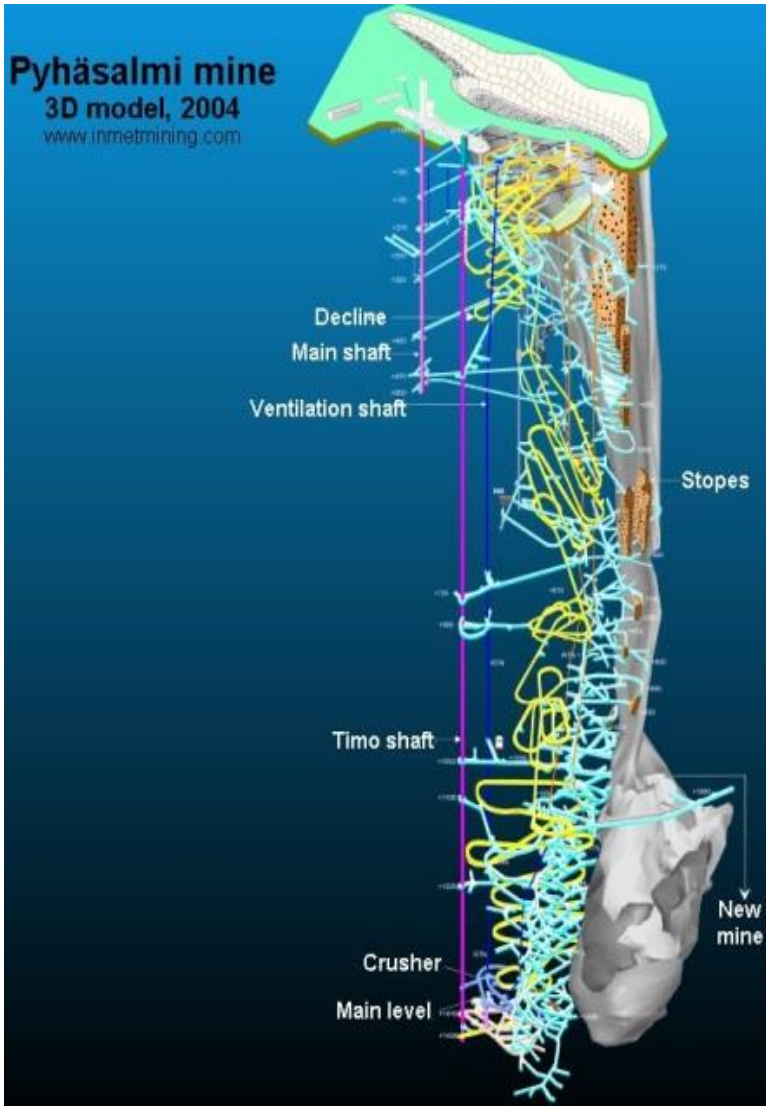
Wrocław University of Technology

Safety related issues of the unexpected Argon release into the tunnel

Maciej Chorowski, Ziemowit Malecha, Jarosław Poliński

Motivation - LAGUNA-LBNO

Large Apparatus studying Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations



- next-generation neutrino observatory
- a huge amount of liquid Argon (LAr) transported in cryogenic-tank trucks
- cistern capacity: 20 m3 (27.6 tons)
- the first Pilot installation:3800 tons of LAr
- GLACIER 150000 tons of LAr
- 10.5 km decline, irregular spiral shape, slope of 7.3°

Work done:
- risk analysis of the LAr transportation
- identification of the worse case scenario
- effects of an uncontrolled LAr leak to the tunnel

Acknowledgments:
- European Union's Seventh Framework Program grant agreement no 284518 [LAGUNA-LBNO]
- financial resources for science 2015, Polish Ministry of Science

Outline

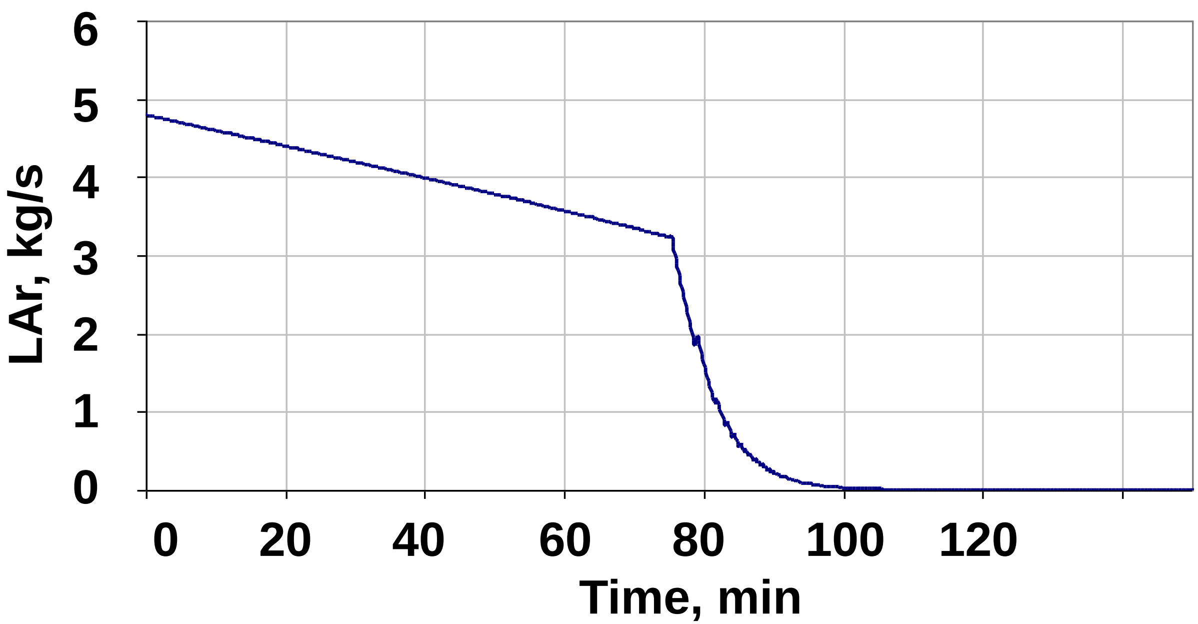
1. Calculation of the LAr mass flow through the rupture hole
2. Calculations of the substitute gas Argon (GAr) area (needed for proposed numerical model)
3. Mathematical model and numerical implementation (GAr propagation in the tunnel)
4. Results of the numerical calculations:
   GAr cloud propagation for different ventilation regime

LAr mass flow through the rupture hole

In 90% of tank rupture: $d \leq 50$ mm (Risk Assessment Data Directory, 2010)

$$q_m = C \cdot A\sqrt{2 \cdot \rho_{LAr} \cdot (p_1 - p_2)}$$

p_1 -- pressure in the tank (2MPa), p_2 -- pressure after the constriction (atmospheric)
ρ_{LAr} -- density of LAr
A -- cross section of the rupture, **A = 0.007854 m2**
C -- dimensionless flow coefficient, *C* = 0.6 (Van den Bosch et al., 1997)



The worse case scenario:

- $d = 50$ mm
- $q_m = 4.7$ kg/s (max value)

Calculation of the substitute GAr area

Goal:
- To create BC for the numerical model of the GAr cloud propagation

Assumptions:
- Temperature of the tunnel ground remains constant: 300 K
  (estimated heat flux from the ground to the LAr: 40 kW/m_2)

Conclusions:
- To evaporate $\boldsymbol{q_m = 4.7}$ **kg/s**, the evaporation area $\boldsymbol{A_{ev} = 20}$ **m²** is necessary
- LAr will stay in the liquid form only locally

Simplifications of the numerical model:
- LAr evaporation process can be considered to be a local event
- The evaporation process can be neglected
- LAr inlet BC can be substitute with GAr inlet BC

Mathematical model and implementation

Compressible flow of the gas mixture: air (79%N_2 + 21%O_2) and Argon

The mixing process: the diffusion-advection equation for each gas

$$\frac{\partial \rho Y_i}{\partial t} + \nabla \cdot (\rho \boldsymbol{u} Y_i) = \nabla(\mu \nabla Y_i) \qquad \sum Y_i = 1$$

Momentum transportation: Navier-Stokes equations

$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \nabla \cdot (\rho \boldsymbol{uu}) = -\nabla p + \nabla \cdot (\mu \nabla \boldsymbol{u}) + \rho g \qquad \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0$$

Mixture: additivity

$$\rho = \sum Y_i \rho_i \quad \mu = \sum Y_i \mu_i \quad Cp = \sum Y_i Cp_i$$

$\rho_i, (T)$ $Cp_i(T)$ – polynomial functions of T

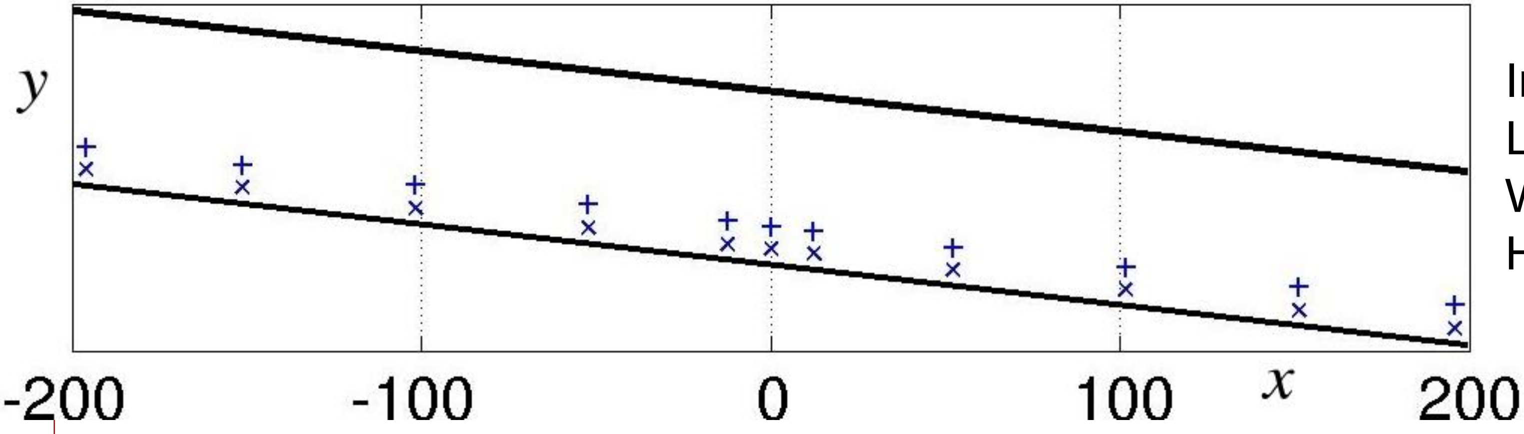
$\mu_i(T)$ – Sutherland approximation

Energy transportation: enthalpy equation

$$\frac{\partial \rho h}{\partial t} + \nabla \cdot (\rho \boldsymbol{u} h) = \frac{Dp}{Dt} + \nabla \cdot \left(\frac{k}{Cp} \nabla h \right)$$

Numerical implementation: OpenFOAM CFD toolbox, FVM, PISO algorithm

Numerical model: the geometry



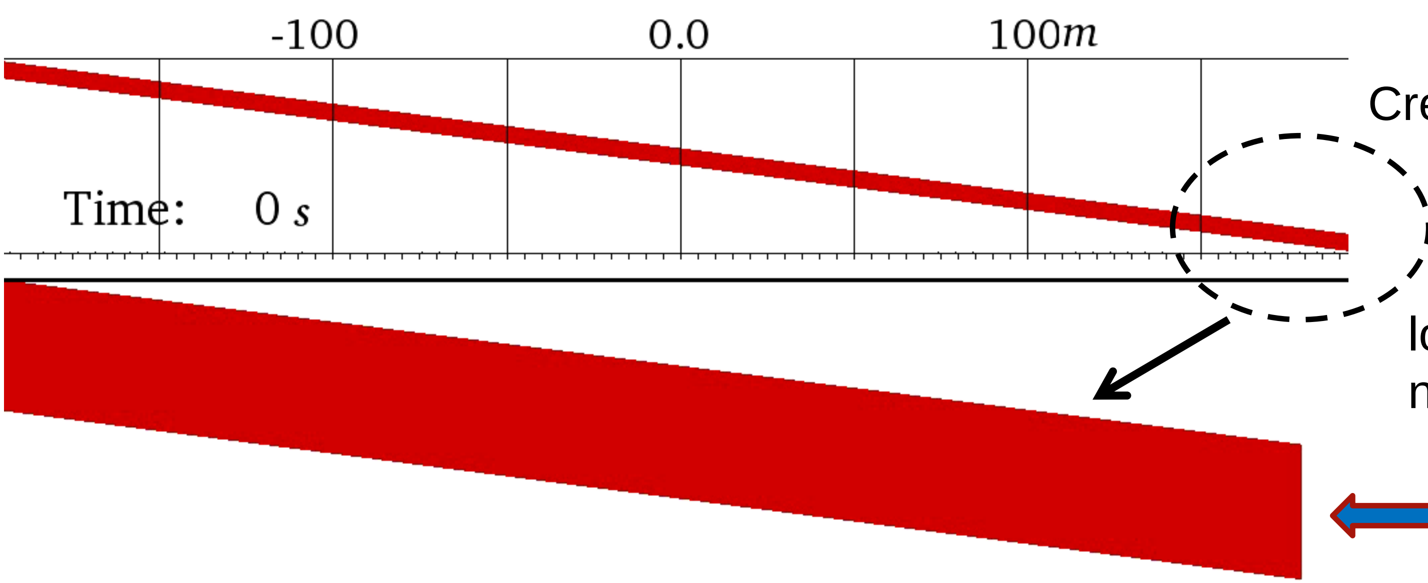
Inclination = 7.3°
Length = 200 m
Width = 5 m
Height = 5 m

- $x = 0$ – middle of the spill area
- The inlet of GAr: $-2 \leq x \leq 2$, $q_m = 4.7$ kg/s, $T = 87$ K
- Ventilation from right to left
  $|U_{air}| = (1, 2.5, 5, 6)$ m/s
- Measuring points:
  + and **x** – 1.75 m and 0.5 m above the ground
  $\mathrm{x} = (0, \pm 10, \pm 50, \pm 100, \pm 150, \pm 195)$ m

Results of the numerical calculations

Table Average velocity and direction of GAr propagation for different ventilation regimes.

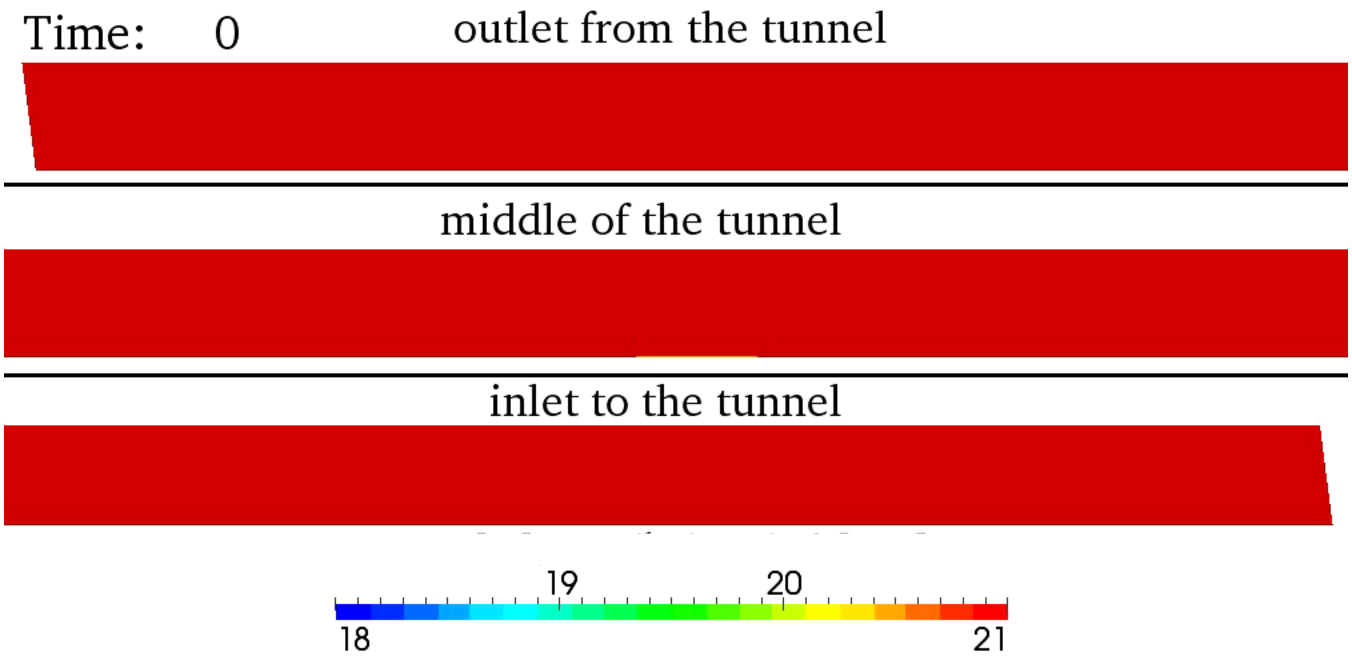
Ventilation speed	U_{av} up the tunnel	U_{av} up the tunnel	direction
1	0	3.7	down the tunnel
2.5	0	2.7	down the tunnel
5	4	1.7	up & down
6	5	0	up the tunnel



Creation of Ar bubble

O_2 <18%
locally for $y = 0.5$m
never for $y = 1.75$m

U_{air} = 1m/s

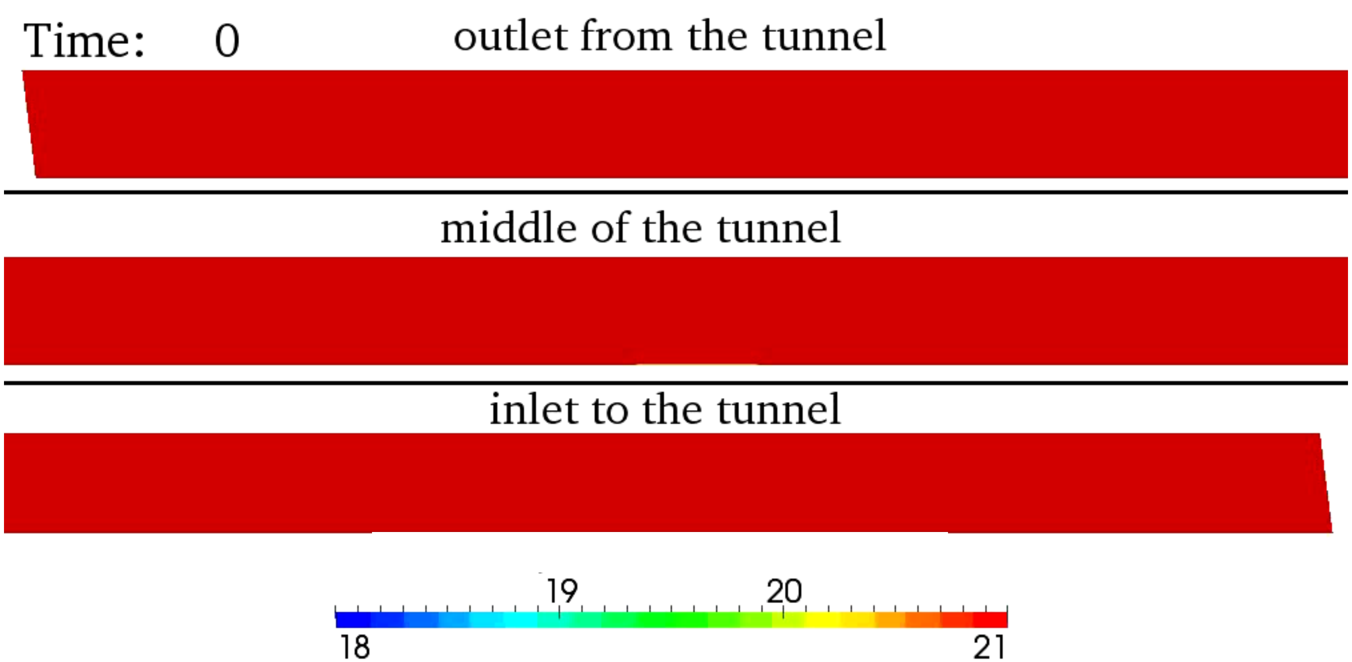


The bubble slows down

Higher GAr content inside the bubble

O_2 <18% for $y = 1.75$ at $x = 10$ m

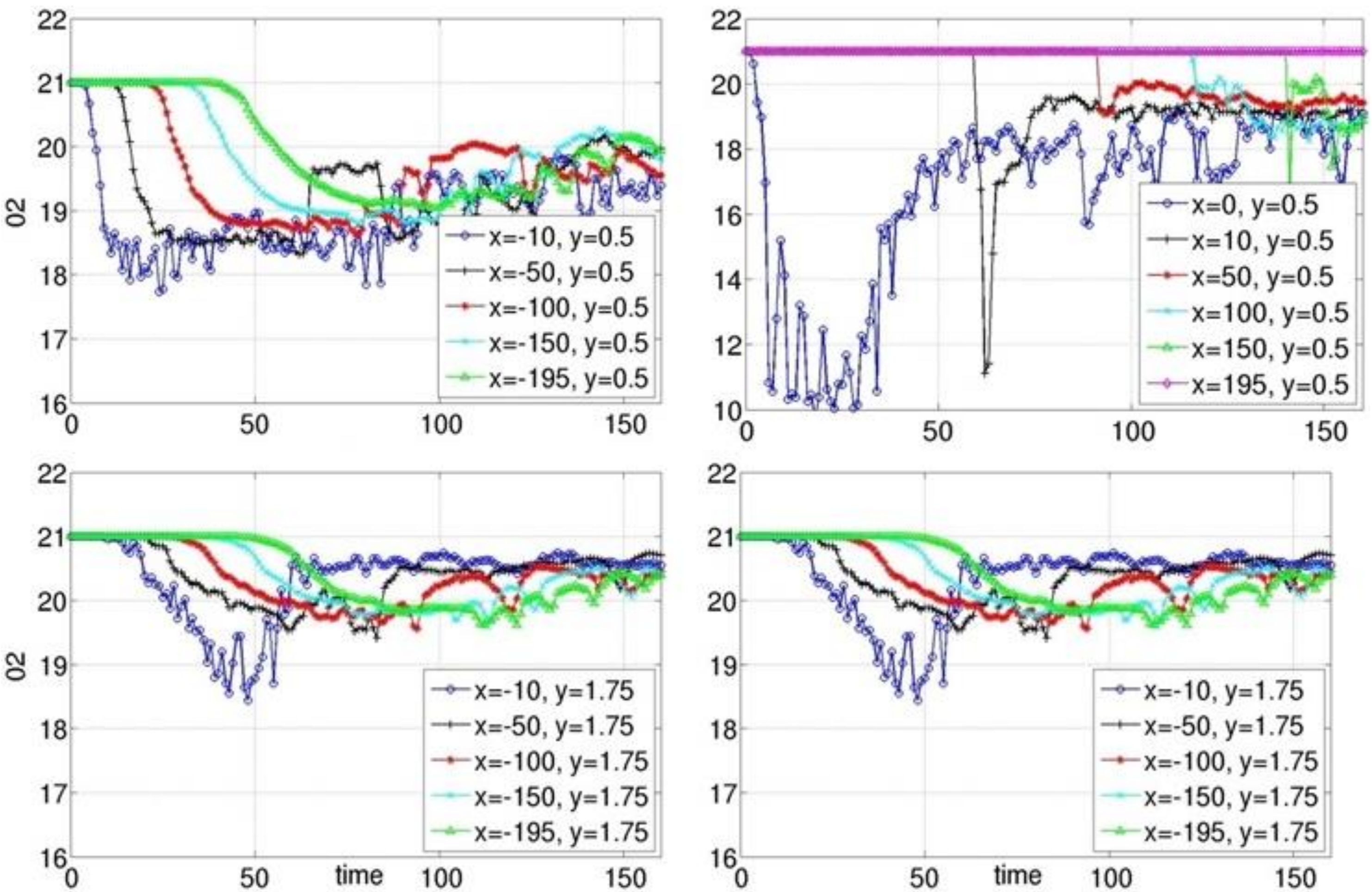
$U_{air} = 2.5$m/s



blocking of GAr bubble until time $t = 50$s

GAr goes up and down the tunnel

$U_{air} = 5$m/s



O_2 <18%
for $y = 0.5$ m
at $x = -10$ m

Figure. Oxygen content in the measuring points, as a function of time, U_{air} = 5 m/s. Upper (lower) row shows results in locations 0.5 m (1.75 m) above the ground. Left (right) column shows results up (down) the tunnel from the Argon spill point.

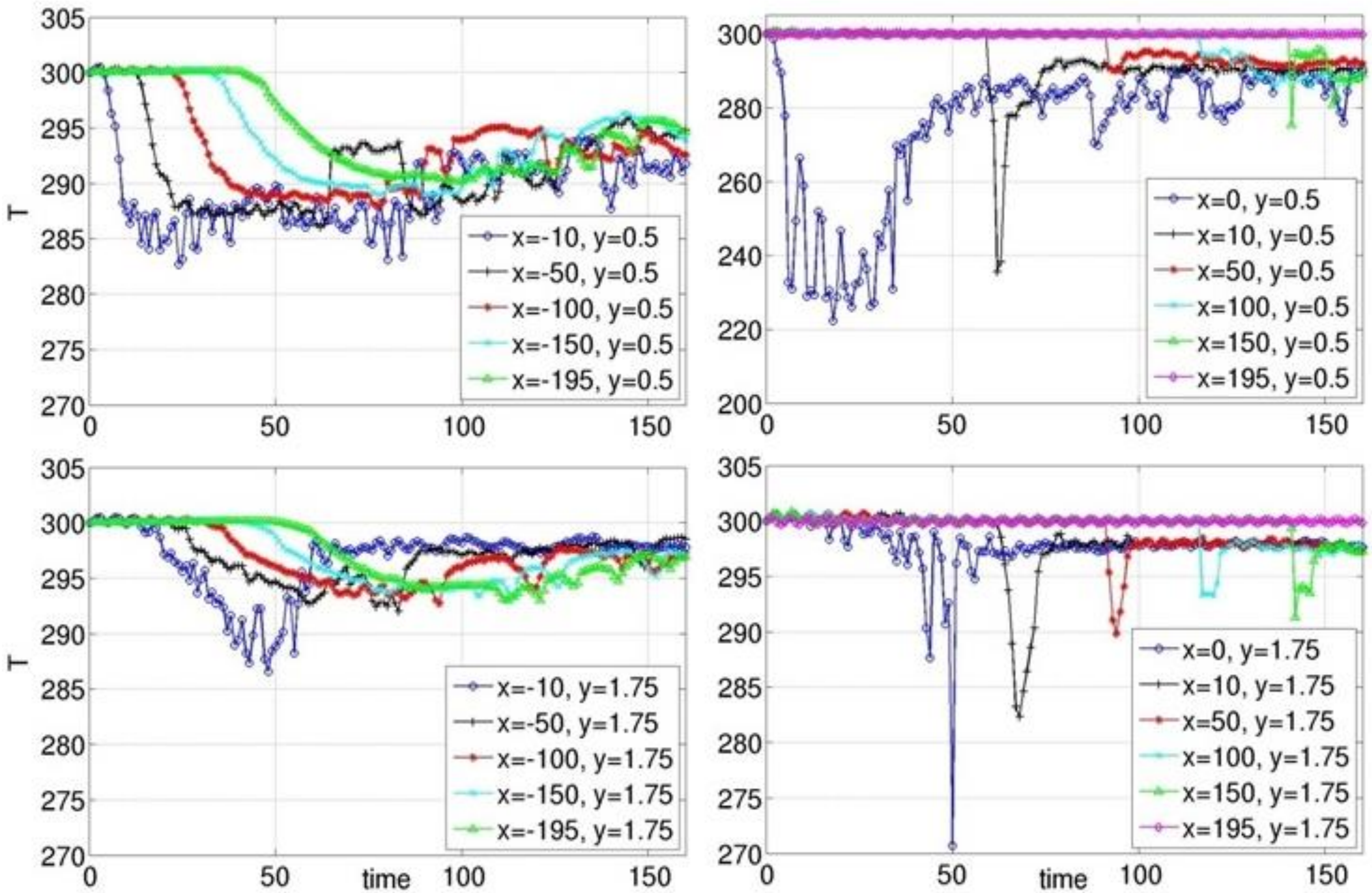
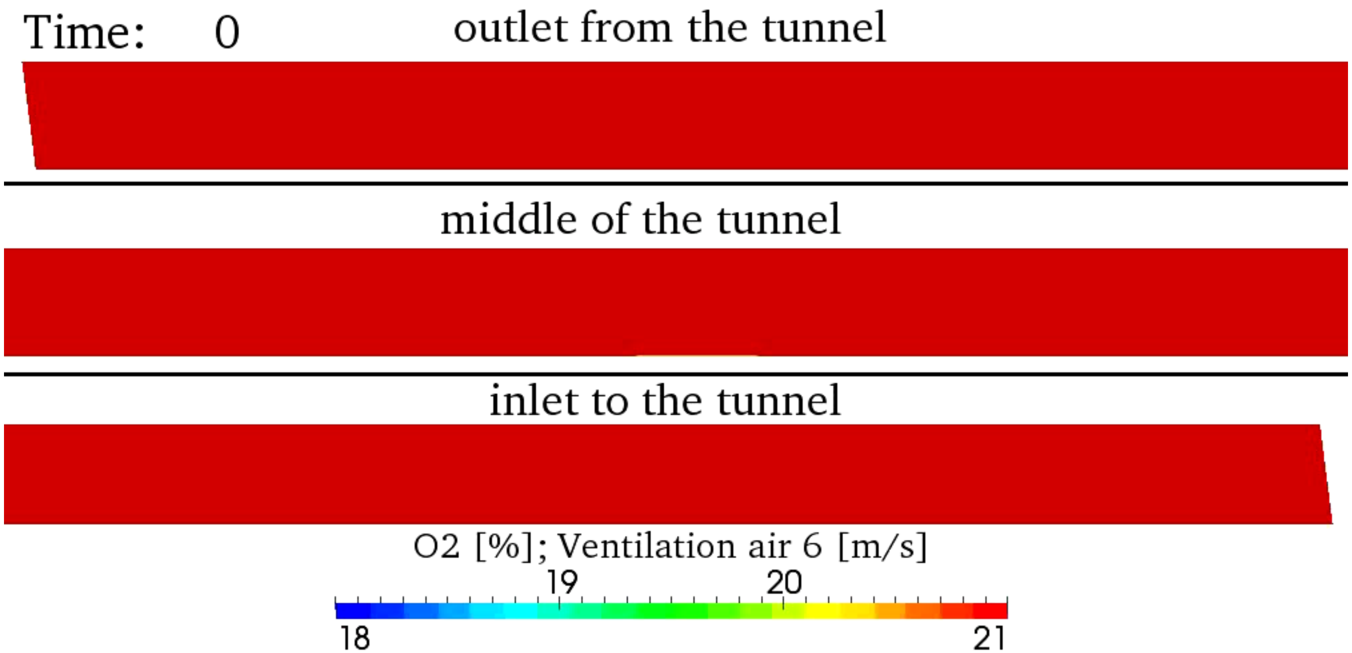


Figure. Temperature in the measuring points, as a function of time, U_{air} = 5 m/s. Upper (lower) row shows results in locations 0.5 m (1.75 m) above the ground. Left (right) column shows results up (down) the tunnel from the Argon spill point.

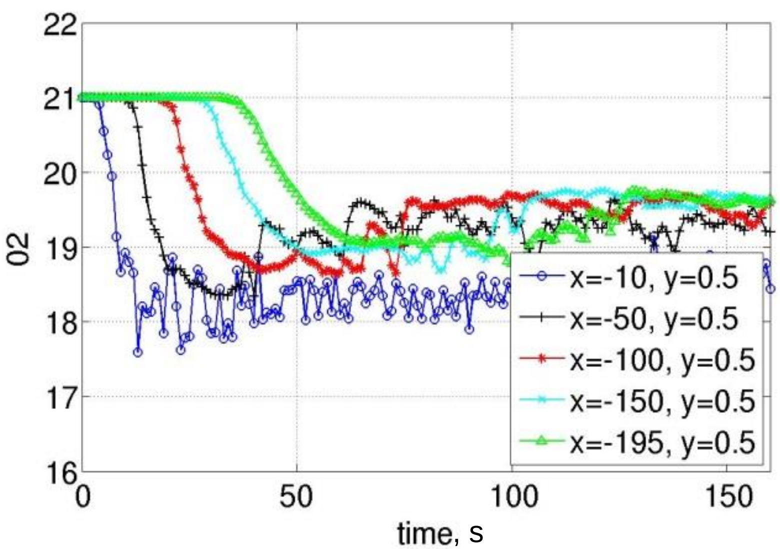
Limiting case: All the GAr goes up the tunnel

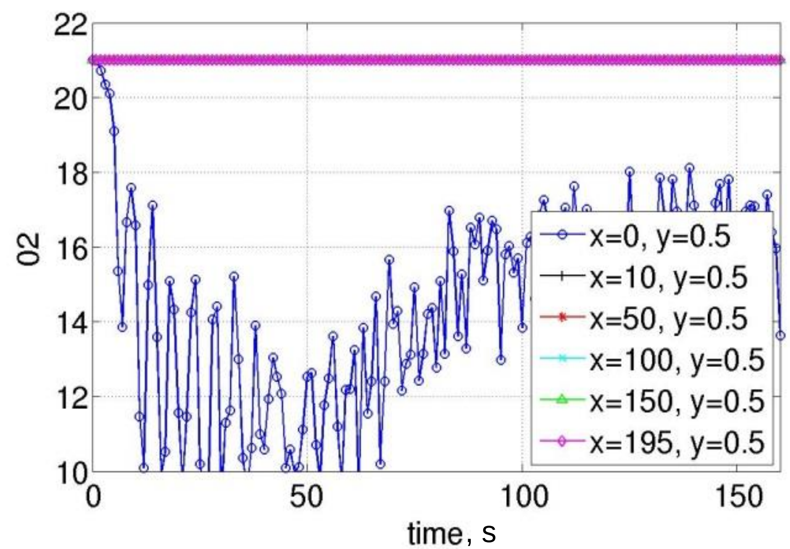


O_2 never below 18%
For $y = 1.75$ m

O_2 <14% for longer time
for $y = 0.5$ m at $x = 0$ m

$U_{air} = 6$ m/s





Conclusions

- Accident of the Argon spill inside the Pyhasalmi mine tunnel was investigated.
- GAr cloud tends to flow down the tunnel for low and moderate ventilation,1-3 m/s Low temperature and O_2 deficiency hazard only at the ground level of the tunnel.
- For air ventilation larger than 5 m/s, the GAr stays in the vicinity of the incident or go slowly up the tunnel. In this case, the temperature and the O_2 deficiency can drop in regions significantly above the ground of the tunnel.
- **In case of Argon spill incident:** ventilation should be reduced to the lowest possible speed (max 2.5 m/s), personnel should be evacuated upwards from the incident location
- Open Source OpenFOAM numerical toolbox is suitable for cryogenics flows analysis.