
CERN
HSE
Occupational Health & Safety
and Environmental Protection unit

Study of HE-LHC ventilation strategy in case of fire.

CFD study of smoke and heat propagation for PBD

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CERN | HSE
Fire Safety Engineering Team

FCC hh ee he

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

CERN

CODE DE SÉCURITÉ
SAFETY CODE

E
Rev.

Issued by: Director-General

Date of revision: July **1995**
Original: French *
(except Appendix IV)

FIRE PROTECTION

What is *safe*?

Process conducted with FCC PBD Working Group

PBD process:

Peer reviewed process

HSE
Fire Safety Engineering Team

FCC Collaboration – Fermilab Workshop Nov. 2017
Fire Risk Assessment Brainstorming sessions
Peer Review exercise

The goal of this document is to provide a peer review among the FCC Collaborations partners on the brainstorming sessions for the fire risk assessment of the Berlin Baseline of the FCC. Peer reviewers in this workshop will be delivered the same presentation and documentation used during the brainstorming sessions. This peer review exercise is not an official statement from the collaborating organization and it is entirely free from any liability.

Name	James Niehoff
Organization	Fermilab
Date and signature	

Choice of PBD as safety design methodology

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

Reviewers: Fire safety experts from:

Fermilab

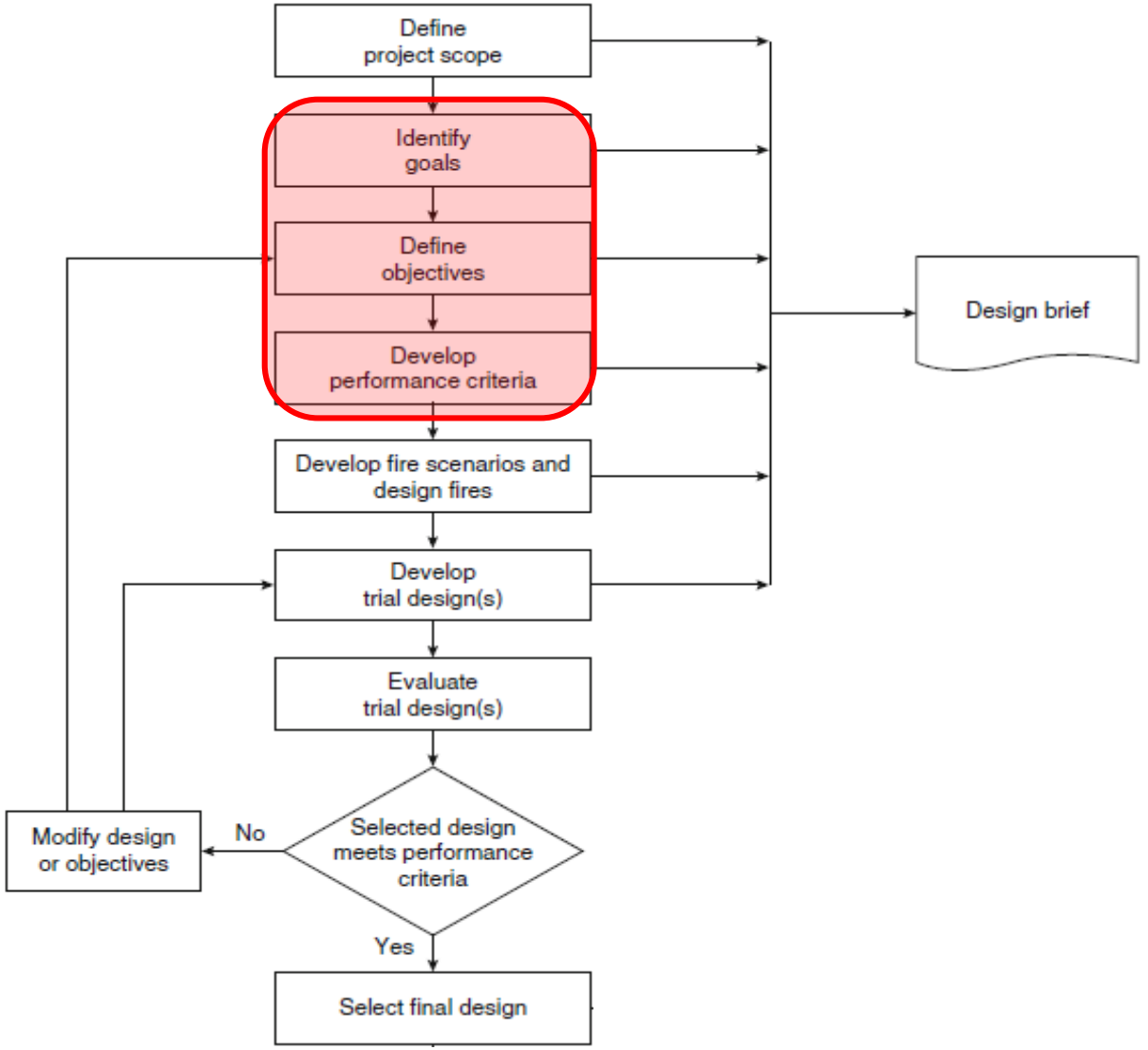
ESS EUROPEAN SPALLATION SOURCE

LUND UNIVERSITY

DESY (awaiting)

Additional peer reviewer:

BROOKHAVEN NATIONAL LABORATORY



Safety Objectives

Fire-induced radiological hazard (to environment, to evacuees or interveners) is not in this study scope. Research in progress: FIRIA project.

	Life	Environment	Property	Continuity of operation
	A	B	C	D
1	Occupants shall be able to evacuate through protected areas, free from smoke/gas and other hazards at any time	Limit the release of polluting (incl. activated) agents to the environment in case of incident	The continuity of essential services and structural stability is assured in case of fire or gas release and other incidents	Limiting the downtime in case of incident
2	Victims and other occupants, not able to self-evacuate, shall reach protected areas, and wait there to be rescued by the intervention teams	Limit the volume of polluted (incl. activated) water released to the environment in case of incidents	An incident shall not cause other potentially dangerous accidental events	-
3	Rescue teams shall be able to intervene safely and according to current CERN SOPs	-	Limiting the property loss in case of incident	-

Source CERN EDMS 1770088v1. La Mendola (2017). Methodology proposal for performance-based safety design, La Mendola, 2017

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

- **Victims**

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

- **Firefighters**

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

01 Any able occupant has a ***reasonable opportunity* of evacuating** the facility without reaching any of the following criteria:

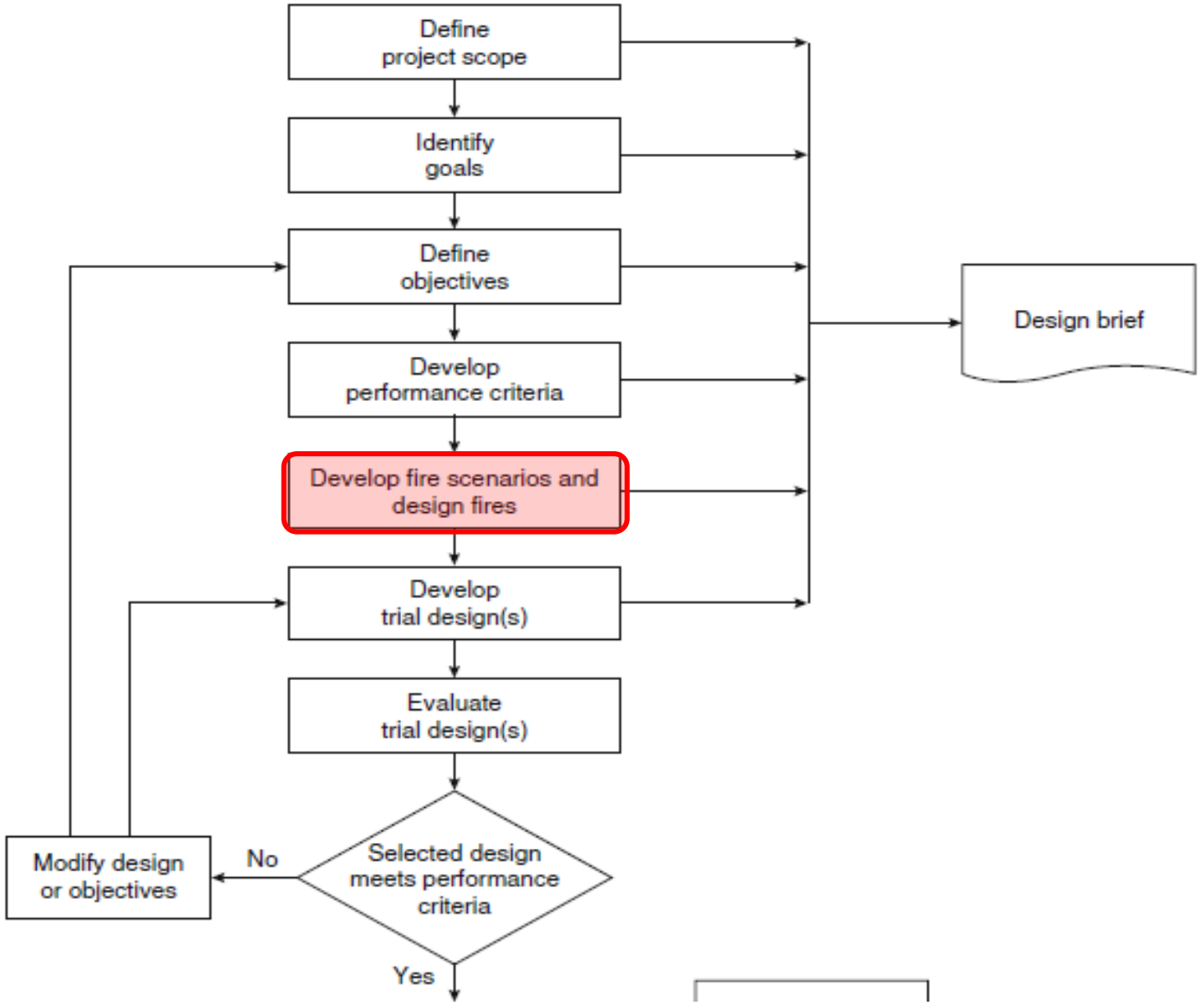
- Visibility < 10m at 1.8m high
- Fractional Effective Dose (FED) > 0.1
- T > 60°C
- Heat flux > 2.5KW/m^2

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

References:

- *ISO 13571:2012. Life-threatening components of fire - Guidelines for the estimation of time to compromised tenability in fires.*
- *Corpo Nazionale dei Vigili del Fuoco (2015). Codice di prevenzione incendi DM 3-8-2015*

PBD process: Fire Scenarios



Fire Designs

Same fire scenarios as those generated for FCC tunnel assessment

3.1 Fire designs: Fire#1 - Tray Fire

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

Description:
This tray fire design **is based on** the work conducted by Isaksson and Olin (Isaksson & Olin, 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 the 4 cable trays. The different cable trays are represented considering their size and location according to cross section. The overall fire curve is presented in Figure 3. All parameters are detailed in Table 5 (see annex).

CABLE TRAY

DRUM

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 (~50kg)** are assumed to catch fire. As a subsequent event, cable trays are ignited after 8 min and thus the HRR curve of fire#1 is added.

The fire is initially represented as a t squared fire with a **growing coefficient of (0.022kW/s²)** which corresponds to half the speed of stacked pallets (fast grow) (Drysdale, 2011). The drums peak HRR corresponds to the maximum heat release rate per unit area (HRRPUA) of 0.2MW/m², (table 4.8 in (Ingason, Li, & Lönnermark, 2015)). Considering a total exposed area of 12m² (from a 1.5m diameter wooden sealed drum, as in Figure 4) the maximum HHR is 2.4MW.

3.1 Fire designs: #Fire3 Kuka Fire

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

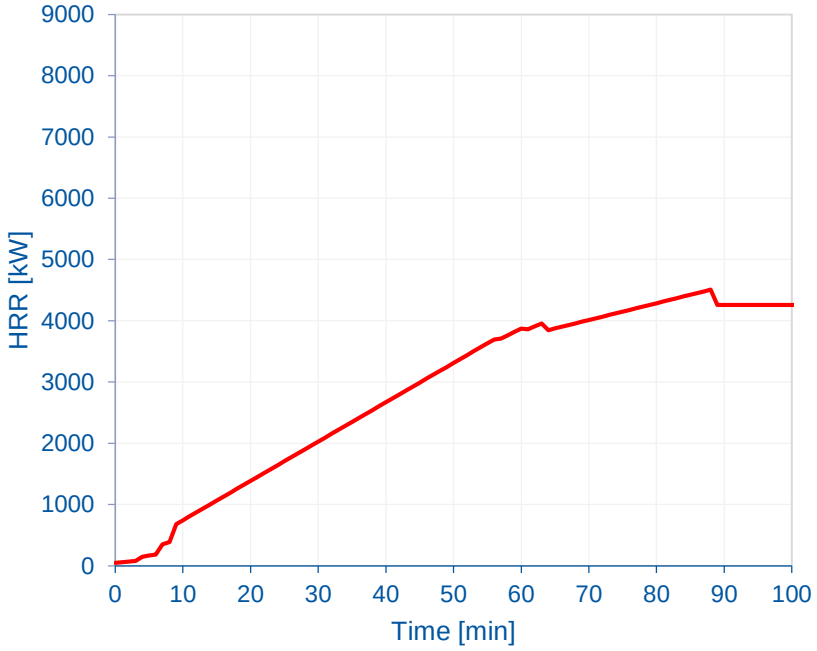
Description:
This fire scenario considers that the Kuka transport vehicle catches fire when loaded with 5 pallets (60kg). Due to the rapid fire spread the load collapses and the tyres are ignited

KUKA

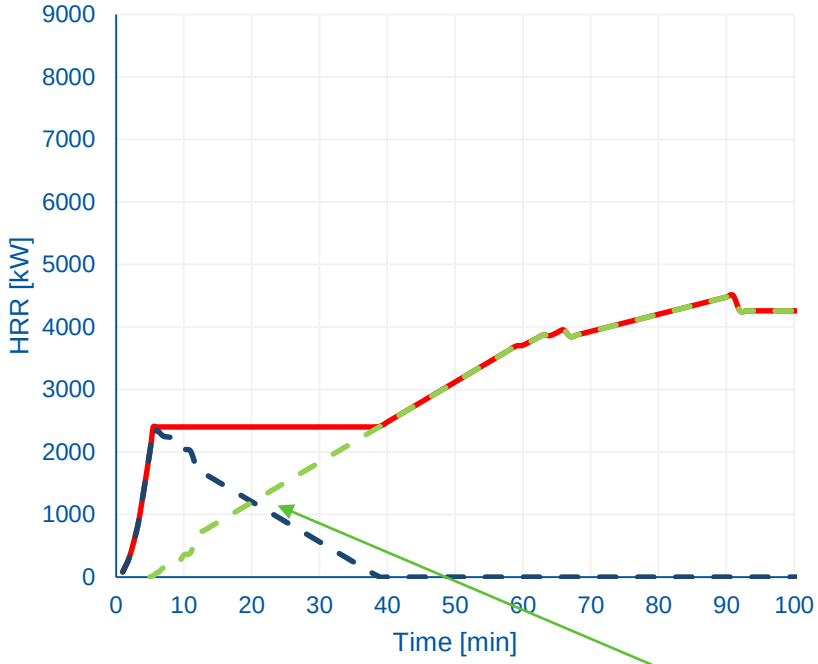
- Those 3 scenarios are considered to be more representatives ones
- Only fire scenarios are considered.
- Fire Scenarios resulting from explosions are not accounted for.

Fire designs: Enveloping cases

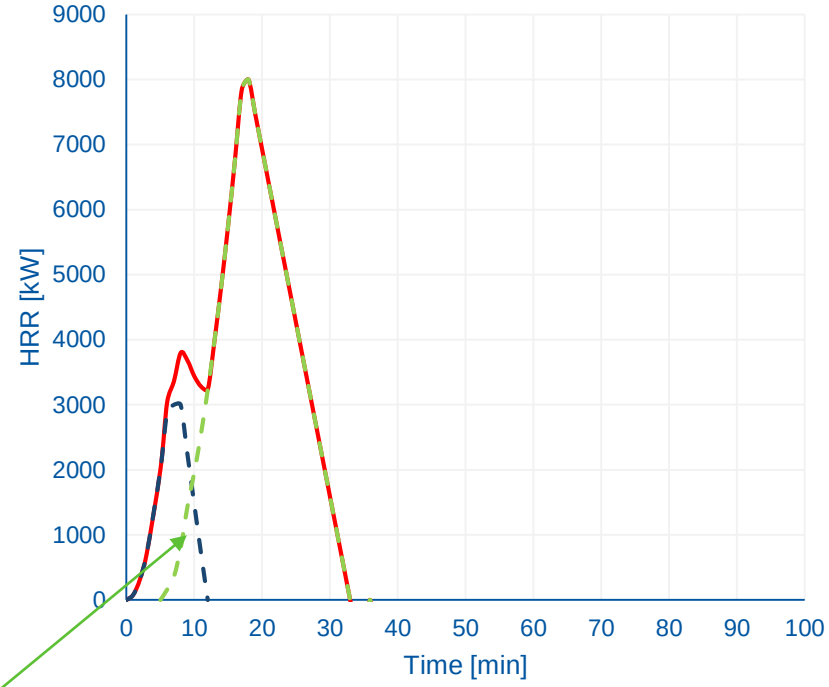
Fire#1 - Tray Fire



Fire#2 – Drum Fire



Fire#3 - Kuka Fire

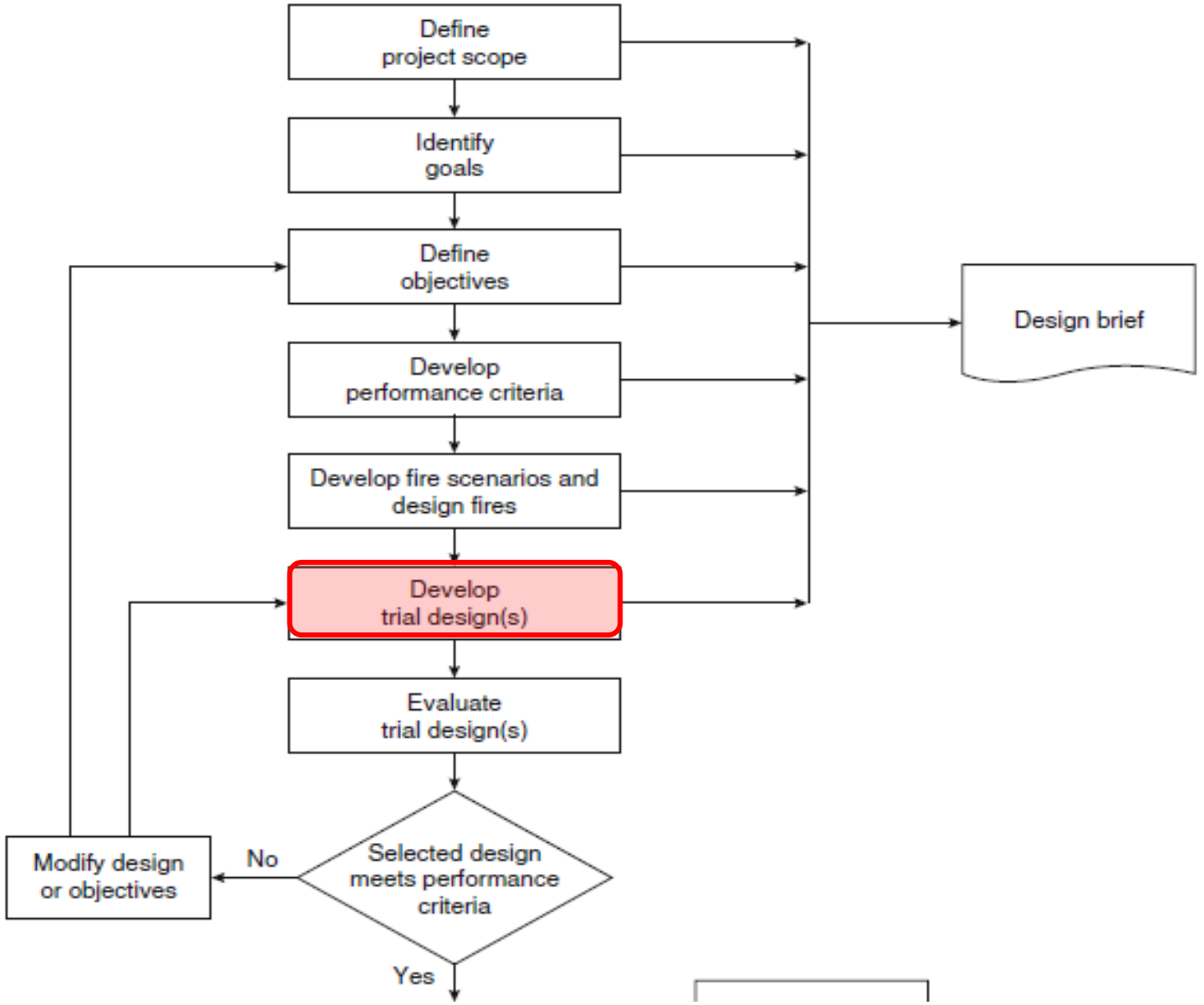


If compartmentation works, with current ventilation system
HRR_{max} < 5MW (ventilation limited)

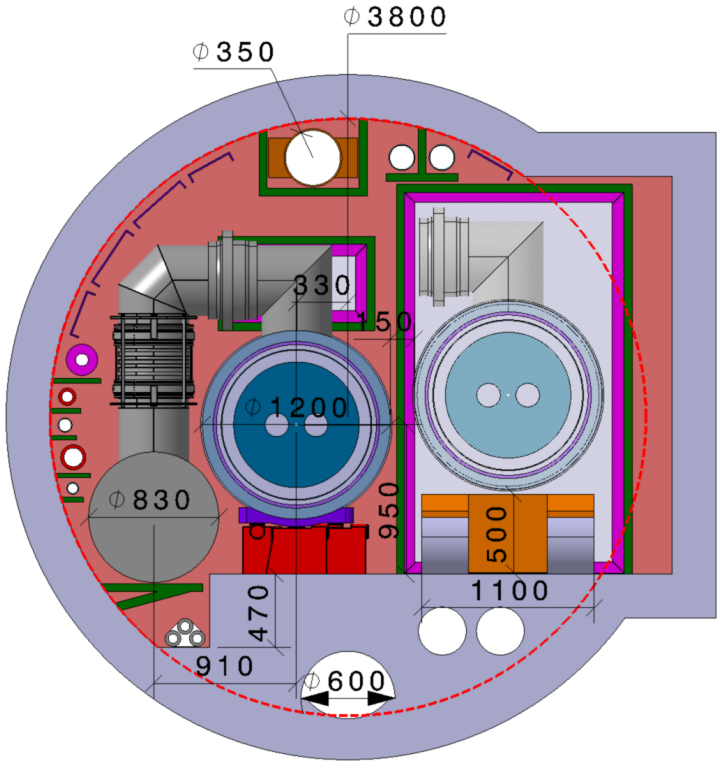
Fire#2 and Fire#3 have same growth up to 8min!

In all cases, the fire is assumed to be located at 1/3 of the length of the compartment

PBD process: Trial Design

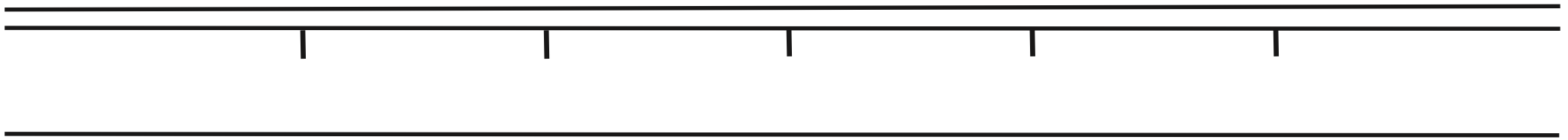


Geometry and safety measures



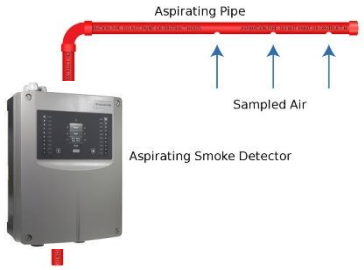
Baseline Safety Features

- **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

	Aspiration	T Line (optical fiber)	Optical smoke detector*
Features	• 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 de development and optimization of the detection algorithm. Hypothesis to be better studied in TDR.	**60<t<120s***



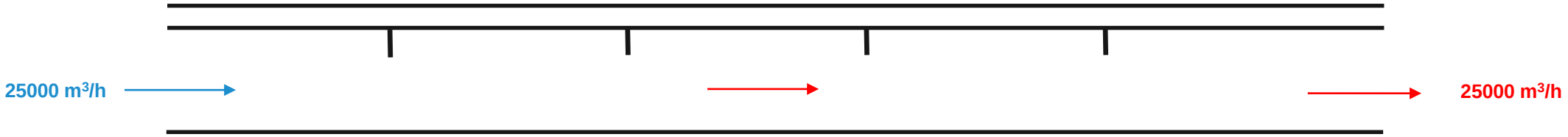
HYBRID SYSTEM?

Assumed SPEC t_{det}= 120s

*Desy (FCC Col)
Yacine Kadi EN-EA

Ventilation: Proposed Strategy

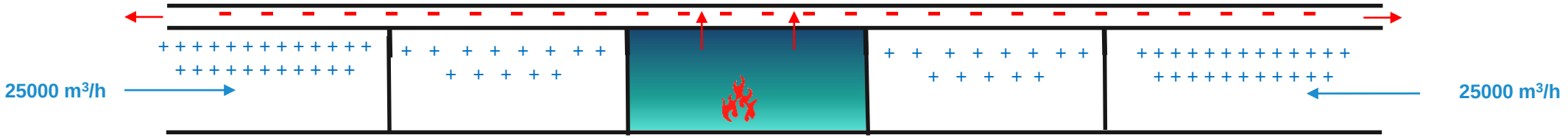
Normal Ventilation Condition



Ventilation: Proposed Strategy

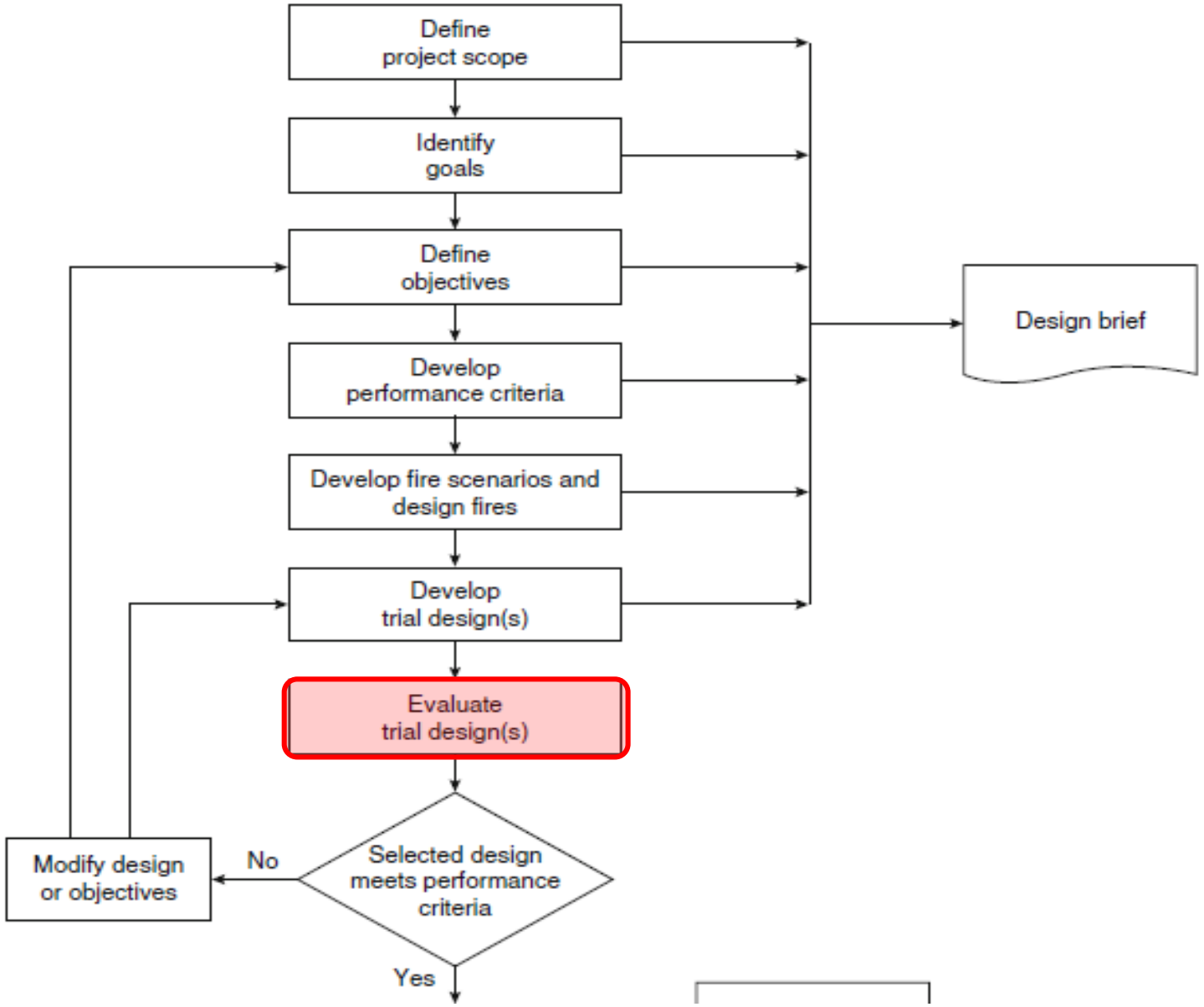
When Fire is detected in a compartment

Small smoke exhaust: ~100 m^3/h



- 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

PBD process: Evaluate Trial Design



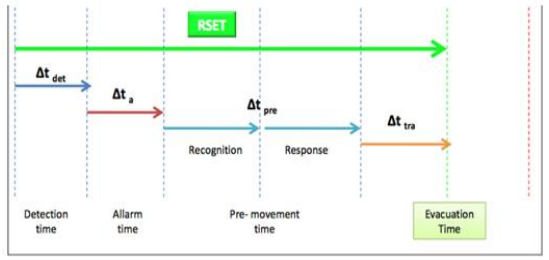
Fire scenarios and human behaviour

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

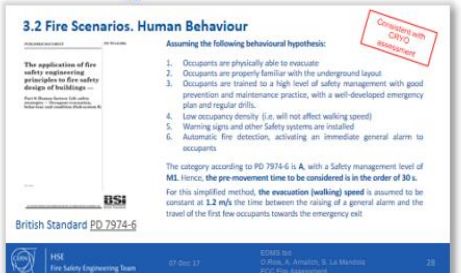
X from fire [m]	1st Cue [s]
0	0
-100 (upstream)	Δt_{det}
+100 (downstream)	Δt_{det}
+150 (downstream)	Δt_{det}

Last man out

Courtesy G. Lindell



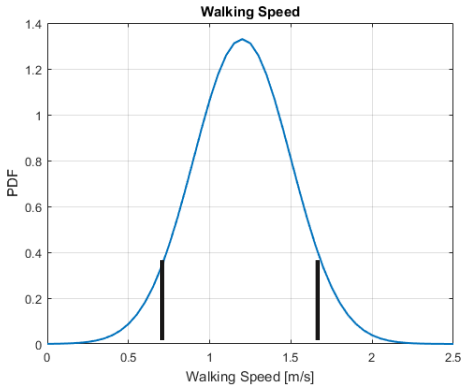
Time [s]	Δt_{det}	Δt_a	Δt_{pre}	Δt_{tra_door}
All Cases	120	0	30	$\frac{x}{1.2}$

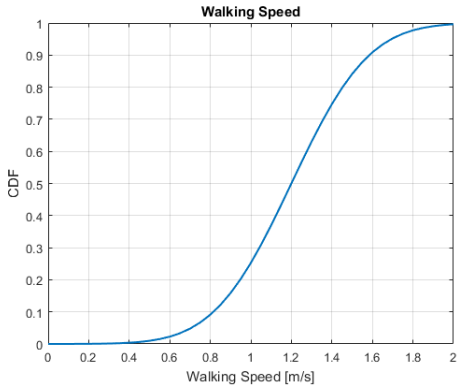


Evacuation. Uncertainty calculations

Walking Speed. Normal([1.2,0.3])

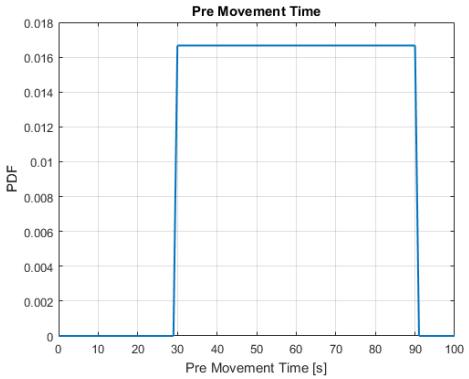
10th percentile = 0.8 m/s
90th percentile = 1.6 m/s

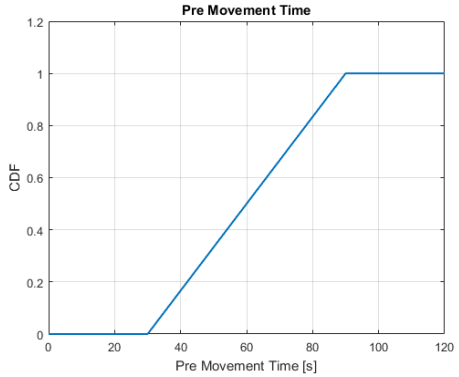




Pre Movement. Uniform([30,90])

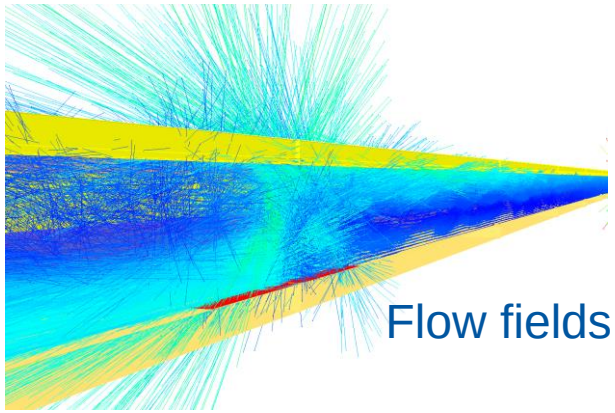
10th percentile = 36 s
90th percentile = 84 s



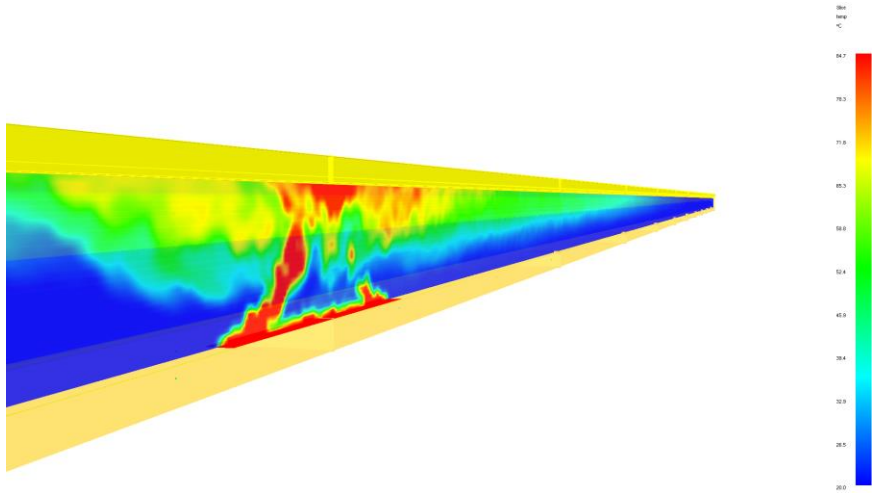


Evaluation: CFD modelling

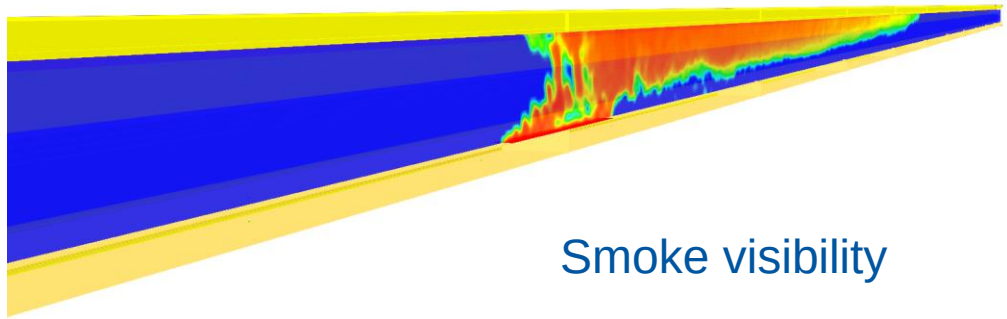
Smoke propagation



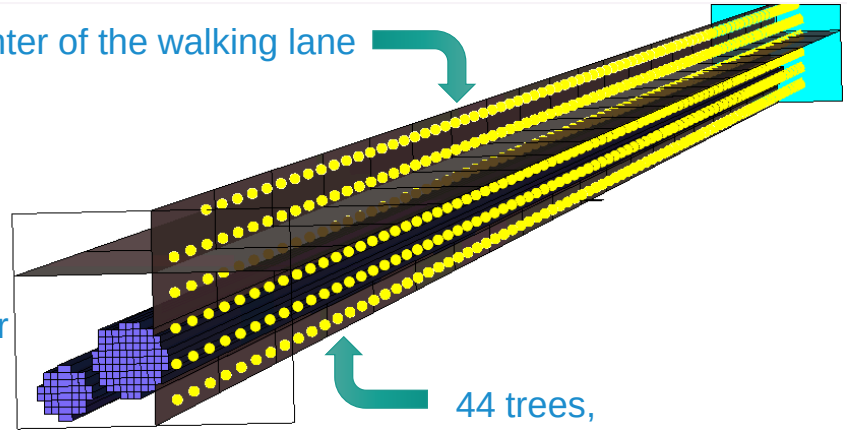
Flow fields

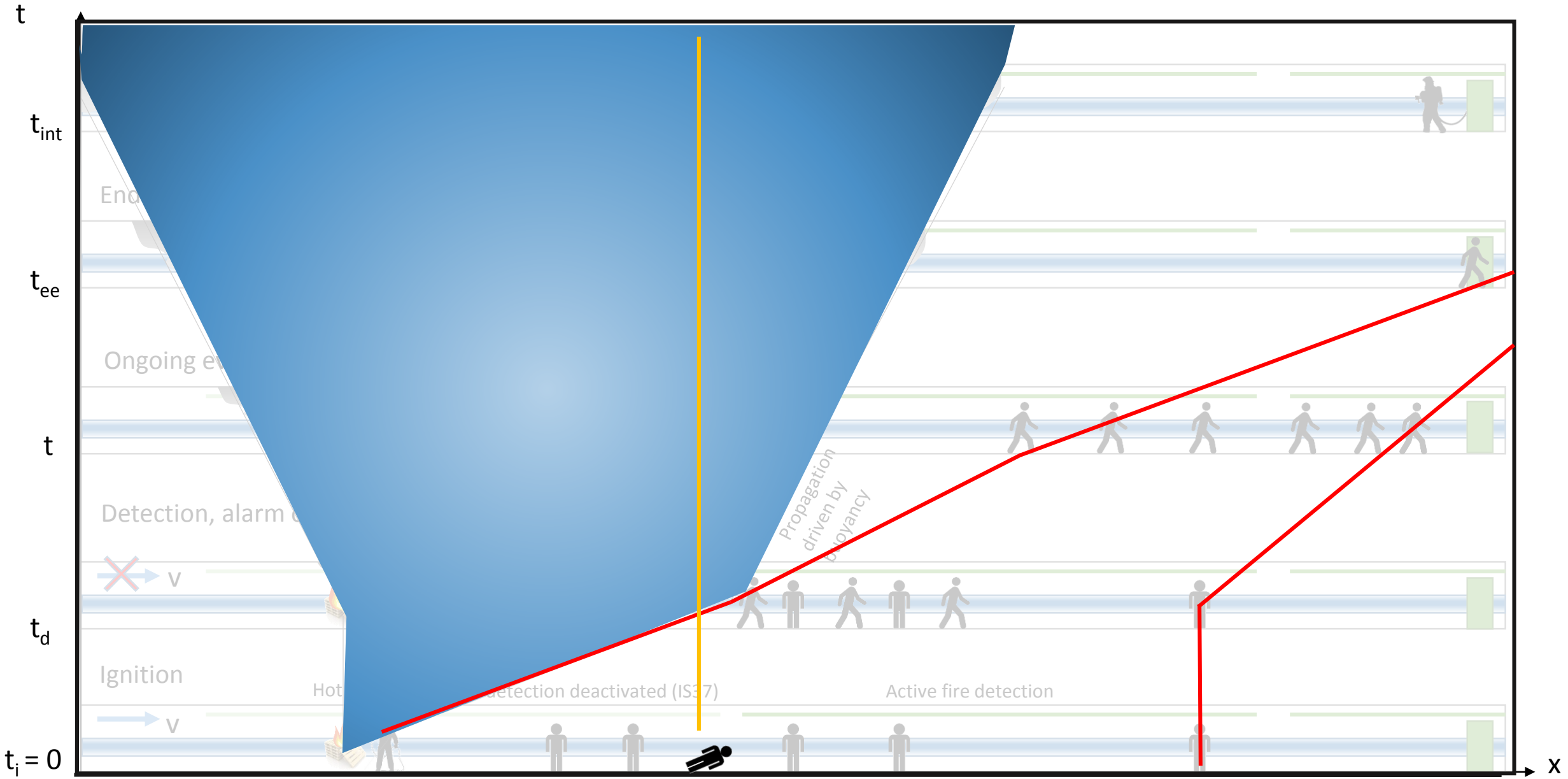


Temperature fields

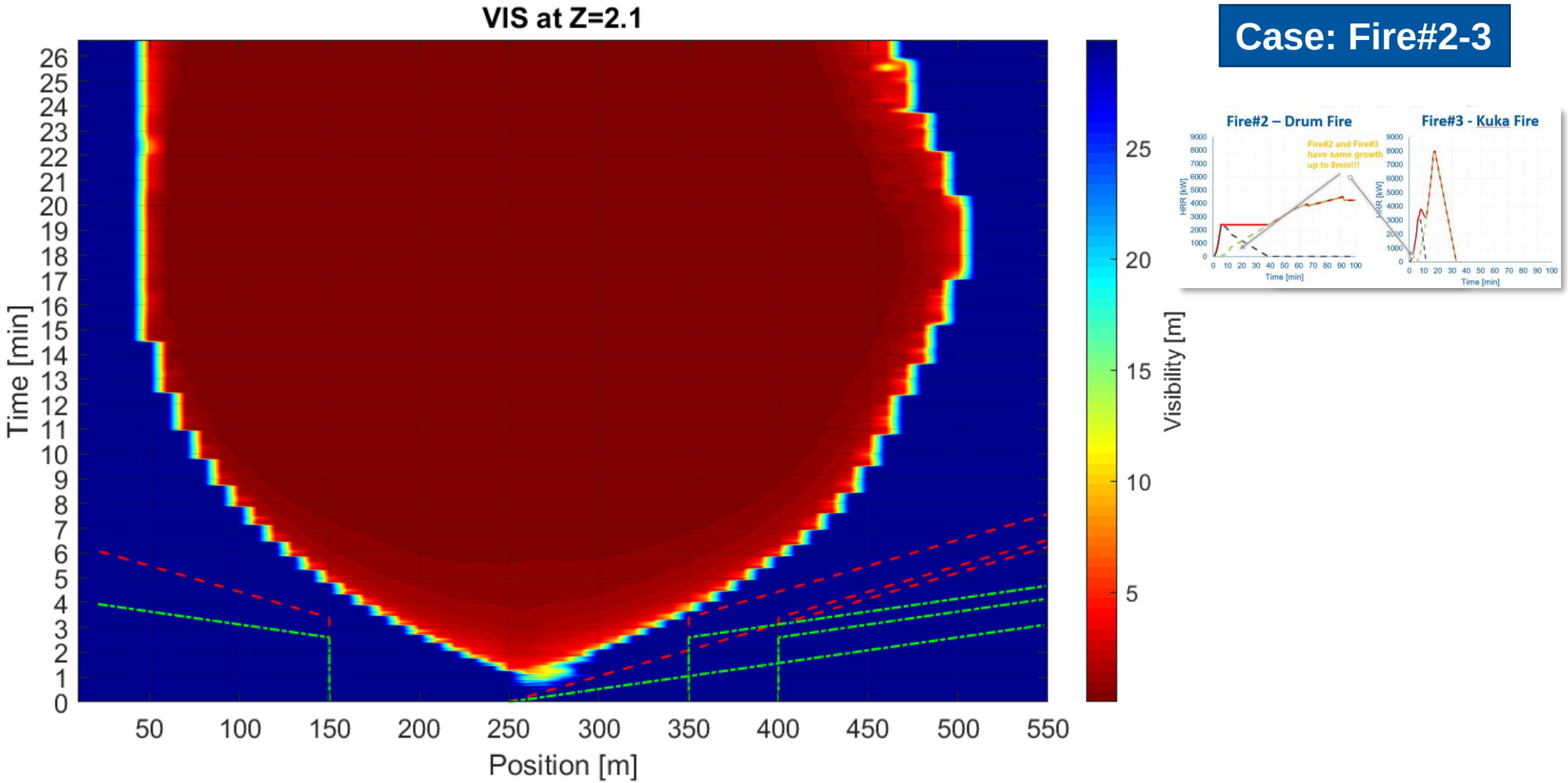


Smoke visibility



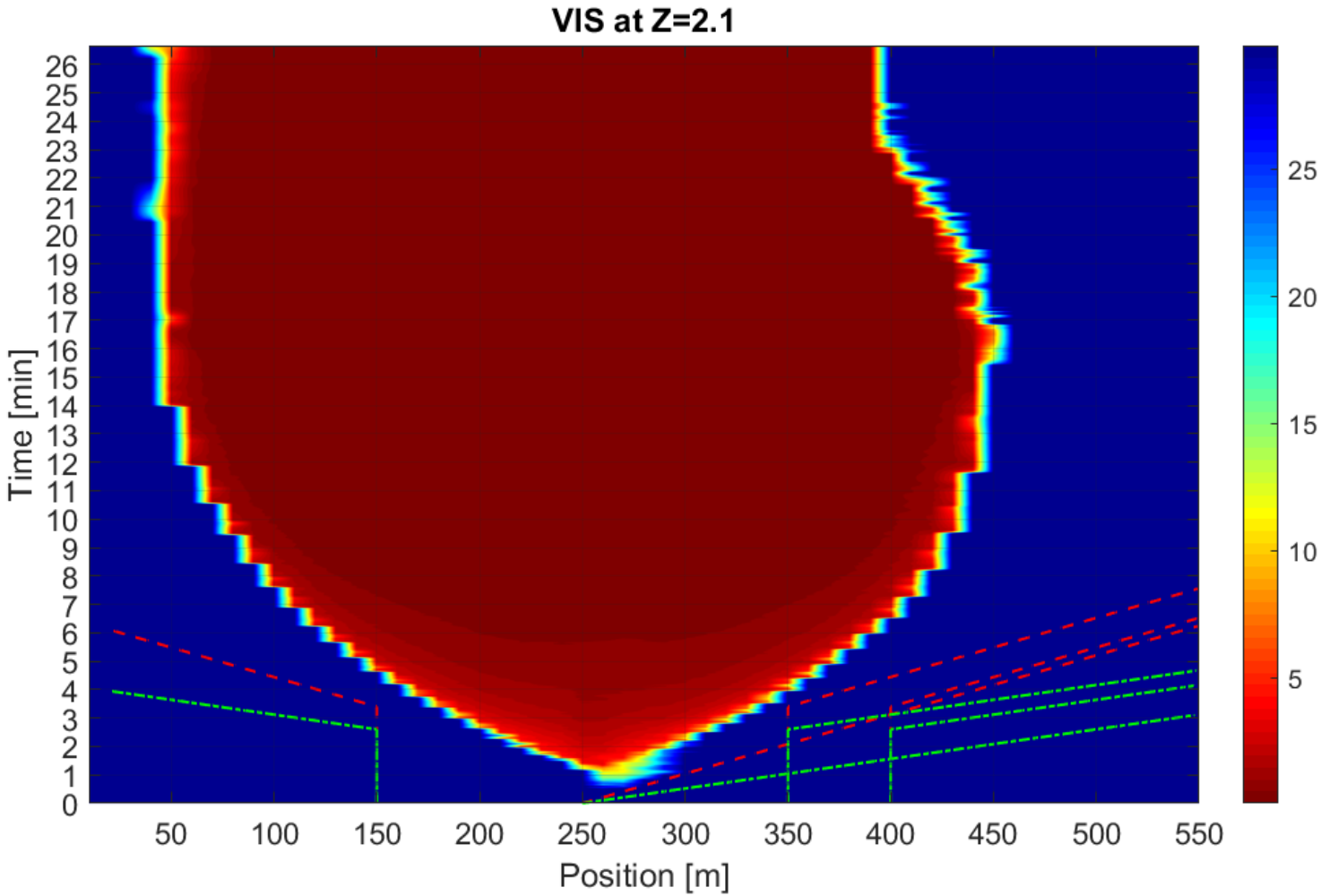

t
t_{int}
t_{ee}
t
t_d
$t_i = 0$
x
Ongoing e
Detection, alarm
v
v
Ignition
Hot
detection deactivated (IS37)
Active fire detection
Propagation driven by buoyancy

Life Safety: no smoke extraction (no inlets)

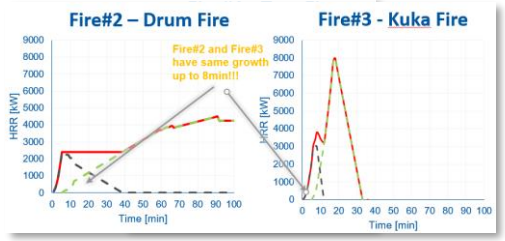


Life Safety: smoke extraction (+inlets)

Flow≈3000m3/h

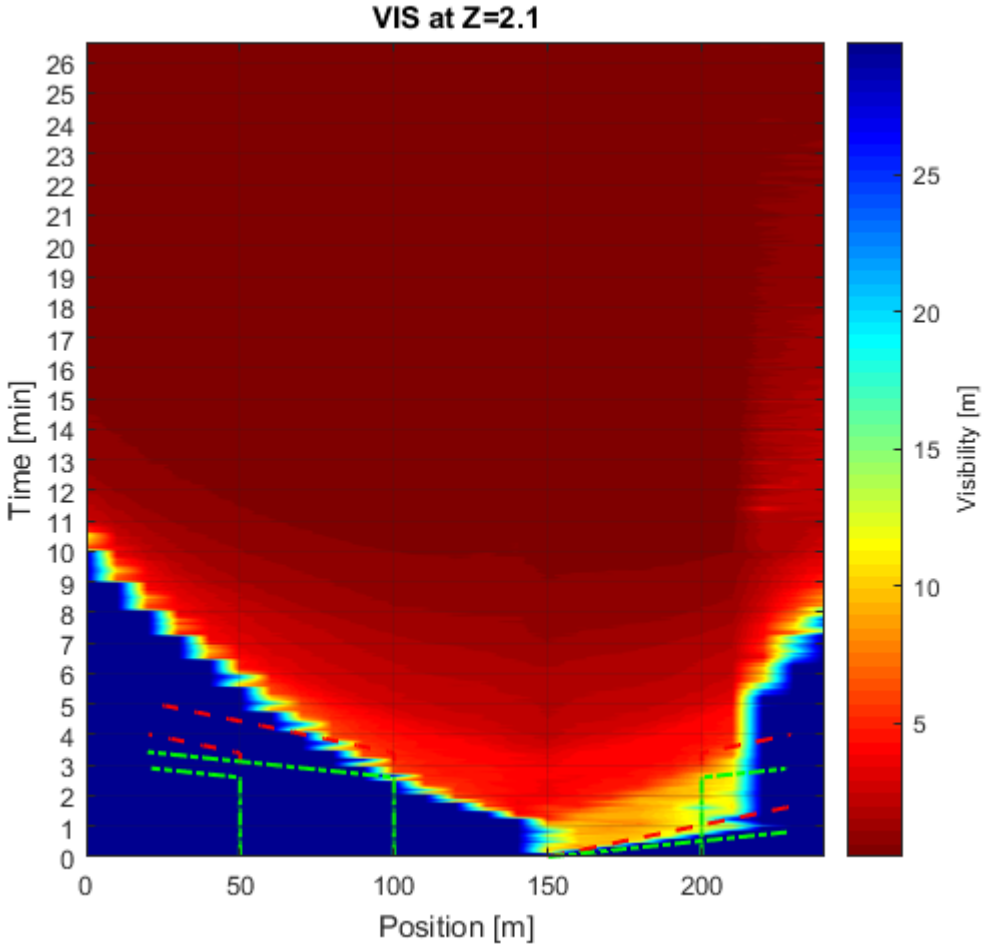


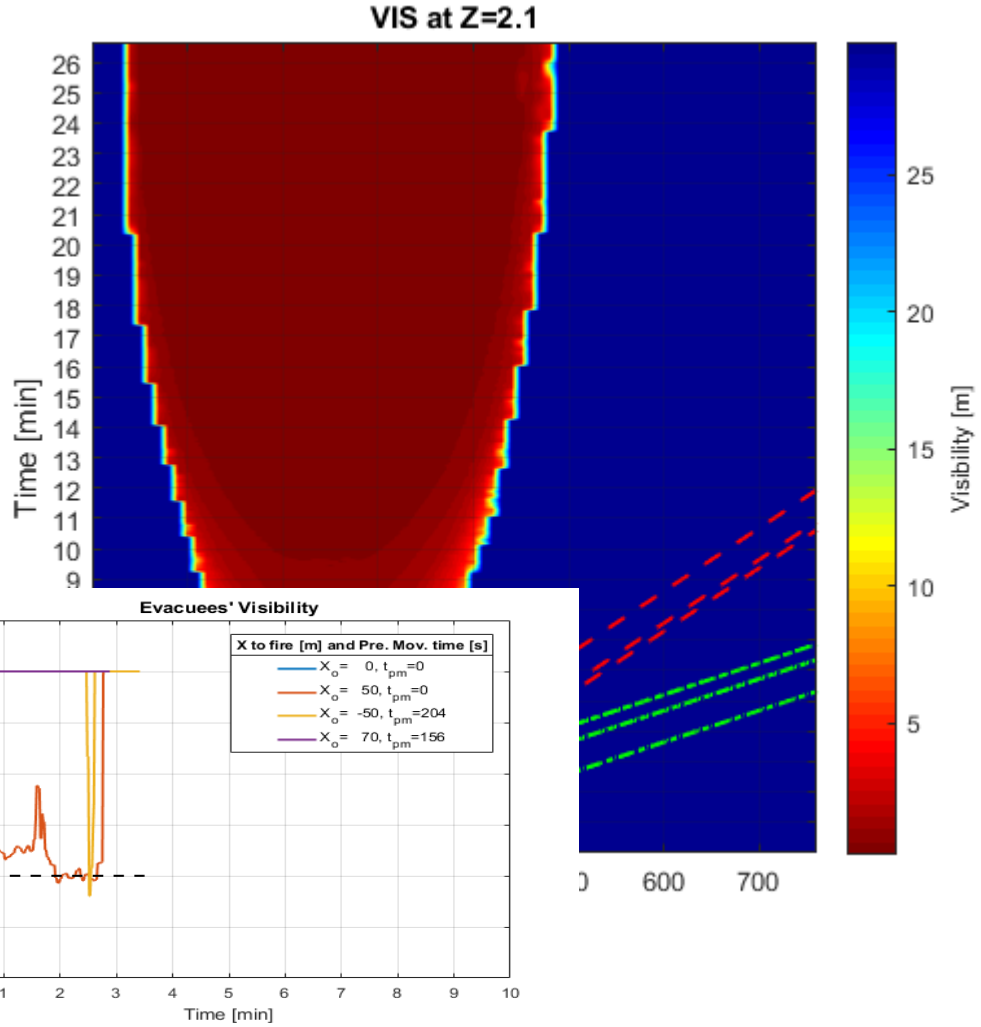
Case: Fire#2-3



Spurce:
http://news.lifesafetyservices.com/

Life Safety: Compartment length (250m vs 772m)





Fire Fighters Life Safety

Fire Fighters Response

Offensive: FB can put out the fire in 60s.
Defensive: FB have to wait for the HRR to lower

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)

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.

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.

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

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/m^2

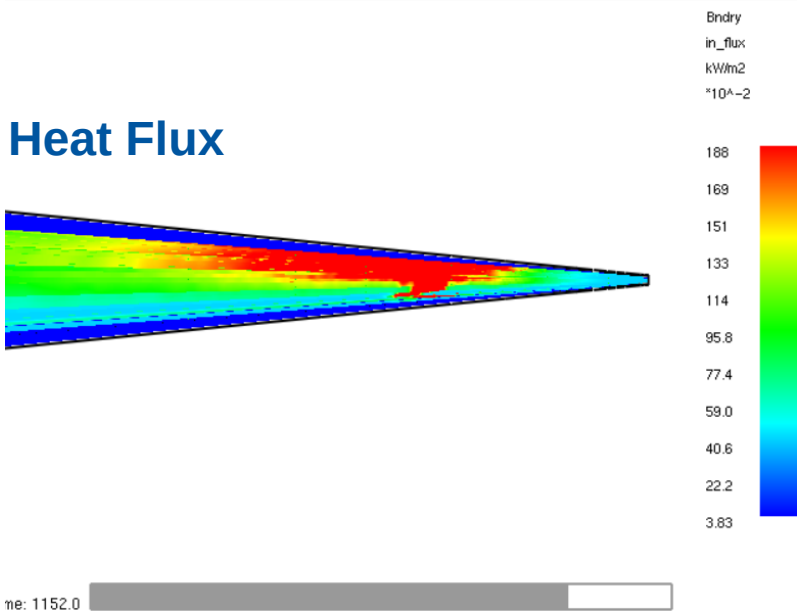
> 80ºC

02: All material and devices that:

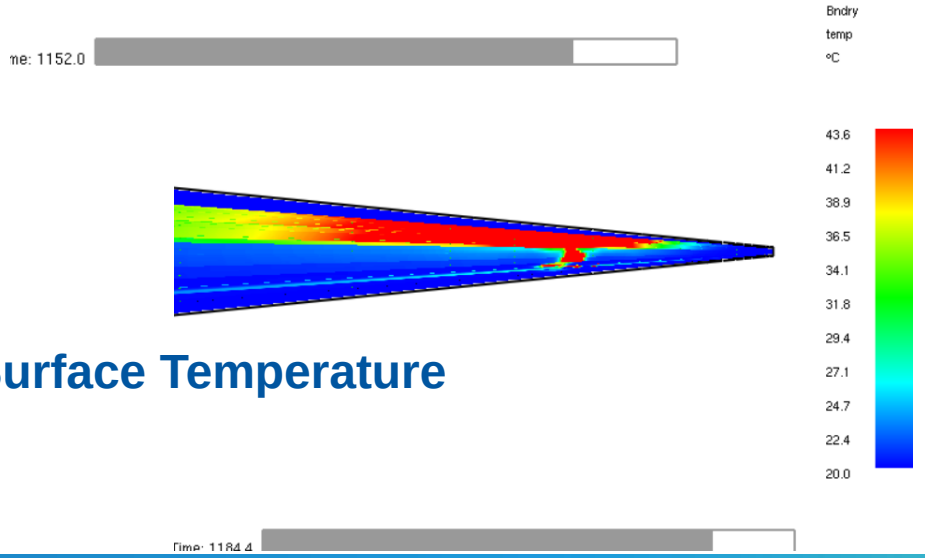
- Undergo a deposition of soot (HCl) larger than:
  - > 100 mg/m^2 [2] (replacement)
  - > 50 mg/m^2 [2] (cleaning)

Impact to property (machine & tunnel)

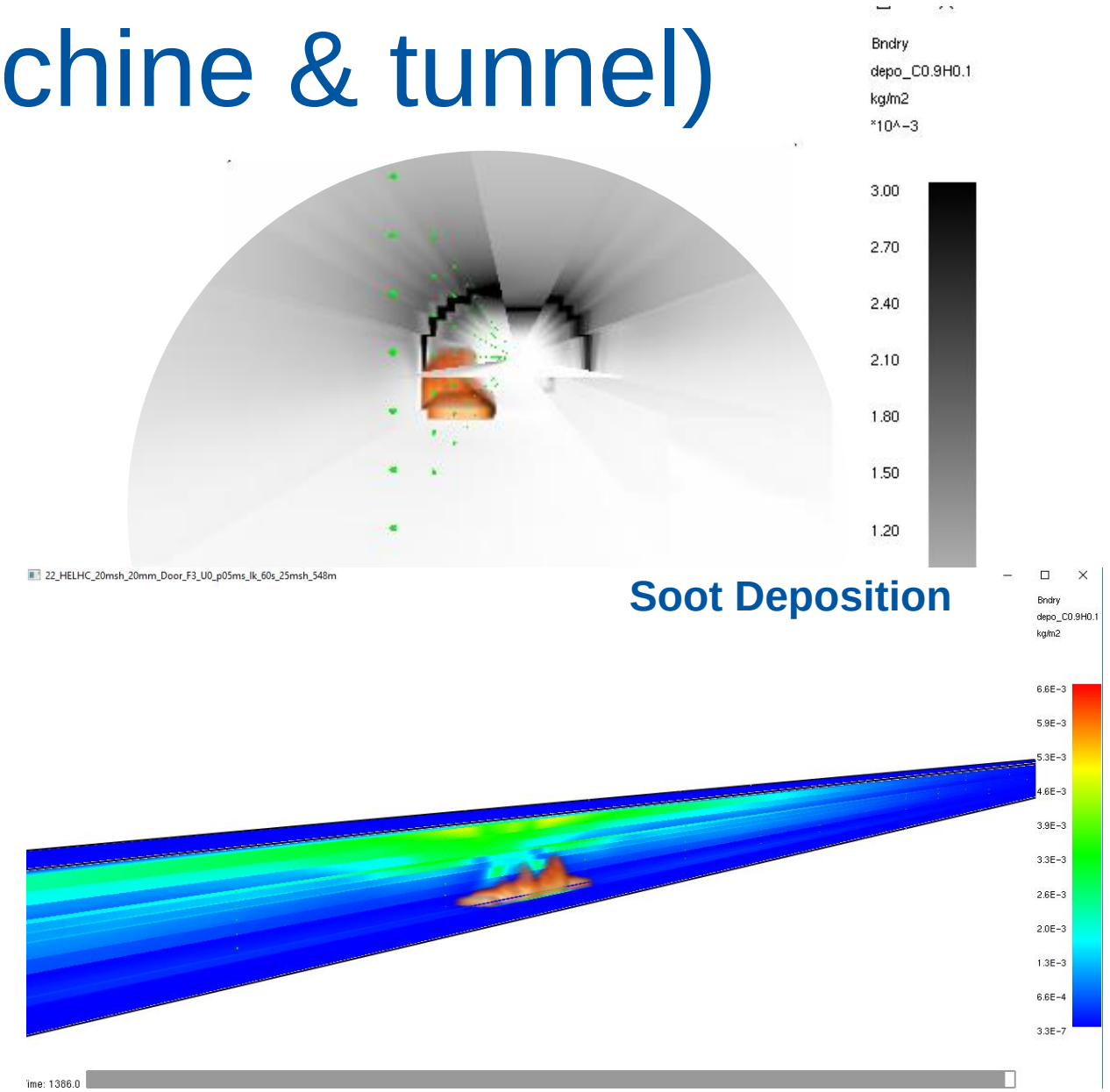
Heat Flux



Surface Temperature



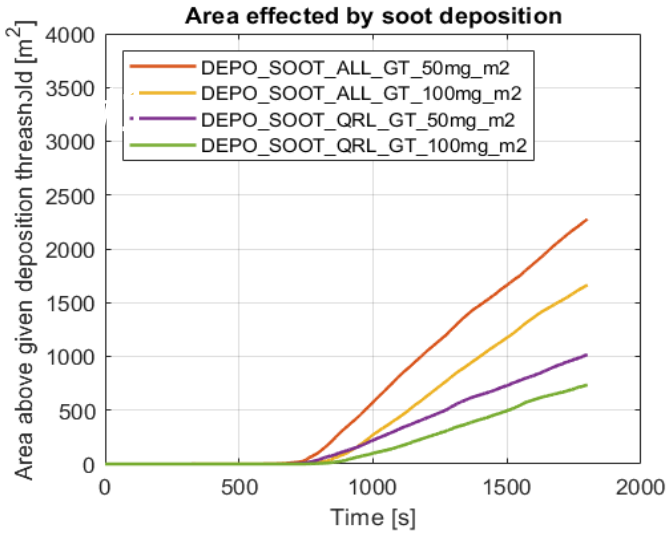
Soot Deposition

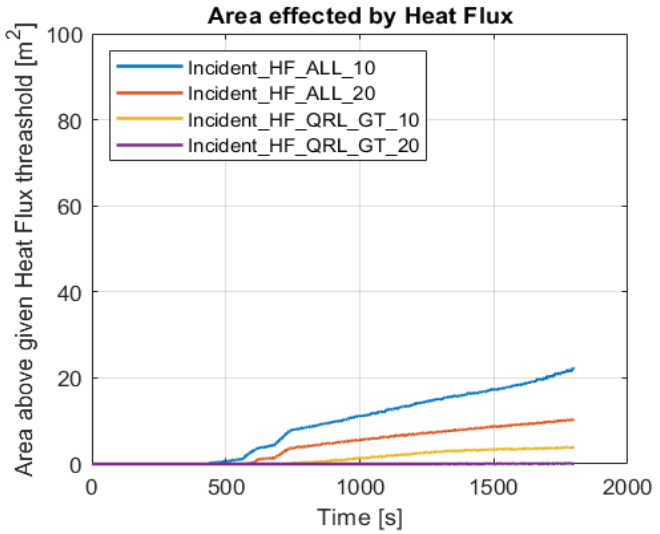


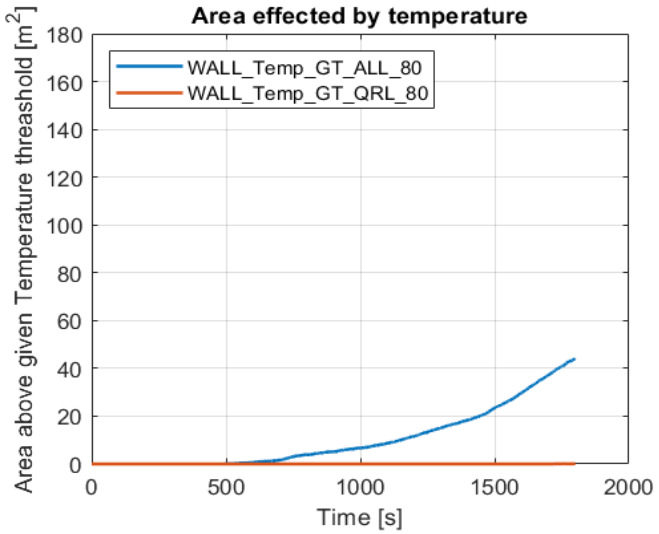
Impact to property (machine & tunnel)

3000m3/h

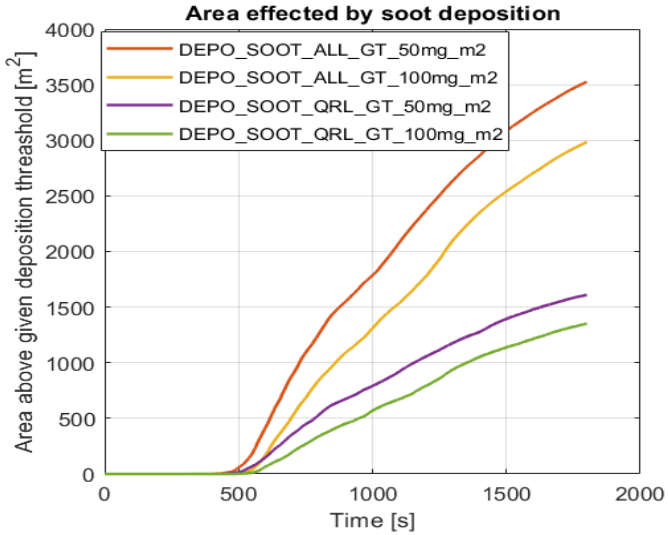
Fire #1

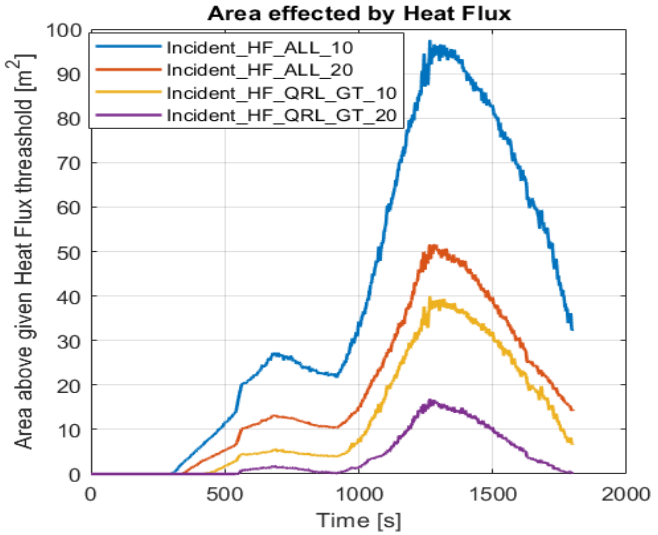


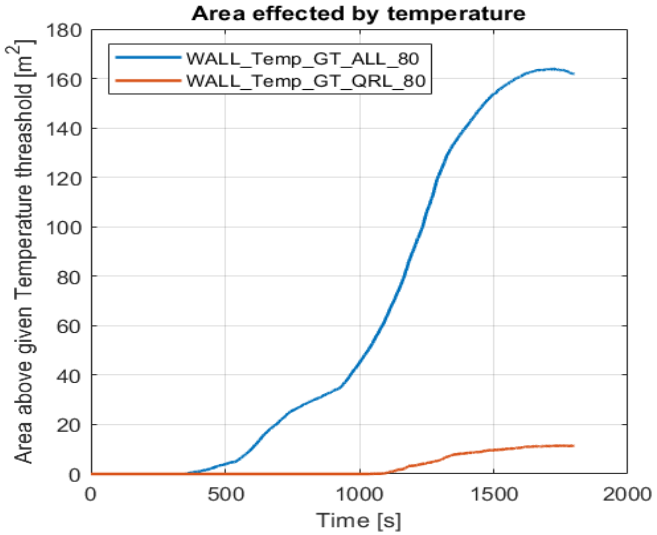




Fire #2(3)



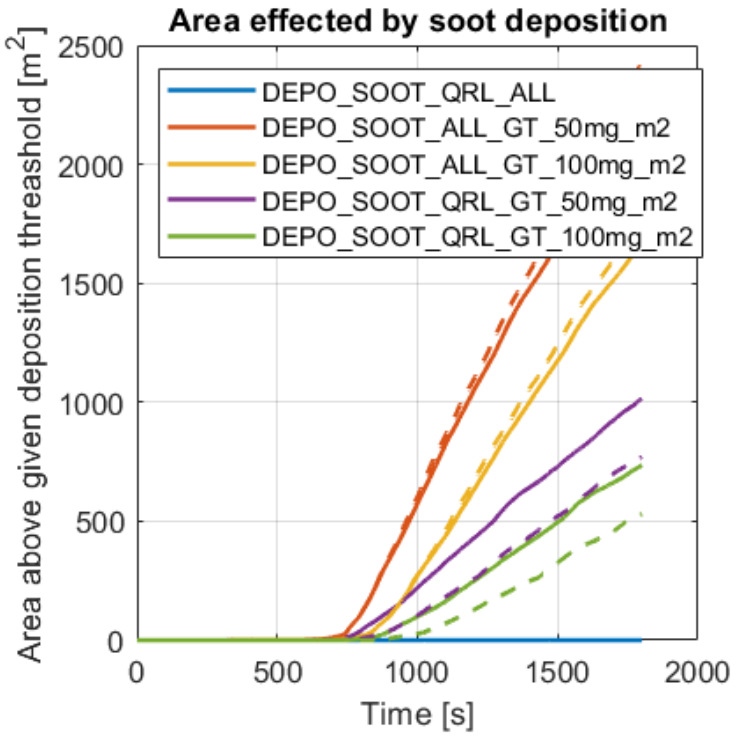


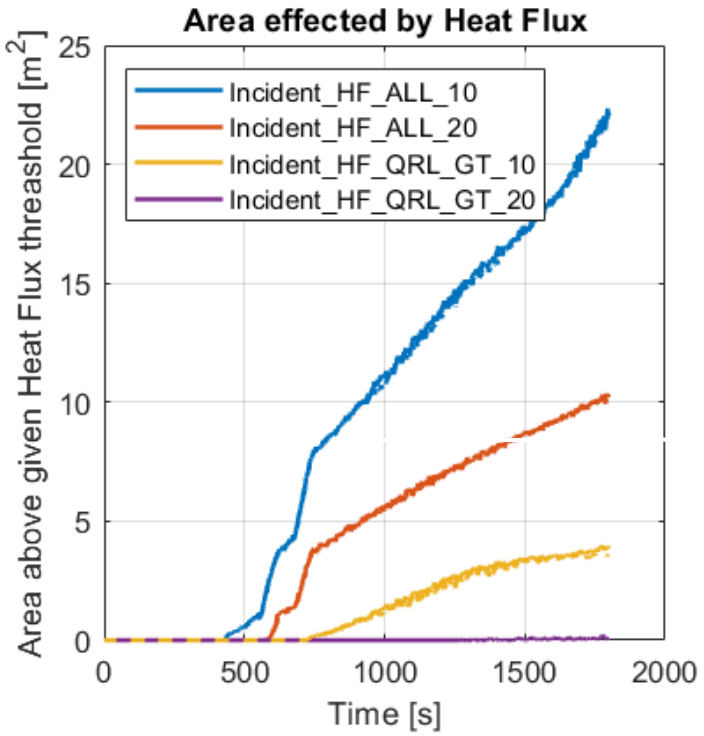


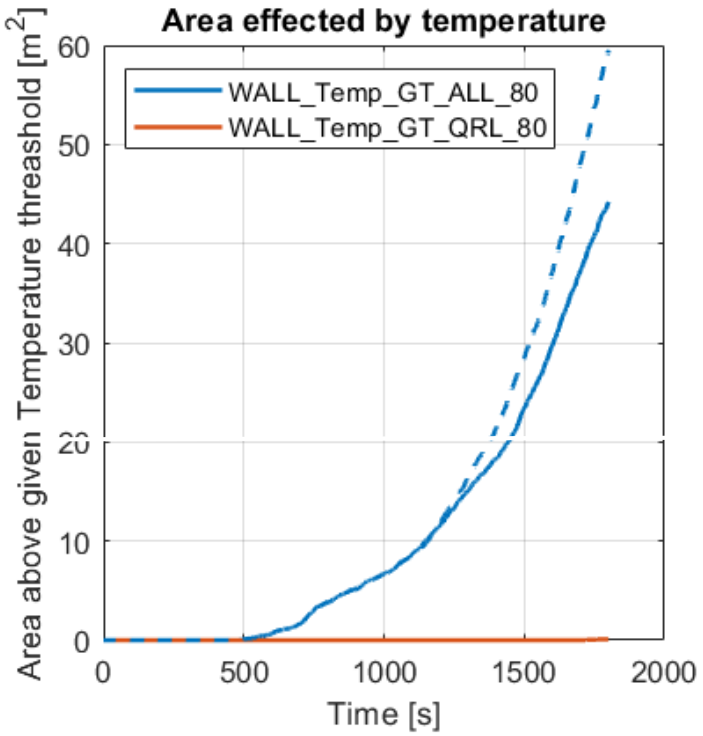
Impact to property (machine & tunnel)

-- 3000 m3/h
- 100 m3/h

Fire #1







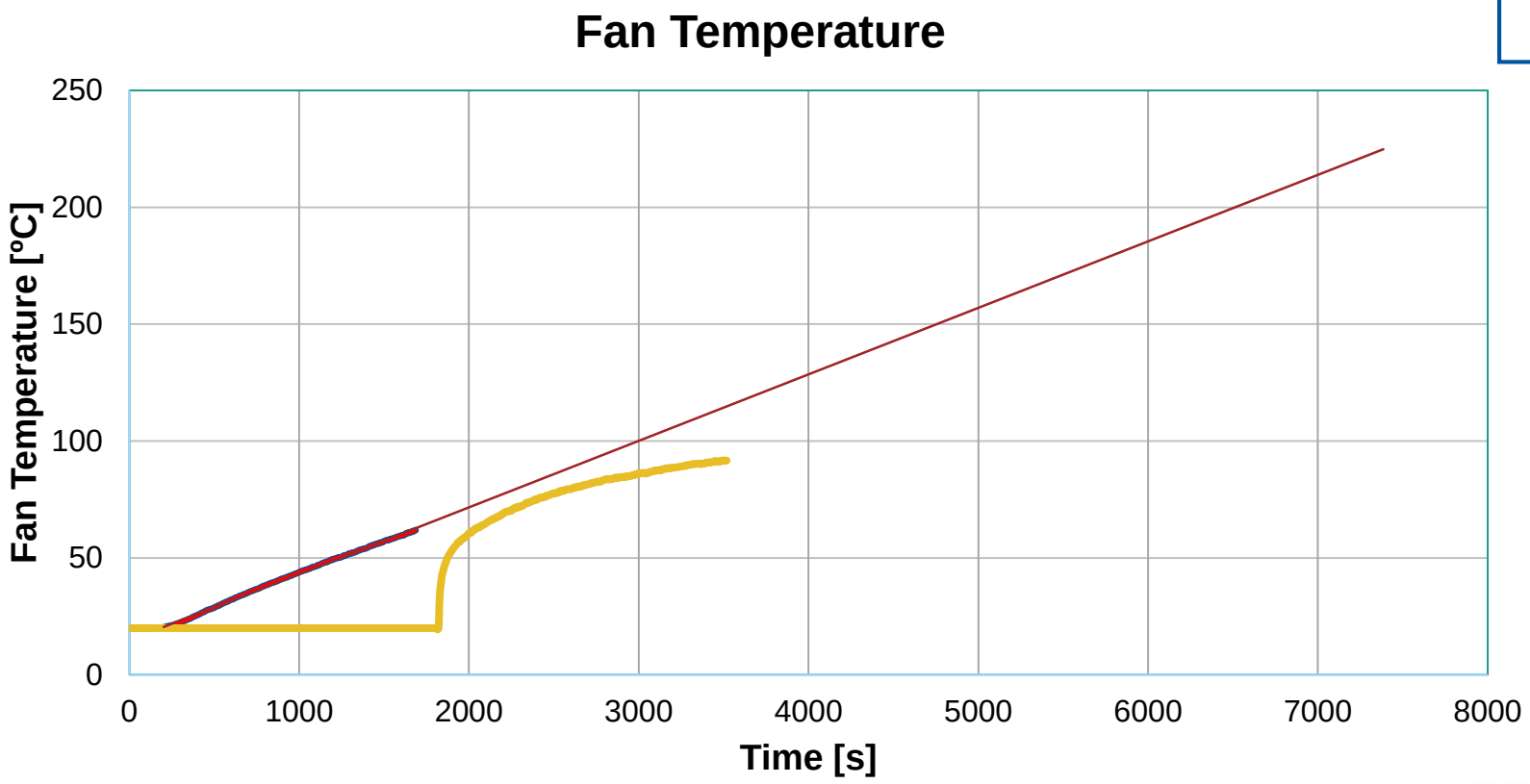
Impact to property (machine & tunnel)

	Tunnels Walls			QRL area		
	Depo >10 µg/m2	HF>20kW/m2	TA>80	Depo >10 µg/m2	HF>20kW/m2	TA>80
Fire 1	1000 m^2 (50 m)	16 m^2	40 m^2	700 m^2	4 m^2	-
Fire 2	1750 m^2 (88 m)	25 m^2	70 m^2	1100 m^2	25 m^2	-
Fire 3	2000 m^2 (100 m)	55 m^2	150 m^2	1500 m^2	40 m^2	11 m^2

Design Optimization

By default:
F600-2h

With the assessment:
F400-2h

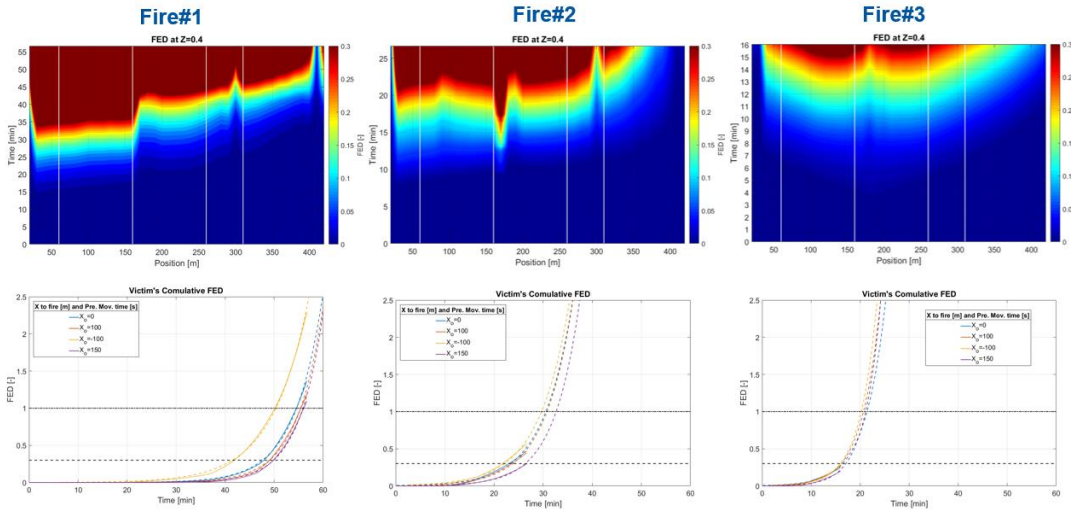


Conclusions

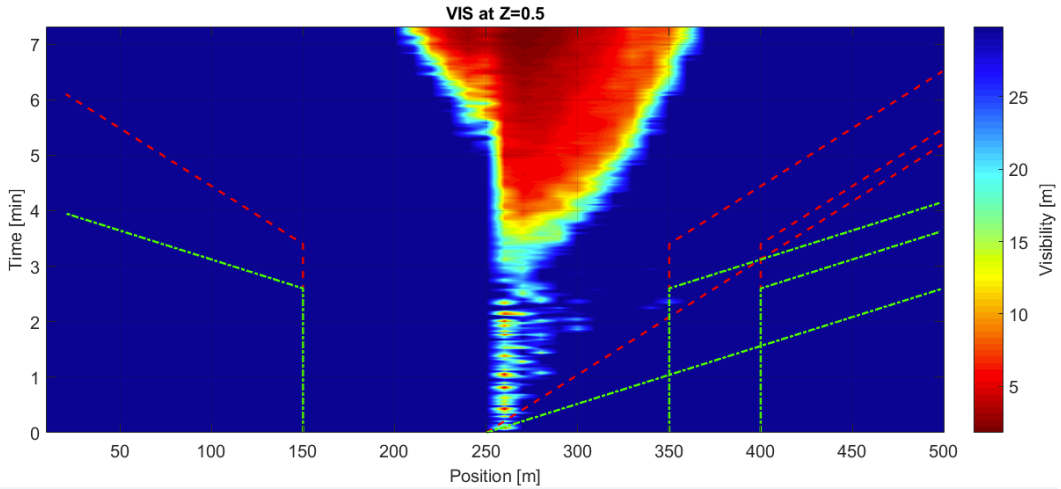
- Life Safety Goal analysed for HE-LHC. **Life safety goals for occupants are reached** with the baseline safety measures
- **Two** different **logics** in the used of the **extraction system** are explored. Extracting 3000m^3/h reduces property damage and increases life safety margin.
- Evaluation of 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

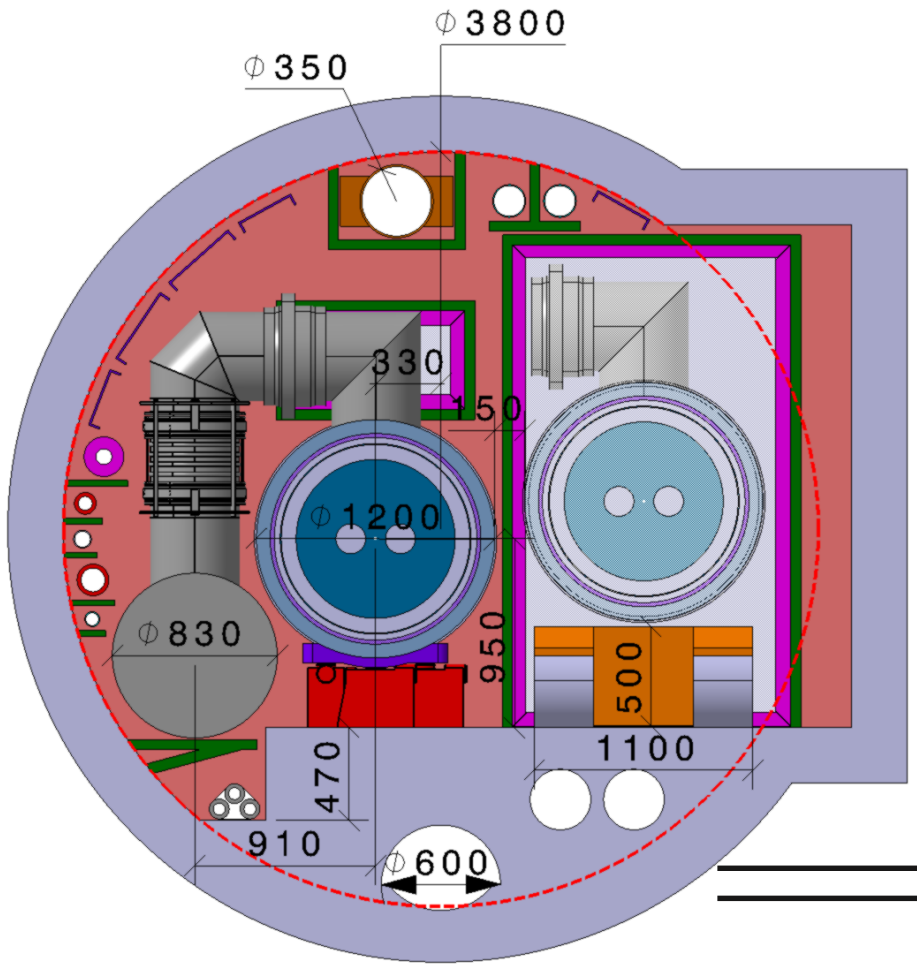


FED assessment on victims
(FF intervention time)



ASET/RSET: Evacuees FED

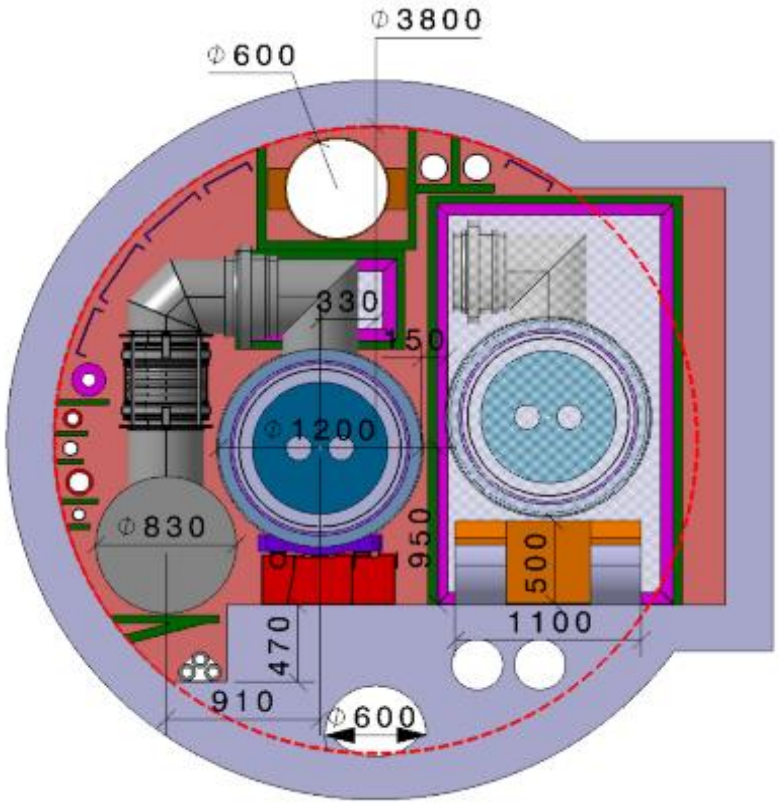
Geometry and safety measures (old)



Baseline Safety Features

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

Geometry and safety measures



Baseline Safety Features

- **Fire compartment** = 4 x cells (137m), 548m
- He-Smoke extraction duct (Ø600)
- Detection in compartments
- Fire extinguishing pipeline on each fire door