
CERN

Fire safety assessment for FCC

PBD study for FCC and HE-LHC

Oriol RIOS, Art ARNALICH, Saverio LA MENDOLA
HSE-OHS-XP

HSE
Occupational Health & Safety
and Environmental Protection Unit

Outline

1. Fire Safety PBD results for FCC Baseline
    - Performance Criteria
    - Scenarios
    - Design Specifications
    - Performance (CFD simulations outputs)
    - Objective Evaluation
2. FCC + sprinklers (impact overview)
3. HE-LHC preliminary Fire Safety assessment
    - Baseline and complementary hypothesis
    - Safety Objective Evaluation
4. Overall Conclusions and outlook

Process conducted with FCC PBD Working Group

PBD process:

→ *Berlin Baseline*

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

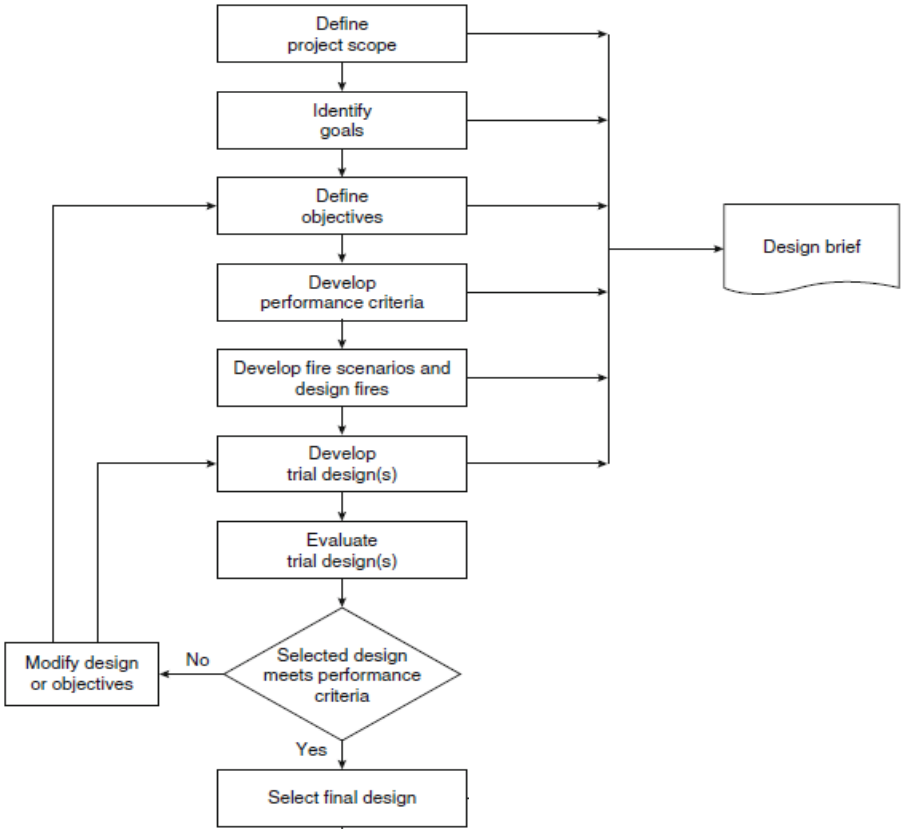
Technical assessment **reviewed** by **FCC fire collaboration** members during the Fermilab FCC Fire Workshop 7-9th November 2017.

Reviewers: Fire safety experts from:

Fermilab, ESS European Spallation Source, Lund University, DESY (awaiting)

Additional peer reviewer:

Brookhaven National Laboratory



Safety Objectives

Radioalogical 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

Life Safety

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*

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

02 Any victim **outside the fire compartment** of the seat of the fire has *reasonable opportunity* of **not reaching a FED>0.1** before being rescued by intervention teams

03 Within the fire compartment of the seat of the fire, any of the two following criteria is met:

03a Fire compartment size and layout is such that there is a *reasonable opportunity* of **not having a victim in the interior**

03b Any victim has a *reasonable opportunity* of **not reaching a FED>0.3** before being rescued by intervention teams

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

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

07 Structural stability of the premises during operations

Acceptance Criteria → SPEC

- **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

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

Acceptance Criteria → SPEC

- **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

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 [illegible] for attack and search & rescue teams **matches fire development**, allowing firefighter protection and fire control under 3 minutes.

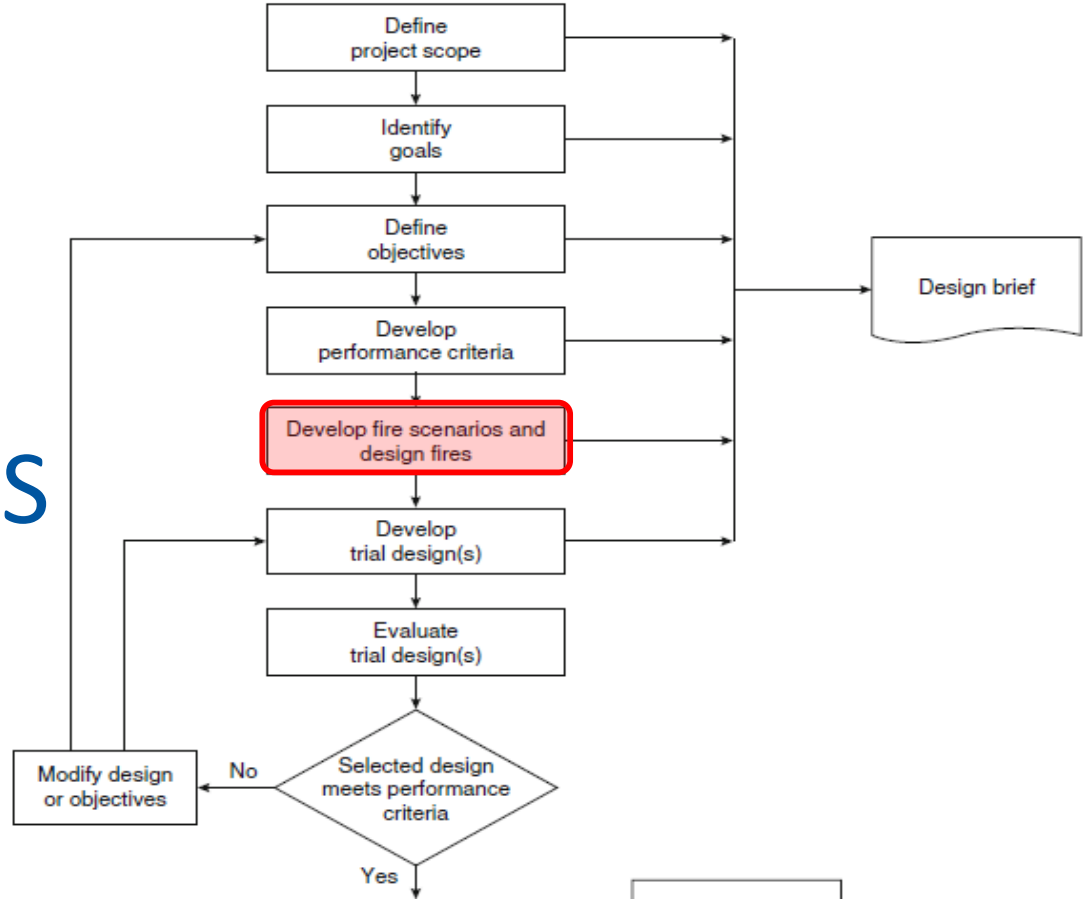
06 DESIGN SPECIFICATION [illegible] engaged teams remain in **communication** with surface incident command post.

07 DESIGN SPECIFICATION **Structural stability** of the premises during operations

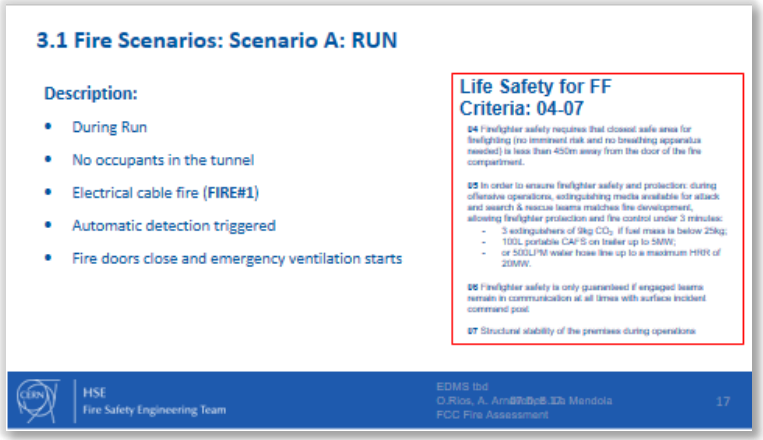
These **DESIGN SPECIFICATIONS** only account for firefighter safety.

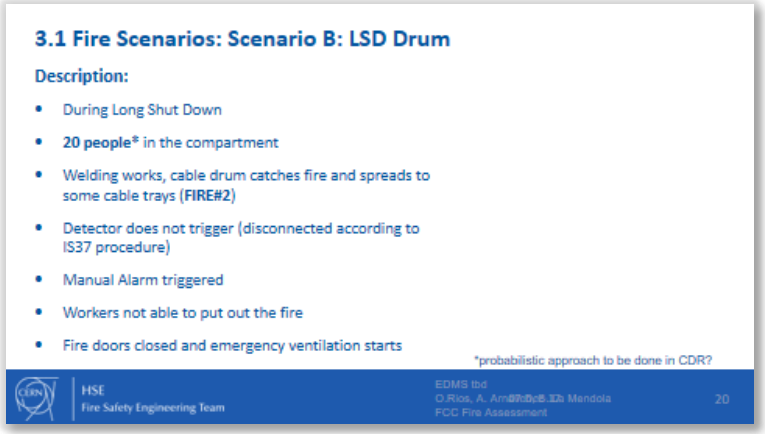
Fire intervention outcome and effectiveness is accounted in property and continuity of operations safety objectives.

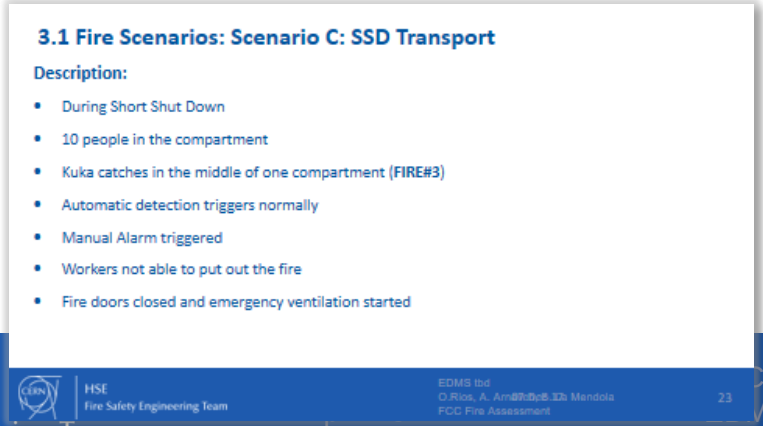
PBD process: FIRE SCENARIOS



Scenarios

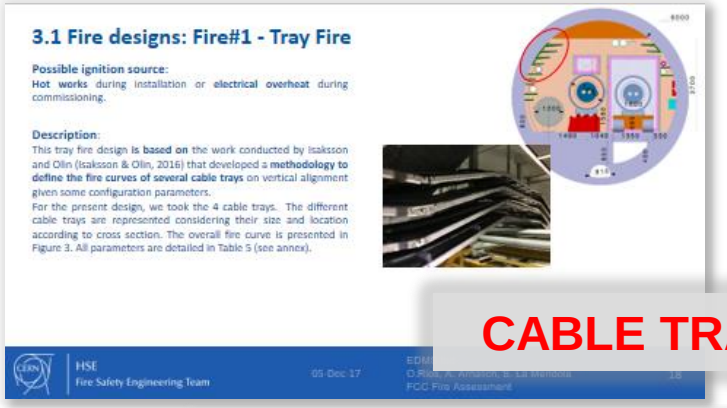






A probabilistic approach might be considered for the TDR

Fire Designs



CABLE TRAY

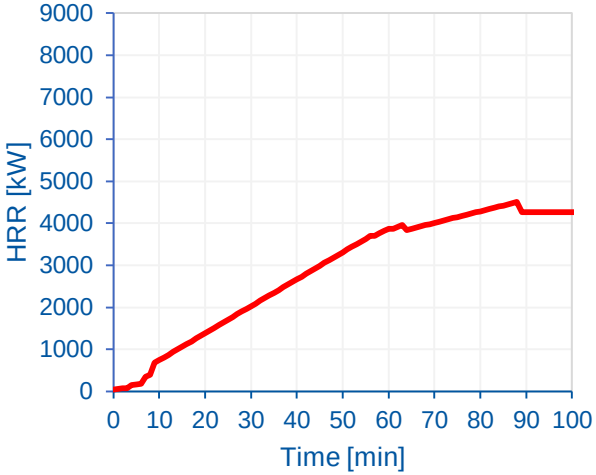
DRUM

KUKA

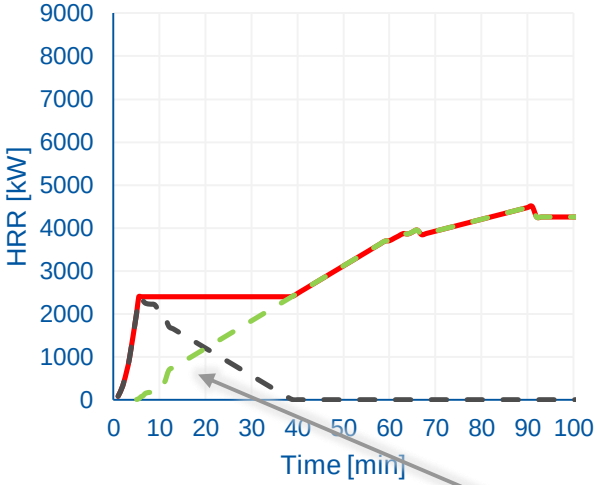
- Those 3 scenarios are considered to be more representatives ones
- Only fire scenarios are considered.
- Fire Scenarios resulting from explosions are not accounted for.

3.1 Fire designs: Enveloping cases

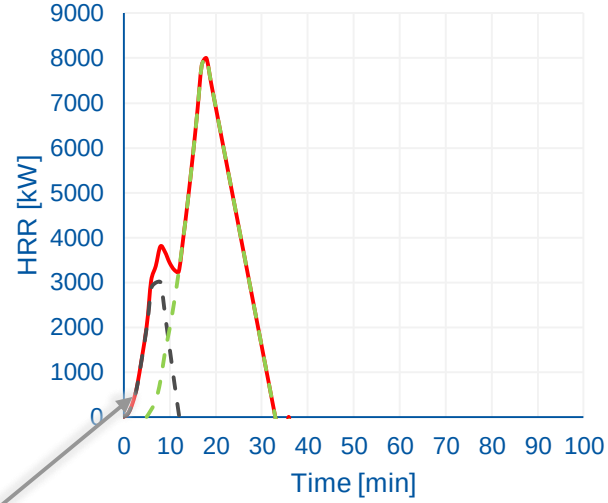
Fire#1 - Tray Fire



Fire#2 – Drum Fire



Fire#3 - Kuka Fire

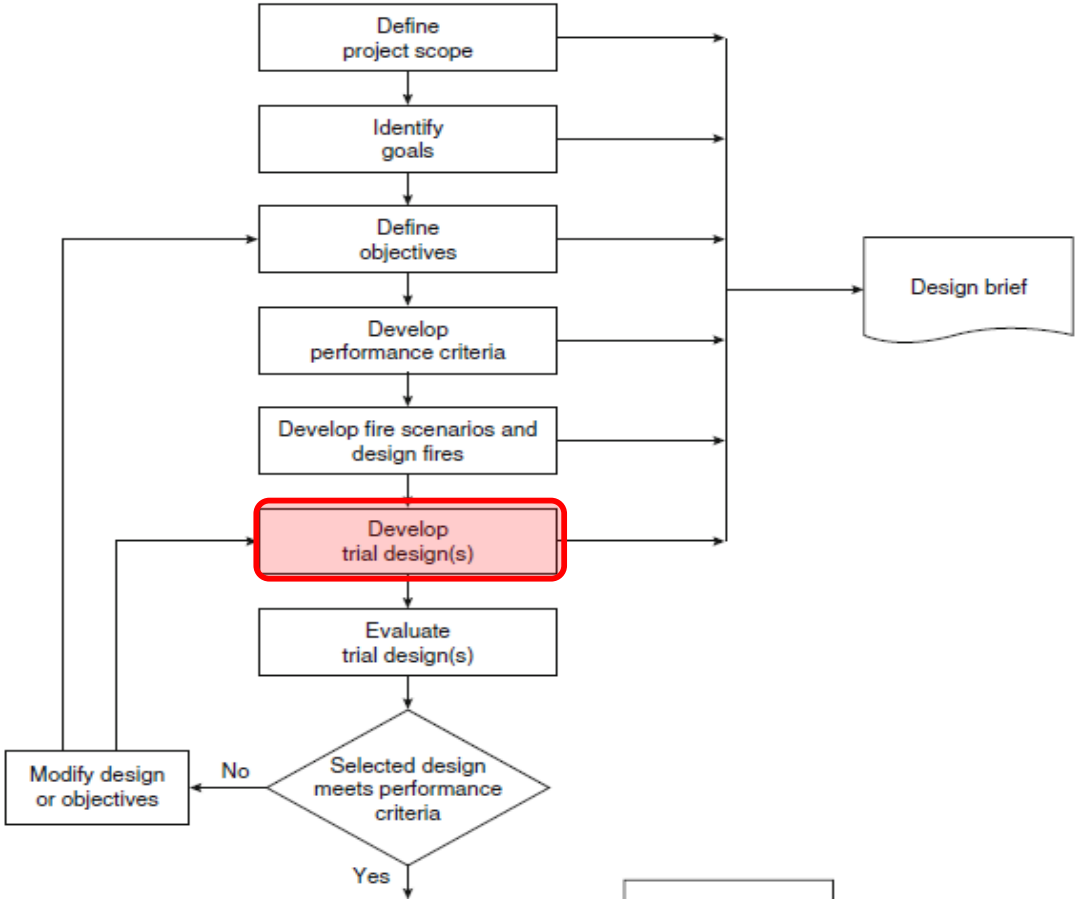


If compartmentation works, with current ventilation system
HRR_{max} < 5MW (ventilation limited)

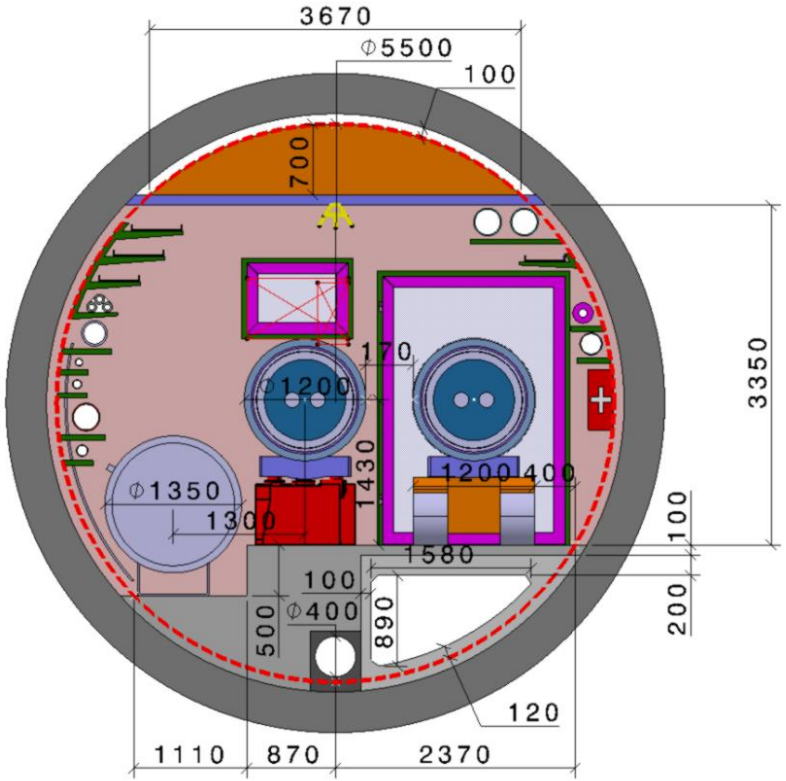
Fire#2 and Fire#3 have same growth up to 8min!

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 = 440m
- Smoke extraction
- Air supply
- TIM (or equivalent)

3.1.1 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	**510s** after the fire starts (sensors in the alcoves)	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***

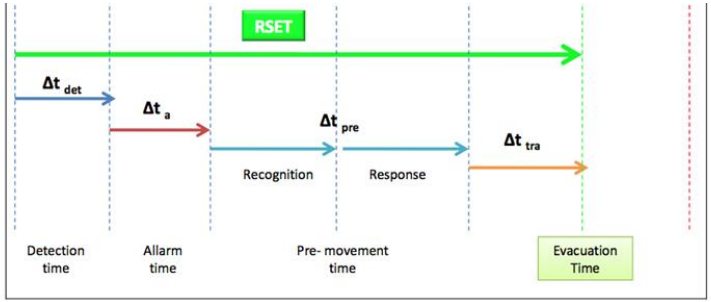
HYBRID SYSTEM

Assumed SPEC t_{det}= 120s

*Desy (FCC Col)
Yacine Kadi EN-EA

3.2 Fire Scenarios. Human Behaviour

Courtesy G. Lindell

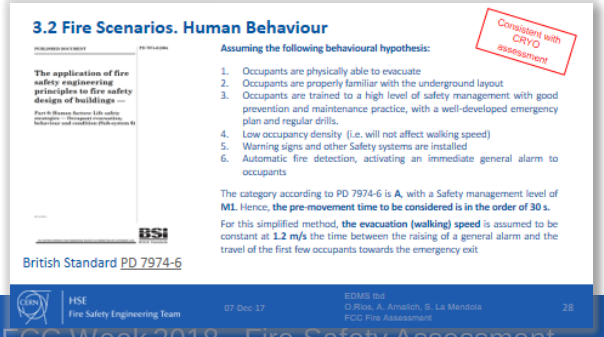


For all scenarios with presence of people we consider occupants to be in 4 different location w.r.t fire site.

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

Last man out

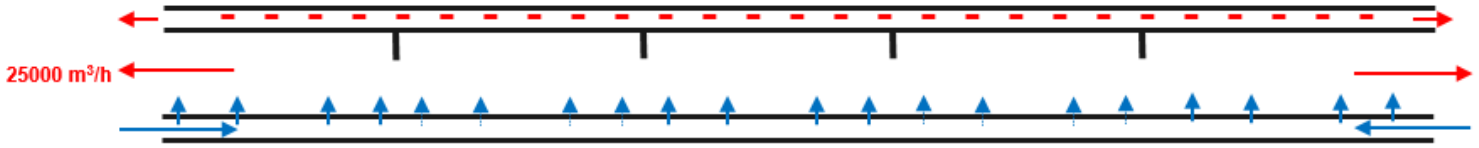
Time [s]	Δt_{det}	Δt_a	Δt_{pre}	Δt_{tra_door}
All Cases	120	0	30	$\frac{x}{1.2}$



Ventilation: Proposed Strategy

Developed with EN/CV
+Info see talk: G. Peon and M. Nonis. Wed 11th 13.30-15.30

Normal Ventilation Condition



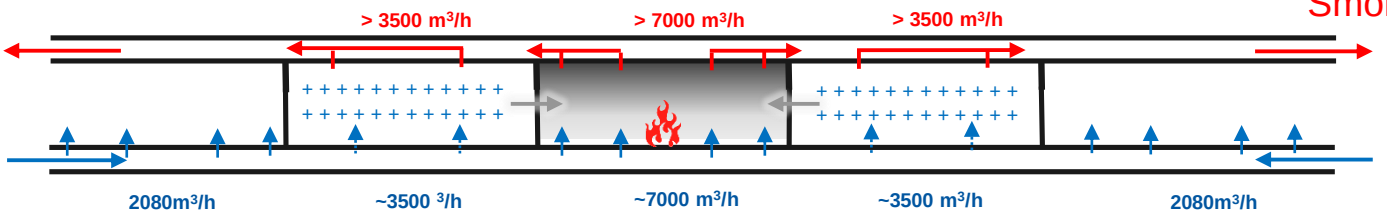
Uo=~ 0.5

Ventilation: Proposed Strategy

Developed with EN/CV
+Info see talk: G. Peon and M. Nonis. Wed 11th 13.30-15.30

When Fire is detected in a compartment

Smoke Exhaust: 14k m^3/h



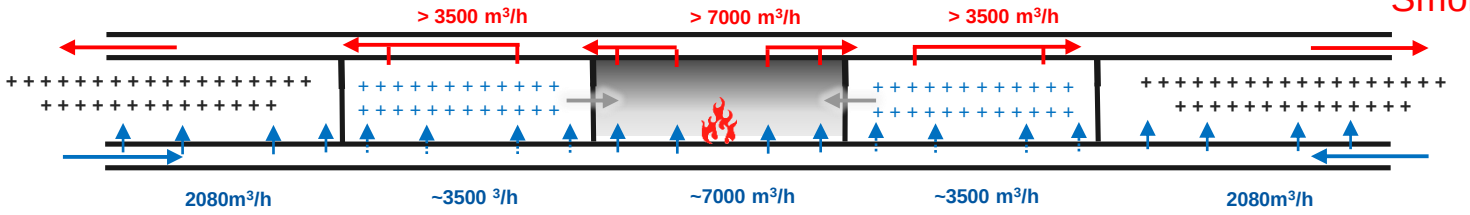
- 3 compartment doors closes (fire compartment and neighbours)
- Air inlets remain as normal condition.
- All arc outlets close, except for:
  - 4 in the fire compartment
  - 2 in adjacent compartments
- Exhaust duct extracts total flow of **14000m^3/h (~1/3 of nominal fans power)**
- **Overpressure** created in neighbouring compartments
- Normal longitudinal ventilation in all other compartments (or not, not influence)
- Fast reaction. Only action dampers in the fire compartment. Duct under pressured.

If fire spreads: Repeat the logic

Degraded scenario to be studied in TDR

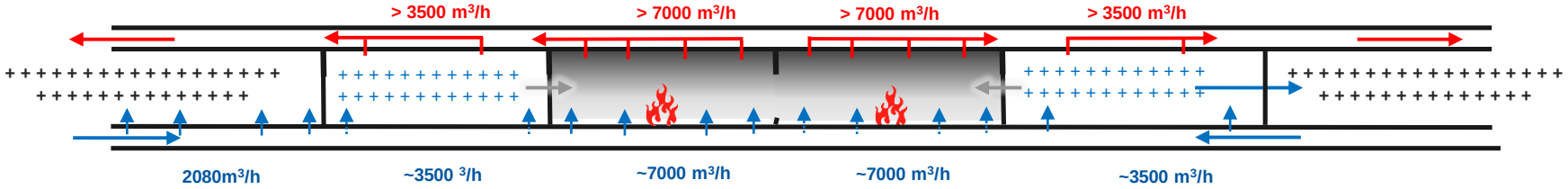
When Fire is detected in a compartment

Smoke Exhaust: 14k m^3/h

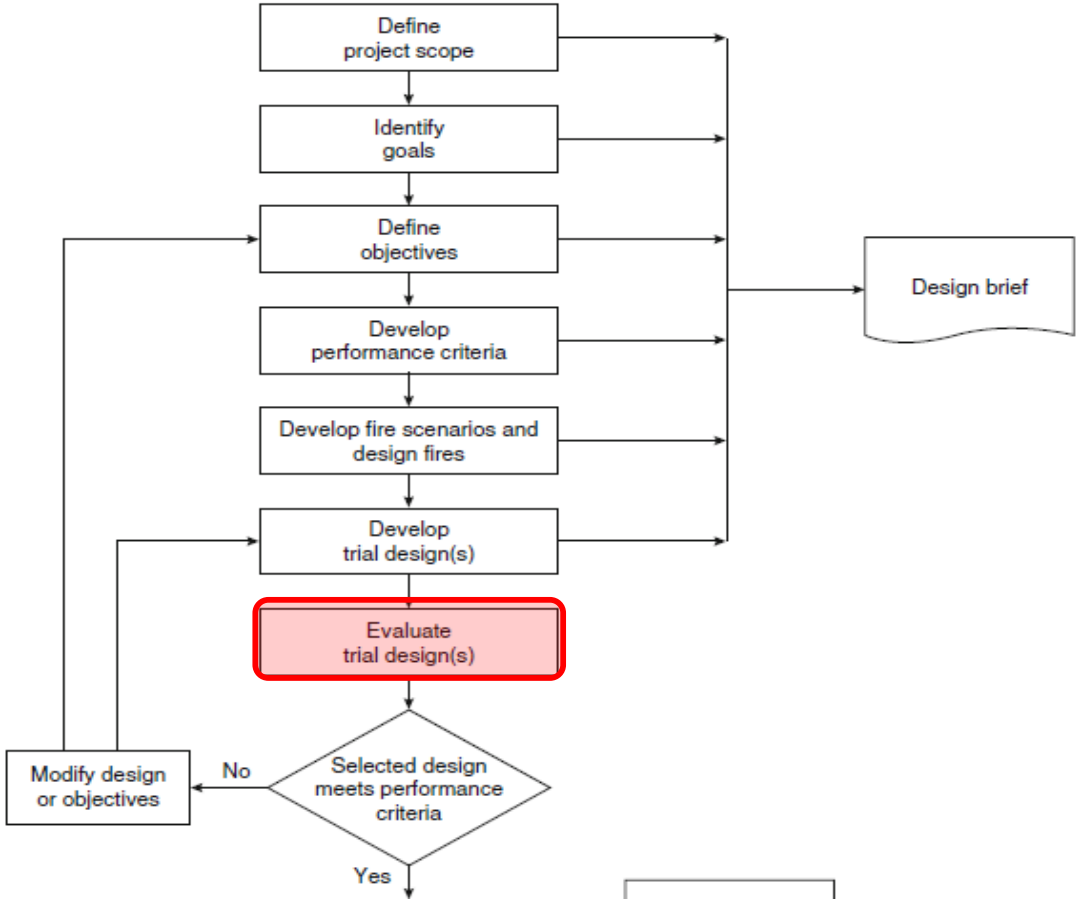


If Fire is detected in a adjacent compartment too

Smoke Exhaust: 21k m^3/h



PBD process: EVALUATE TRIAL DESIGN



Tools used and developed

- 1D Toxicity Model Developed in cooperation with Lund University. (see EDMS: 1843123 v.1 in FCC-INF-TE-0015 v.1, 1853869 v.1)

FCC Fire Safety Collaboration

Fermilab · ESS European Spallation Source · Lund University · DESY · MAX IV

- Fire Response Probabilistic Analysis Model (FRPAM) Developed by CERN-FSE team. See (EDMS: 1849846 v.1)

FCC Fire Safety Collaboration

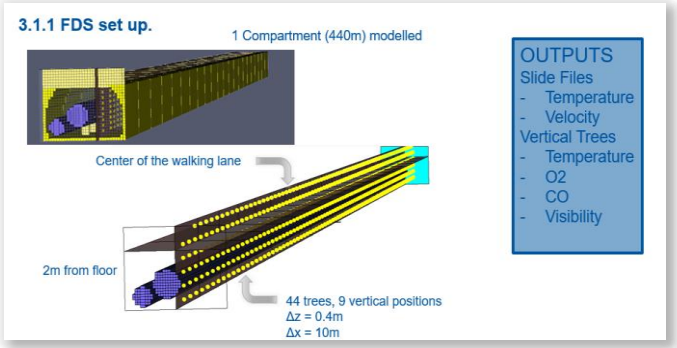
- Fire Dynamics Simulator-FDS (CFD tool developed by NIST fire research, 1853876 v.1)

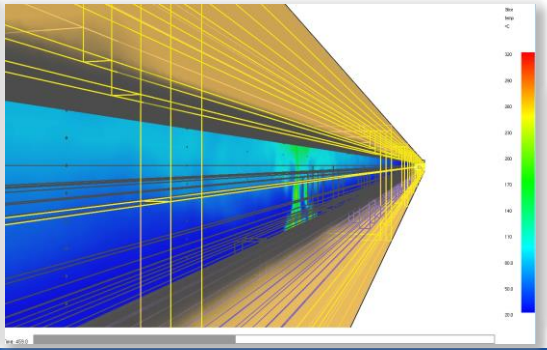
computational time required to evaluate solutions, particularly FDS

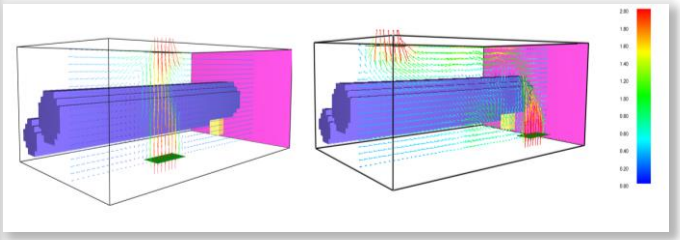
HPC-batch cluster ~1200 cores

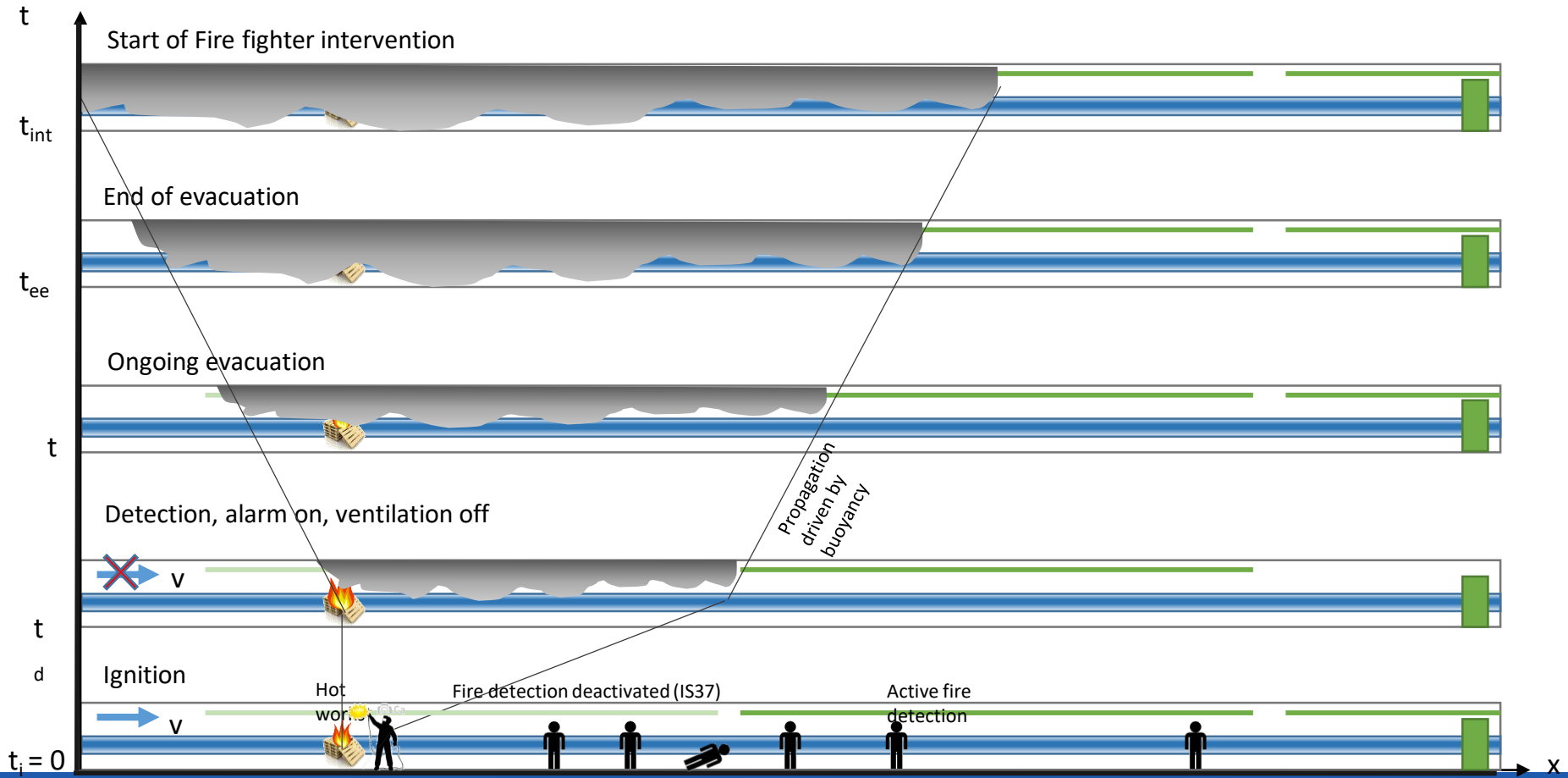
- Virtual Reality Experiments for Evacuation Safety Measures

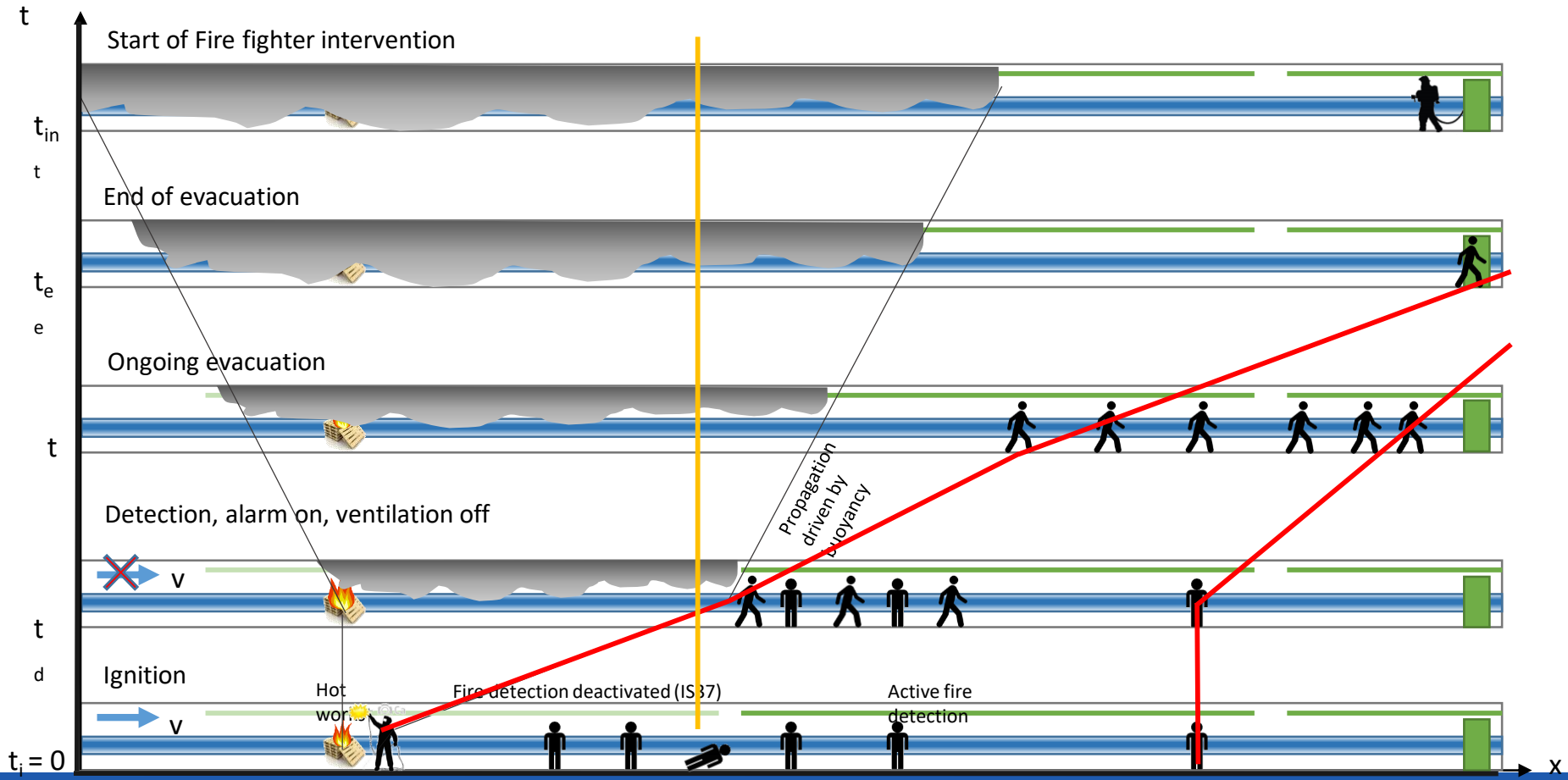
Following talk: S. Arias

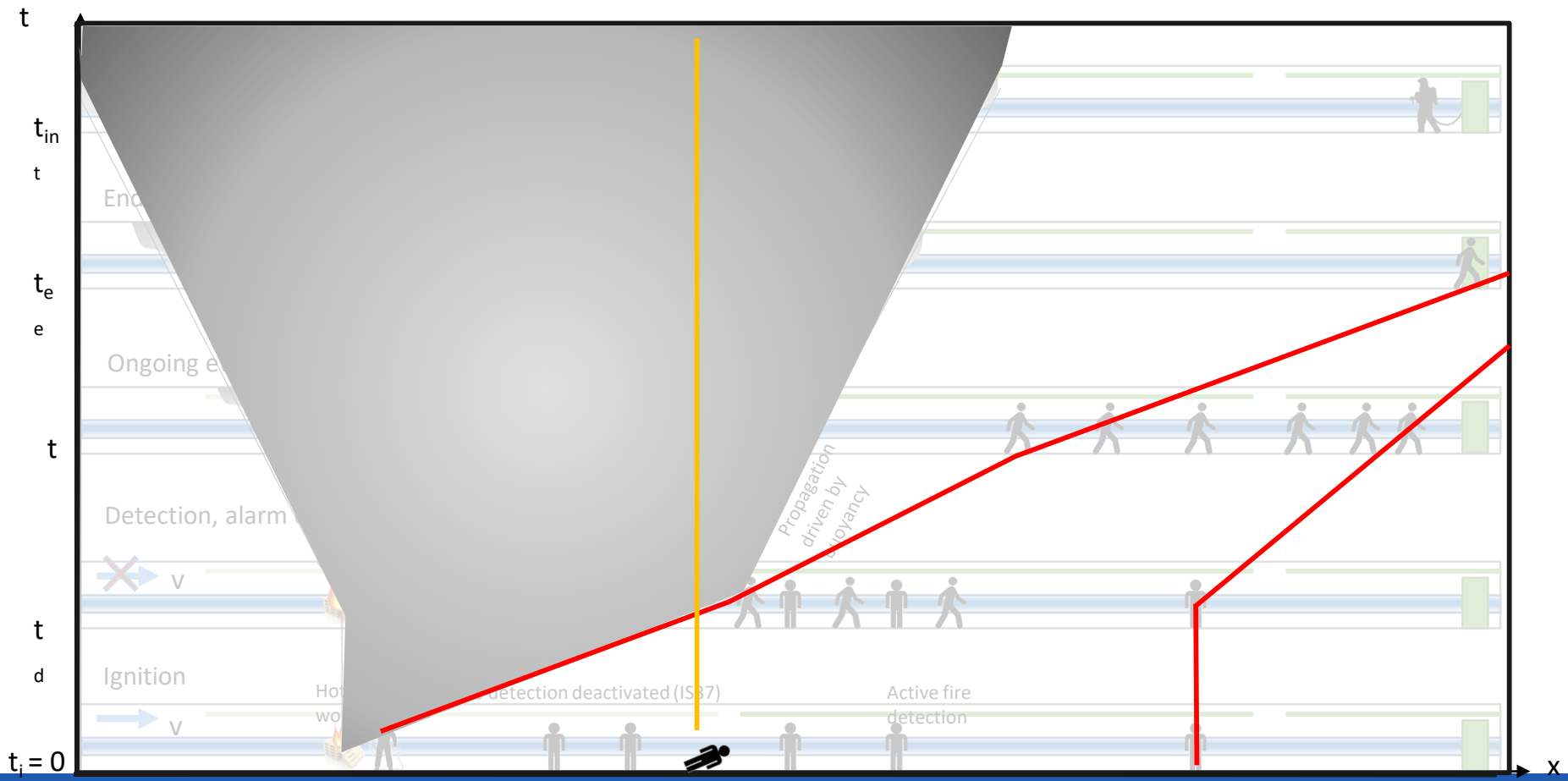




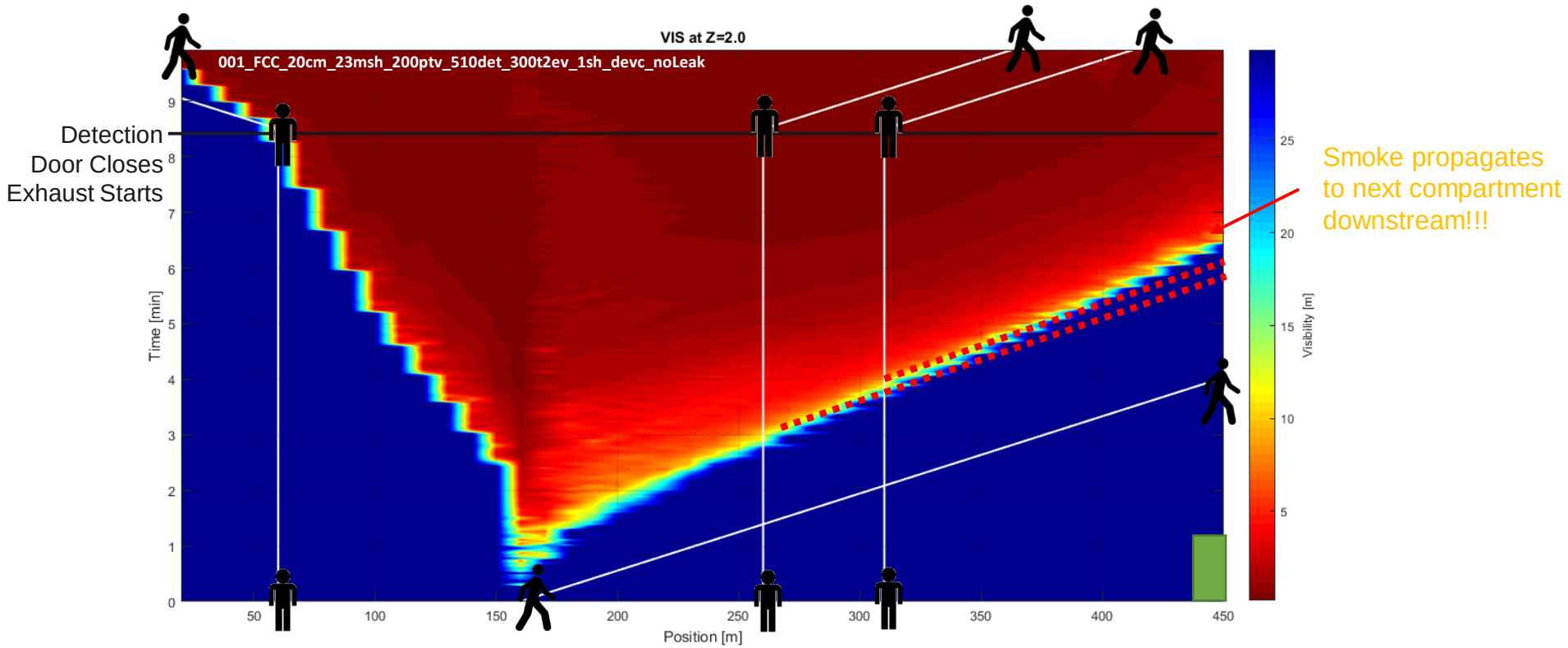



t
Start of Fire fighter intervention
t_{int}
End of evacuation
t_{ee}
Ongoing evacuation
t
Detection, alarm on, ventilation off
v
t
d
Ignition
v
$t_i = 0$
Hot
Fire detection deactivated (IS37)
Active fire
detection
Propagation
driven by
buoyancy
x

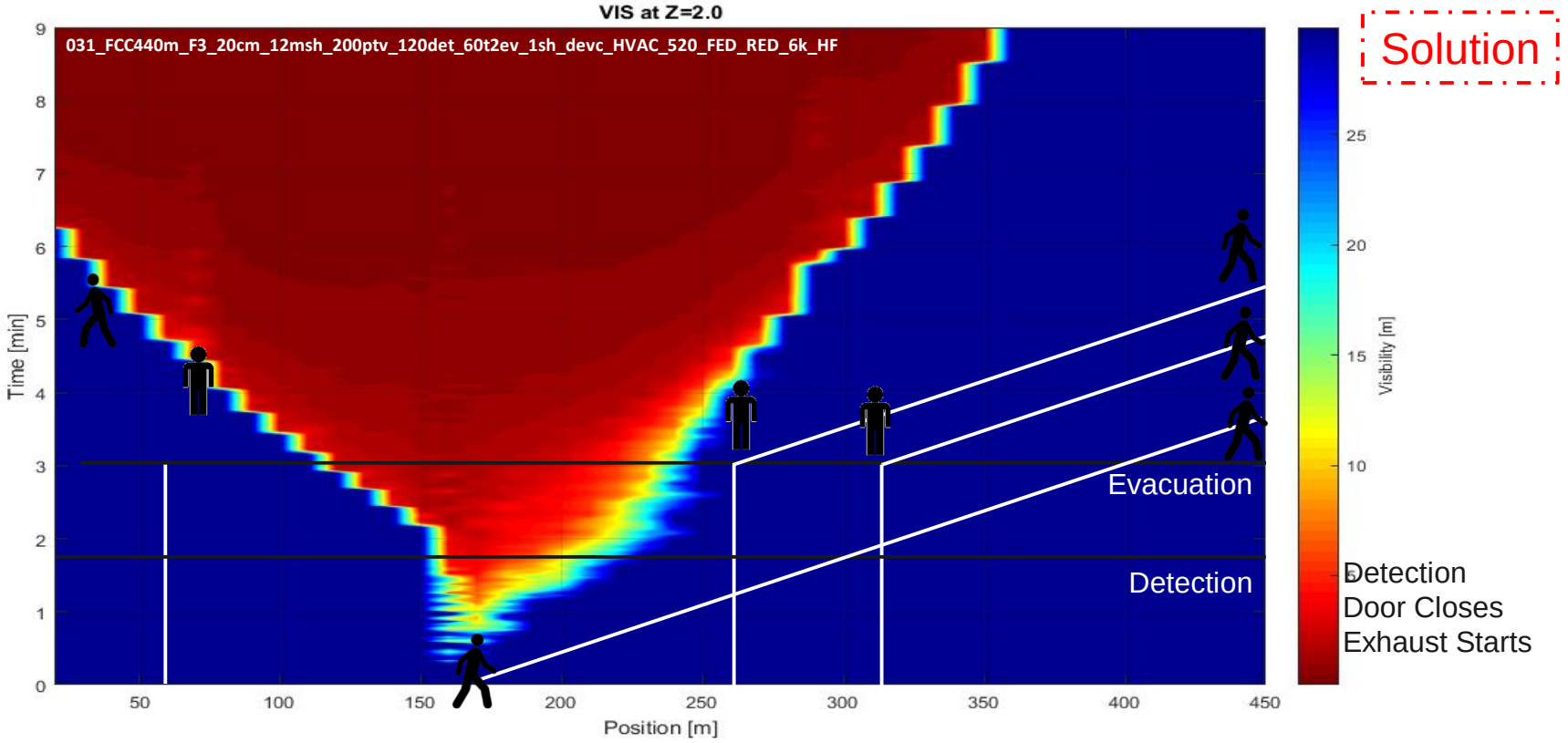

t
Start of Fire fighter intervention
t_{in}
t
End of evacuation
t_e
e
Ongoing evacuation
t
Detection, alarm on, ventilation off
v
t
d
Ignition
v
$t_i = 0$
Hot
Fire detection deactivated (IS 37)
Active fire
detection
Propagation
driven by
buoyancy
x


t
t_{in}
t
t_e
e
t
t
d
$t_i = 0$
x
Ongoing e
Detection, alarm
v
Ignition
v
detection deactivated (IS37)
Active fire
detection
Propagation
driven by
buoyancy

Berlin Baseline. Det. 510s. No supply. Emergency extraction 300s to ramp up. FIRE#2 and FIRE#3

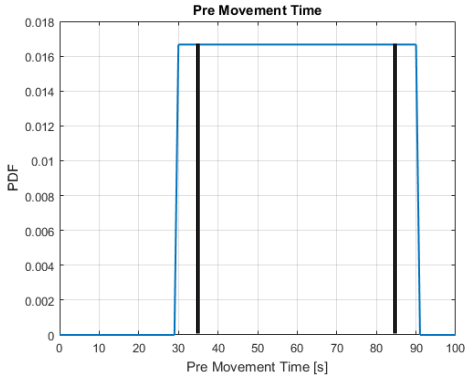


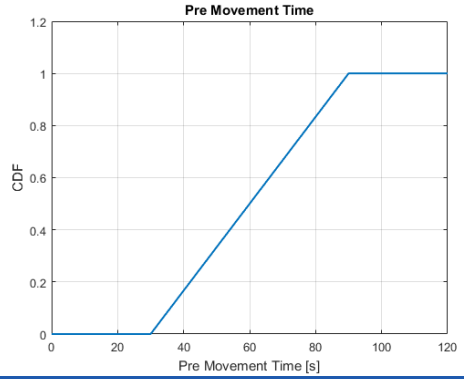
Improved Design: Detection 120s. 7000m³/h per compartment. Extraction 60s to ramp up. FIRE#3



Evacuation. Uncertainty calculations

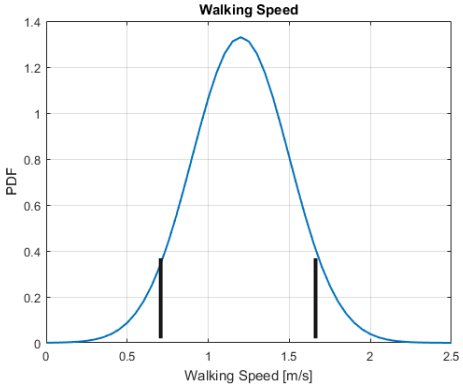
Pre Movement. Uniform([30,90])

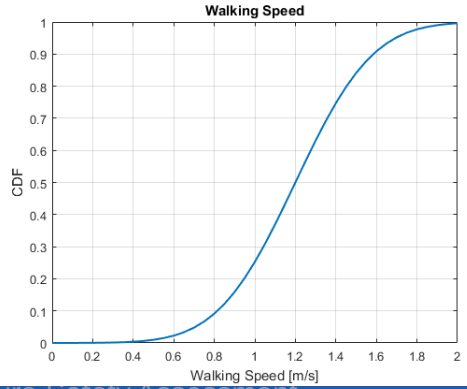




10^{th} percentile = 36 s
90^{th} percentile = 84 s

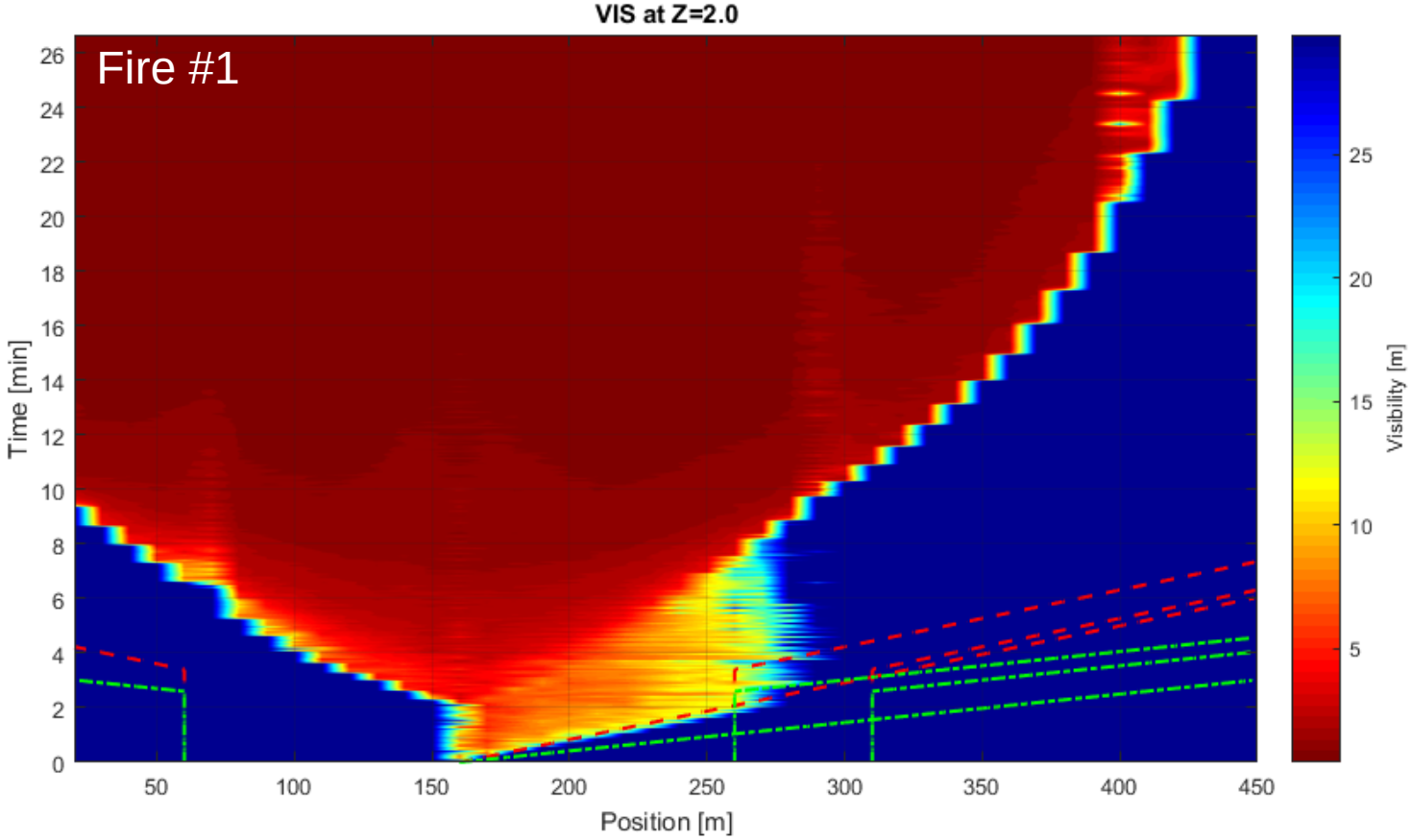
Walking Speed. Normal([1.2,0.3])





10^{th} percentile = 0.8 m/s
90^{th} percentile = 1.6 m/s

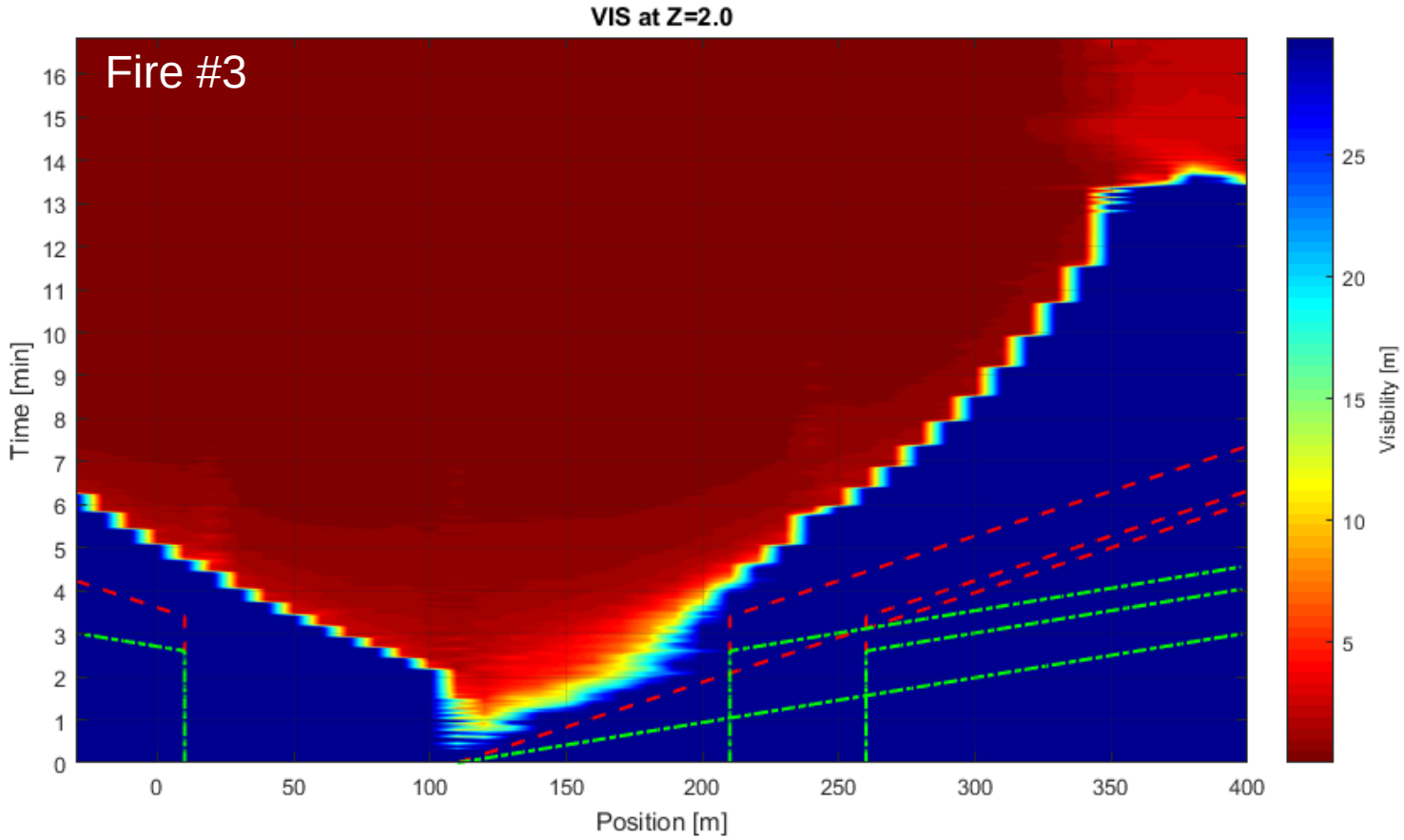
Evacuation. Uncertainty calculations. Fire#1 VS Fire#2(3)



10th percentile
→120+84s, 0.8m/s

90th percentile
→120+36s, 1.6m/s

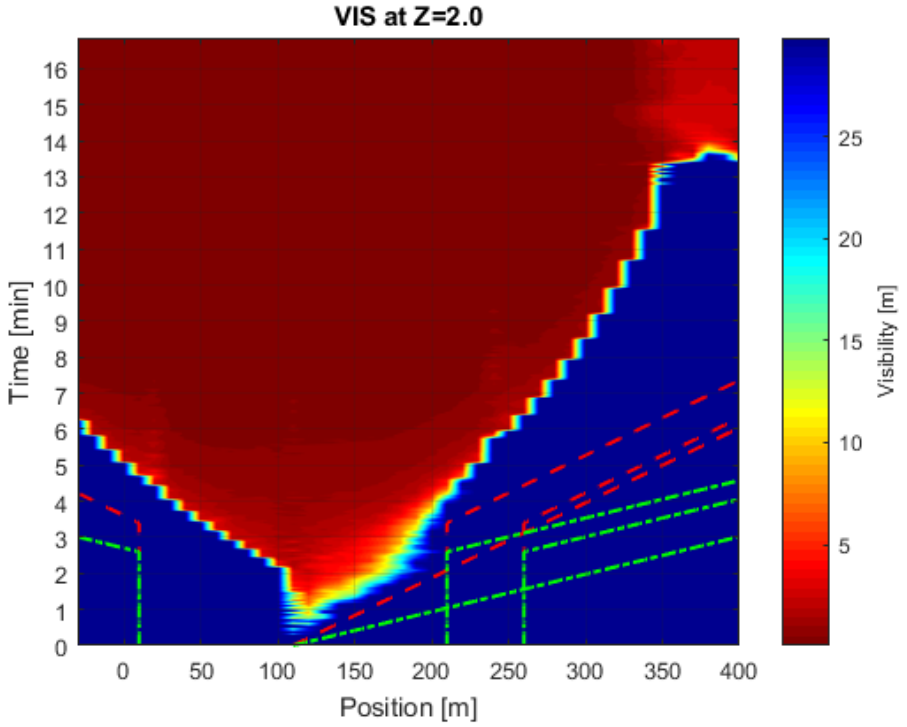
Evacuation. Uncertainty calculations. Fire#1 VS Fire#2(3)

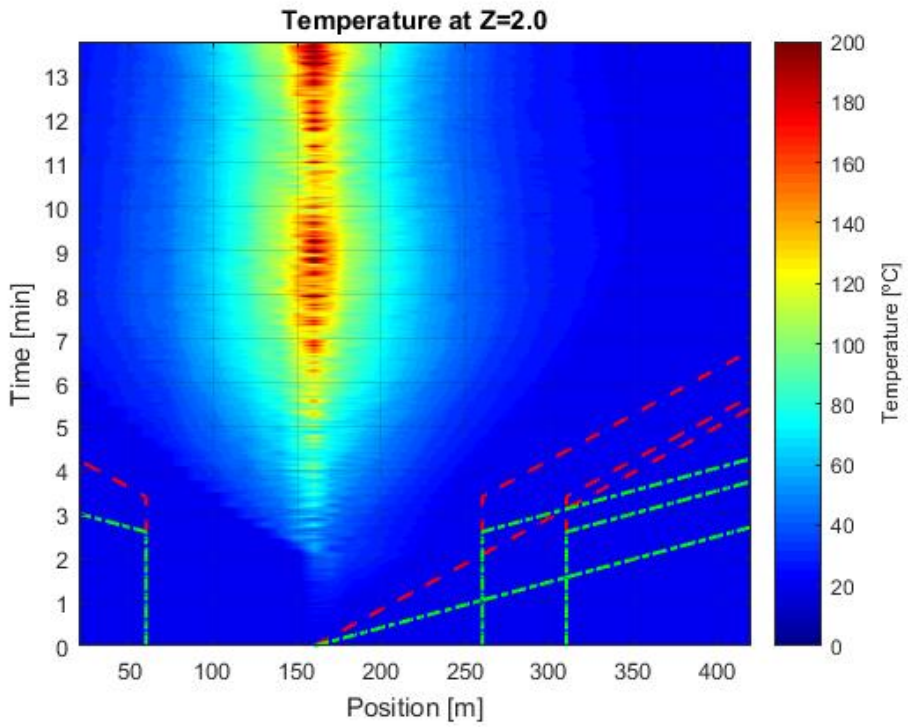


10th percentile
→120+84s, 0.8m/s

90th percentile
→120+36s, 1.6m/s

Temperature Fire#3





Environment Protection
(in case of fire)

Safety Objectives

	Environment
	B
1	Limit the release of polluting (incl. activated) agents to the environment in case of incident
2	Limit the volume of polluted (incl. activated) water released to the environment in case of incidents
3	-

Acceptance Criteria → SPEC

01 DESIGN SPECIFICATION Fire Fighting water and water based extinguishing agents shall only be released under controlled conditions

02 DESIGN SPECIFICATION Smoke release shall only be released under controlled conditions

- Compartmentation Doors
- Control over smoke extraction
- Sump Pumps

Deemed acceptable

References:

- *In order to foresee compliance with upcoming codes (actual environmental trend) limiting smoke and water released after a fire event .*

Property Protection

Performance Criteria (for Property Protection)

- **Burnt Areas**

  Full replacement of equipment

- **Smoke damage**

  Cleaning operations and partial/complete replacement.

- **Structure impact**

Performance Criteria (for Property Protection)

- **Burnt Areas**

  Full replacement of equipment

- **Smoke damage**

  Cleaning operations and partial/complete replacement.

- **Structural impact**

01: All material and devices that:

-Caught fire

-Are exposed to 20 kW/m^2 or 80ºC

Performance Criteria (for Property Protection)

- **Burnt Areas**

  Full replacement of equipment

- **Smoke damage**

  Cleaning operations and partial/complete replacement.

- **Structural impact**

02: All material and devices that:

- are exposed to environmental smoke density of $> 3 \cdot 10^{-4}$ kg/m^3 [2]
- Equivalent visibility of <5m

$$V = \frac{C}{K_m \rho Y_s}$$

K_m = 8700 m^2/kg
Y_s = 0.1
C = 3

CFD parameters

[2] Produced deposition of Sippola M R, Nazaroff W W. (2004). Experiments measuring particle deposition from fully developed turbulent flow in ventilation ducts. *Aerosol Science and Technology*, **38**(9), 914–925.

TanakaT.J.,BaynesE.Jr.,NowlenS.P.,BrockmannJ.,GritzoL.,ShaddixC., LDRD Report: Smoke effects on Electrical Equipment, SAND2000-0599, Sandia National Laboratories 2000

Performance Criteria (for Property Protection)

- **Burnt Areas**

  Full replacement of equipment

- **Smoke damage**

  Cleaning operations and partial/complete replacement.

- **Structural impact**

03: DESIGN SPECIFICATION: Avoid total or partial collapse the tunnel structure should be designed to:

- Withstand HRR >10MW
- Withstand Heat Flux > 250kW/m^2
- Limited spalling

OR direct compliance to standard fire curve

[3] Hertz K D. (2003). Limits of spalling of fire-exposed concrete. *Fire Safety Journal*, **38**(2), 103–116. doi:10.1016/S0379-7112(02)00051-6

Fire Fighters Response

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

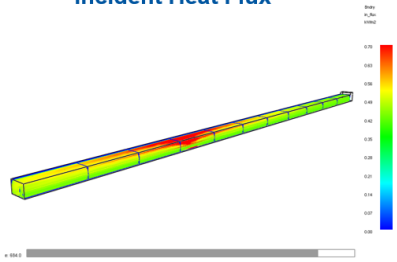
Distance from door < 80m

- HRR < 20MW offensive
- HRR > 20MW defensive

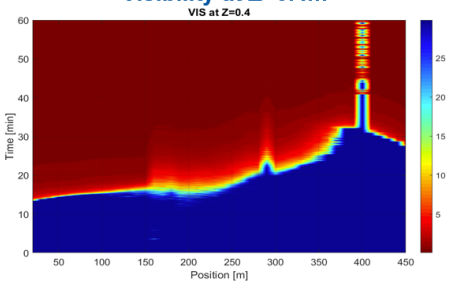
If compartmentation works, with current ventilation system
HRR_{max} < 5MW (ventilation limited)

Results

Incident Heat Flux

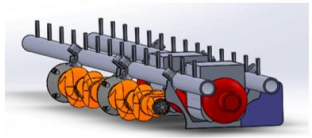


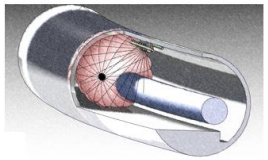
Visibility at Z=0.4m

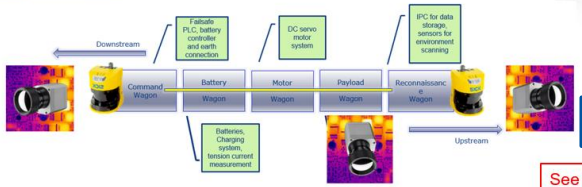


TIM development

The DSPA aerosol generating fire extinguishing system







1st TIM on place <15min

See talk: M. Di Castro. Thu 12th,14.10h

TIM Fire Brigade Wagon proposal, A. Masi, 03/11/17

Results

T: TIM (15 min in place)
FF1: Fire Fighters (on each shaft, at surface, tShowUp = **30min**)
FF2: Fire Fighters (every two shaft, at surface, tShowUp = **60min**)

Fire	Burnt Area [m of tunnel]			Smoke Damage [m of tunnel]			Cleaning time [days]			Recommissioning [days]		
Case	T	FF1	FF2	T	FF1	FF2	T	FF1	FF2	T	FF1	FF2
Fire#1 Tray Fire	1.5	2.5	4	20	424	424						
Fire#2 Drum Fire	2.5	3.5	5	300	424	424						
Fire#3 Kuka Fire	3.5	4.5	6	300	424	424						

Similar cost

TIM useful in small-medium fires

424 = the entire fire compartment. Reduced?

Conclusions on FCC tunnel safety assessment

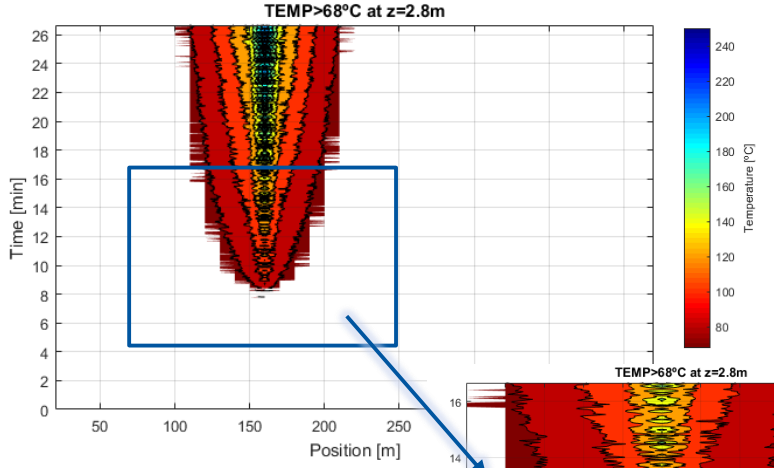
- **Detection and ventilation** designs explored and revised to meet Life Safety requirements for occupants. Together with **compartmentalization**, they are a **keystone to ensure Life Safety goal**
- **Injured occupants** (not able to self-evacuate) have **limited time** before exposed **to untenable conditions**
- **Fire Fighters** life safety goals can be met upon **design specs**
- **Environmental protection** goals (upon fire event) can be met upon **design specs**
- **Property protection** can be **reduced** with the used of **FF-TIM**

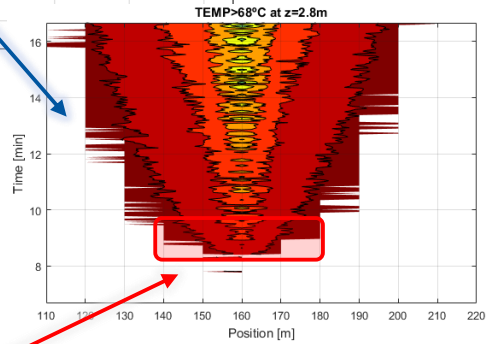
SPRINKLERS
impact on FCC ?

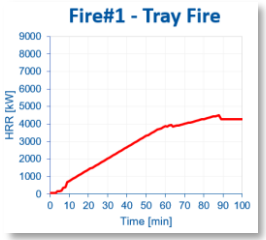
Source: Russ Leavitt, CFPS

Sprinkler activation time

We assume it activates at 68ºC at 2.8m

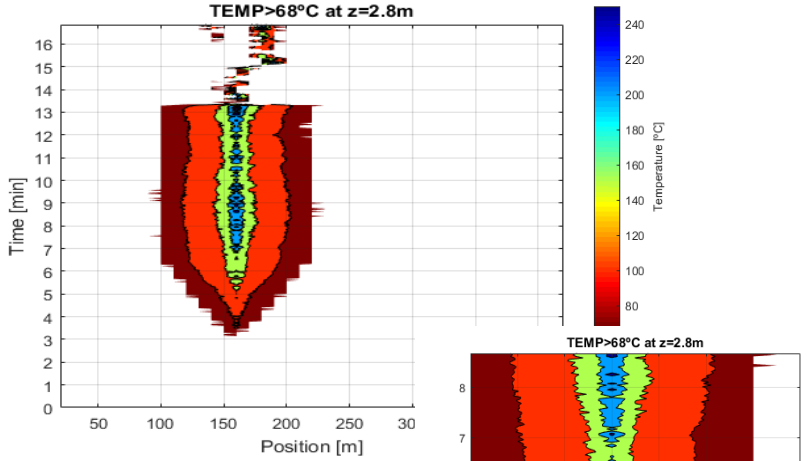


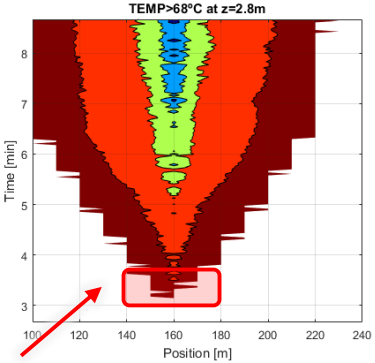


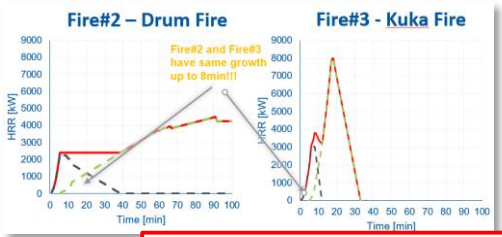


Sprinkler activation time = 9min, ±20m

Colored Ta>68ºC

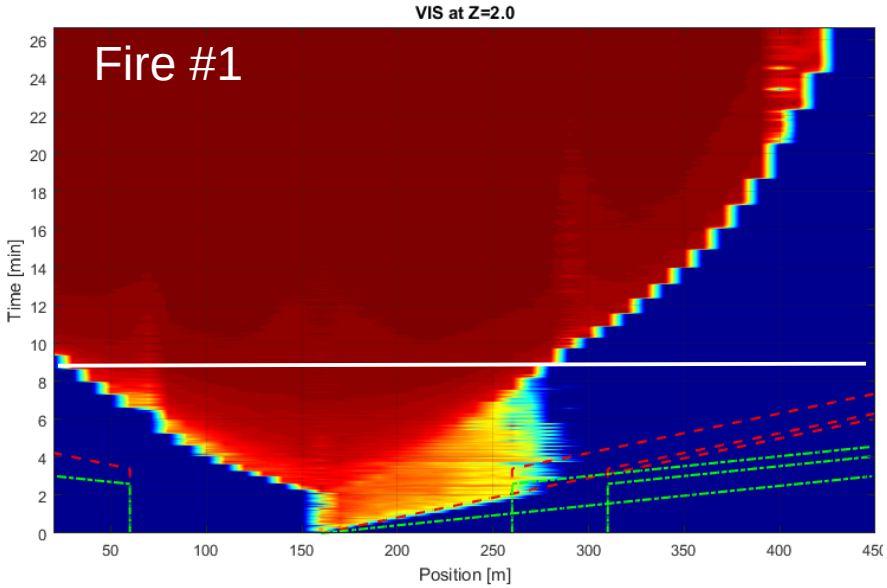


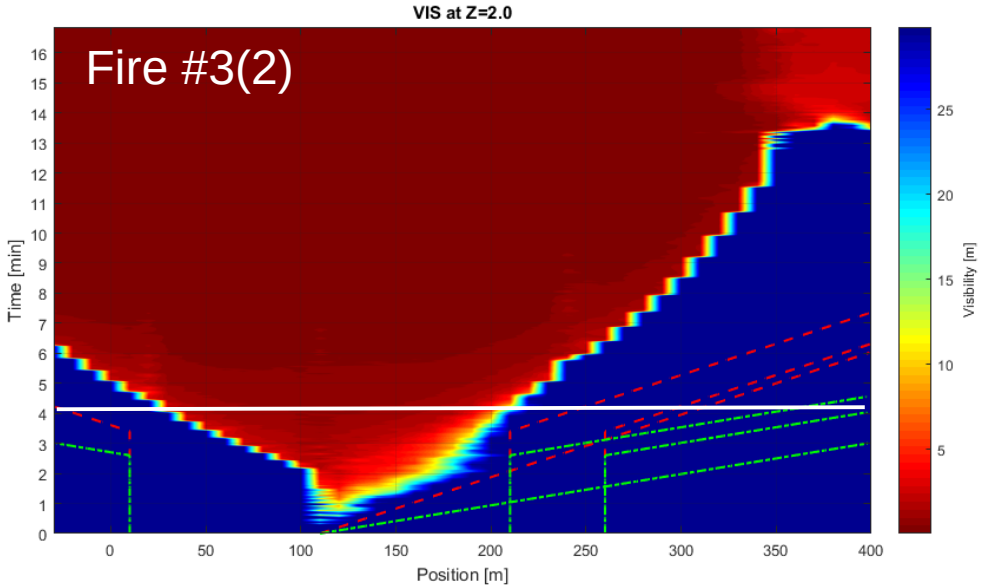




Sprinkler activation time = 4min ±20m

Evacuation. Uncertainty calculations. Fire#1 VS Fire#2(3)





Local activation on the fire site.

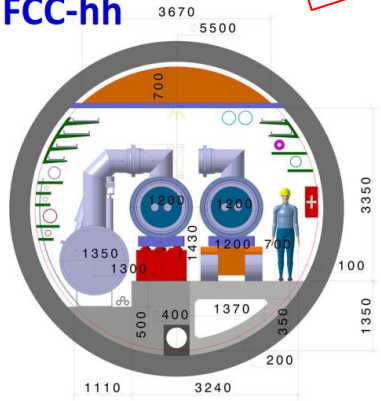
Sprinkler: Remarks and Technical Challenges

- Activation times > Evacuation times → does not impact **occupants life safety**
- Positive **impact on victims** (impeded occupants) and FF intervention.
- Impact on **property protection**. Potential damage reduction to machine and equipment
- Possible hybrid implementation. Protect fire-prone and critical areas only (DESY strategy, original SPS…)
- **Technical challenges**:
  - Long piping
  - Stagnation water
  - Dry system with intermediate deposits (long delays…)
  - Costly
- System **cost-effectiveness** could be considered with a fully **QRA**

Fire Safety assessment of HE-LHC

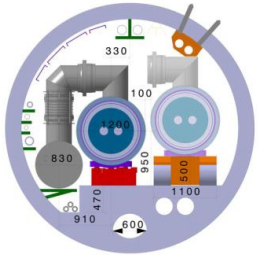
Same scale

FCC-hh



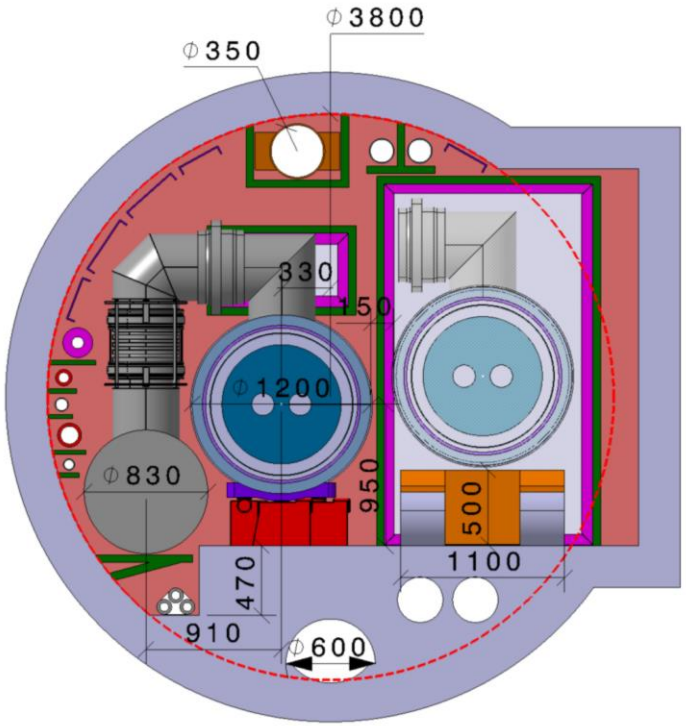
5.5 m inner tunnel diameter

HE-LHC



3.8 m inner tunnel diameter

Geometry and safety measures



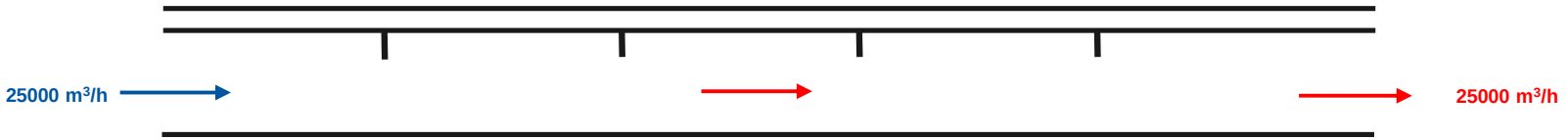
Baseline Safety Features

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

Ventilation: Proposed Strategy

Developed with EN/CV
+Info see talk: G. Peon and M. Nonis. Wed 11th 13.30-15.30

Normal Ventilation Condition

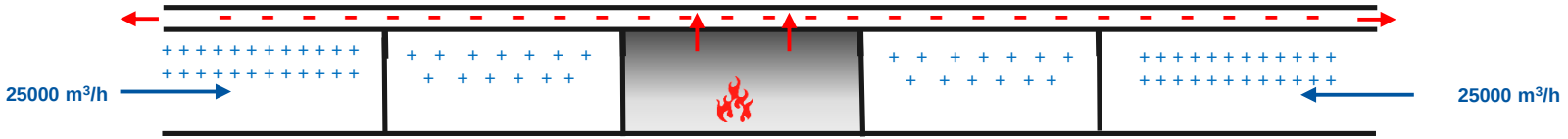


Ventilation: Proposed Strategy

Developed with EN/CV
+Info see talk: G. Peon and M. Nonis. Wed 11th 13.30-15.30

When Fire is detected in a compartment

Small smoke exhaust: ~100 m³/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 underpresure)
- **Overpressure** created in neighbouring compartments
- Safe situation for Fire Fighters intervention

Fire scenarios and human behaviour

Fire Designs

DRUM

CABLE TRAY

KUKA

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

HSE Fire Safety Engineering Team 12-April-18 FCC Week 2018 - Fire Safety Assessment EDMS: 1961929 O. Rios, A. Arnalich, S. La Mendola 17

3.2 Fire Scenarios. Human Behaviour

Courtesy G. Lindell

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

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

HSE Fire Safety Engineering Team 12-April-18 FCC Week 2018 - Fire Safety Assessment EDMS: 1961929 O. Rios, A. Arnalich, S. La Mendola 22

3.1.1 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	**510s** after the fire starts (sensors in the alcoves)	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

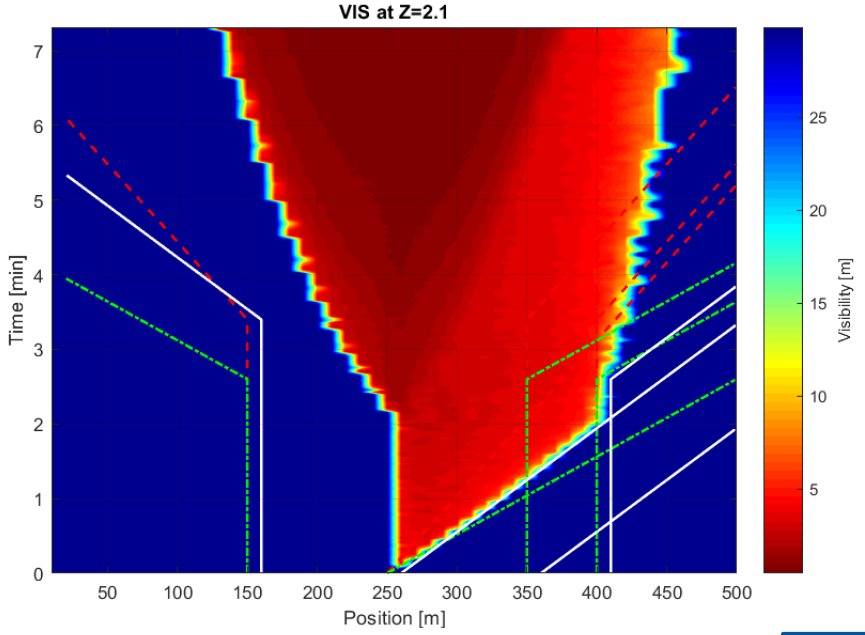
Assumed SPEC t_{det}= 120s

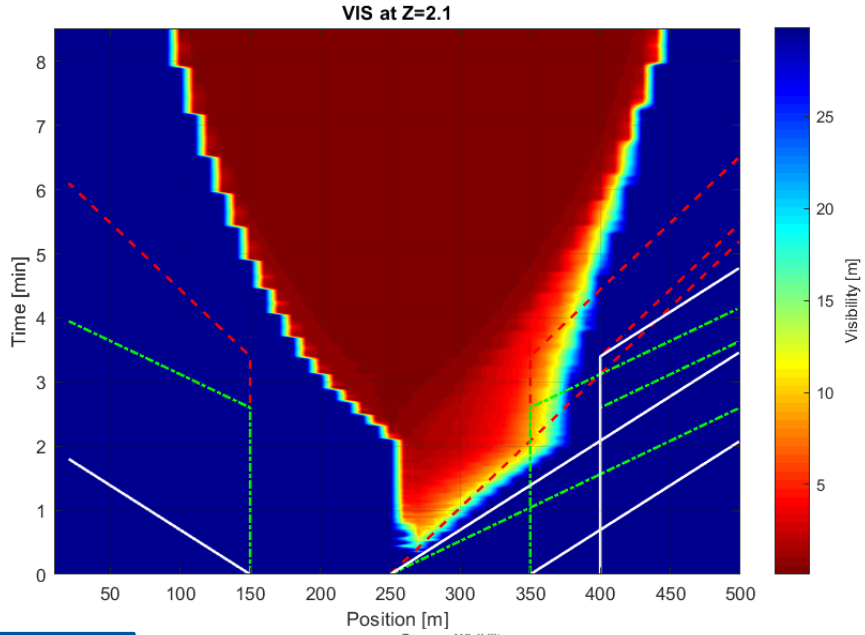
*Desy (FCC Col)
Yacine Kadi EN-EA

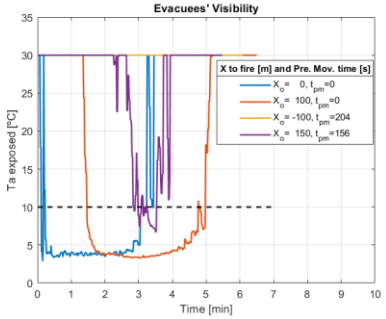
HSE Fire Safety Engineering Team 12-April-18 FCC Week 2018 - Fire Safety Assessment EDMS: 1961929 O. Rios, A. Arnalich, S. La Mendola 21

Same scenarios and same detection delays as for FCC tunnel

Life Safety. HE-LHC. Fire#1 VS Fire#2(3)

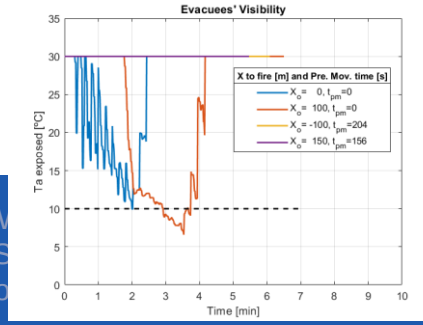






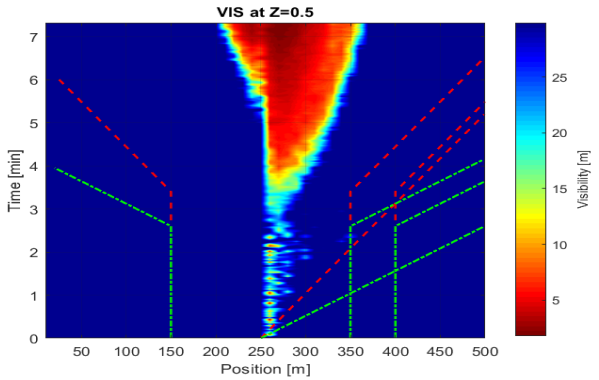
Worse case:
Pre.Mov = 84s
V = 1.6m/s

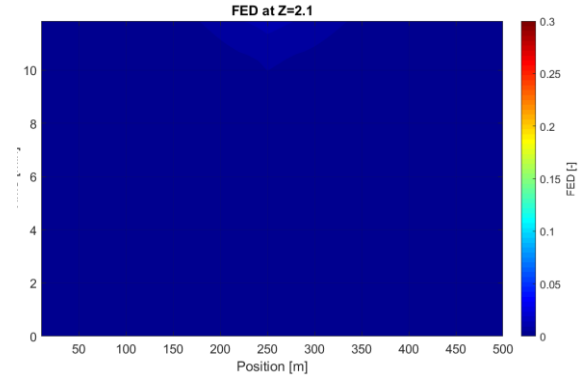
No safety margin



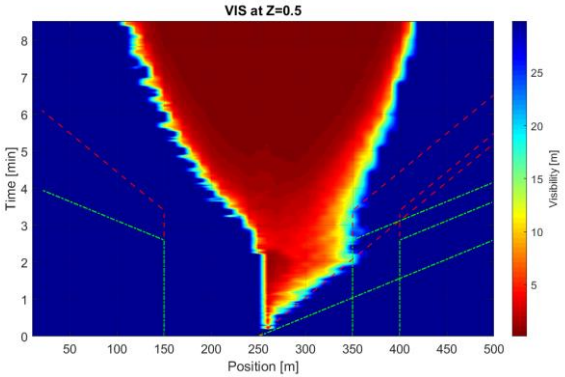
Close Look. **Visibility** (@Z=0.5m) and **FED** (@Z=2.1m)

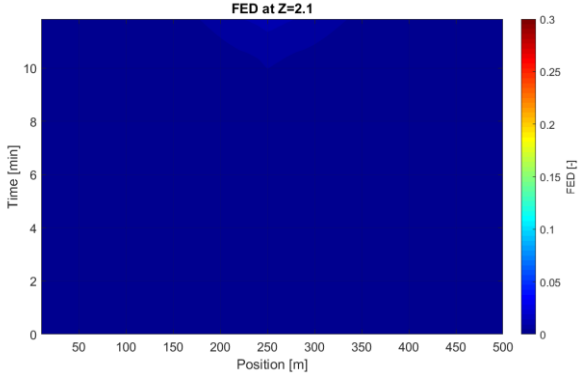
Fire #1





Fire #2(3)





Worse Case Cumulative FED

FED=0

FED<$1 \cdot 10^{-4}$

1000 times smaller than threshold

Conclusions HE-LHC

- **Life Safety Goal analysed for HE-LHC**
- **Same designs scenarios** considered as for **FCC tunnel**
- The performance criteria is met with no safety margin. **Further measures** (e.g. intermediate smoke curtain) could be considered to make the design more robust**.**
- **FF-TIM would help to increase the safety design** as well as **meet the other safety goals**


CERN