Study of HE-LHC ventilation strategy in case of fire.
CFD study of smoke and heat propagation for PBD

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HSE-OHS
Outline

Intro to PBD methodology used
FCC developed framework

Fire Safety PBD for HE-HLC
Life Safety Objective Evaluation
Occupants
  Ventilation system design performance
  Effect of compartmentalization length

Fire Fighters

Property Protection
Soot and thermal impact

Design Optimization
Dampers and ducts fire resistance
External fans fire resistance

Overall conclusions
Performance-Based Design, the *working* solution for safety

**What is safe?**
PBD process:

Technical assessment reviewed by FCC fire collaboration members during the Fermilab FCC Fire Workshop 7-9th November 2017.

Reviewers: Fire safety experts from:

- Fermilab
- Lund University
- EURATOM

Additional peer reviewer:

- Brookhaven National Laboratory
## Safety Objectives

<table>
<thead>
<tr>
<th></th>
<th>Life</th>
<th>Environment</th>
<th>Property</th>
<th>Continuity of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<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>
</tr>
<tr>
<td>2</td>
<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>
<td>Limit the volume of polluted (incl. activated) water released to the environment in case of incidents</td>
<td>An incident shall not cause other potentially dangerous accidental events</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Rescue teams shall be able to intervene safely and according to current CERN SOPs</td>
<td>-</td>
<td>Limiting the property loss in case of incident</td>
<td>-</td>
</tr>
</tbody>
</table>

Acceptance Criteria (for Life Safety Objectives)

• Occupants

Occupants shall be able to evacuate through protected areas, free from smoke/gas and other hazards at any time.

01 Any able occupant has a reasonable opportunity of evacuating the facility without reaching any of the following criteria:
  - Visibility < 10m at 1.8m high
  - Fractional Effective Dose (FED) > 0.1
  - T > 60°C
  - Heat flux > 2.5KW/m²

• Victims

Victims and other occupants, not able to self-evacuate, shall reach protected areas, and wait there to be rescued by the intervention teams.

In a later stage, the probabilistic concept could be introduced. (needs a call for a background study in the acceptable individual risk by the organization)

i.e. reasonable opportunity = frequency greater than $10^{-3}$/year

• Firefighters

Rescue teams shall be able to intervene safely and according to current CERN SOPs.

References:
PBD process:
Fire Scenarios
3.1 Fire designs: Fire#1 - Tray Fire

Possible ignition source:
Hot works during installation or electrical overheat during commissioning.

Description:
This fire tray design is based on the work conducted by Sainson and Dinh (Sainson & Dinh, 2016) that developed a methodology to define the fire curves of several cable trays on vertical alignment given some configuration parameters. For the present design, we took 4 cable trays. The different cable trays are represented considering their size and location according to the section. The overall fire curve is presented in Figure 1. All parameters are detailed in Table 5 (see annex).

3.1 Fire designs: Fire#2 - Drum Fire

Possible ignition source:
Hot works during installation.

Description:
This scenario is developed considering the external fire load of a cable drum. Both, the wooden drum (40kg) and the full rolled cable (40kg) are assumed to catch fire. As a subsequent event, cable trays are ignited after 8 min and thus the HR flue of fire#1 is added. The fire is initially represented as a flat square fire with a growing coefficient of 0.023 W/s/m² which corresponds to half the speed of extended pallets (test case) (Draudt, 2013). The drum's peak HR corresponds to the maximum fuel release rate per unit area (1.36 kW/m²). The total 8.4 m (Ingezerv,Li & Labouvré, 2010). Considering a total exposed area of 72 m² (from a 1.5 m diameter wooden sealed drum, as in Figure 6) the maximum HR is 2.4MW.

3.1 Fire designs: #Fire3 Kuka Fire

Possible ignition sources:
Battery malfunction that causes a thermal runaway and further explosion to transported goods and Kuka robot. Mechanical friction on bearings or moving parts. Possible hydraulic oil ignition.

Description:
This fire scenario considers that the Kuka transport vehicle catches fire when loaded with 3 pallets (60kg). Due to the rapid fire spread the load collapses and the tire is ignited.

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- Those 3 scenarios are considered to be more representative ones
- Only fire scenarios are considered.
- Fire Scenarios resulting from explosions are not accounted for.
If compartmentation works, with current ventilation system $HRR_{\text{max}} < 5\text{MW}$ (ventilation limited)

Fire#2 and Fire#3 have same growth up to 8min!

In all cases, the fire is assumed to be located at 1/3 of the length of the compartment
PBD process: Trial Design
Geometry and safety measures

Baseline Safety Features

- **Fire compartment** = 4 x cells (137m), 548m
- He-Smoke extraction duct (Ø350)
- Detection in compartments
- Fire extinguishing pipeline on each fire door
## Trial design features: Detection

<table>
<thead>
<tr>
<th>Features</th>
<th>Aspiration</th>
<th>T Line (optical fiber)</th>
<th>Optical smoke detector*</th>
</tr>
</thead>
</table>
|          | • Resolution: 100m  
• Max Sampling Speed: 1-1.5 m/s  
• **Analyzer must be put in the alcoves** (i.e. 1.5km distance)  
• Thus, worst case scenario (fire at 750m from alcove) the transport (i.e. sampling) time is 500s. | • Resolution: order of cm  
• Sampling speed of some seconds (for the signal processing algorithm)  
• It detects temperature trends (more useful than absolute temperatures in terms of detection) | • They are currently not radiation resistant *  
• Resolution of 100m (4 per compartment)  
• Instant signal communication  
• Technology to be developed |
| Detection time | Central has to be shielded from radiation (installed in the tunnel) | We assume it will take up to **120s** to detect a fire after development and optimization of the detection algorithm. Hypothesis to be better studied in TDR. | **60<t<120s*** |

**HYBRID SYSTEM?**

Assumed SPEC $t_{det} = 120s$

[Desy (FCC Col)
Yacine Kadi EN-EA]
Ventilation: Proposed Strategy

Normal Ventilation Condition

25000 m³/h

O.Rlos, S. La Mendola, FCC WEEK 2019.
Ventilation: Proposed Strategy

When Fire is detected in a compartment

- 3 compartment doors closes (fire compartment and neighbours)
- Longitudinal ventilation blows towards the compartment
- Small air extract in fire compartment (~100m³/h) (to ensure under pressure)
- **Overpressure** created in neighbouring compartments
- Safe situation for Fire Fighters intervention

Small smoke exhaust: ~100 m³/h
PBD process:
Evaluate Trial Design
Fire scenarios and human behaviour

For all scenarios with presence of people we consider occupants to be in 4 different location w.r.t fire site.

<table>
<thead>
<tr>
<th>$X$ from fire [m]</th>
<th>1st Cue [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-100 (upstream)</td>
<td>$\Delta t_{det}$</td>
</tr>
<tr>
<td>+100 (downstream)</td>
<td>$\Delta t_{det}$</td>
</tr>
<tr>
<td>+150 (downstream)</td>
<td>$\Delta t_{det}$</td>
</tr>
</tbody>
</table>

**Last man out**

Evacuation. Uncertainty calculations

Walking Speed. Normal([1.2,0.3])

- 10th percentile = 0.8 m/s
- 90th percentile = 1.6 m/s

Pre Movement. Uniform([30,90])

- 10th percentile = 36 s
- 90th percentile = 84 s

![Diagram of evacuation process and human behaviour](image-url)
Evaluation: CFD modelling

- Smoke propagation
- Flow fields
- Temperature fields
- Smoke visibility

Center of the walking lane

2m from floor

44 trees, \( \Delta z = 0.4 \) m, \( \Delta x = 10 \) m
Life Safety: no smoke extraction (no inlets)
Life Safety: smoke extraction (+inlets)

Flow $\approx 3000 \text{m}^3/\text{h}$

VIS at $Z=2.1$
Life Safety: Compartment length (250m vs 772m)
Fire Fighters Life Safety

**Fire Fighters Response**

- **Distance from door > 80m**
  - HRR < 5MW offensive
  - HRR > 5MW defensive

- **Distance from door < 80m**
  - HRR < 20MW offensive
  - HRR > 20MW defensive

If compartmentation works, with current ventilation system HRR_{max} < 5MW (ventilation limited)

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**04 DESIGN SPECIFICATION** Firefighter safety requires that closest **safe area** for firefighting (no imminent risk and no breathing apparatus needed) is **less than 450m away** from the door of the fire compartment.

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**05 DESIGN SPECIFICATION** In order to ensure firefighter safety and protection: during offensive operations, **extinguishing media available** for attack and search & rescue teams matches **fire development**, allowing firefighter protection and fire control under 3 minutes:

- 3 extinguishers of 9kg CO\(_2\) if fuel mass is below 25kg;
- 100L portable CAFS on trailer up to 5MW;
- or 500LPM water hose line up to a maximum HRR of 20MW.

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**06 DESIGN SPECIFICATION** Firefighter safety is only guaranteed if engaged teams remain in **communication** at all times with surface incident command post.

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**07 DESIGN SPECIFICATION** **Structural stability** of the premises during operations.
Property Protection: Performance Criteria

• **Burnt Areas**
  Full replacement of equipment

• **Smoke damage**
  Cleaning operations and partial/complete replacement.

01: All material and devices that:
- Caught fire
- Are exposed to:
  > 20 kW/m²
  > 80ºC

02: All material and devices that:
- Undergo a deposition of soot (HCl) larger than:
  - > 100 mg/m² [2] (replacement)
  - > 50 mg/m² [2] (cleaning)
Impact to property (machine & tunnel)

Heat Flux

Surface Temperature

Soot Deposition
Impact to property (machine & tunnel)

Fire #1

Area affected by soot deposition
- DEPO_SOOT_ALL_GT_50mg/m²
- DEPO_SOOT_ALL_GT_100mg/m²
- DEPO_SOOT_QRL_GT_50mg/m²
- DEPO_SOOT_QRL_GT_100mg/m²

Area affected by Heat Flux
- Incident_HF_ALL_10
- Incident_HF_ALL_20
- Incident_HF_QRL_GT_10
- Incident_HF_QRL_GT_20

Area affected by temperature
- WALL_Temp_GT_ALL_80
- WALL_Temp_GT_QRL_80

Time [s]
Area above given deposition threshold [m²]

3000 m³/h

Fire #2(3)

Area affected by soot deposition
- DEPO_SOOT_ALL_GT_50mg/m²
- DEPO_SOOT_ALL_GT_100mg/m²
- DEPO_SOOT_QRL_GT_50mg/m²
- DEPO_SOOT_QRL_GT_100mg/m²

Area affected by Heat Flux
- Incident_HF_ALL_10
- Incident_HF_ALL_20
- Incident_HF_QRL_GT_10
- Incident_HF_QRL_GT_20

Area affected by temperature
- WALL_Temp_GT_ALL_80
- WALL_Temp_GT_QRL_80

Time [s]
Area above given Heat flux threshold [m²]

Time [s]
Area above given Temperature threshold [°C]
Impact to property (machine & tunnel)

- Area effected by soot deposition
- Area effected by Heat Flux
- Area effected by temperature

Fire #1

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Area above given deposition threshold [m^2]

Area above given Heat threshold [m^2]

Area above given Temperature threshold [m^2]

-- 3000 m^3/h
- 100 m^3/h
### Impact to property (machine & tunnel)

<table>
<thead>
<tr>
<th></th>
<th>Tunnels Walls</th>
<th>QRL area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depo &gt;10 μg/m²</td>
<td>HF&gt;20kW/m²</td>
</tr>
<tr>
<td>Fire 1</td>
<td>1000 m² (50 m)</td>
<td>16 m²</td>
</tr>
<tr>
<td>Fire 2</td>
<td>1750 m² (88 m)</td>
<td>25 m²</td>
</tr>
<tr>
<td>Fire 3</td>
<td>2000 m² (100 m)</td>
<td>55 m²</td>
</tr>
</tbody>
</table>
Design Optimization

By default: F600-2h
With the assessment: F400-2h
Conclusions

• Life Safety Goal analysed for HE-LHC. **Life safety goals for occupants are reached** with the baseline safety measures

• **Two different logics** in the used of the **extraction system** are explored. Extracting 3000m$^3$/h reduces property damage and increases life safety margin.

• Evaluation of potential **impact of the fire to property** quantified as affected **area to be replaced and cleaned**. Input data to be used in future cost-benefit analysis.

• **Hot smoke extraction** system can be most **efficiently designed** and its **fire resistance lowered** thanks to PBD approach
THANK YOU
Victims assessment

FED assessment on victims (FF intervention time)

ASET/RSET: Evacuees FED
Geometry and safety measures (old)

Baseline Safety Features

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Geometry and safety measures

Baseline Safety Features

- **Fire compartment** = 4 x cells (137m), 548m
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