Performance Based Safety Design and results on Cryogenic hazards

André Henriques, Saverio La Mendola

Thanks to the FCC I&O WG members

FCC Week 2018
Amsterdam, NL
Introduction

Legislative references are applicable

Project Safety Requirements

Legislative references are NOT applicable

‘Standard Best Practices’

‘Performance Based Design’

Ex:

Egress routes

Automatically conform, without additional measures

Adaptation & additional measures needed

HSE
Occupational Health & Safety
and Environmental Protection Unit

11-Apr-18

EDMS N. 1962701
**Introduction**

**FCC Hazard Register:**
Systematic collection of Hazards in the FCC facilities during different phases of its lifetime
No assessment of probability or severity

*Thursday 08:55: Fire safety assessment for FCC (O. Rios)*

*HSE*
Occupational Health & Safety and Environmental Protection Unit

11-Apr-18
EDMS N. 1962701
Performance Based Design

Safety Goals

Safety Objectives

Performance criteria

Accidental Scenarios

New trial design

Additional measures

Trial Design

Evaluation

Meets Objectives
Performance Based Design

Safety Goals

Defined by Organizations' Safety Policy
## Safety Goals

### CERN’s Safety Policy

<table>
<thead>
<tr>
<th>Safety Goals:</th>
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<th>Property Protection</th>
<th>Continuity of Operation</th>
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*Independent of the Safety domain / project*

### Priority

- Workers
- Visitors
- Water
- Property protection
- Downtime
Performance Based Design

Safety Goals

Safety Objectives

Defined by Organizations' Safety Policy

Requirements of the project i.e. Applicable Rules
## Safety Objectives – FCC Study

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<td>Occupants shall be able to evacuate through protected areas, free from smoke/gas and other hazards at any time</td>
<td>Limit the release of polluting (incl. activated) agents to the environment in case of incident</td>
<td>The continuity of essential services and structural stability is assured in case of fire or gas release and other incidents</td>
<td>Limiting the downtime in case of incident</td>
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<td>Victims and other occupants, not able to self-evacuate, shall reach protected areas, and wait there to be rescued by the intervention teams</td>
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<td></td>
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**Independent on the Safety Domain!**
Performance Based Design

Safety Goals

Safety Objectives

Performance criteria

Defined by Organizations' Safety Policy

Requirements of the project
i.e. Applicable Rules

Measurable requirements
i.e. Harmonized Standard
Performance criteria

**Qualitative**
- Presence of toxic smoke shall not influence the evacuation of occupants
- Helium cloud shall not reach the compartment door before the occupant evacuating

**Quantitative**
- Exposure to:
  - FED < 0.1 (e.g.)
  - Exposure temperature < 60°C (e.g.)
  - Visibility > 10 m (e.g.)
- Exposed to:
  - $O_2$ level > 18%
  - $V_{ventilation} < V_{walking} = 1.2$ m/s

Technical specification can also become performance criteria
Performance Based Design

Safety Goals

Safey Objectives

Accidental Scenarios

- Defined by Organizations' Safety Policy
- Requirements of the project i.e. Applicable Rules
- Measurable requirements i.e. Harmonized Standard
- List of scenarios based on Risk Assessment

Performance criteria
Performance Based Design

1. Safety Objectives
   - Performance criteria

2. Accidental Scenarios

3. Trial Design

- Defined by Organizations' Safety Policy
- Requirements of the project i.e. Applicable Rules
- Measurable requirements i.e. Harmonized Standard
- List of scenarios based on Risk Assessment
- First iteration with initial specification

Safety Goals
Characteristics

<table>
<thead>
<tr>
<th>Feature</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>6 m</td>
</tr>
<tr>
<td>Total floor width</td>
<td>5.3m</td>
</tr>
<tr>
<td>Safe Passage</td>
<td>X</td>
</tr>
<tr>
<td>Fire compartment</td>
<td>OPEN</td>
</tr>
<tr>
<td>Compartment door status</td>
<td>OPEN</td>
</tr>
<tr>
<td>Compartment door status (nominal)</td>
<td>OPEN</td>
</tr>
<tr>
<td>Compartment door status (ODH)</td>
<td>OPEN</td>
</tr>
<tr>
<td>Fresh air supply</td>
<td>✔️</td>
</tr>
<tr>
<td>Emergency extraction system</td>
<td>✔️</td>
</tr>
</tbody>
</table>

Baseline includes Safety features
Performance Based Design

Safety Objectives

Accidental Scenarios

New trial design

Additional measures

Evaluation

Meets Objectives

Defined by Organizations' Safety Policy

Requirements of the project i.e. Applicable Rules

Measurable requirements i.e. Harmonized Standard

List of scenarios based on Risk Assessment

First iteration with initial specification

Measured against the safety objectives (iterative process)
Evaluation

Deterministic

Qualitative
Consequences are described on a qualitative basis (e.g. egress possible, compartments doors open/close)

Quantitative
Same as above but consequences are quantified (e.g. smoke/He propagation, damage to equipment, etc.)

Probabilistic
Consequences and probabilities of scenarios are quantified and their combination evaluated in a risk matrix

Probabilistic

Full Probabilistic
Every scenario is evaluated through risk profiles and other risk indicators.
Performance Based Design

Safety Objectives → Accidental Scenarios

Evaluation

Trial Design

Meets Objectives

New trial design

Additional measures

Trial Design is valid

Safety Goals

Performance criteria

Defined by Organizations' Safety Policy

Requirements of the project i.e. Applicable Rules

Measurable requirements i.e. Harmonized Standard

List of scenarios based on Risk Assessment

First iteration with initial specification

Measured against the safety objectives (iterative process)
Cryogenic Safety studies – FCC-hh

Based on contributions from the FCC PBD Working Group
Input Data

- Air/He velocity in the tunnel
  - Nominal: **0.3 m/s**
  - For the first 100s seconds after a helium release, downstream: **0.7 m/s**

- Helium inventory:
  - Superconducting magnets: **33 l LHe / m**
  - Cryogenic ring line (QRL): **49 l supercritical He / m**

- Helium sectorisation:
  - Superconducting magnets: **220 m** (corresponding to 1 cell)
  - Cryogenic ring line (QRL): **8400 m** (corresponding to sub-sector)

- Gaseous helium inventory
  - Superconducting magnets: **1 t**
  - Cryogenic ring line (QRL): **22 t**

*header E*
Input Data

- Distance from a helium release in the tunnel that can be detected by human senses (sight or hearing): ~150 m
- 2 ODH detectors per compartment
**Input Data**

- **Evacuation time** (according to British Standard PD 7974-6):
  - $\Delta t_{det} = \text{distance to ODH detector} / \text{He cloud prop. velocity}$
  - $\Delta t_a = 5s$
  - $\Delta t_{pre} = 30s$ *
  - $\Delta t_{tra} = \text{walking speed} \times \text{evac. distance}$
    - *Walking speed = 1.2 m/s*

* Occupants are properly familiar with the underground layout and trained to a high level of safety management

- Release point is next to one door
- Evacuation is made downstream
- Occupant doesn’t stop to put on SRM
Release scenarios

a. MCI* (design) \(\rightarrow\) \(~\) 30 kg/s

b. Relief plate release \(\rightarrow\) \(~\) 1 kg/s

c. Small leak \(\rightarrow\) \(~\) 300 g/s

d. Minor leak \(\rightarrow\) \(~\) 100 g/s

*Maximum Credible Incident

Note: No detailed studies yet made for FCC cryostats
### Accidental scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryo1</td>
<td>1 kg/s ; 5 m from release point</td>
</tr>
<tr>
<td>Cryo2</td>
<td>1 kg/s ; 5 m from release point; emergency extraction ON</td>
</tr>
<tr>
<td>Cryo3</td>
<td>1 kg/s ; 200 m from release point</td>
</tr>
<tr>
<td>Cryo4</td>
<td>0.3 kg/s; 150 m from release point</td>
</tr>
<tr>
<td>Cryo5</td>
<td>0.1 kg/s; 5 m from release point</td>
</tr>
<tr>
<td>Cryo6</td>
<td>32 kg/s during operation</td>
</tr>
</tbody>
</table>

Varying the relief mass flow & distance to the release
Evaluation of the Trial Design

Summary

Based on simplified model
**Cryo1**: 1 kg/s ; 5 m from release point

- Time lapse after release (d=5m)

**t=40s**

- Fire door open

\[d = 0 \quad 20 \quad 30 \quad 440\] [m]

- Critical distance in the ‘Turbulent zone’

- ‘Turbulent Zone’ – non-stay areas

**t=390s**

- Fire door open

\[d = 0 \quad 160 \quad 440\] [m]

- ‘Stratified Zone’

Illustrations are not to scale
Cryo2: 1 kg/s ; 5 m from release point; extraction ON

- $t = [5, 10]$ min $\rightarrow$ The extraction is ON @ full capacity
- Cloud propagation stops after 220 m

Wednesday 13:30: Development for cooling and ventilation systems (M. Nonis; G. Peon)

After passing 2 fire doors (880m) is considered ‘safe’ to wait for transportation
**Cryo4**: 0.3 kg/s; 150 m from release point

- Time lapse after release (d=150m)

Illustrations are not to scale

Less mass flow = smaller GHe layer $\rightarrow$ t.b.c via CFD
**Cryo4**: 0.3 kg/s ; 150 m from release point

- Time lapse after release (d=150m)

![Diagram showing time lapse and distance](image)

- Door open
- He extraction ON after 5 min

**Critical distance for this exercise is the ‘acknowledgment limit’ of the warning signs**

- He extraction critical
- Innovative emergency evacuation signs

Thursday 09:20: Virtual reality experiments for evacuation in the FCC (S. Arias)
# Evaluation of Trial design - FCC

## Trial design #1

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<td>Cryo1</td>
<td>X</td>
<td>X</td>
<td>X(?)</td>
<td>✓</td>
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<td>Cryo5</td>
<td>✓</td>
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Evaluation of Trial design - FCC

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(?) → Cannot be determined with 100% certainty, due to the lack of data (simulations/studies are needed)

X → To be mitigated by organisational measures (e.g. access restrictions, non-stay areas, accept property loss)
Conclusions

- PBD is very useful as Risk Assessment method for non-standard installations → used for FCC CDR

- Trial Design (with safety features) fulfils the majority of the Safety Objectives
- Unfulfilled objectives can be mitigated by organisational measures
  - No affect on the infrastructure of the FCC tunnel
  - Baseline FCC cross-section is acceptable

- A more qualitative evaluation shall be carried out at a TDR level
  - Transportation system in case of evacuation
  - Studies on the height of the helium gas layer (CFD simulations)
- FCC-ee & HE-LHC studies are ongoing and will be ready for the CDR
Thank you very much
for your attention

Acknowledgements:

Spare slides
Evacuation distance in road tunnels

L’Association mondiale de la Route (AIPCR), Manuel des tunnels routiers

“L’inter distance optimale entre deux issues de secours résulte de l’Analyse des Risques.”

EU Directive 2004/54/EC on minimum safety requirements for tunnels in the Trans-European Road Network

“Where emergency exits are provided, the distance between two emergency exits shall not exceed 500 m.”
Case study: **Quantitative** deterministic evaluation

Main assumptions (e.g.):
- ventilation velocity;
- length of detection zone;
- When ventilation on, He propagates with the ventilation velocity;
- When ventilation off, He propagates due to buoyancy

Based on these assumptions we can calculate:
- He propagation downstream;
- He propagation upstream;
- Total tunnel length interested by He
- estimated downtime cost;

Other quantities can be calculated: gas temperature, O2 levels, visibility, etc.

*Courtesy of S. La Mendola*
Case study: **Probabilistic** evaluation

Estimated total cost of an accidental scenario. It was chosen because considered likely. We can now try to estimate **quantitatively** its likelihood through a probability calculation.

Assumptions (e.g.):
- 20% of lifetime the facility is expected to be in shutdown;
- 10% of shutdown there will be works in arcs;
- The probability of having a He release caused by works \([10^{-x}/d]\);
- ODH detection and actions (alarm and ventilation off) work as foreseen;

Calculate probability (Poisson process) for this scenario;

The expected cost (risk) is \(\text{Estimate\_cost} \times \text{Poisson\_prob}\ [\text{kCHF/y}]\)

Consequences and probabilities can be used to locate this scenario in a risk matrix.

*Courtesy of S. La Mendola*
Case study: **Probabilistic** evaluation. Risk matrix (adapted from SFPE guide)

**Description of Consequence**
- Negligible: Minimum damage to building, minimal operational downtime;
- Low: Damage < CHFyy value, reparable damage to building, significant operational downtime, no impact on surroundings;
- Moderate: CHFyy < damage < CHFxx, major equipment destroyed, minor impact on surroundings;
- High: Damage > CHFxx, building destroyed, surrounding property damaged.

**Description of Frequency – SFPE approach**
- Anticipated, expected: incidents that might occur several times during the lifetime of the facility ($f > 10^{-2}/y$);
- Unlikely: events that are not anticipated to occur during the lifetime of the facility ($10^{-4}/y < f \leq 10^{-2}/y$);
- Extremely unlikely: events that will probably not occur during the life cycle of the facility ($10^{-6}/y < f \leq 10^{-4}/y$);
- Beyond extremely unlikely: all other incidents ($f > 10^{-6}/y$).

The star indicates the position of the scenario (example)
Case study: **Probabilistic** evaluation.

Scenarios can be seen as a particular path in an event tree:

**Event tree: tunnel arc - long shutdown phase – ignition due to hot work**

<table>
<thead>
<tr>
<th>Extinction by Occupants (E)</th>
<th>Fire Detection (D)</th>
<th>Sound Alarm (A)</th>
<th>Ventilation stops (V)</th>
<th>Scenario ID</th>
<th>Prob. / y</th>
<th>Consequence [kCHF]</th>
<th>Expected cost [kCHF/y]</th>
</tr>
</thead>
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<tr>
<td>(P(E</td>
<td>I_{HW}))</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>(P(A</td>
<td>D \cap \overline{E} \cap I_{HW}))</td>
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<td>(P(V</td>
<td>A \cap D \cap \overline{E} \cap I_{HW}))</td>
<td>(2)</td>
<td>(10^x)</td>
</tr>
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<td>(P(D</td>
<td>\overline{E} \cap I_{HW}))</td>
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</table>
Case study: fire in the arc of a generic accelerator tunnel during a long shutdown. **Full probabilistic** evaluation.

If the risk profile of a project:
- is above the upper ALARP curve, the design solution is unacceptable;
- is below the lower ALARP curve, the design solution is acceptable;
- If the risk profile of a project lies between the upper and the lower ALARP curves, a cost – benefit analysis should be made.

**Cost – Benefit analysis**
If C is the total cost of fire protection measures and \( C_F \) is the expected fire loss, the optimum design minimizes:

\[
C_T = C + C_F
\]

\[\text{Unacceptable} \]

\[\text{Acceptable} \]
Cryo3: 1 kg/s ; 200 m from release point

- Propagation of He cloud and evacuation distance

- Occupant is always ‘ahead’ the He cloud
Cryo6: 32 kg/s during operation

- Sectorise the He inventory each 2 half-cells ~ 220m
- 33 l LHe / m → 7260 l LHe @ 300 K → ~ 1 ton GHe
- Fire compartment: 440 m

5.5 m Ø → 7000 m³ of air + 5 600 m³ GHe
→ 1300 mbar pressure increase

Property protection
- Loss of one compartment & 1 cell
- Downtime
- 1 year of operation

CFD calculation needed…

With doors closed

With doors open