CRYOGENIC HAZARD AT ESS

STRATEGY, SAFETY STUDIES AND LESSONS LEARNT

D.Phan with the contribution of S.Birch, E.Lundh, J.Fydrych, IK-partners and others

CERN Cryogenic Safety – HSE seminar, 21-23 September 2016

Contact: duy.phan@esss.se

AGENDA

1. Overview of the **ESS ODH Safety process and implementation** ESS-0038692

2. **Safety studies and concept against Oxygen Deficiency Hazard** in the accelerator tunnel

3. **Results and lessons learnt from the Computational Fluid Dynamics (CFD)** simulations in the accelerator tunnel

4. **Upcoming activities and challenges**

Introduction

2014: construction work started on the site

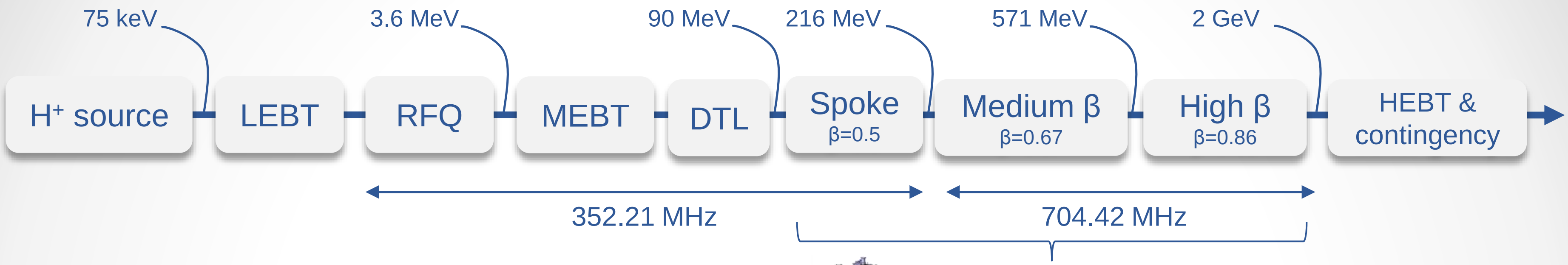
2019: first neutrons on instruments

2023: ESS starts user program

2025: ESS construction complete

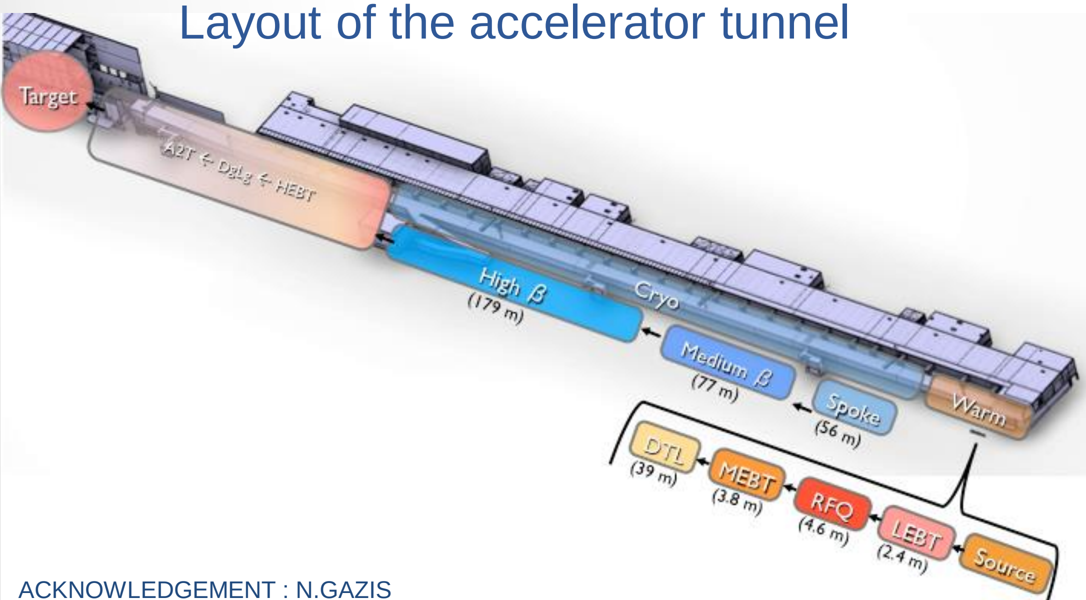
Introduction

Main parameters of the ESS Linac



Helium inventory (nominal operation)
Elliptical CM - 1014 kg
Spoke CM – 277 kg
CDS – 215 kg

Layout of the accelerator tunnel



Parameters	ESS LINAC
E [GeV]	2
$P_{average}$ [MW]	5
I_{pulse} [mA]	62.5
f_{rep} [Hz]	14
t_{pulse} [ms]	2.86

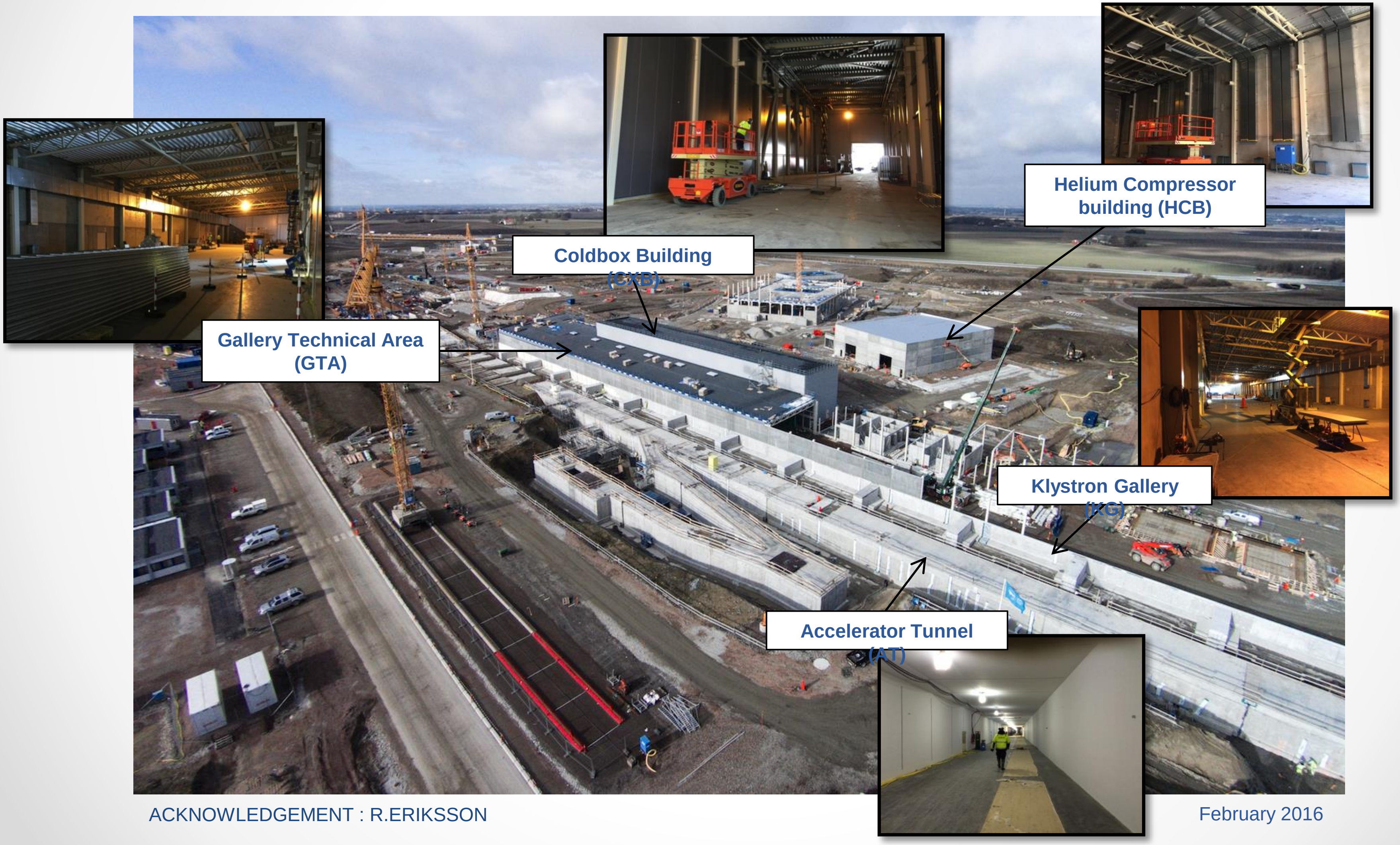
First beam on target at 572 MeV in **June 2019**

Full beam power in **2022-2023**

ACKNOWLEDGEMENT : N.GAZIS

Introduction

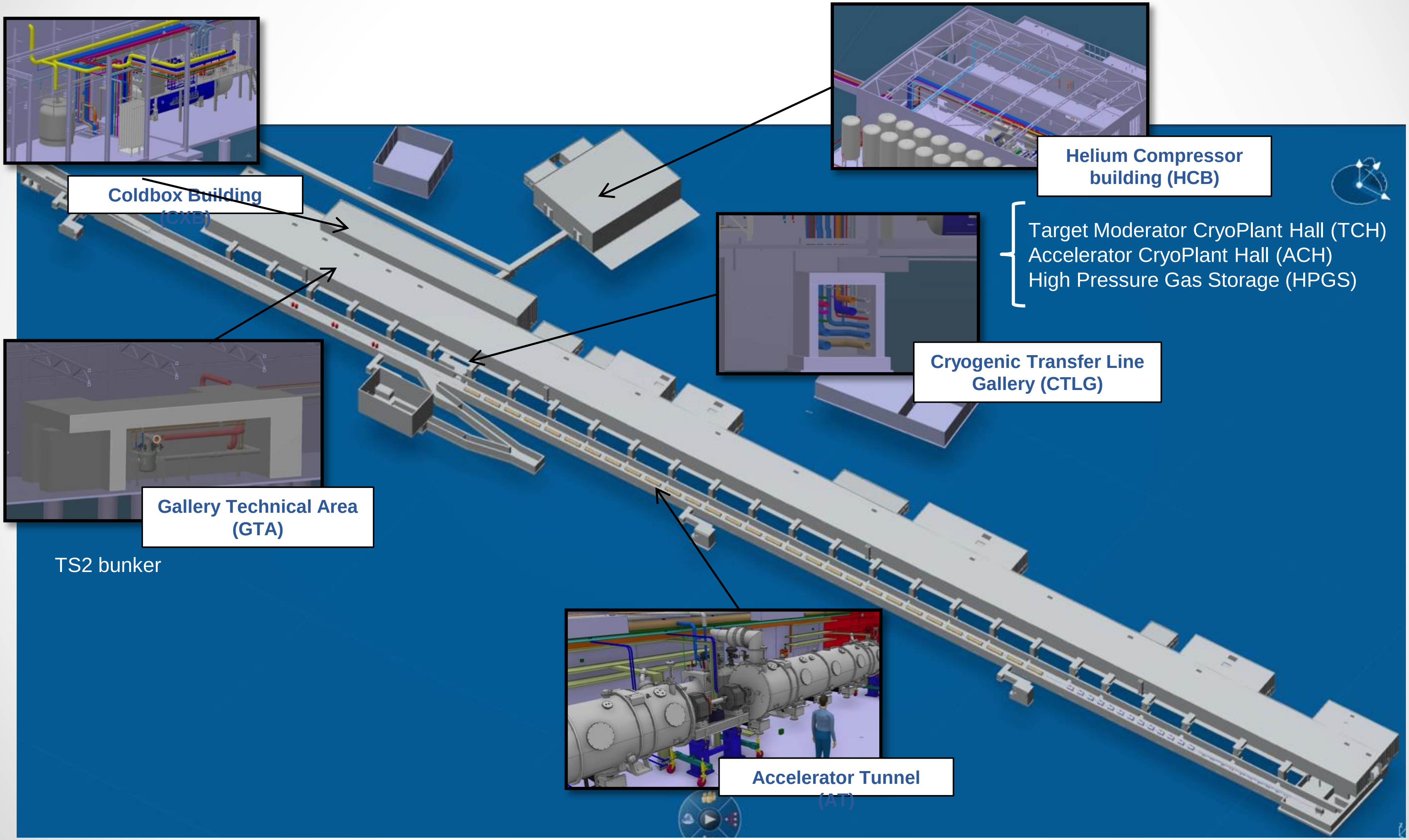
View of the accelerator buildings



ACKNOWLEDGEMENT : R.ERIKSSON

Introduction

View of the accelerator buildings (3D model)



ACKNOWLEDGEMENT : N.GAZIS

ODH Safety process & implementation

Overview and progress

[Mainly inspired by **FESHM 4240: Oxygen Deficiency Hazard**]

Objectives

- Enforcement of the ODH safety process at ESS
- Description of the following:
  - ✓ **Applicable rules** (EU, Swedish, ESS)
  - ✓ ODH calculation **methodology**
  - ✓ List of **control measures** (training, PPE, ventilation, etc.)
  - ✓ **Cryogenic Safety Committee**
  - ✓ Content of the **Safety File**

Oxygen Deficiency Hazard (ODH)
Safety Process & Implementation

Distribution: <<add names>>

ESS-0038692

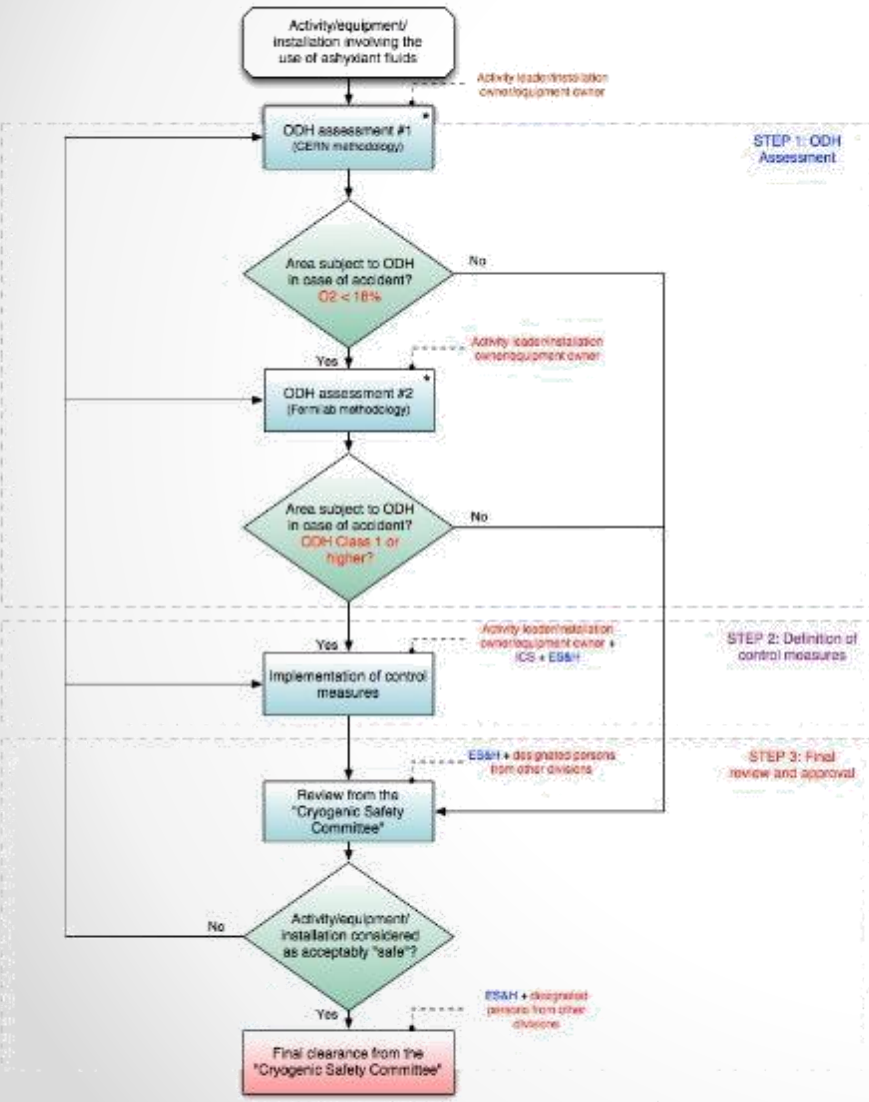
→

→

ESS wide

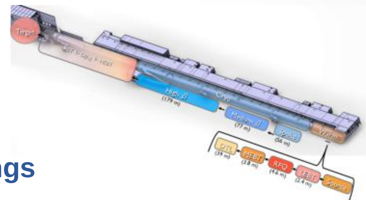
ODH Safety process & implementation

Example of implementation



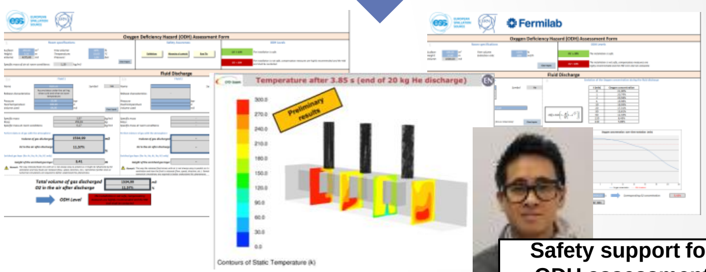
* For specific and complex cases, further ODH analyses such as Computational Fluid Dynamics (CFD) might be necessary

1 Accelerator buildings



Area responsible

2 ODH assessment



Safety support for ODH assessment

3 Control measures

ODH detection

Control measures

4 Review & approval

September 16th 2016

EUROPEAN SPALLATION SOURCE

CERN

Cryo. Safety Review Committee

ODH working group

Overview

Objectives

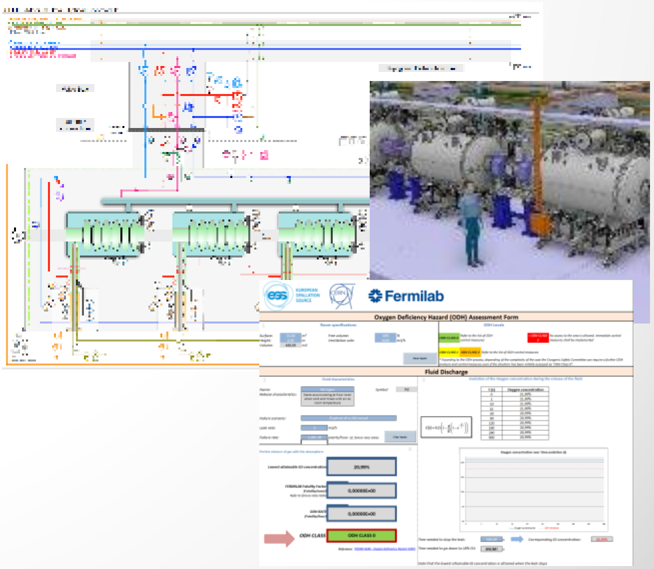
1. Collect missing information for ODH studies
2. Discuss the failure scenarios chosen for the on-going ODH assessments
3. Tailor the ODH safety process & strategy to ESS' needs
4. Discuss the implementation of control measures such as ventilation, training, etc.

Frequency: once every 2 months

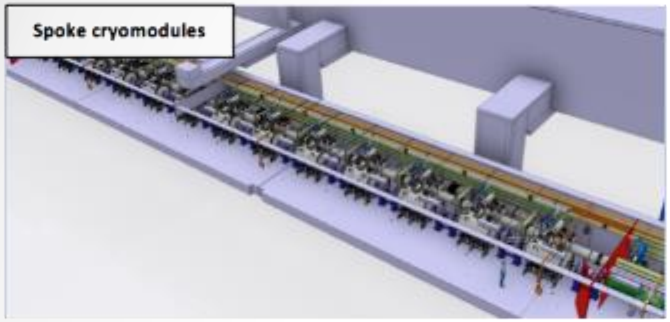
Working Group:

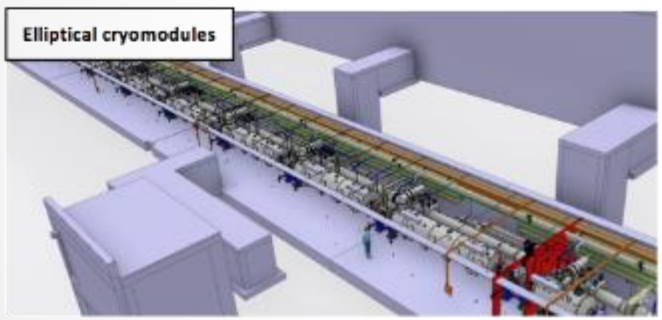
- 1 representative from *AD RP & Safety*
- 1 representative from *Cryomodules*
- 1 representative from *Cryogenics*
- 1 representative from *ES&H*
- 1 representative from *ICS*
- *1 representative from Target Safety*
- *1 representative form Science*

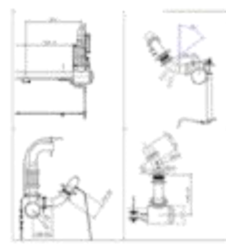
5 Sessions carried out so far



Results from the preliminary ODH assessment ESS-0063324



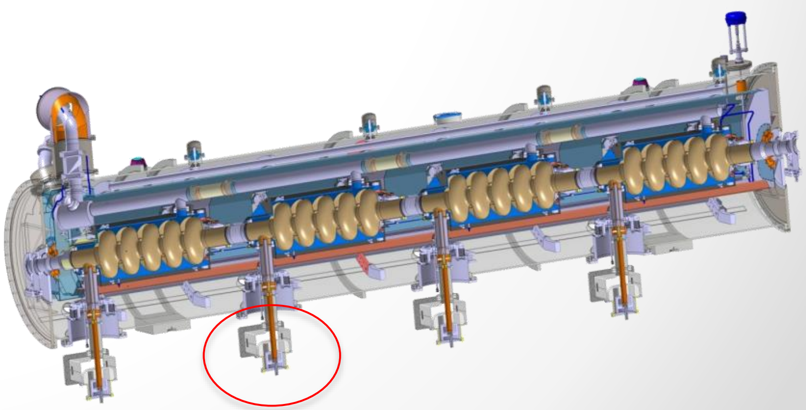




Ground surface	Height	Volume	Temperature	Pressure	Ventilation rate
3600 m^2	3.5 m	12 600 m^3	18°C	1 atm	25 200 m^3/h

Most credible accidental scenario

sudden loss of the beam vacuum leading to the release of the full helium inventory from one cryomodule (e.g. rupture of one of the power coupler ceramic windows)



Results from the preliminary ODH assessment ESS-0063324

Step 1: steady-state calculation model

$$C = \frac{0,21(V - Vgas)}{V}$$

Fluid	State	Volume	Operational pressure	Temperature
Helium (High-β elliptical cryomodule)	Liquid	$0.226\ m^3$	Max 1.43 bara	2 K

Volume of gas discharged: 203 m^3 | **O_2 in the air after discharge: 20%**

ODH CLASS 0

Special case: due to the particular geometry (low height and presence of a dead-end in the A2T area) of the tunnel and the numbers of helium discharge points in the tunnel, it was decided to perform a **CFD simulation** in order to estimate the temperature, the oxygen concentration as well as the pressure evolution at various locations and times in the tunnel in case of a release of helium

Accelerator tunnel

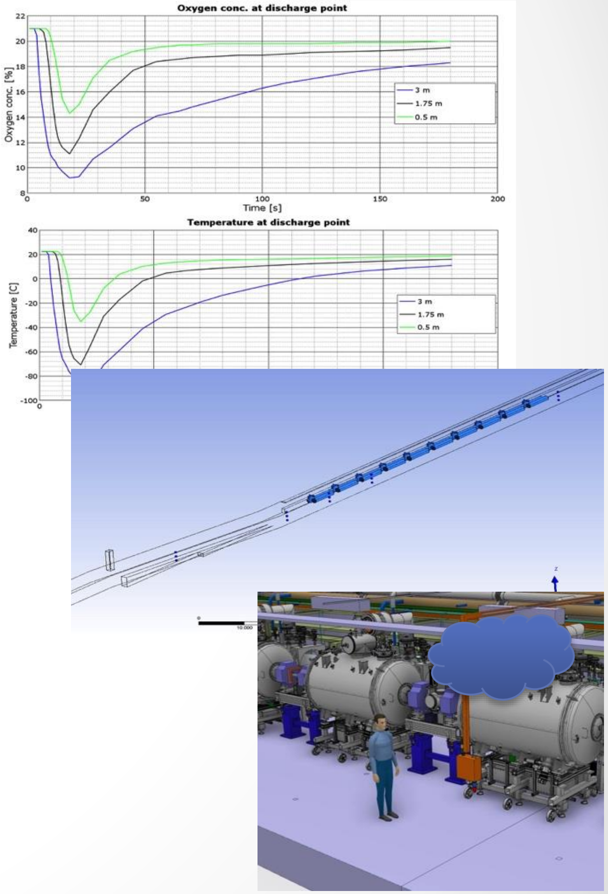
ODH studies – CFD simulation of helium discharge

① **Temperature and O_2 concentration** need to be evaluated locally (close to the He discharge points) as well as pressure rise

② Assessment of **human evacuation** (pathway, time) in case of a helium release

③ Help in the decision-making to CF for the **design of the ventilation system**

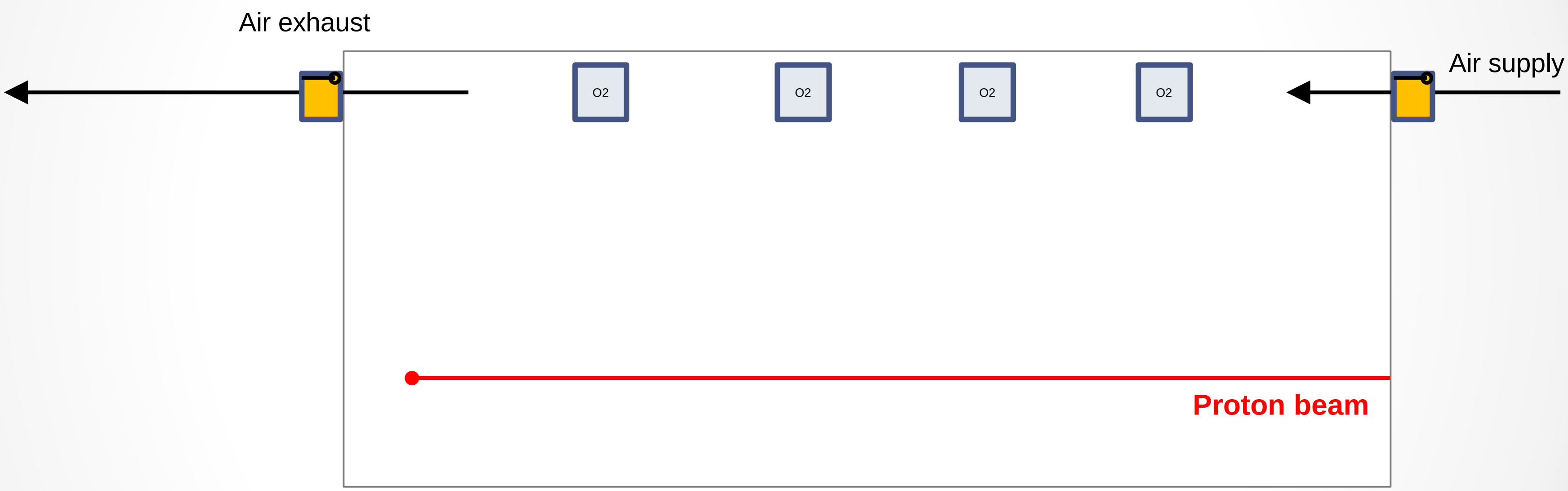
④ Help in the definition of the **access procedure** to the LINAC (warm-up, cool-down, steady-state)



ACKNOWLEDGEMENT : E.LUNDH

Accelerator tunnel

Conceptual design for the air management system



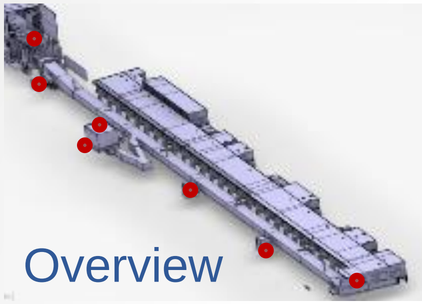
Fire damper

O2 O_2 detector – Oxigraf 4 port multiport sampling (laser diode technology)

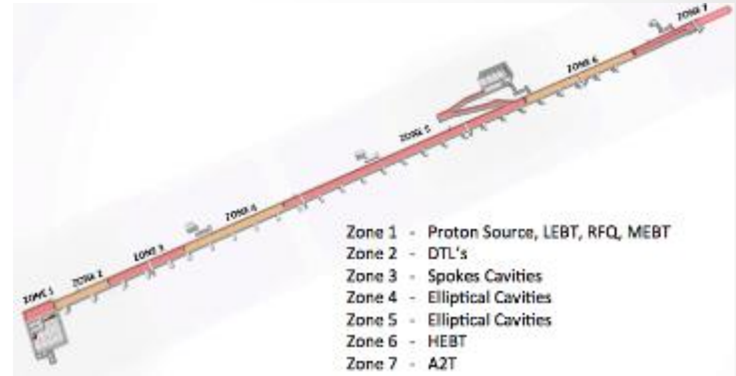
ODH is not relevant during beam operation

Accelerator tunnel

Layout of the ODH monitoring system

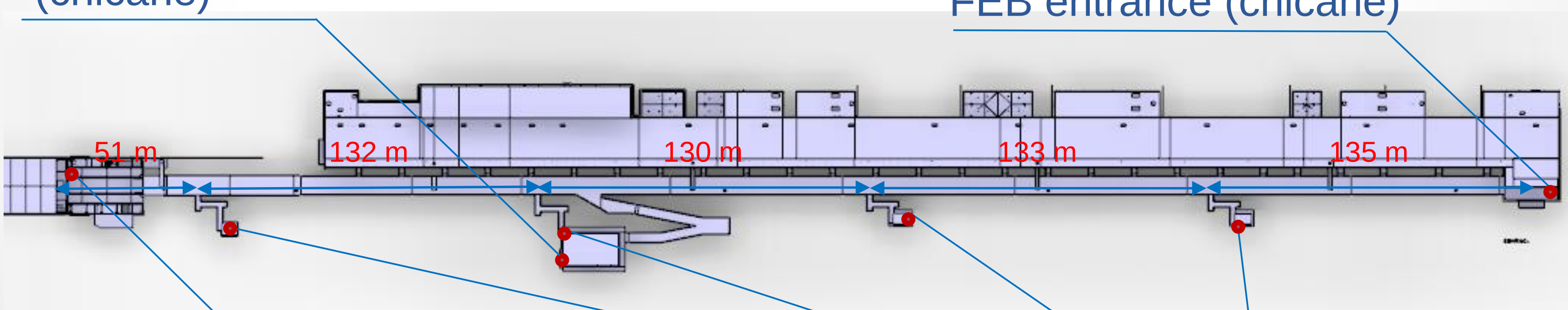


Overview



HEBT entrance (chicane)

FEB entrance (chicane)



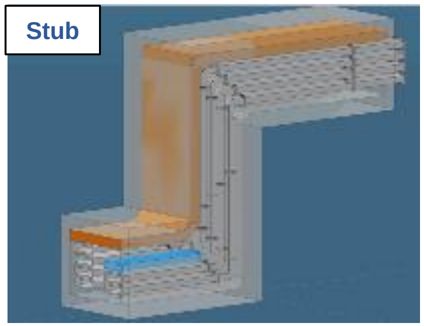
A2T egress

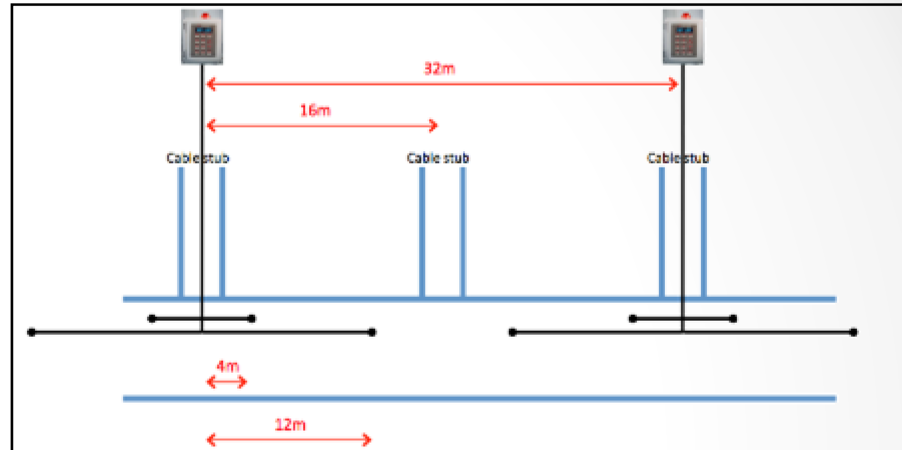
Emergency exits

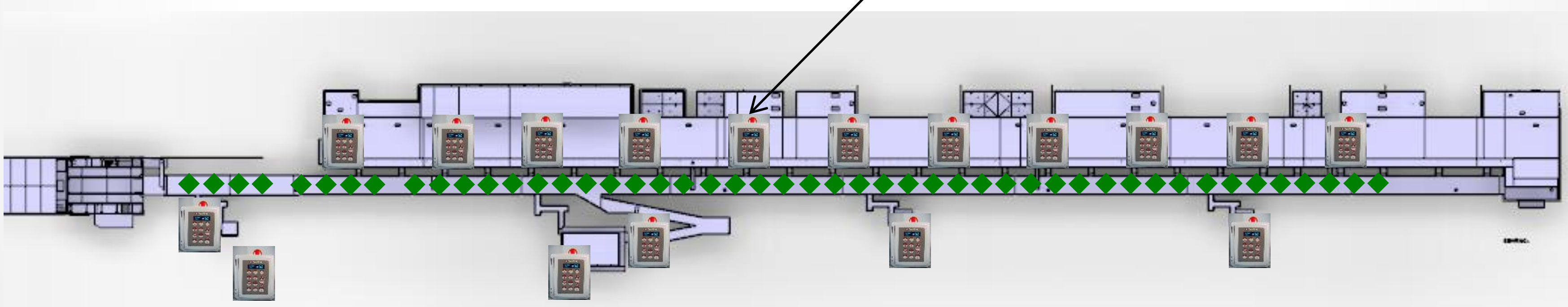
ACKNOWLEDGEMENT : S.BIRCH

Accelerator tunnel

Layout of the ODH monitoring system







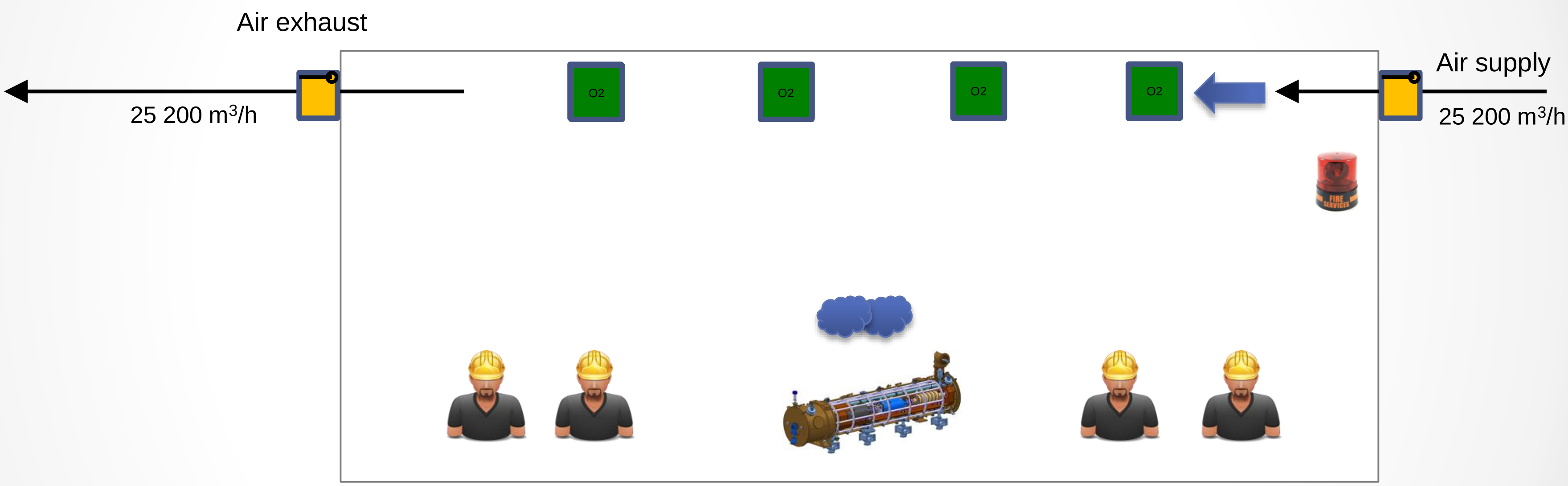
- ✓ Accelerator tunnel 14 x 4 port Oxigraf Model O2iM oxygen deficiency Monitors mounted at high level.
- ✓ Accelerator Tunnel exits and entrances 6 x 1 port Oxigraf Model O2iM oxygen deficiency Monitors mounted at high level.
- ✓ 50 Accelerator Beam Off Stations + 30 strobes and sirens.

ACKNOWLEDGEMENT : S.BIRCH

Accelerator tunnel

Conceptual design for the air management system

≈140 hours of maintenance/year

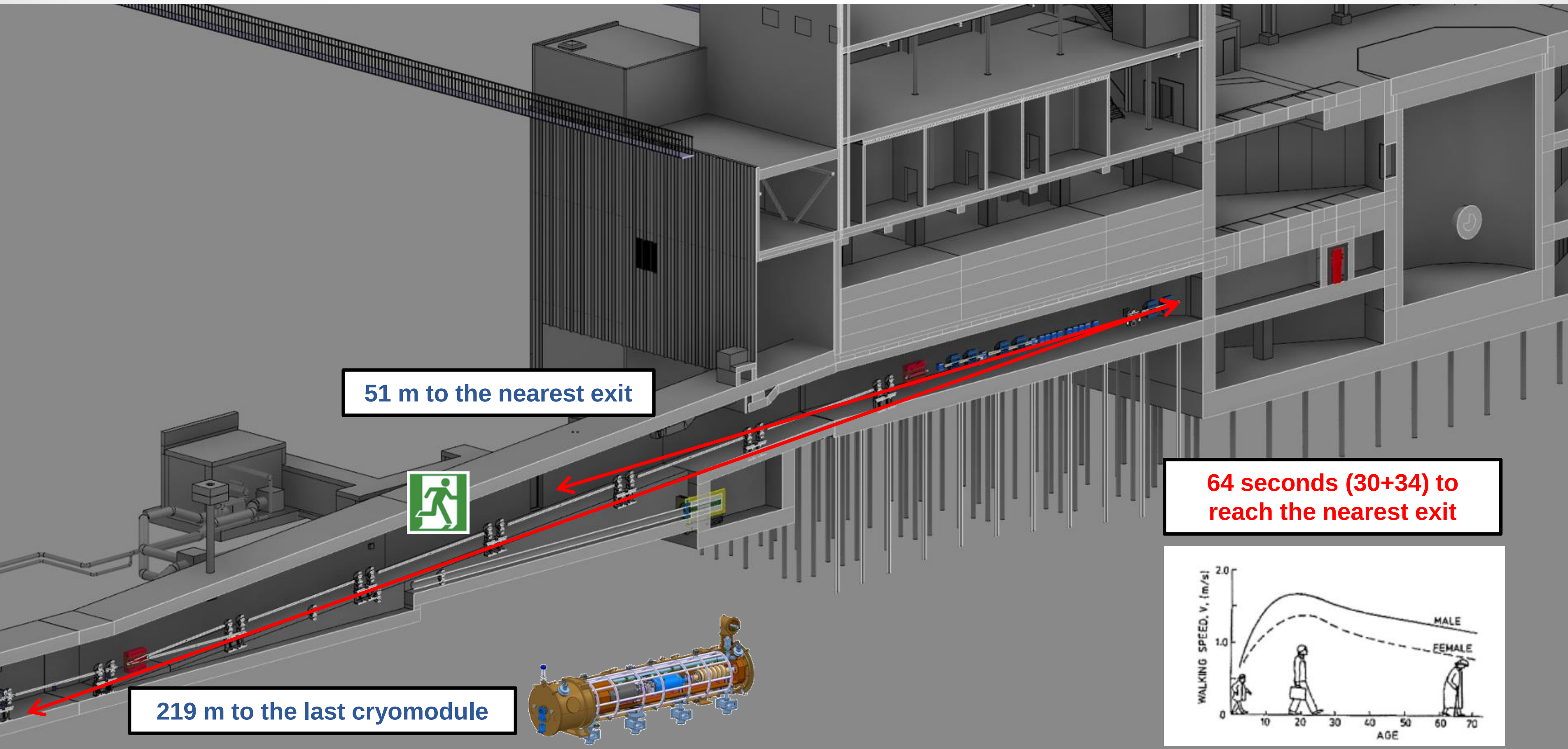


If a Helium discharge occurs, **it will be partly handled by the ventilation system…**

Lesson learnt from CERN's visit (2 July 2015)
→ air speed from the ventilation **should not exceed 1 m.s^{-1}** to facilitate evacuation

Accelerator tunnel

Safety issue in the A2T area

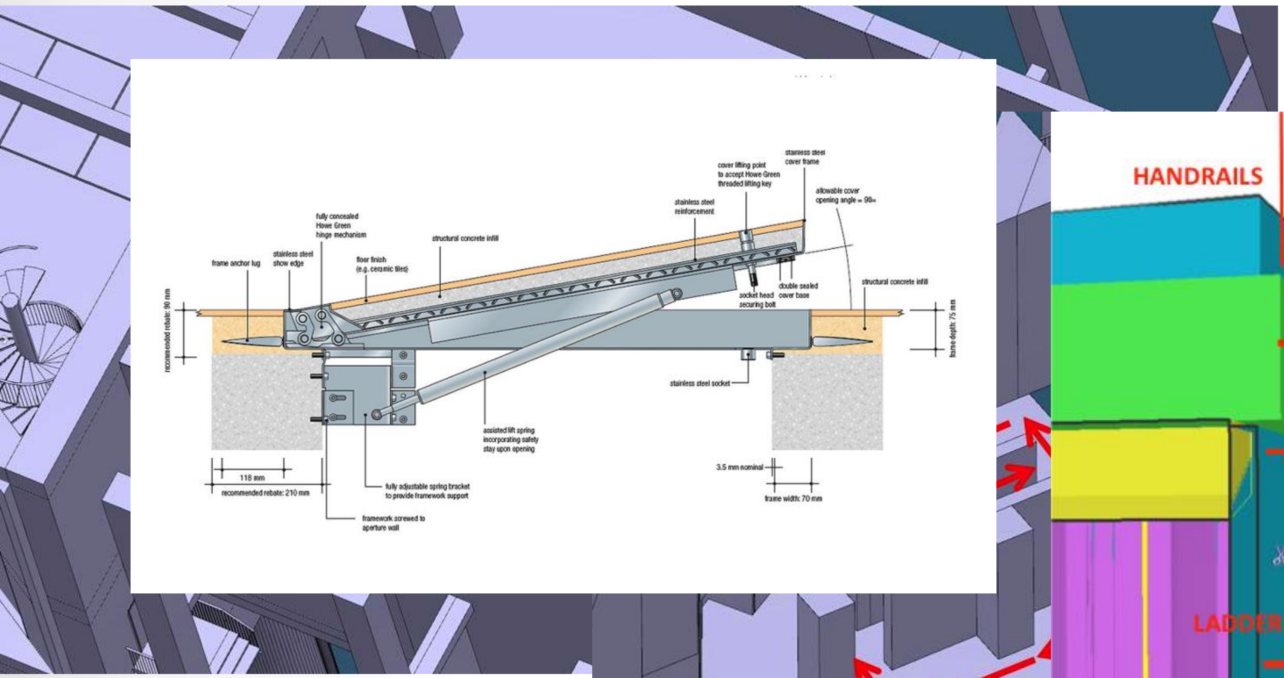


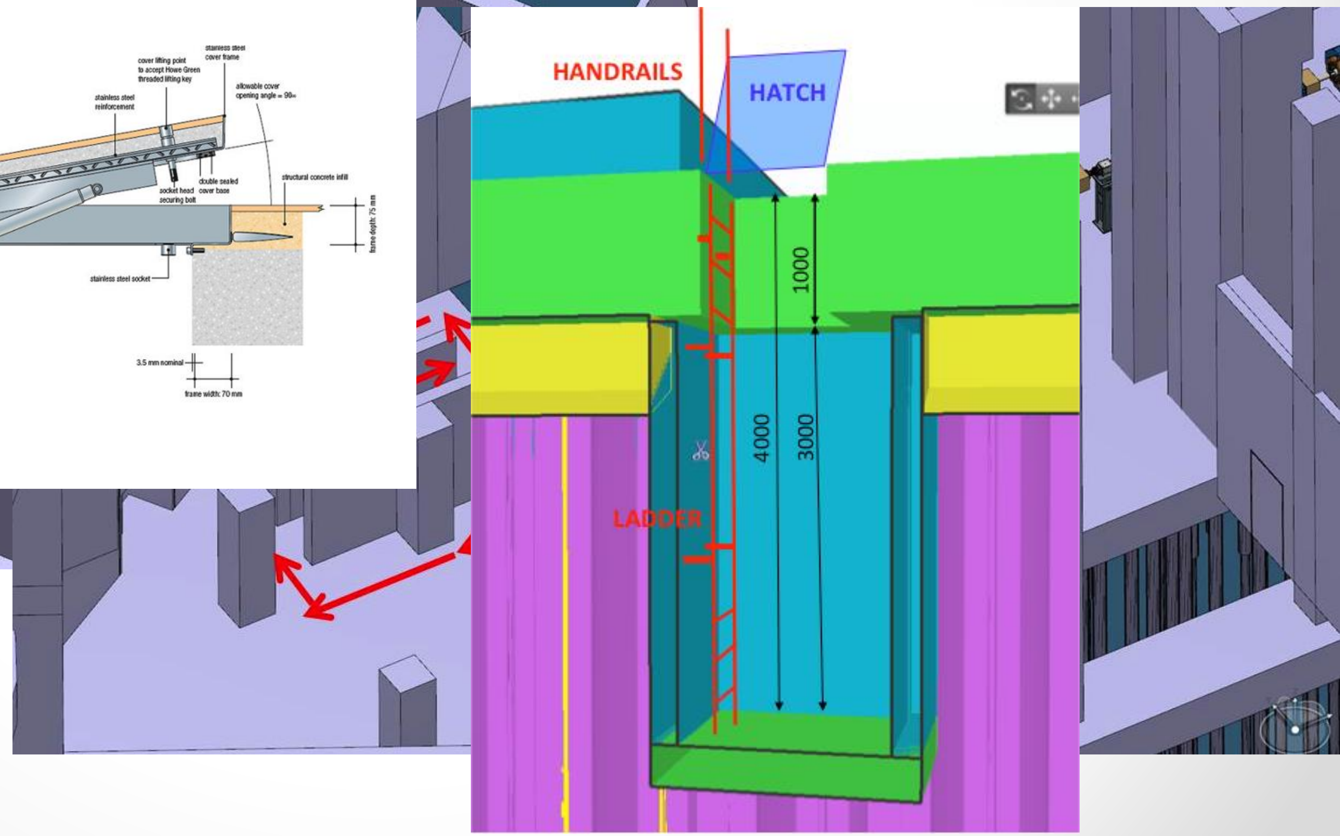
ACKNOWLEDGEMENT : N.GAZIS

Accelerator tunnel

Safety issue in the A2T area

Decision taken on December 7th to implement the safety hatch in the A2T area





ACKNOWLEDGEMENT : N.GAZIS

Accelerator tunnel

CFD simulations

Failure scenarios considered (during access)

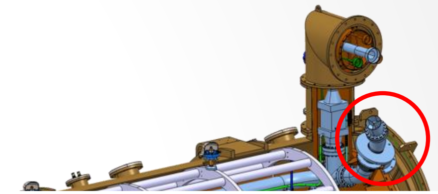
Scenario 1

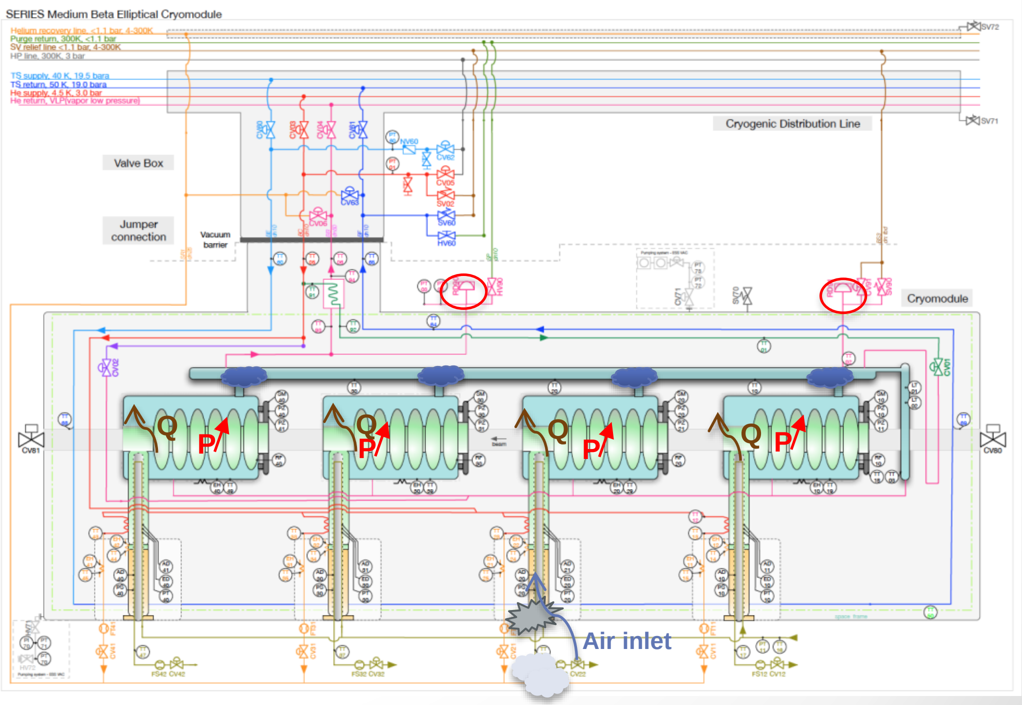
Rupture of the power coupler's window or beam line

Loss of the content of 1 High-β* cryomodule (**28,4 kg at 2 K and 2.** **bara**)

Discharge of GHe through the 2 ru disks located on the LHe line (**1,9 s**

Max. mass flow rate = **15,2 kg.s^{-1}**





*the loss of 2 High-Beta cryomodules has not been considered thanks to the CLOSE position of the gate valves in-between cryomodules during access

ACKNOWLEDGEMENT : J.P THERMEAU – WP5_SAFETYSIZING_SAFETY_DEVICES

Accelerator tunnel

CFD simulations

Failure scenarios considered (during access)

Scenario 2

Rupture of the insulation vacuum vessel of 1 High-β cryomodule

↓

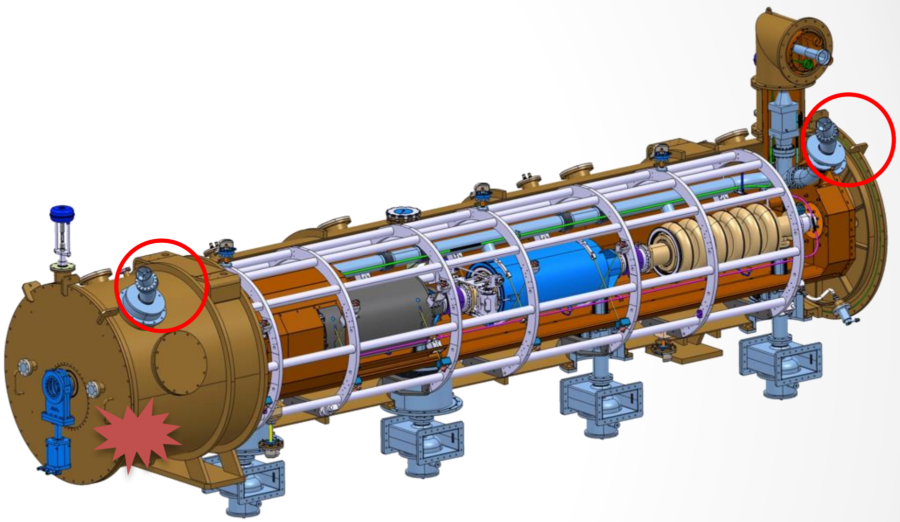
Loss of the content of 1 High-β* cryomodule (**28,4 kg at 2 K and 2.04 bara**)

↓

Discharge of GHe through the 2 rupture disks located on the LHe line (**11,8 s**)

↓

Max. mass flow rate = **2,4 kg/s**



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ACKNOWLEDGEMENT : J.P THERMEAU – WP5_SAFETYSIZING_SAFETY_DEVICES

Accelerator tunnel

CFD simulations

Assumptions

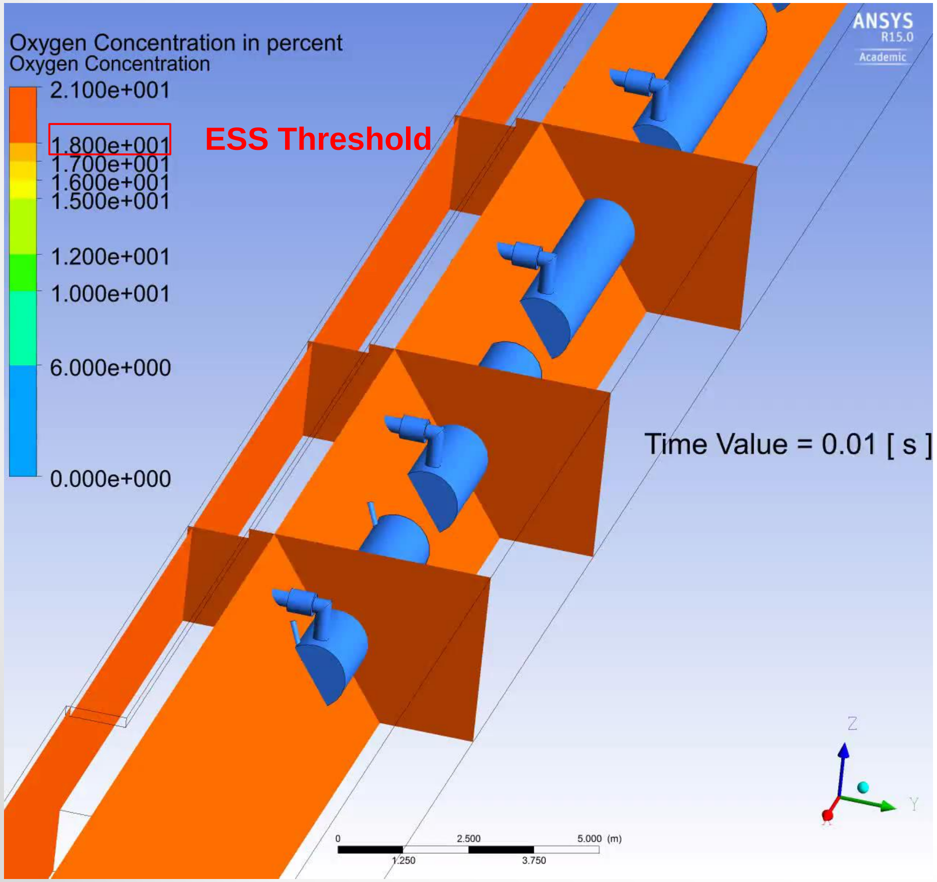
- GHe released at **5 K** (coldest value from the designer)
- **Constant mass flow rates** from the burst disks
- **Atmospheric pressure** in the tunnel
- **100% leak tightness** in the tunnel
- Walls and equipment held at a constant temperature of **22.5 °C**
- Constantly forced ventilation (about **0.3 – 0.4 $m.s^{-1}$** in the tunnel)
- **Simplified geometry**
- CDS and cryomodules installed in the **contingency space**
- **Cryogenic helium properties** from the *NIST Chemistry WebBook*
- The simulation software **CFX** (ANSYS) is used

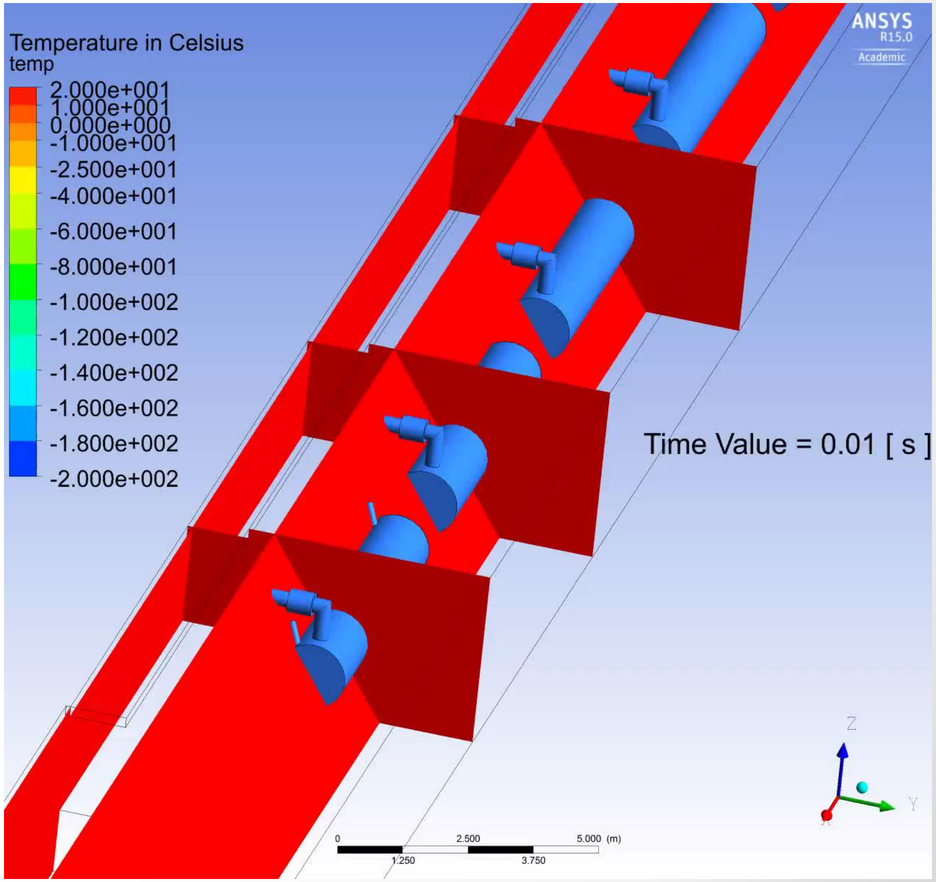
ACKNOWLEDGEMENT : E.LUNDH

Accelerator tunnel

CFD simulations

Scenario 1 (15.2 kg.s^{-1} during 2 s) – rupture of the beam line



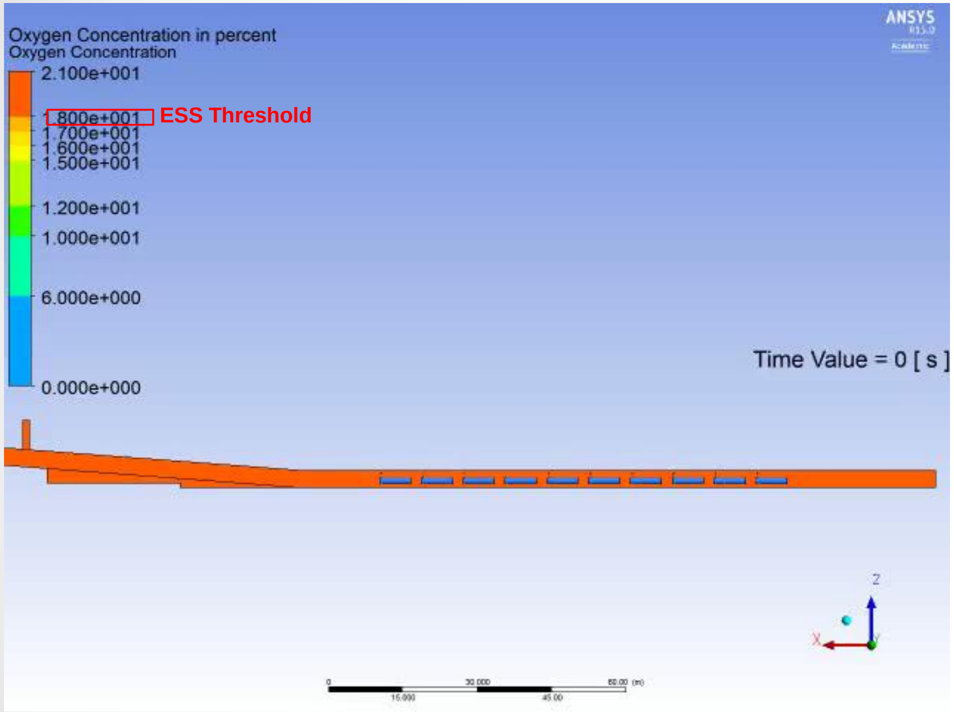


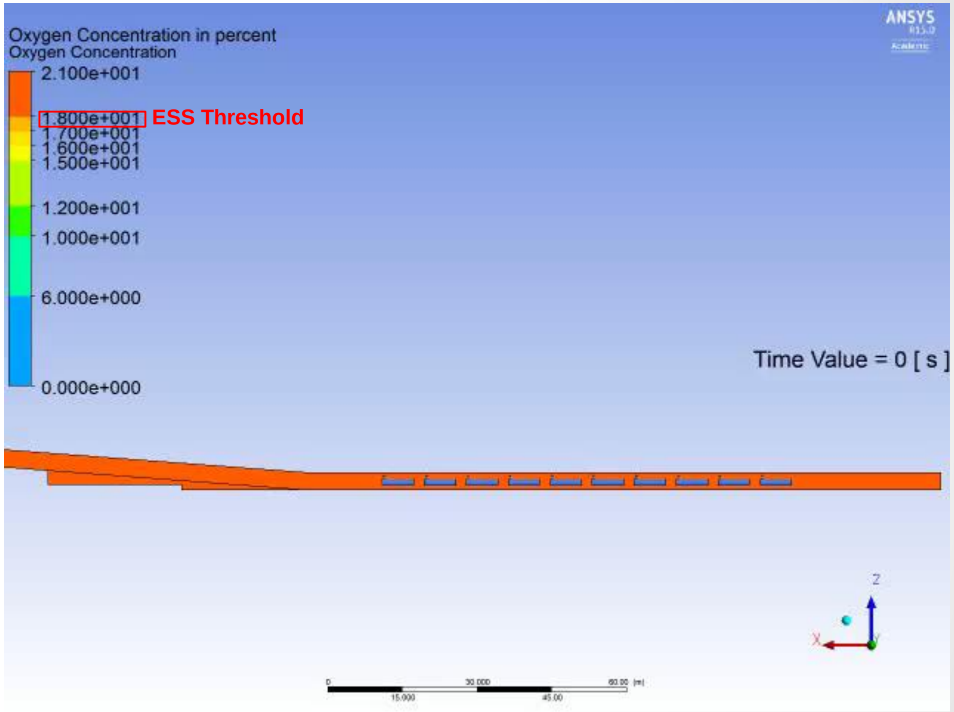
ACKNOWLEDGEMENT : E.LUNDH

Accelerator tunnel

CFD simulations

Scenario 2 (2.4 kg.s^{-1} during 2 s) – rupture of the vacuum vessel of a High-β





Mass flow rate: 2,4 kg.s^{-1}
Volume: 28,8 kg
Leak duration: 12 s
Location: contingency space (A2T area)
Ventilation mode: ON – 25 200 m^3/h

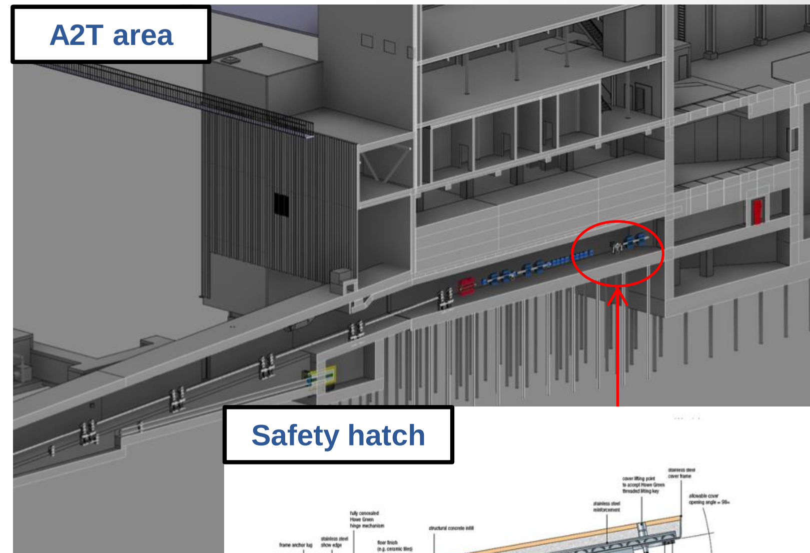
Mass flow rate: 2,4 kg.s^{-1}
Volume: 28,8 kg
Leak duration: 12 s
Location: contingency space (A2T area)
Ventilation mode: OFF

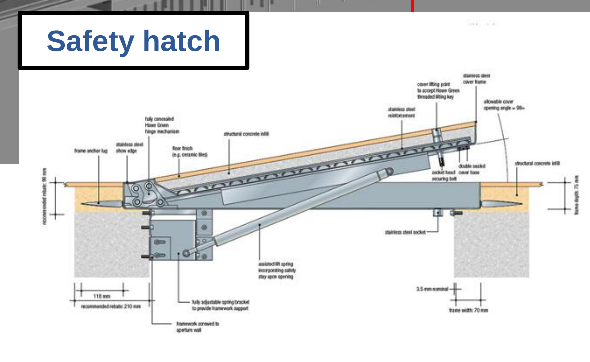
ACKNOWLEDGEMENT : E.LUNDH

Accelerator tunnel

CFD simulations – Preliminary conclusions

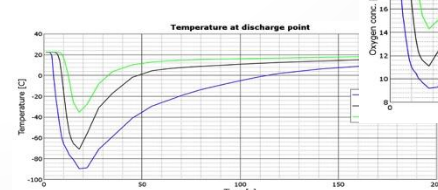
1 Implementation of a **safety hatch** in the A2T area to facilitate evacuation
→ The minimum time needed to reach the nearest exit from the A2T area (64 seconds) does not allow a safe evacuation

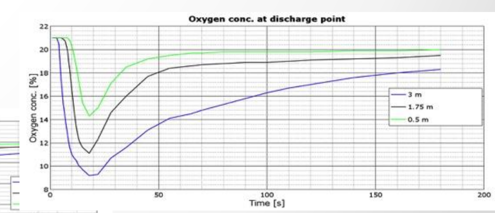




2 Reinforcement of the **hinges** and frame of the emergency exit doors
→ The force applied on the doors in case of a failure of a cryomodules would be around 50 kN.m^{-2} (500 kg.m^{-2})

3 Investigation on **compensatory measures** close to the discharge points
(e.g. helium collection header)
→ Lowest attainable O2 concentration = 6%
→ Lowest attainable temperature = -135°C





ESS Cryogenic Safety Workshop February 10-11, 2016

Highlights

Objective: share experience and technical expertise with cryogenic and safety experts regarding cryogenic safety in accelerator tunnels

7 institutes represented

2-days workshop

10 recommendations addressed to ESS

Presentations available here: https://indico.esss.lu.se/event/438/

ESS Cryomodules Safety Review June 9, 2016

Highlights

Objective: evaluate the design of the Spoke and Elliptical cryomodules against failures and risks to humans and equipment during operation

The design of the collector is however still in a preliminary state, and it is was not possible for the committee to review the solution in depth. ***The committee supports the continuation of this work with high priority, as well as the evaluation of the impact of this system on the cryomodule design and integration aspects in the tunnel.***

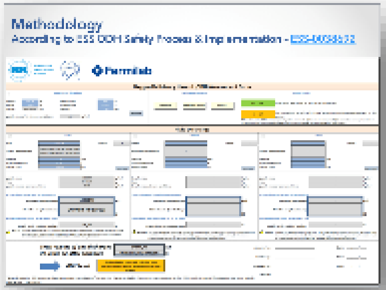
Presentations and report from the committee available here: https://indico.esss.lu.se/event/542/

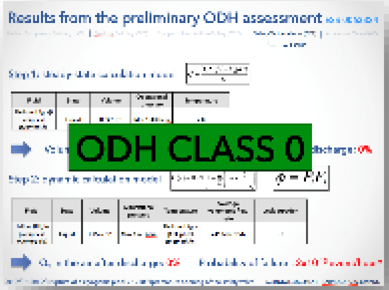
ESS ODH Safety Review September 16, 2016

Highlights

Objective:

1. Review **the ODH scenarios** of the accelerator buildings (relevancy, calculation model, etc.)
2. Review the **strategy and layout of the ODH monitoring system**
3. Advice on **control measures to be put in place** to guarantee the safety of the activity/equipment/installation
4. Provide a formal recommendation on whether the **ODH monitoring system should proceed to procurement and installation phases**





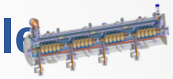
Presentations and report from the committee available here: https://indico.esss.lu.se/event/635/

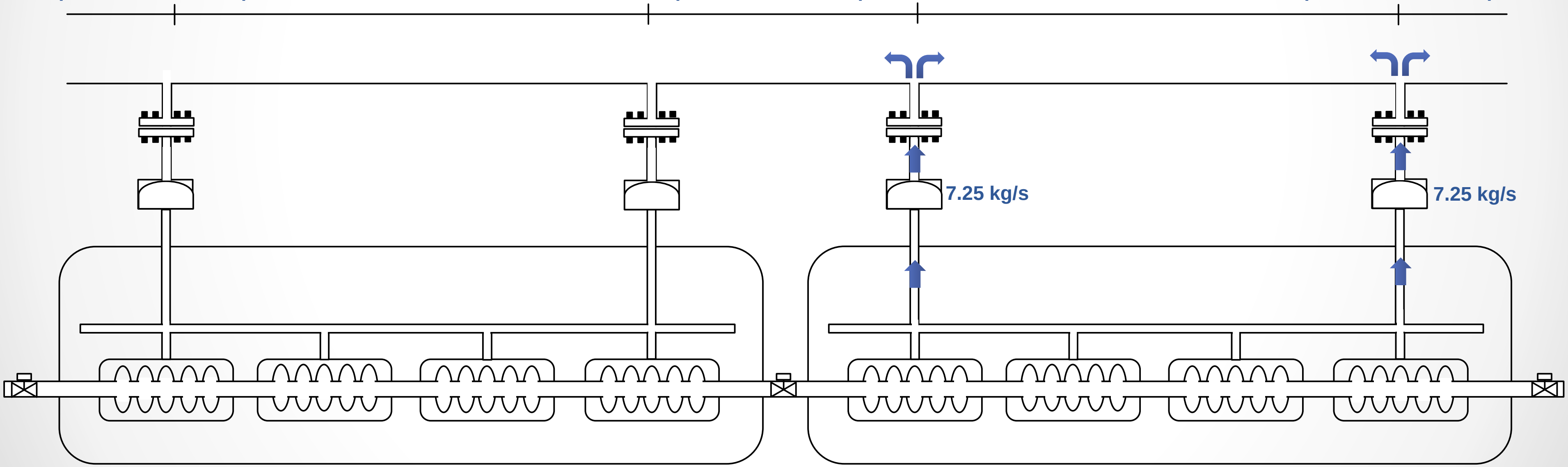
Accelerator tunnel

Conceptual design of the Helium collection header

Access Mode

Most credible accidental scenario: loss of one High-β cryomodule



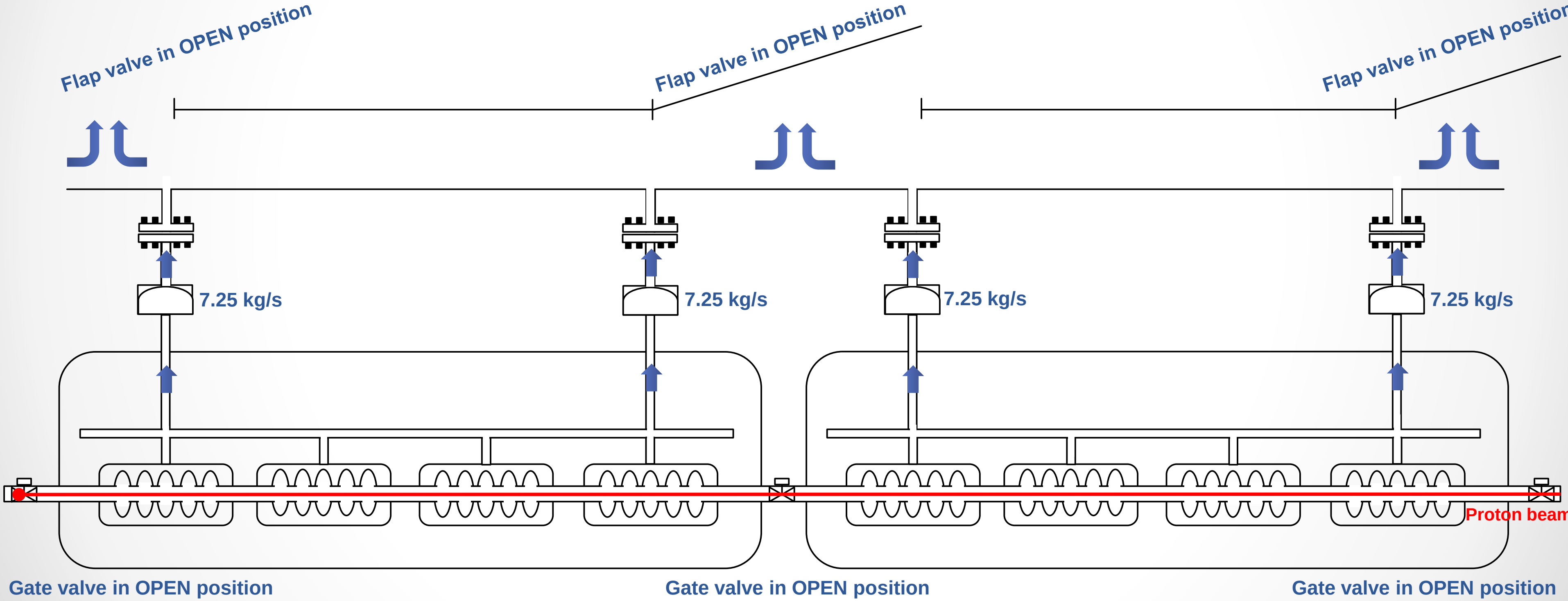


Accelerator tunnel

Conceptual design of the Helium collection header

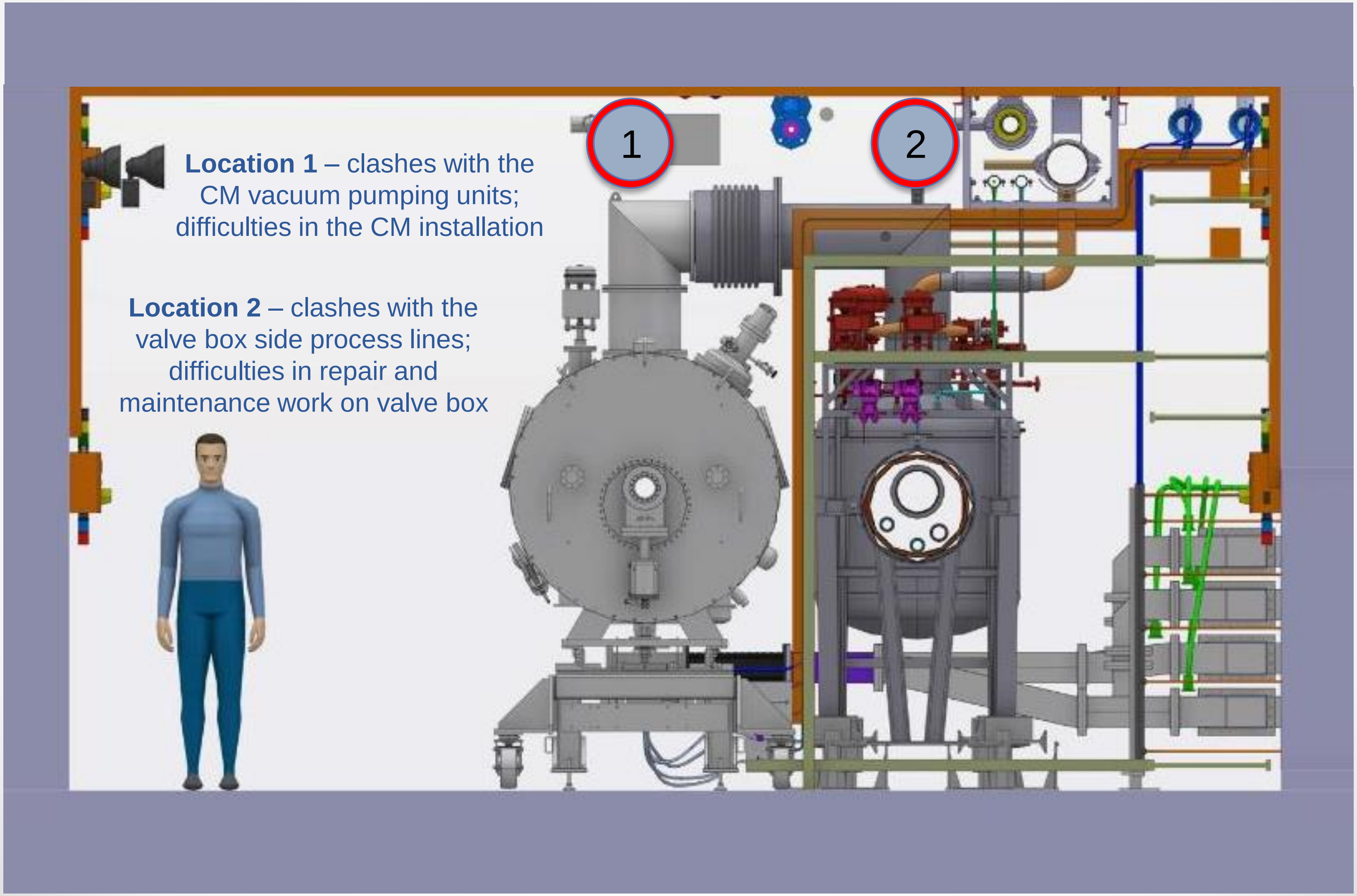
Beam Mode

Most credible accidental scenario: loss of six High-β cryomodules



Accelerator tunnel

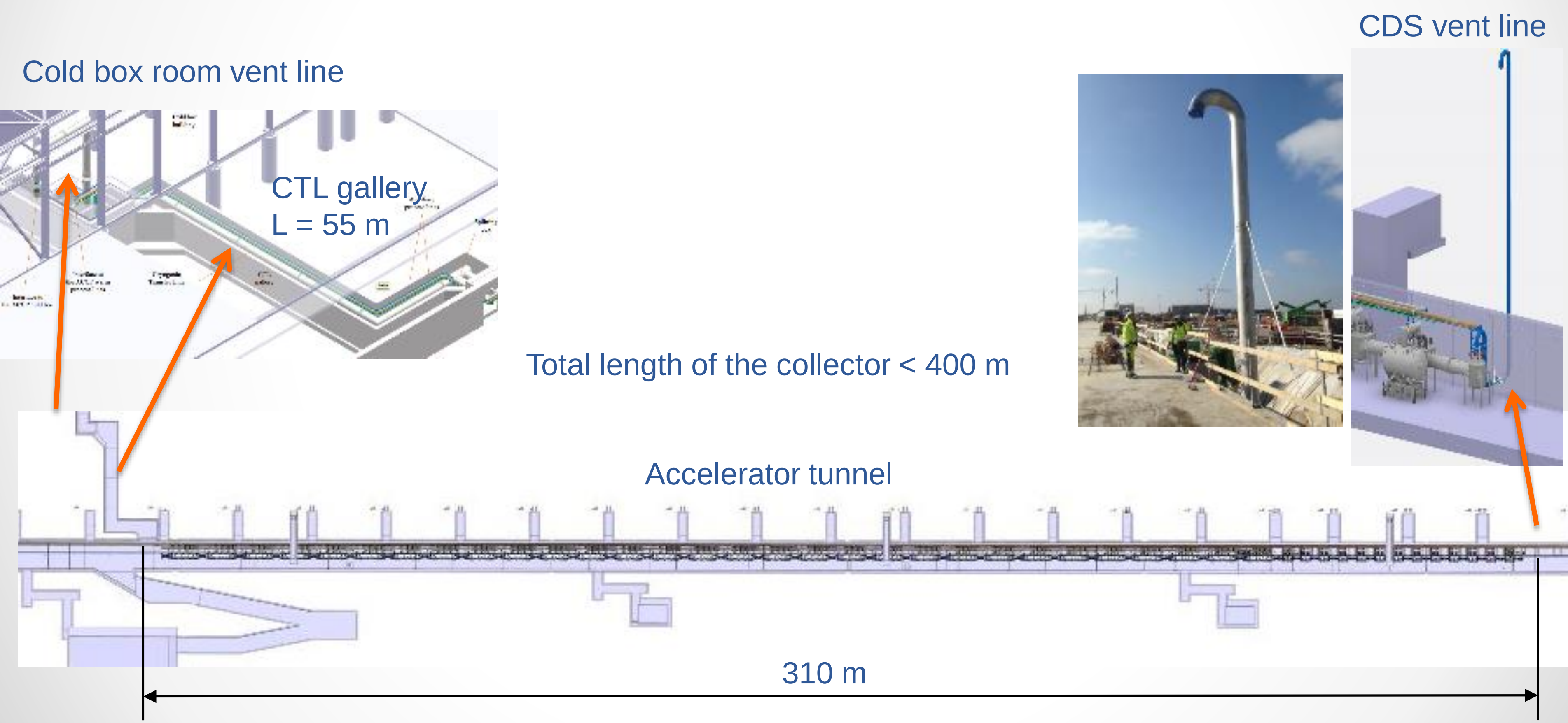
Conceptual design of the Helium collection header



ACKNOWLEDGEMENT : J.FYDRYCH

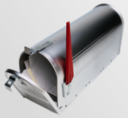
Accelerator tunnel

Conceptual design of the Helium collection header



Design report expected for mid-November

Any Questions



Contact: duy.phan@esss.se

BACK-UP SLIDES