HIE-ISOLDE tunnel CFD studies
Controlled release of He from cryomodule via rupture disk

Scenario: 20 kg helium release, 15 K, in 2.5 sec

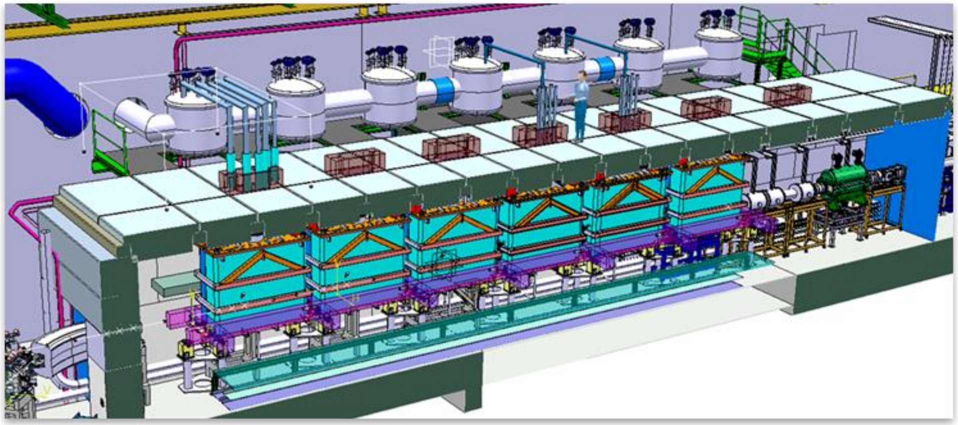
- ***Estimation of oxygen deficiency and cold burns hazards***
- ***Possibility of using a shield to confine He in a "non-accessible" zone of the tunnel***
- ***Influence of tunnel doors opening***

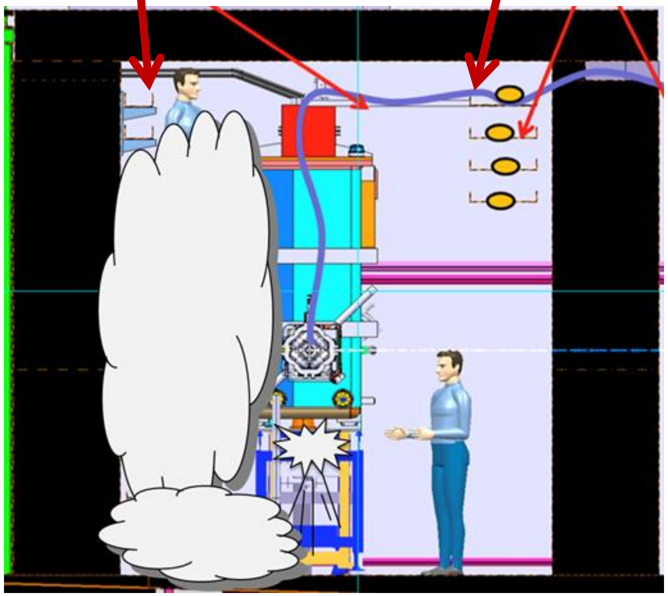
- Enrico Da Riva -
CERN (EN/CV/PJ)

HIE-ISOLDE Safety Review, 5 November 2013

Preliminary estimations

- Internal rupture of vacuum vessel scenario (from Project Request EDMS1279878):
    - Total mass of helium leaking: 20 kg;
    - Flow rate from 165 mm burst disk: 5~8 kg s^{-1};
    - Leak temperature: 15~40 K;
- Volume available in the tunnel: ~260 m^3;
- Air mass in the tunnel: ~300 kg;
- Time needed to empty the vessel: 2.5~4.0 sec;





Preliminary estimations 2/2

- Volume occupied by 20 kg of He if warmed up to 300 K: 125 m^3 corresponding to 50% of volume available;

- As a first approximation, we can assume that helium and air perfectly mix in the tunnel;
- Mixing 20 kg of He (40 K, 1 bar) + 300 kg of air (300 K, 1 bar):

  -) equilibrium temperature: ~230 K.

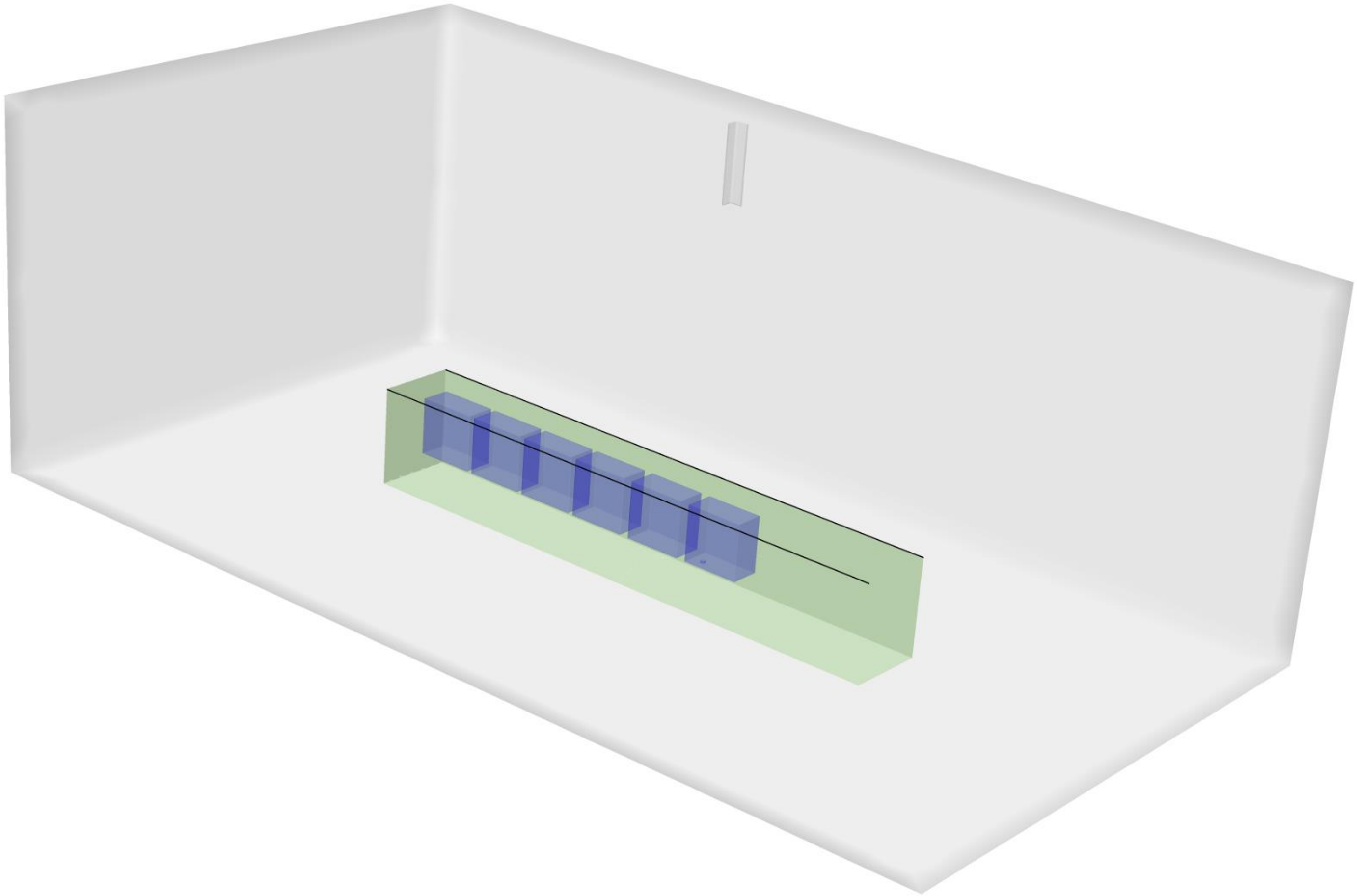
  -) equilibrium molar fraction of He: ~ 0.33 (i.e. 14% volume of O_2).

- In the reality, the local conditions can be worse (i.e. lower temperature and O_2 concentration).

Tunnel volume is small as compared to the amount of helium present in the cryomodules

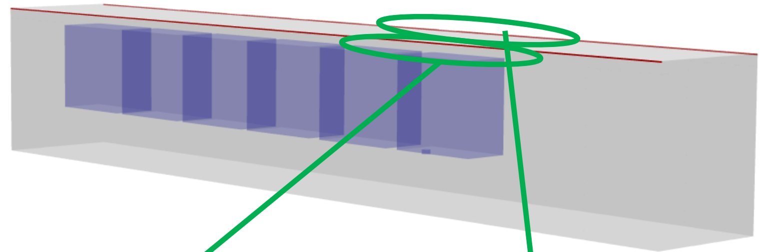
1. Simulations set up

Computational domain

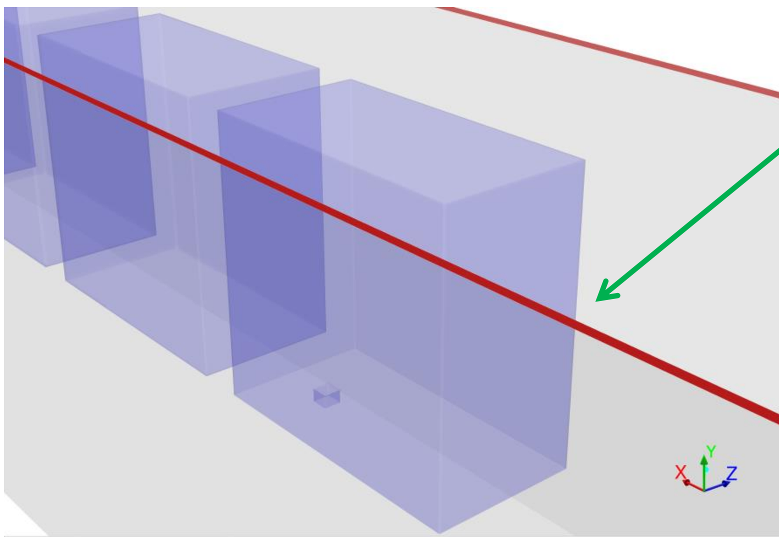


- Tunnel dimensions: 23.400 m x 3.226 m x 4.000 m.
- Cryomodules dimensions: 2.38 m x 1.20 m x 2.30 m
- Tunnel placed inside a ‘dummy volume’ 44 m x 18 m x 15 m.
- Outlet/inlet stack on the top of this volume.

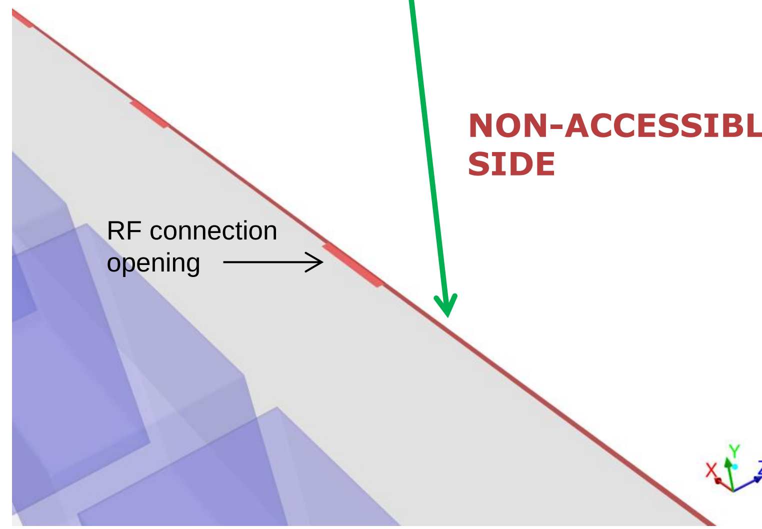
Tunnel openings



ACCESSIBLE SIDE



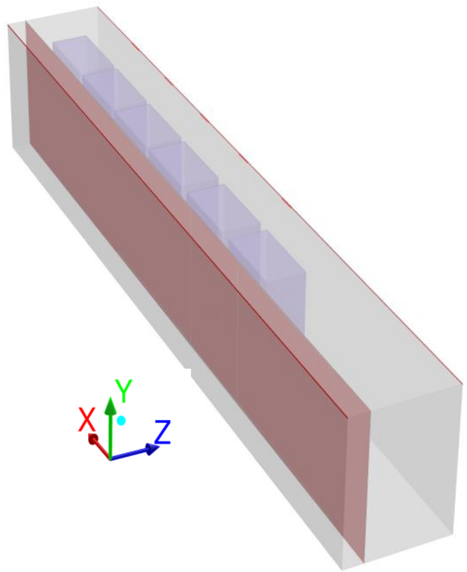
NON-ACCESSIBLE SIDE

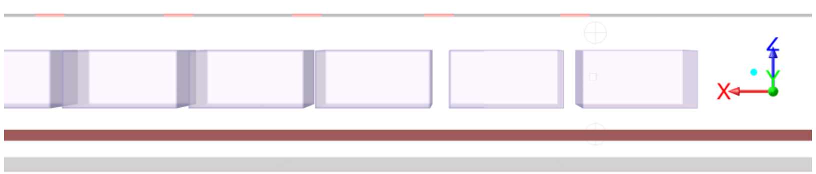


- Openings at the tunnel ceiling: 0.94 m^2 at the 'accessible side' and 1.12 m^2 at the 'non-accessible side'.
- Slightly bigger at the 'non-accessible side' because of the RF connections openings.

Accessible and non-accessible sides

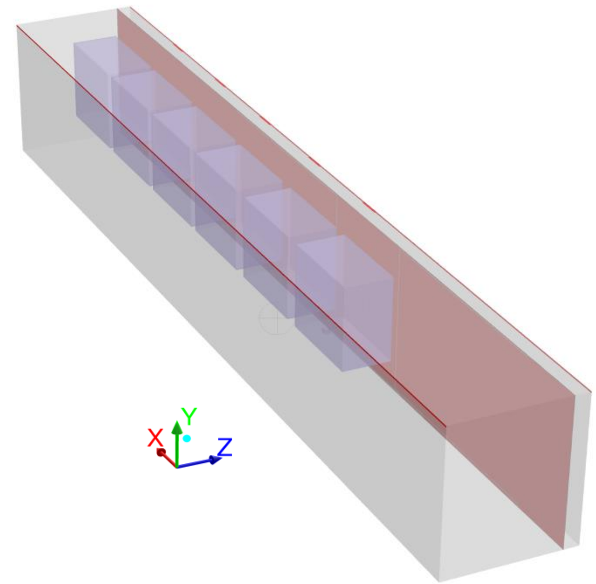
ACCESSIBLE SIDE





Distance cryomodules-wall: 1.271 m

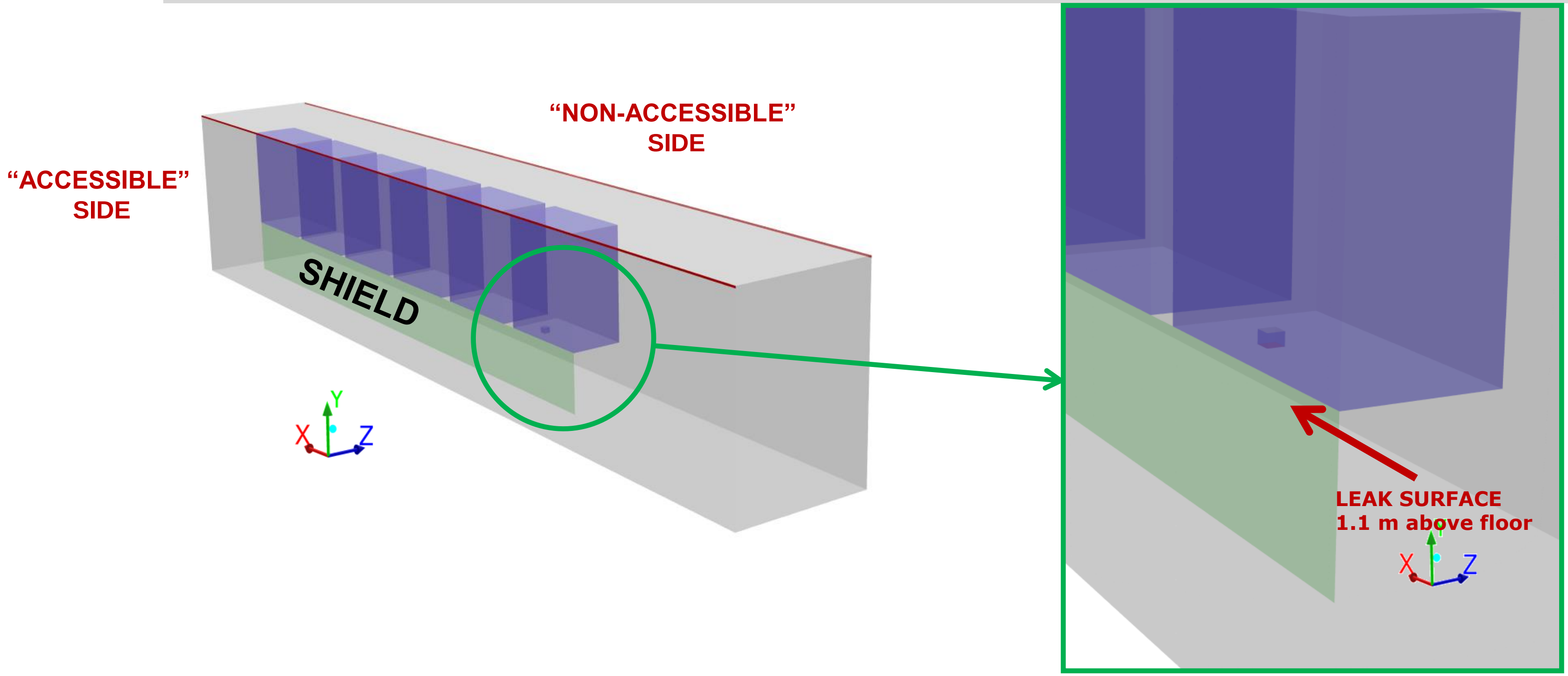
NON-ACCESSIBLE SIDE



Distance cryomodules-wall: 0.755 m

- Surfaces at middle distance between lateral walls and cryomodules (in red in the pictures) used for post-processing of results

Shield and leak orientation



- Possibility of adding a shield below the cryomodules to:
  1) provide immediate local protection against cold burns from helium leak at possibly 15 K;
  2) try to prevent the helium from flowing towards the 'accessible-side'.
- The orientation of the rupture disk could also be varied.

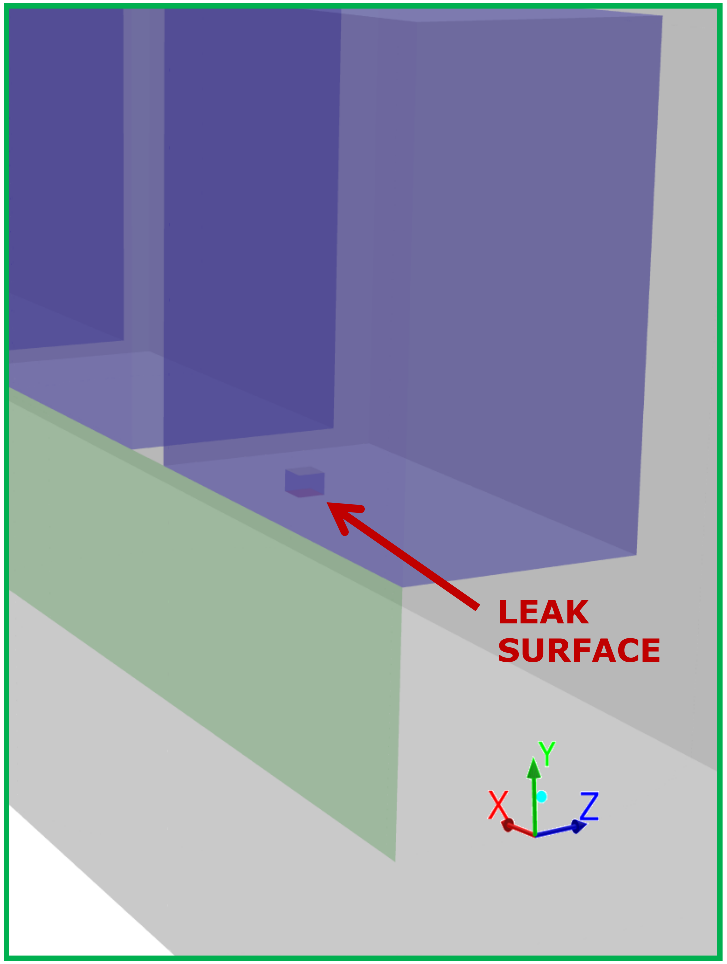
Three different configurations have been studied:

A. <u>'Reference-case'</u>: no shield + leak perpendicular to floor;

B. <u>'90-shield'</u>: shield + leak perpendicular to floor;

C. <u>'60-shield'</u>: shield + leak at 60° (with respect to the horizontal plane) towards the 'non-accessible' side.

Boundary conditions and assumptions



BOUNDARY CONDITIONS

- Leak surface: 0.0213 m^2 (corresponding to Φ 165 mm disk);
- Flow rate: 8 kg s^{-1} (20 kg released in 2.5 s);
- Temperature: 15 K.

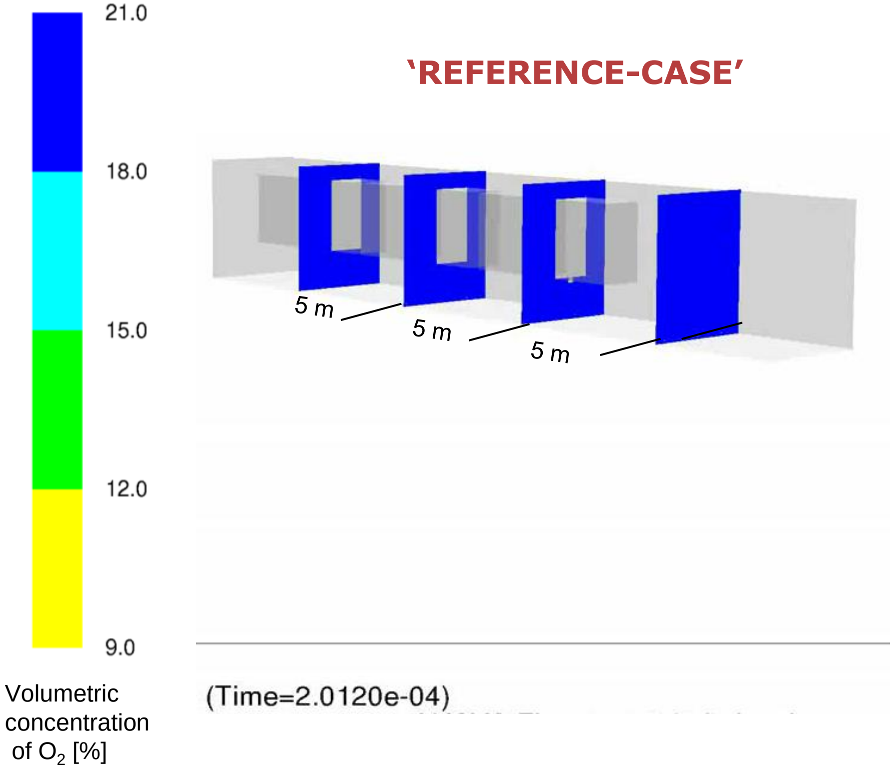
ASSUMPTIONS AND SIMPLIFICATIONS

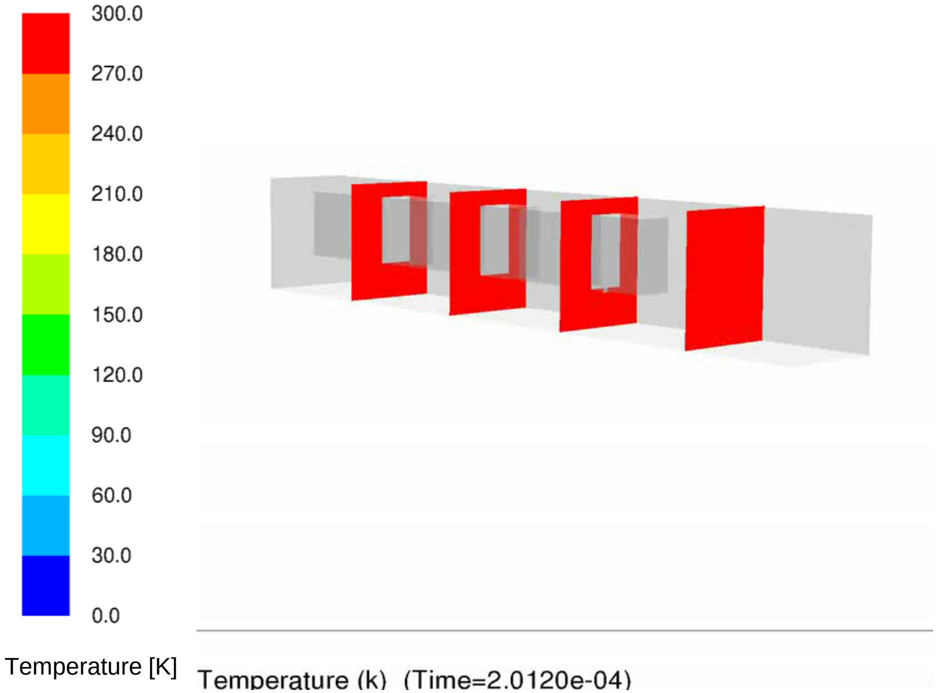
- Helium and air treated as ideal gases;
- O_2, N_2 (and water) condensation neglected;
- Specific heat, thermal conductivity and viscosity dependence on temperature neglected;
- Heat transfer with walls and equipment (as well as their thermal inertia) neglected;
- Gravity and buoyancy taken into account;
- Turbulence taken into account ('Realizable k-ε model').

2. Helium release (0-2.5 s)

-) ***Estimation of oxygen deficiency and cold burns hazards***
-) ***Influence of shield***

Cryogenic hazard for reference case (w/o shield)



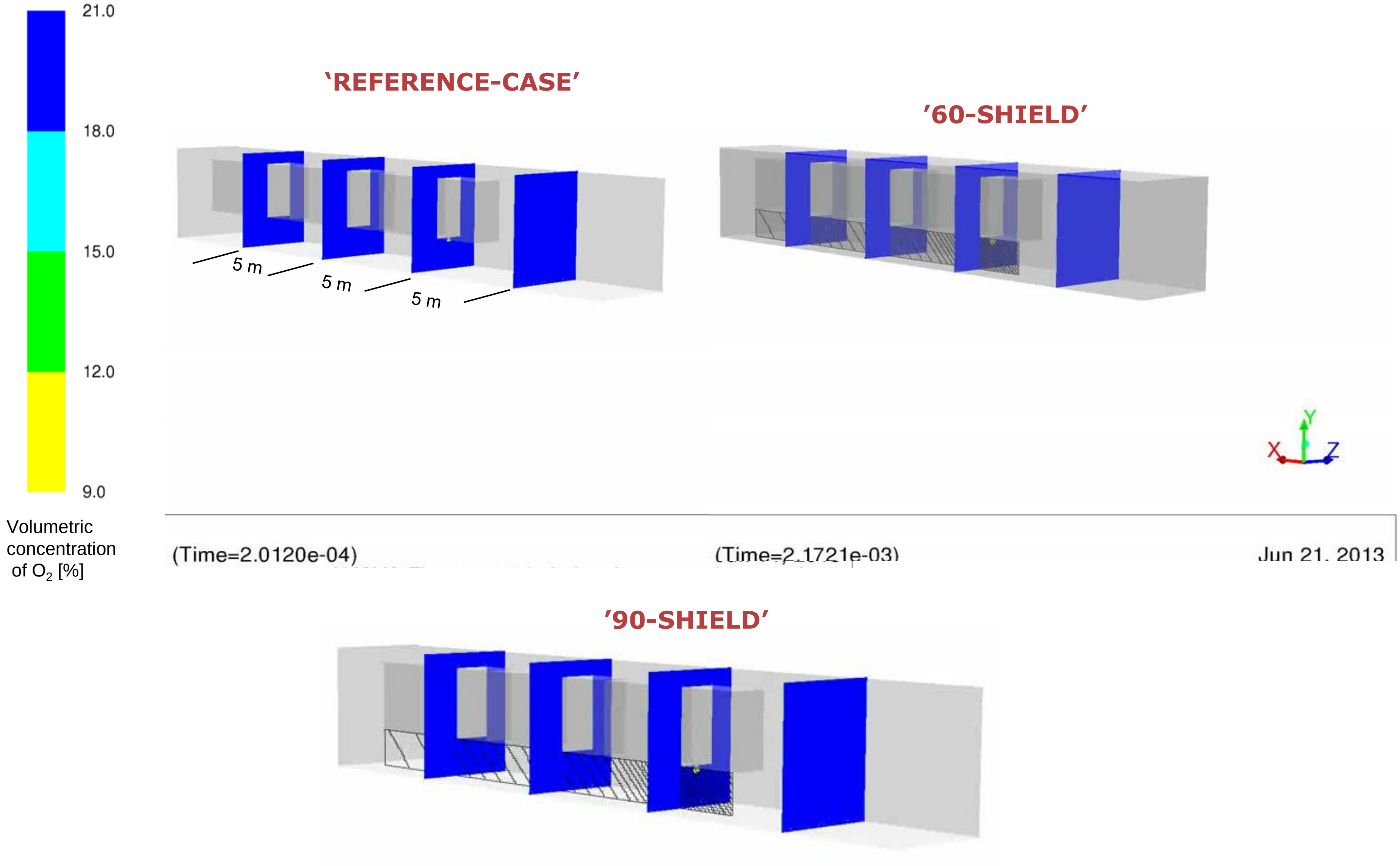


Body immersed in helium cloud after:

- 0~0.5 s if just in front of the rupture disk;
- 1~1.5 s at 5 meters distance from the rupture disk.

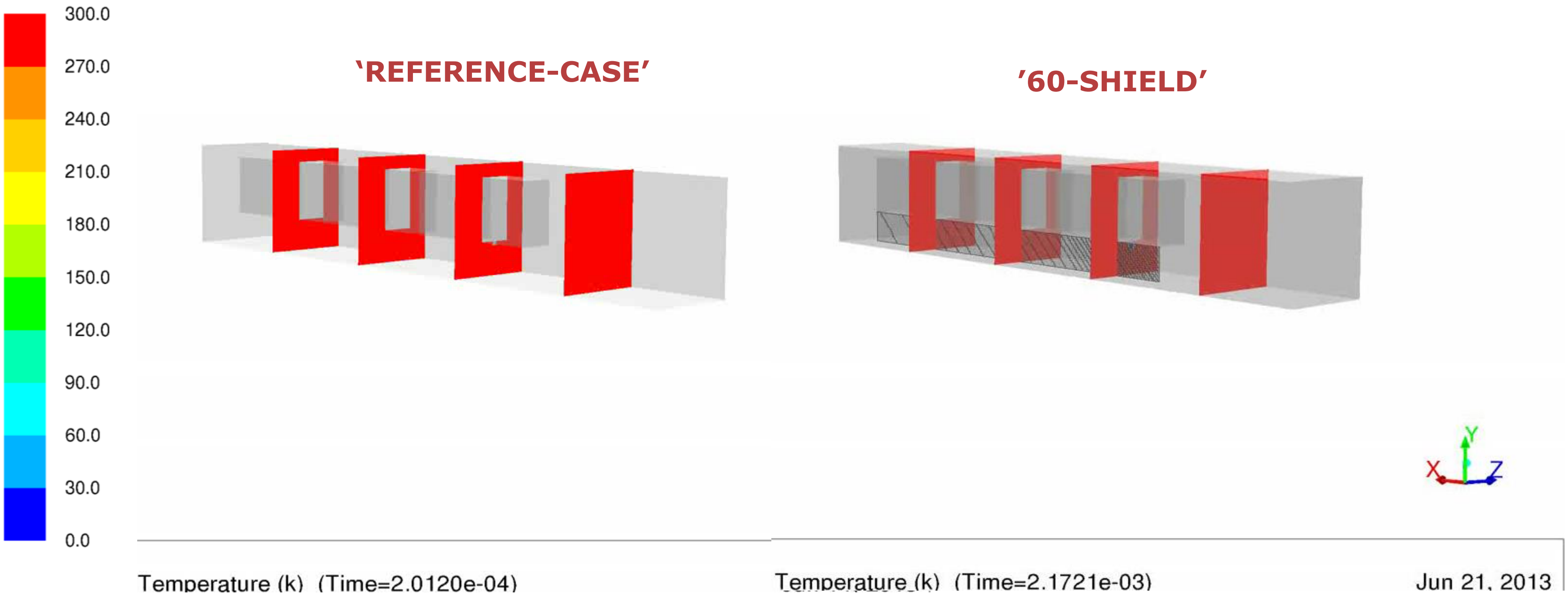
Temperature of the helium cloud is estimated to be in the range 100~200 K.

Movie: *x* cross sections, volumetric concentration of O_2

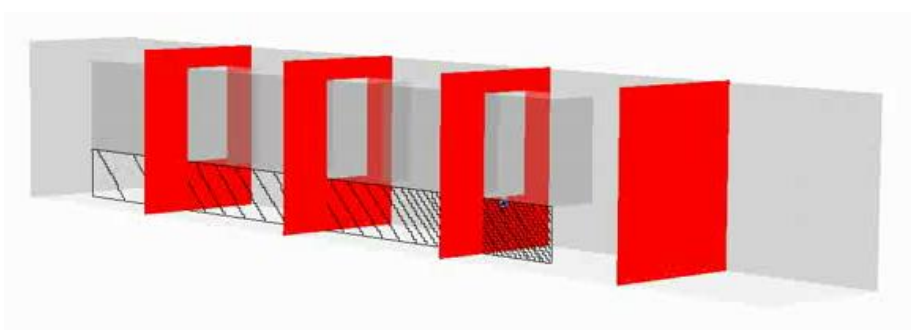


Movie: *x* cross sections, temperature

'REFERENCE-CASE' **'60-SHIELD'**



'90-SHIELD'



3. Tunnel evacuation (2.5-20 s)

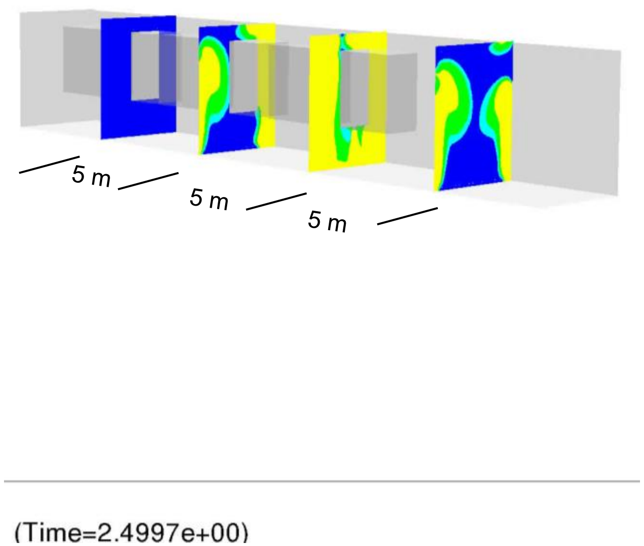
-) Estimation of oxygen deficiency and cold burns hazards

-) Influence of shield

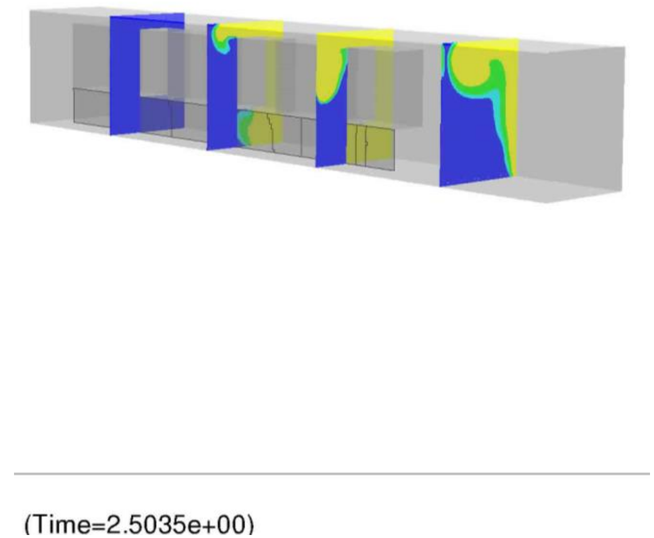
Movie: *x* cross sections, volumetric concentration of O_2

Volumetric concentration of O_2 [%]

'REFERENCE-CASE'



'60-SHIELD'



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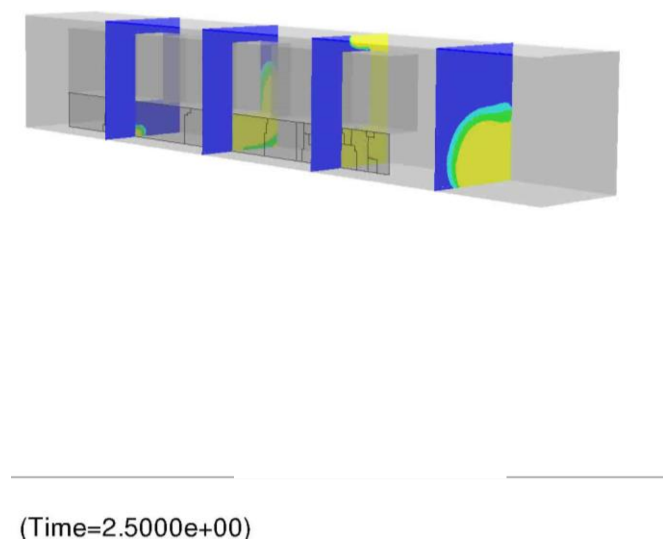
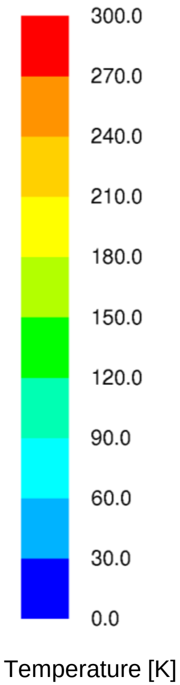
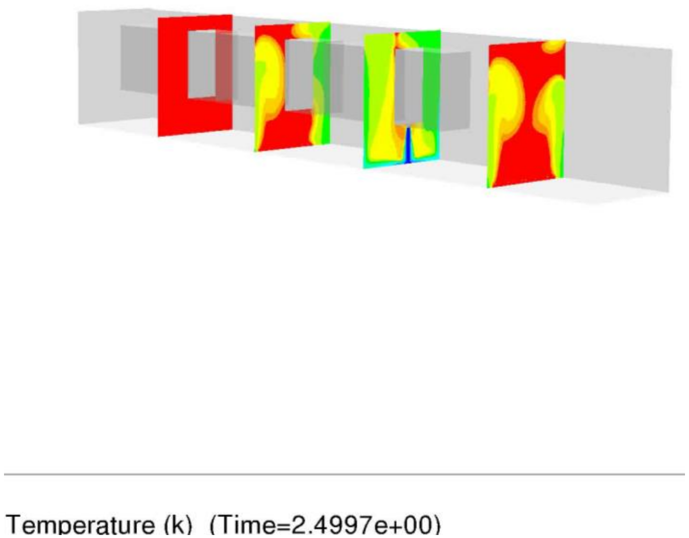


Movie: *x* cross sections, temperature



'REFERENCE-CASE'



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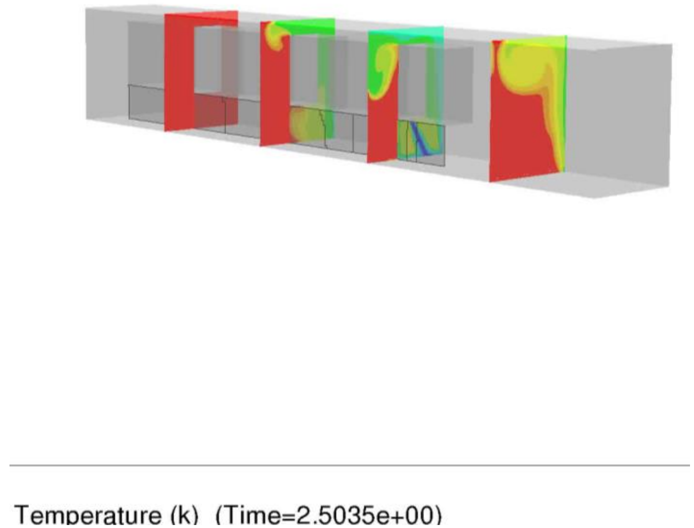
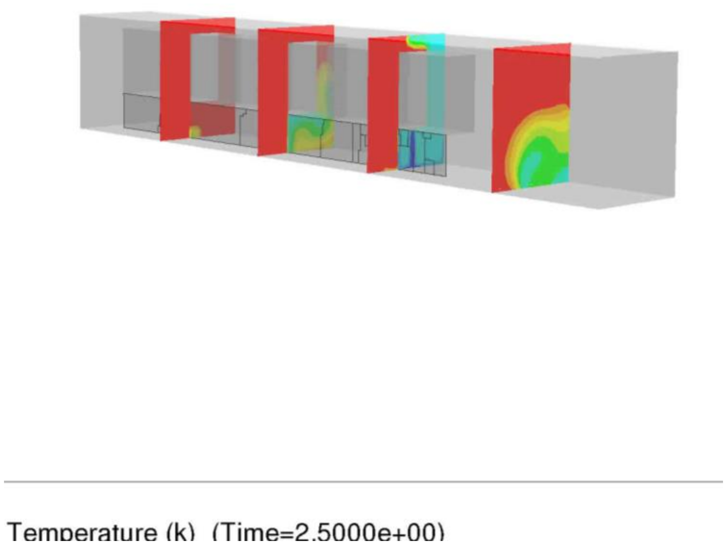
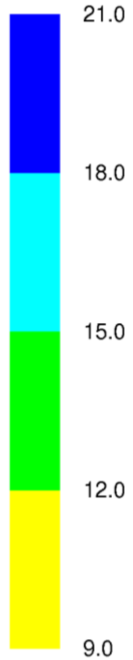


'90-SHIELD'

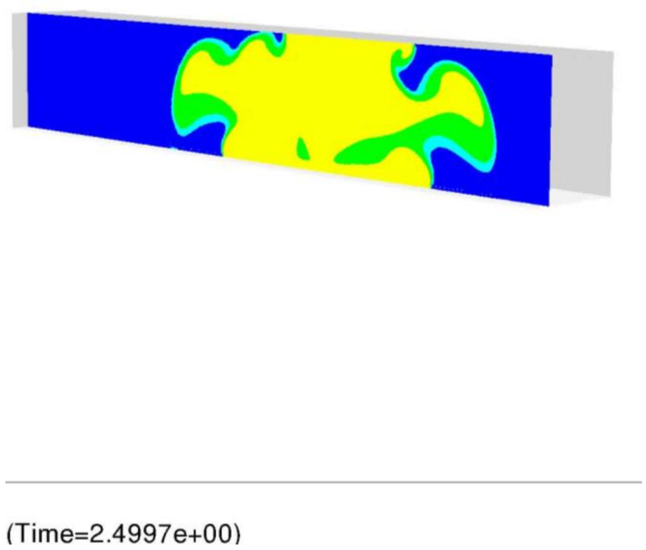


Movie: accessible side, volumetric concentration of O_2

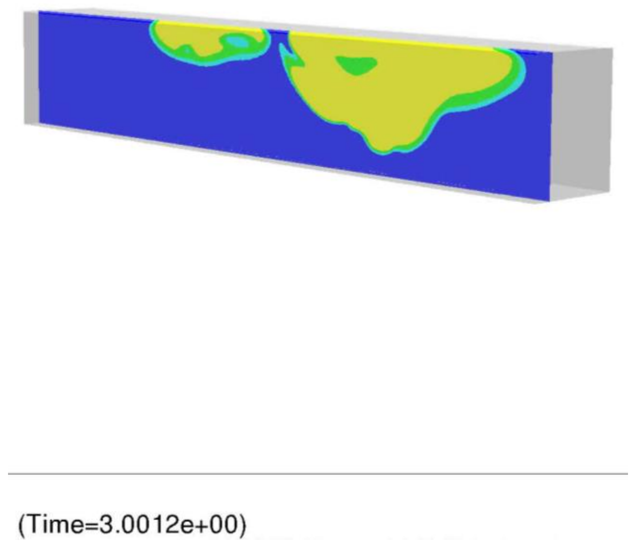


Volumetric concentration of O_2 [%]

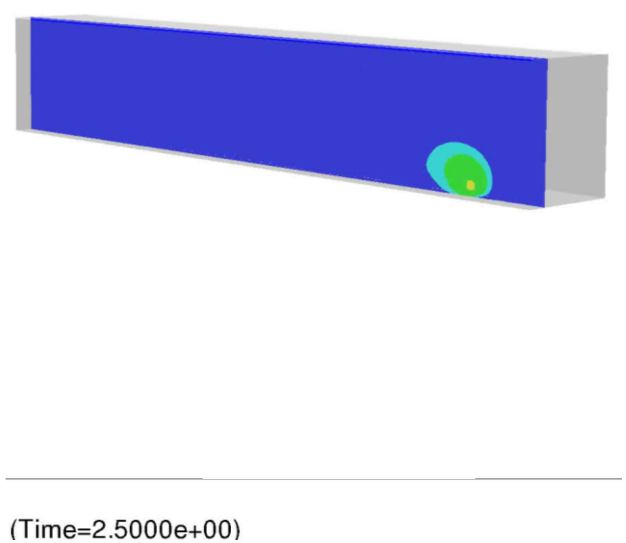
'REFERENCE-CASE'



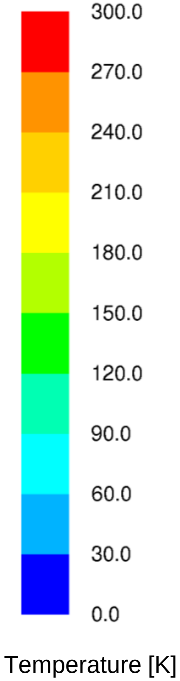
'60-SHIELD'



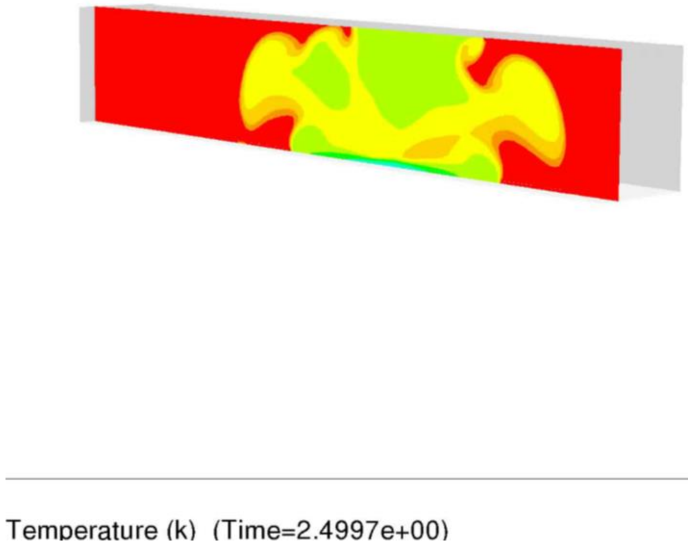
'90-SHIELD'



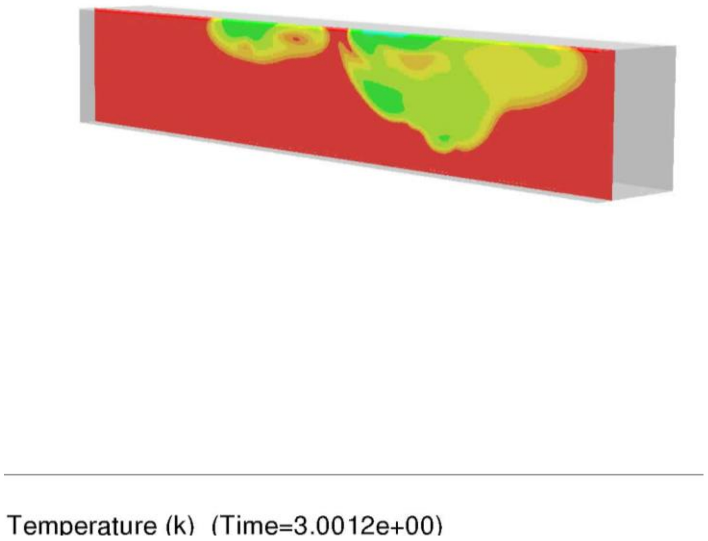
Movie: accessible side, temperature



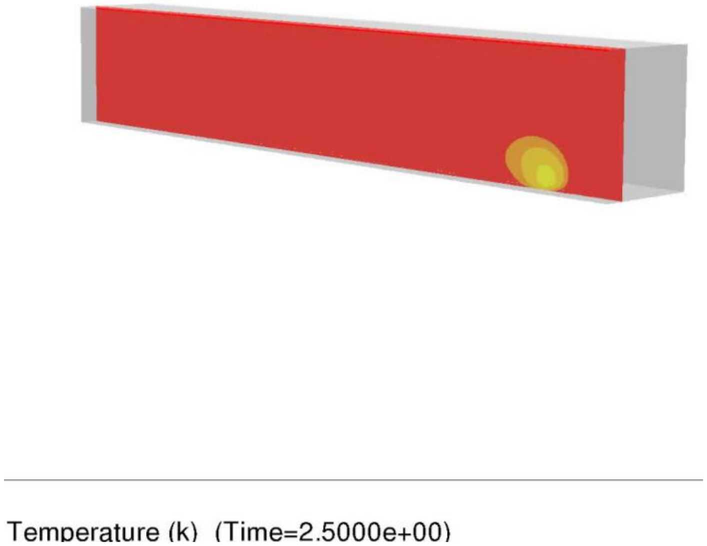
'REFERENCE-CASE'



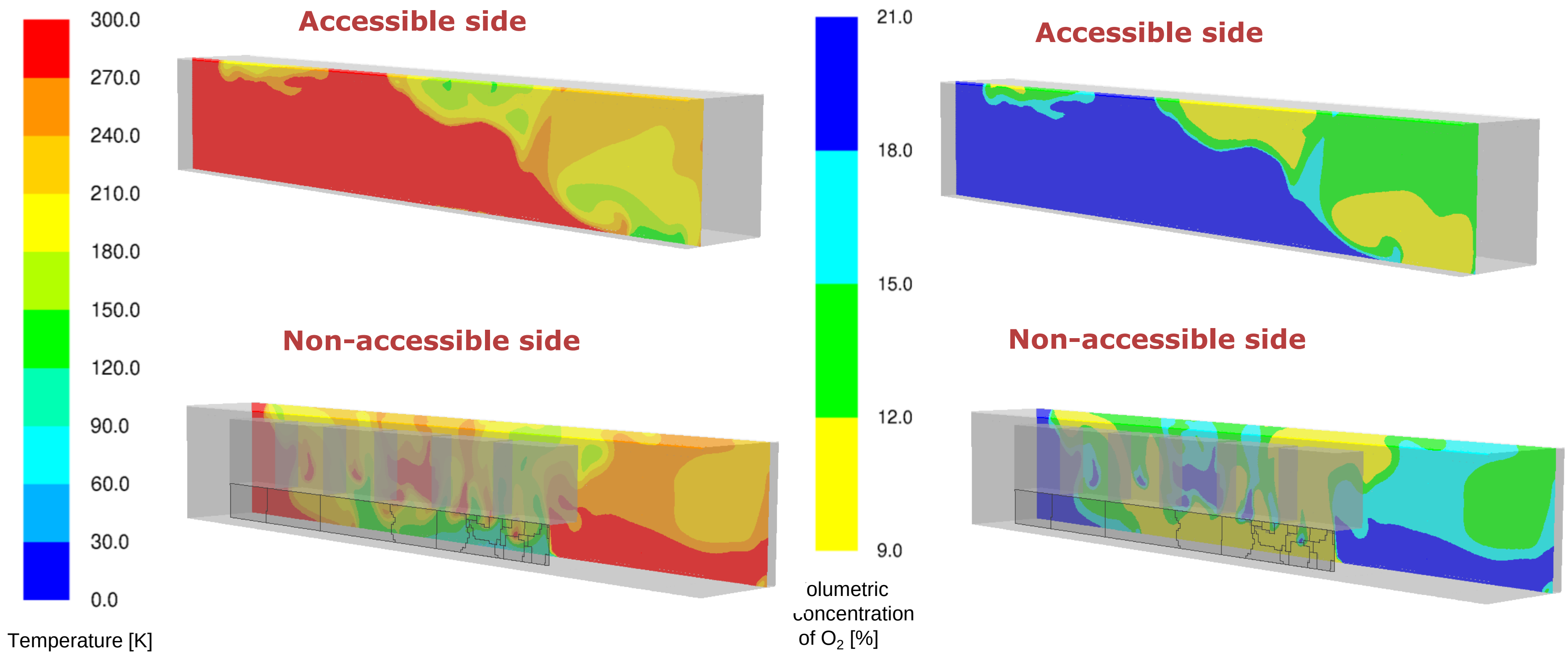
'60-SHIELD'



'90-SHIELD'



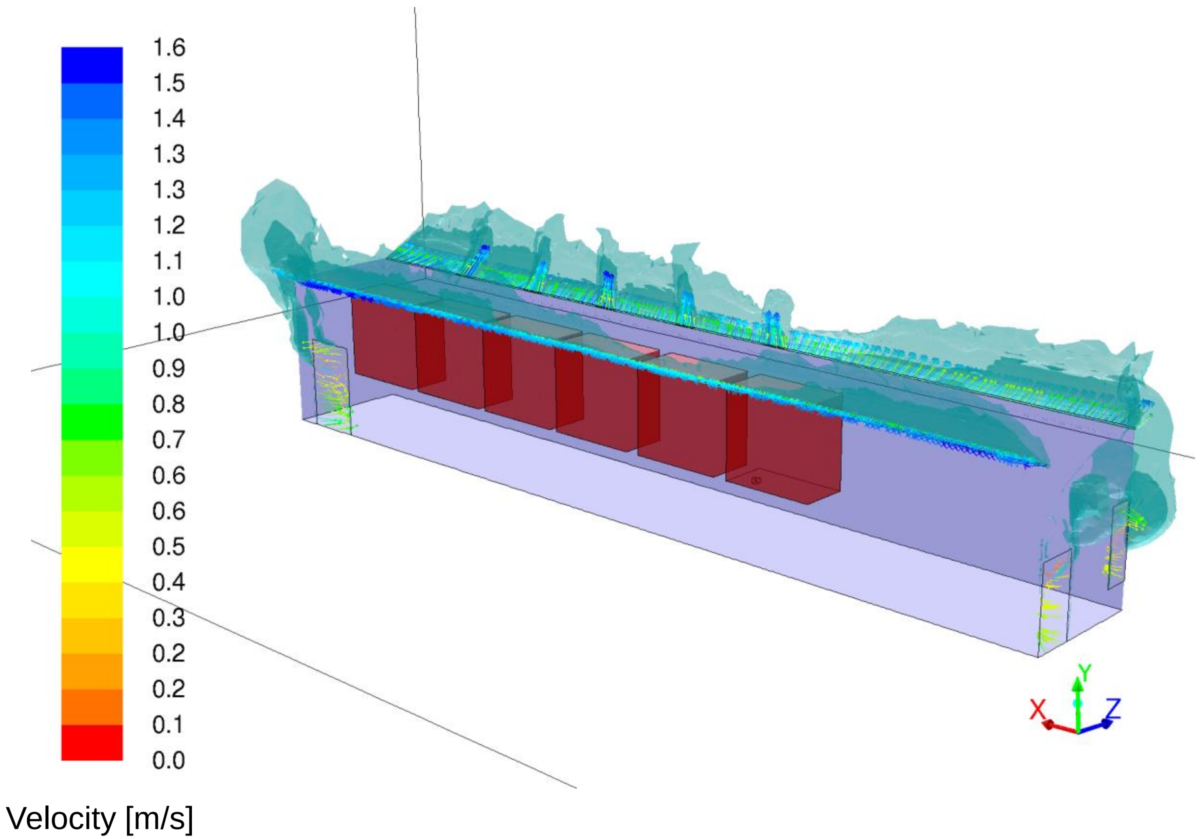
Condition at *t*=10 s for '90-shield'



- According to the present CFD results, for the best configuration tested (90-shield) at *t* =10 s it may still be possible to escape towards the big door on the left of the tunnel (not shown in the pics above) without touching the helium cloud.

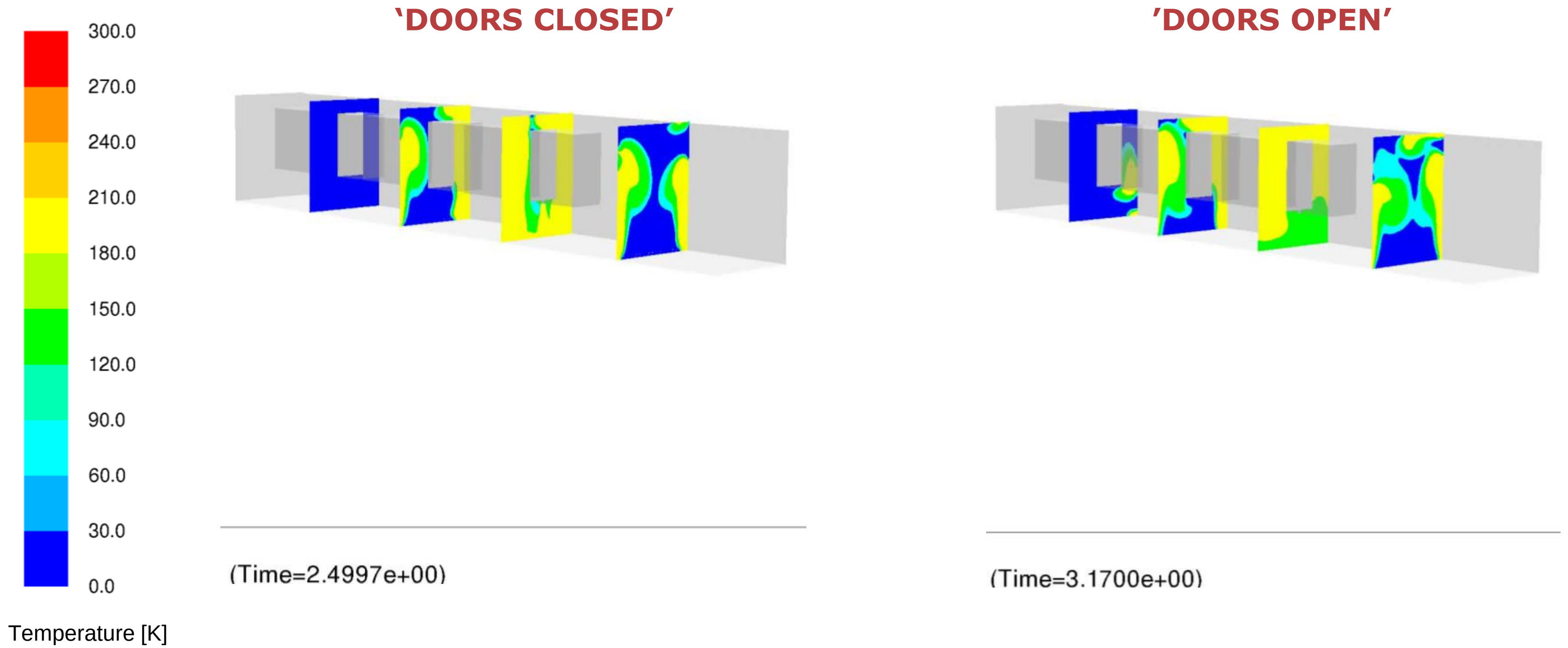
3. Influence of doors opening during evacuation

Tunnel doors



- Three doors are present in the tunnel (EDMS 1279878 v.3).
- One simulation has been run assuming that for the 'reference case' (i.e. without shield) all the 3 doors are opened at time = 2.5 s.

Movie: x-slices, O_2 concentration, reference case



- Opening of the doors doesn`t show a relevant impact on the first 20 seconds after the helium leak.
- The time scale (~ 20 s) is too short for the door opening to have a relevant impact during evacuation.
- Doors opening is anyhow estimated to be useful to heavily reduce the time needed to flush the helium.

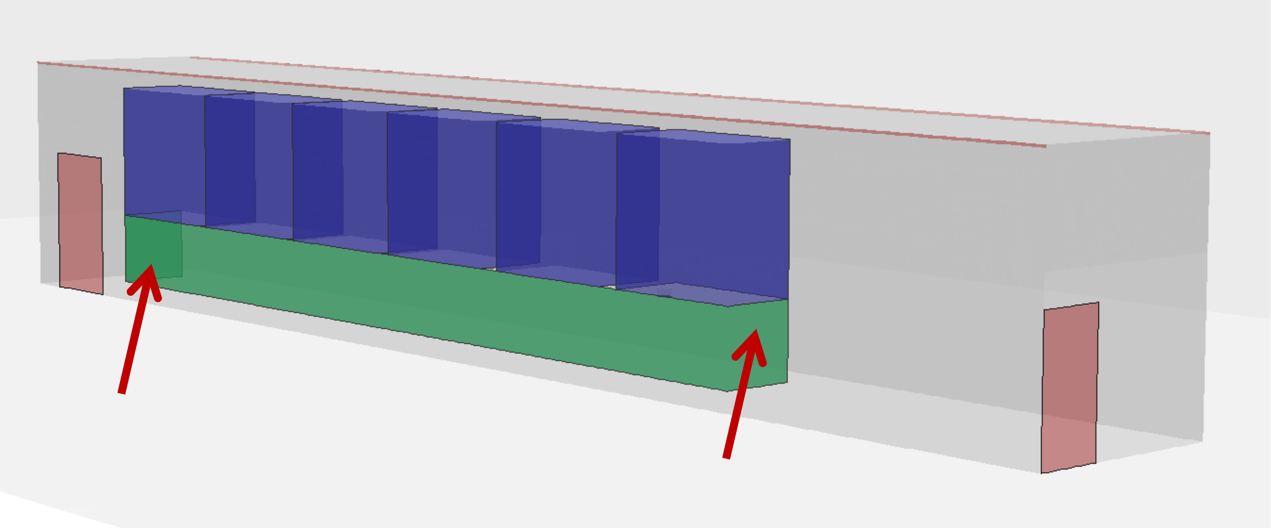
4. Next steps (on going work)

A) Simulations at lower flow rate (2 kg s^{-1} instead of 8 kg s^{-1})

Since the results presented strongly depends on the very high momentum of the helium leak, it has been considered interesting to run a simulation at a lower leak flow rate.

B) Shield geometry update

The shield geometry shown in the picture below could further restrict the propagation of the helium cloud along the longitudinal direction of the tunnel.



CONCLUSIONS

- The release of 20 kg of He at 15 K in 2.5 seconds has been chosen as worst case (EDMS 1279878 v.3).
- In case of perfect mixing: ~14% volume O_2, ~230 K (much worse local conditions expected).
- The helium cloud is estimated to reach 5 m distance in around one second time and display a temperature in the range 100~200 K;
- A shield below the cryomodules can provide immediate local protection against cold burns from helium leak at possibly 15 K and could help to confine He in a “non-accessible” zone of the tunnel;
- Possible strategy: keeping the helium confined in the non-accessible side of the tunnel as much as possible. The risk is reduced in the ‘accessible side’ , but increased in the ‘non-accessible side’;
- Rupture disk oriented perpendicularly to the floor is to be preferred to 60° and 30° orientation*, since the helium flow is slowed down more efficiently (preventing it from flowing around the modules ad falling back from the ceiling in the ‘accessible-side’ because of the high momentum);
- A ‘safe’ escape from the tunnel in 20 sec maximum time cannot be guaranteed, but the suggested configuration (shield + disk perpendicular to floor) is expected to reduce the risk on the ‘accessible-side’ without any manifest drawback nor major costs;
- According to the present CFD results, with the suggested configuration, after 10 seconds from the release beginning it may still be possible to evacuate the tunnel without touching the helium cloud;
- Visibility will be very low and noise will be very loud during evacuation;
- Opening the doors is not expected to reduce the risk during evacuation (0-20 s).

*30° orientation already studied and discarded during preliminary analyses