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

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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**
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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ESS LINAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>E [GeV]</td>
<td>2</td>
</tr>
<tr>
<td>$P_{\text{average}}$ [MW]</td>
<td>5</td>
</tr>
<tr>
<td>$I_{\text{pulse}}$ [mA]</td>
<td>62.5</td>
</tr>
<tr>
<td>$f_{\text{rep}}$ [Hz]</td>
<td>14</td>
</tr>
<tr>
<td>$t_{\text{pulse}}$ [ms]</td>
<td>2.86</td>
</tr>
</tbody>
</table>

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
Introduction

View of the accelerator buildings (3D model)
ODH Safety process & implementation
Overview and progress

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

Mainly inspired by FESHM 4240: Oxygen Deficiency Hazard

ESS-0038692
ODH Safety process & implementation

Example of implementation

1. Accelerator buildings

2. ODH assessment

3. Control measures

4. Review & approval

September 16th, 2016
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 from Science

5 Sessions carried out so far
Results from the preliminary ODH assessment ESS-0063324

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)

<table>
<thead>
<tr>
<th>Ground surface</th>
<th>Height</th>
<th>Volume</th>
<th>Temperature</th>
<th>Pressure</th>
<th>Ventilation rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>3600 m²</td>
<td>3.5 m</td>
<td>12 600 m³</td>
<td>18°C</td>
<td>1 atm</td>
<td>25 200 m³/h</td>
</tr>
</tbody>
</table>
Results from the preliminary ODH assessment **ESS-0063324**

**Step 1: steady-state calculation model**

\[
C = \frac{0.21(V - V_{gas})}{V}
\]

<table>
<thead>
<tr>
<th>Fluid</th>
<th>State</th>
<th>Volume</th>
<th>Operational pressure</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium (High-β elliptical cryomodule)</td>
<td>Liquid</td>
<td>0.226 m³</td>
<td>Max 1.43 bara</td>
<td>2 K</td>
</tr>
</tbody>
</table>

Volume of gas discharged: **203 m³**  
O₂ 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 O₂ 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).
Accelerator tunnel
Conceptual design for the air management system

- Fire damper
- O₂ 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

135 m
133 m
133 m
130 m
132 m
130 m
133 m
135 m

51 m
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

51 m to the nearest exit

219 m to the last cryomodule

64 seconds (30+34) to reach the nearest exit

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 2.04 bara**)\n
Discharge of GHe through the 2 rupture 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*
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

*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

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
Accelerator tunnel
CFD simulations

Scenario 1 (15.2 kg.s\(^{-1}\) during 2 s) — rupture of the beam line
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/
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/625
Accelerator tunnel
Conceptual design of the Helium collection header

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

Flap valve in CLOSED position
Flap valve in CLOSED position
Flap valve in CLOSED position

Gate valve in CLOSED position
Gate valve in CLOSED position
Gate valve in CLOSED position

7.25 kg/s
7.25 kg/s

Upcoming activities and challenges
Accelerator tunnel
Conceptual design of the Helium collection header

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

Gate valve in OPEN position

Flap valve in OPEN position

Proton beam

7.25 kg/s
Accelerator tunnel
Conceptual design of the Helium collection header

**Location 1** – clashes with the CM vacuum pumping units; difficulties in the CM installation

**Location 2** – clashes with the valve box side process lines; difficulties in repair and maintenance work on valve box
Accelerator tunnel
Conceptual design of the Helium collection header

Cold box room vent line

CTL gallery
$L = 55 \text{ m}$

Total length of the collector $< 400 \text{ m}$

Accelerator tunnel

310 m

CDS vent line

Design report expected for mid-November
Any Questions

Contact: duy.phan@esss.se
BACK-UP SLIDES