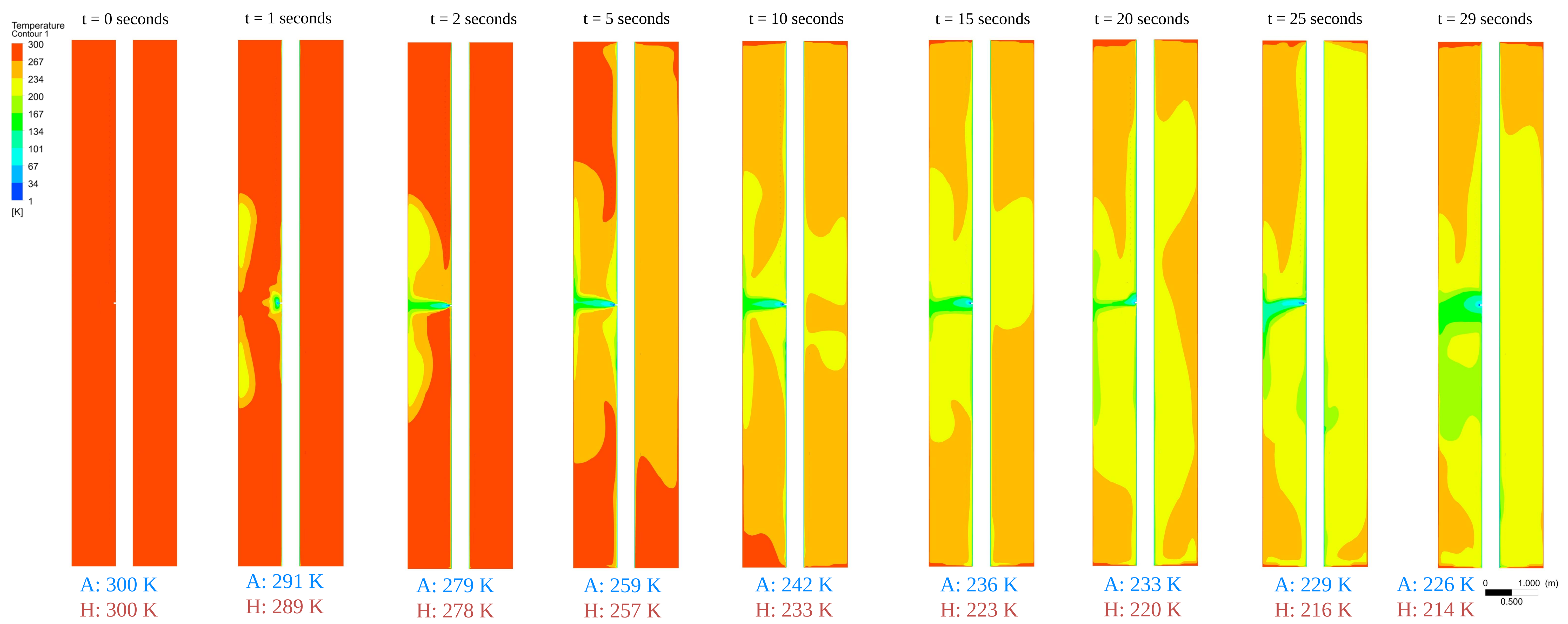
Validation using analytical modeling



Development of detailed model in ASPEN HYSYS®

Validation of Average Temperatures using ANSYS Fluent ®

Temperature , Mass flow from OVJ to EV at opening of rupture disc



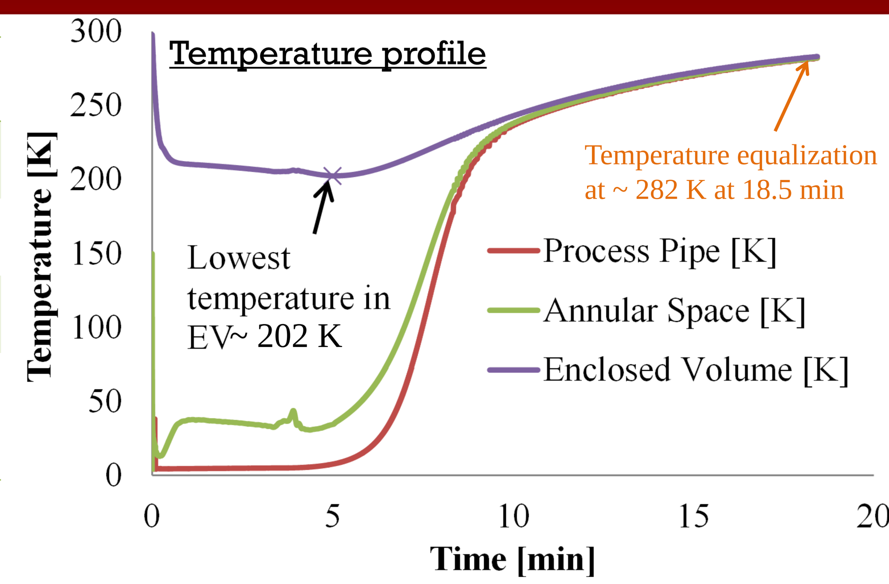
A: Global average temperature from ANSYS Fluent ®
H: Global average temperature from ASPEN HYSYS®

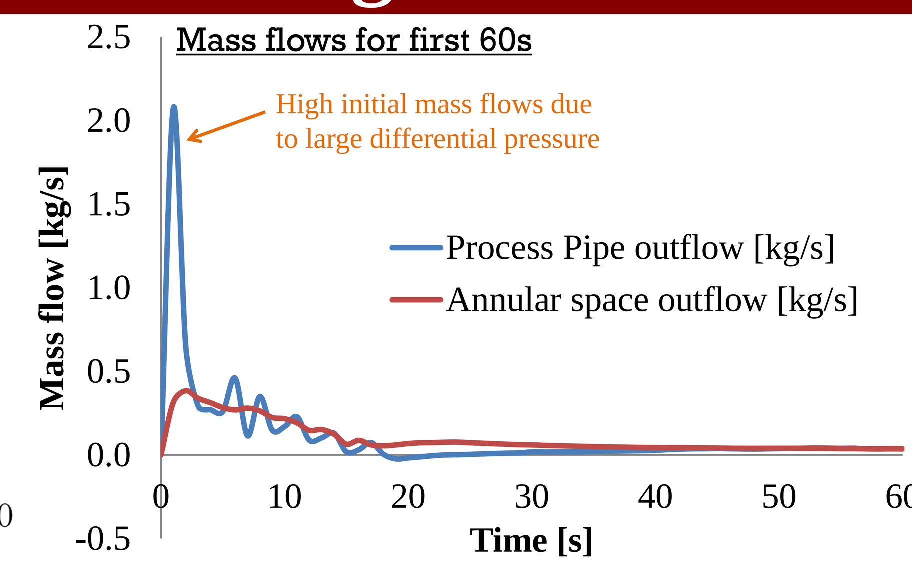
The parameters of helium mass flow from OVJ to EV are varied as a function of time.
The same temperature of mass flow is assigned for the entire length of the OVJ, for successive time steps.
Realizable k-epsilon viscous model was employed with enhanced wall treatment.

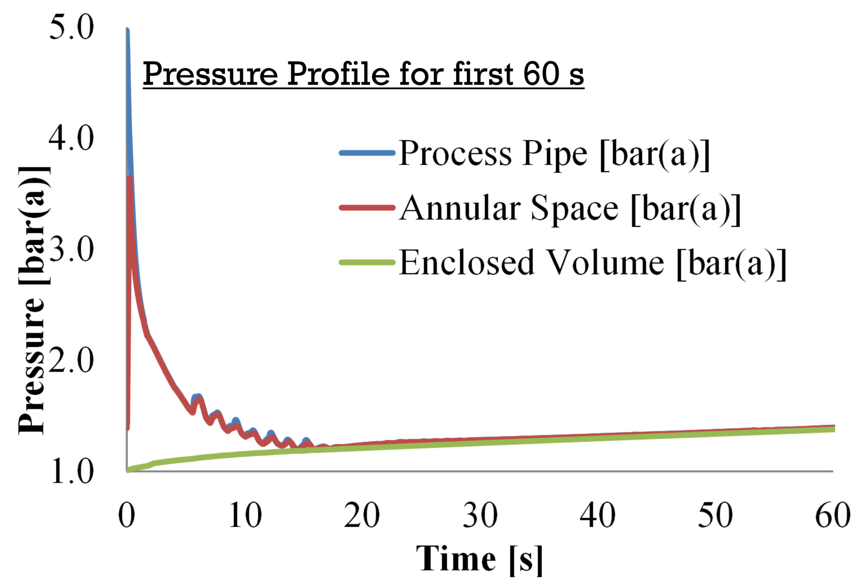
Results from ASPEN HYSYS® modelling

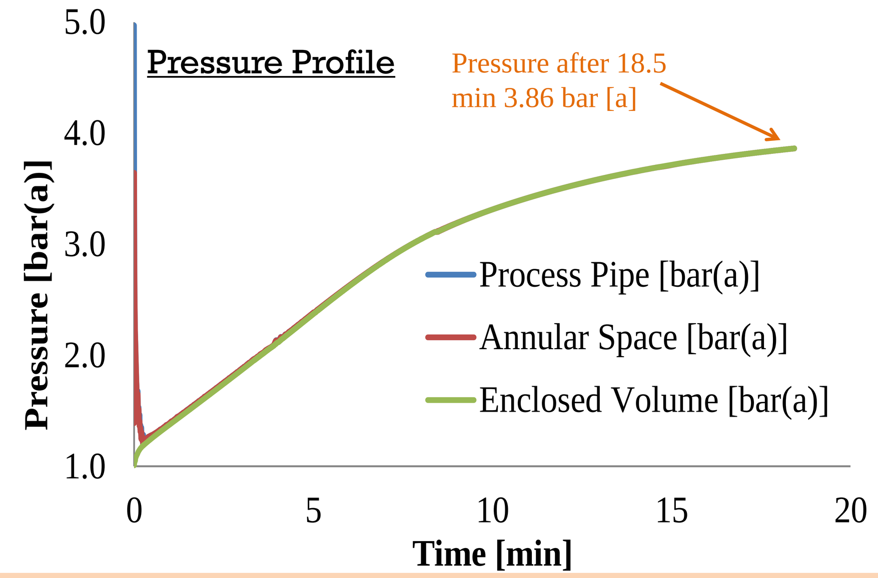
Process parameters at t = 18.5 min (t = 0: considered to be the rupture of process pipe)

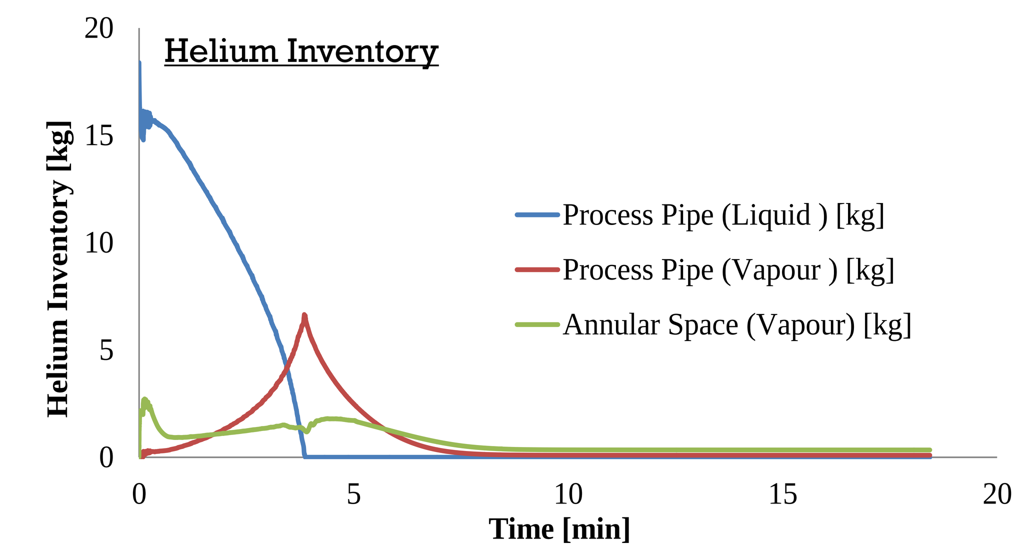
Process Parameters	Process Pipe	Annular space	EV
Pressure bar (a)	3.86	3.86	3.86
Temperature (K)	282	282.2	283.1
Composition	Helium	Helium	Air (x=0.71) + Helium (x=0.29)







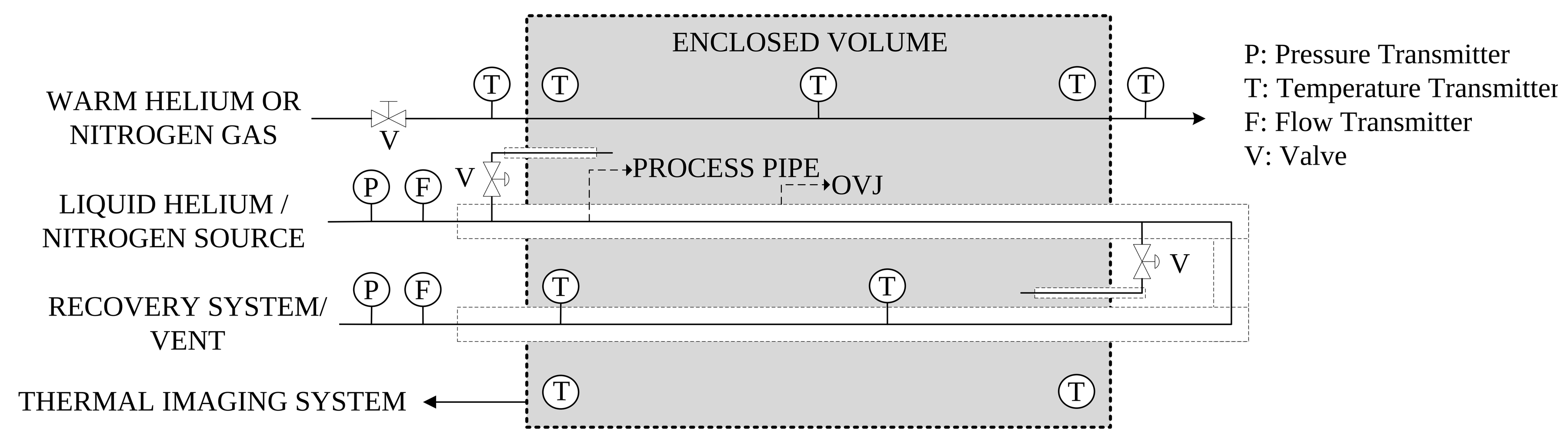




The lowest temperature has been observed to be function of (i) cold helium inventory, (ii) size of opening in process pipe, (iii) discharge area of safety rupture disc of OVJ, (iv) size of the surrounding duct or mass of surrounding air.

Preliminary test proposal

- Cold helium / liquid nitrogen cryogenic transfer line is enclosed inside duct made of concrete sheet with normal leak tight sealing.
- Control valves for simulating leak through process pipe and OVJ.
- Mass flow meters for measuring the amount of helium entering into OVJ and further to Enclosed Volume (EV).
- The facility of ventilation for relieving the pressure inside EV will be provided.



Further attention to safety

- Quantifying an accidental event requires near reality assumptions. It is to be understood that the accidental events are the driving factor for ascertaining the safety of the designed system.
- The minimum design temperature of surrounding components and systems should be decided based on minimum temperature possible in such enclosed environment with a more realistic approach.
- The impact on process pipe and OVJ due to stored energy of gaseous helium in OVJ annular space and mixture (air + helium) in EV respectively should be considered, as it will act similar to a pneumatic testing of a vessel with a leak.

Conclusion

- EV's pressurization profile demands detailed experimental investigation, considering the most severe case of accidental scenarios based on, (i) maximum cold helium inventory, (ii) size of EV and (iii) ventilation requirements, which has to be considered while designing the subsystems of large fusion reactor related devices.
- For the purpose of investment protection, the outer vacuum jacket needs to be designed for internal pressure and with the careful design of rupture disc considering the maximum inventories in the process pipe.
- Ventilation systems have to be designed considering the possible pressurization of the enclosed volume.

References

1. Chorowski M. et. Al, Risk analysis update of the LHC cryogenic system following the 19th September 2008 incident, Proceedings of ICEC-23/ ICMC 2010, pp 879-884
2. Barron R. F. , Cryogenic Heat transfer, 1999, , ISBN-1-56032-551-8
3. Holman J. P., Heat Transfer