CERN

Performance Based Safety Design and results on Cryogenic hazards

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HSE
Occupational Health & Safety
and Environmental Protection Unit

Thanks to the FCC I&O WG members

FCC Week 2018
Amsterdam, NL

Outline

1 Introduction

2 Performance Based Design

3 Cryogenic Safety studies (FCC-hh)

4 Conclusions

Introduction

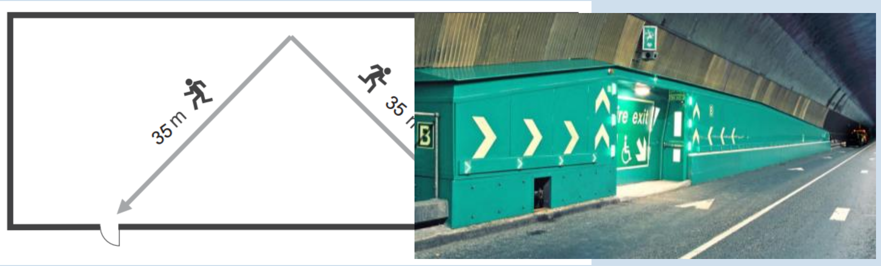
Legislative references are applicable

Project Safety Requirements

Legislative references are **NOT** applicable

‘Standard Best Practices’
SBP

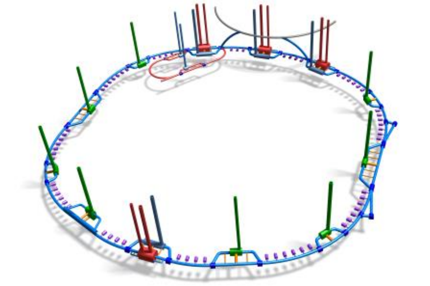
‘Performance Based Design’
PBD



35 m *500 m**

Automatically conform, without additional measures

Ex: Egress routes



6.5-9.5 km

Adaptation & additional measures needed

Introduction

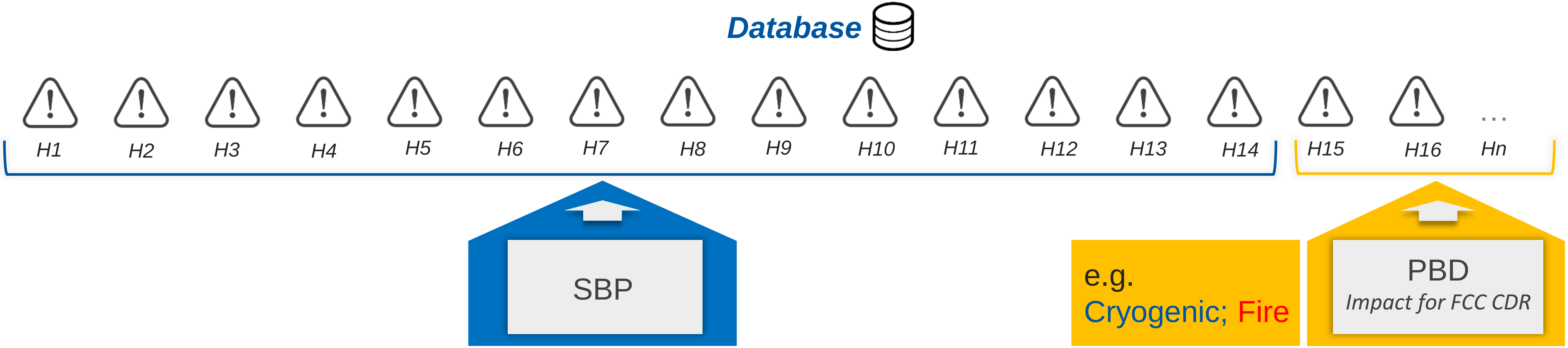
Hazard Register

FCC Hazard Register:

Systematic collection of Hazards in the FCC facilities during different phases of its lifetime

No assessment of probability or severity

T. Otto



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

Performance Based Design

Performance Based Design

Defined by Organizations' Safety Policy

Safety Goals

Safety Goals

Occupational Health and Safety

Workers | Visitors

…

Safety Goals:

1. Occupational Health & Safety
2. Environmental Protection
3. Property Protection
4. Continuity of Operation

Independent of the Safety domain / project

Water

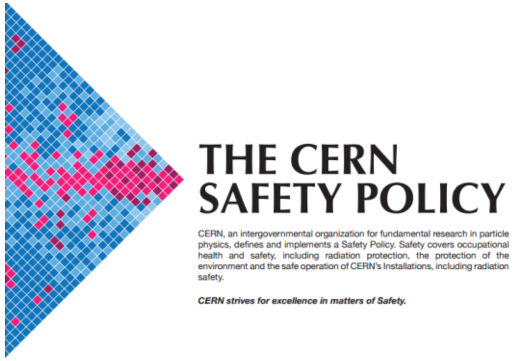
…

Property protection

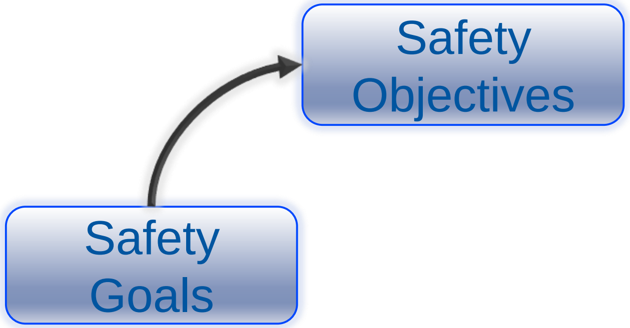
Downtime | …

Priority

CERN's Safety Policy



Performance Based Design



Safety Objectives – FCC Study

	Occupational Health and Safety	Environmental protection	Property protection	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	-

Safety Objectives – FCC Study

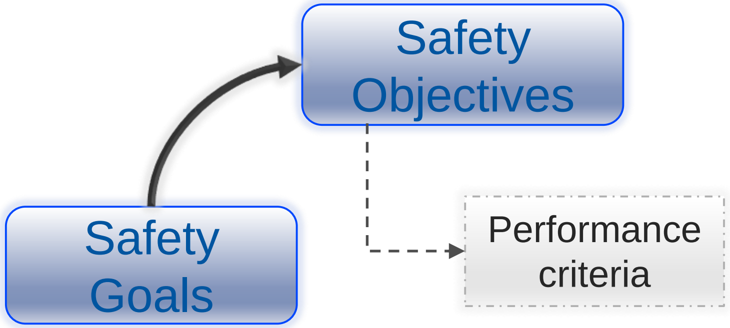
	Occupational Health and Safety	Environmental protection	Property protection	Continuity of operation
	A	B	C	D
1	Occupants shall be able to evacuate throug … om smoke … any time **Occupants**	Limit the release of polluting (incl. activated) agents to the environment in case of incident **Env. impact**	The continuity of essential services and structural stability is assured in case of fire or gas release and other incidents	Lim … e of i … **Downtime**
2	Victims and other occupants, not able to self-ev … ted areas, … ued by the intervention teams **Victims**	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 … ERN SOPs **Rescue teams**	-	Li … n ca … **Property loss**	-

Safety Objectives – FCC Study

	Occupational Health and Safety	Environmental protection	Property protection	Continuity of operation
	A	B	C	D
1	Occupants shall be able to evacuate throug… om smoke… any time **Occupants**	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	Lim… e of i… **Downtime**
2	Victims and other occupants, not self-ev… t areas, … ued by the intervention teams **Victims**	… environment in case of incidents	… e … us accidental events	-
3	Rescue teams shall be able to intervene safely … ERN SOPs **Rescue teams**	-	Li… n ca… **Property loss**	-

Independent on the Safety Domain !

Performance Based Design



- Defined by Organizations' Safety Policy
- Requirements of the project i.e. Applicable Rules
- Measurable requirements i.e. Harmonized Standard

Performance criteria

Qualitative

Performance goals

- Presence of toxic smoke shall not influence the evacuation of occupants

- Helium cloud shall not reach the compartment door before the occupant evacuating

Quantitative

Threshold values

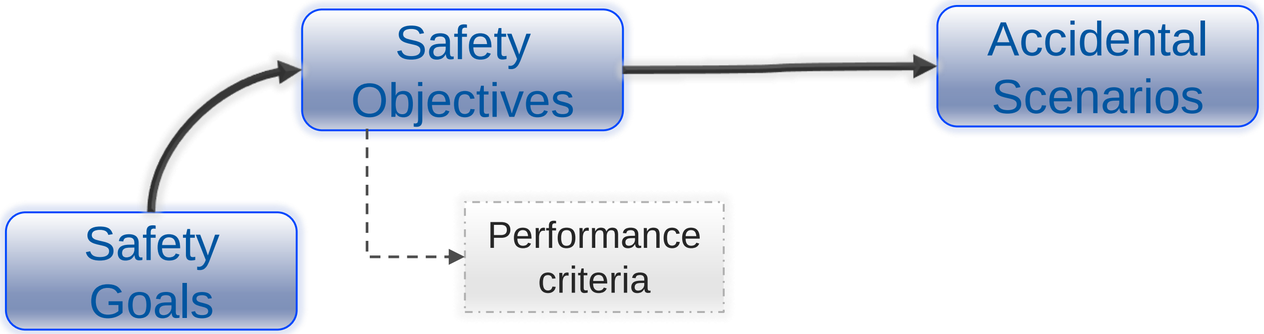
- Exposure to :
  FED < 0.1 (e.g.)
  Exposure temperature < 60°C (e.g.)
  Visibility > 10 m (e.g.)
- Exposed to:
  O_2 level > 18 %
  $V_{ventilation} < V_{walking} = 1.2$ m/s

CDR

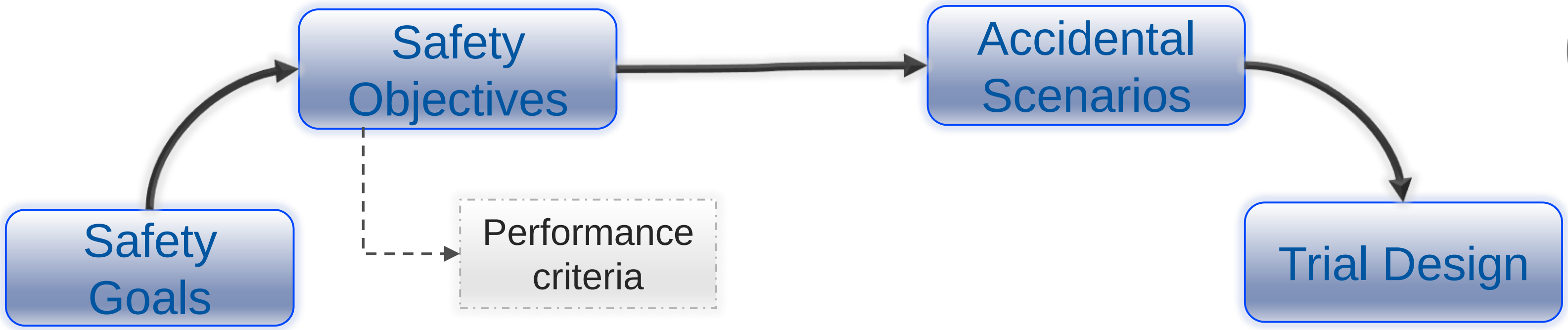
TDR

Technical specification can also become performance criteria

Performance Based Design



Performance Based Design



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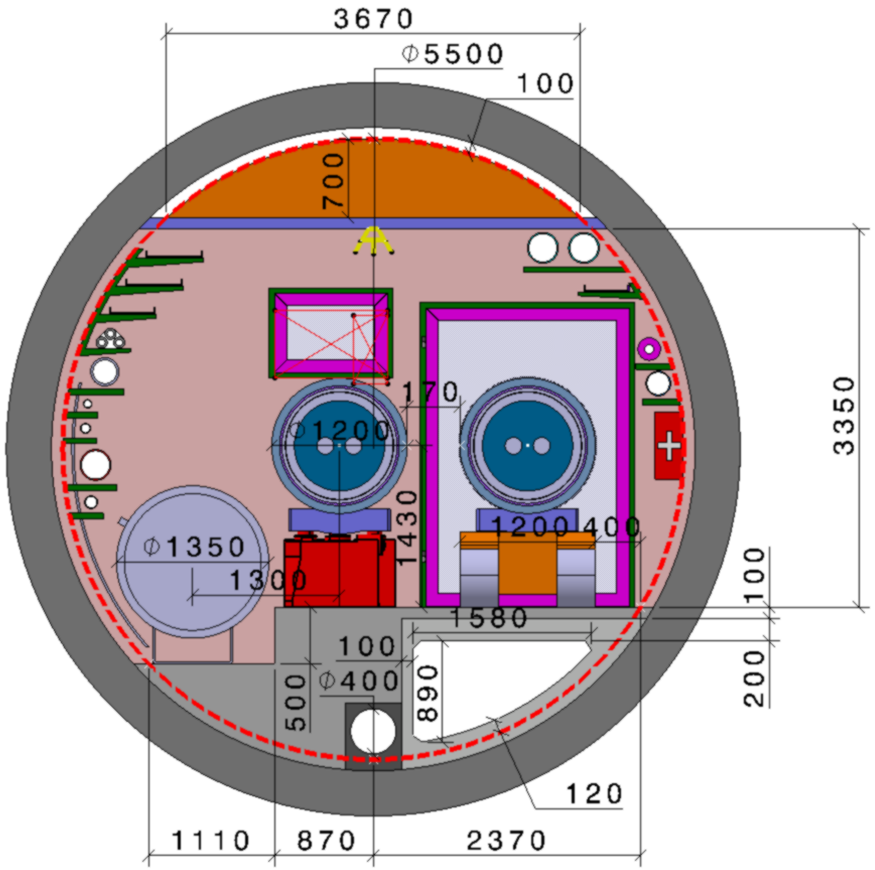
- List of scenarios based on Risk Assessment
- NEW First iteration with initial specification

Trial Design

F. Valchkova-Georgieva

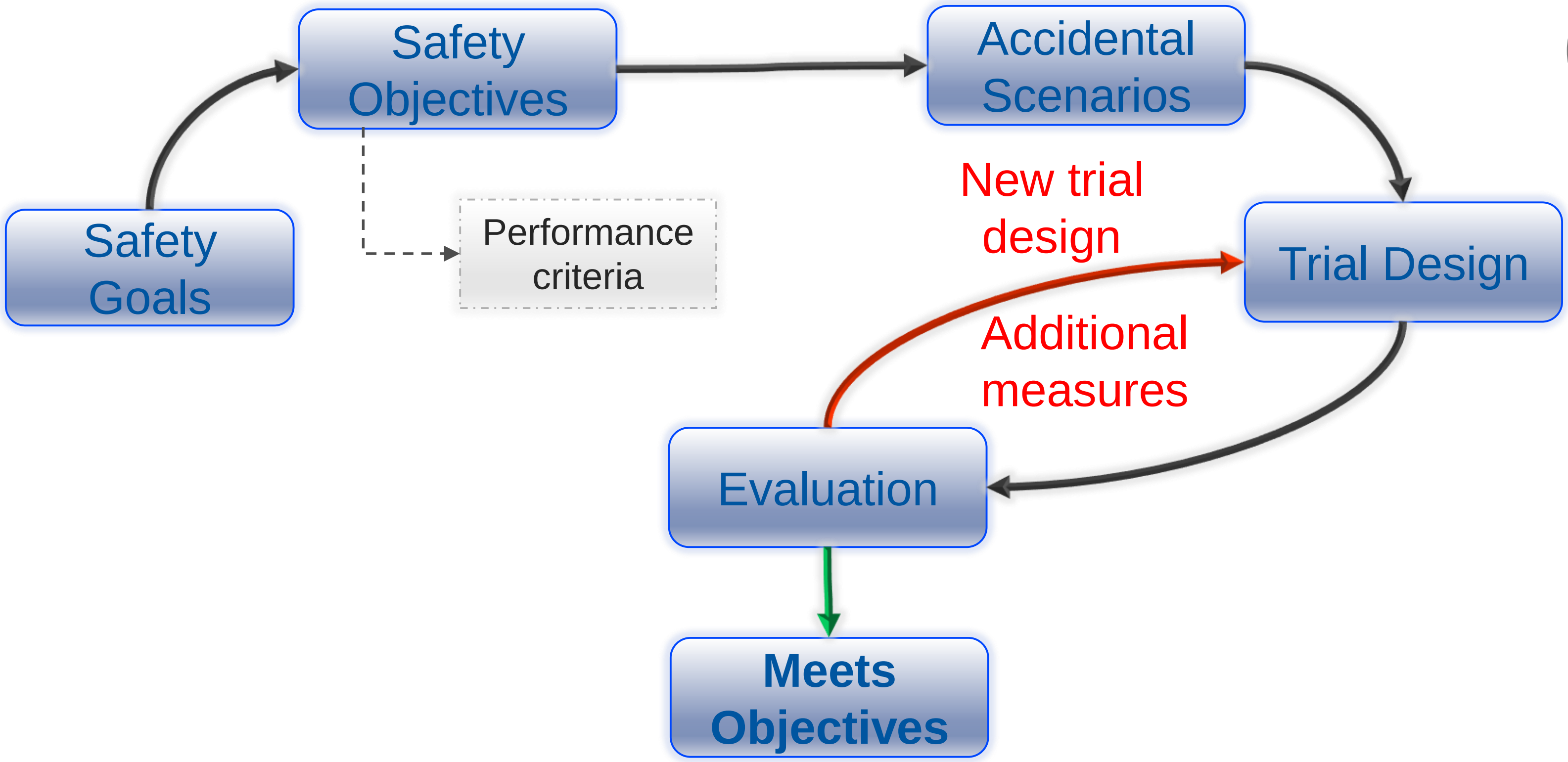


FCC-hh

Characteristics	
Diameter	6 m
Total floor width	5.3m
Safe Passage	X
Fire compartment	✓ (every 440 m)
Compartment door status (nominal) (ODH)	OPEN OPEN
Fresh air supply	✓
Emergency extraction system	✓

Baseline includes Safety features

Performance Based Design



- Defined by Organizations' Safety Policy
- Requirements of the project i.e. Applicable Rules
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- 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

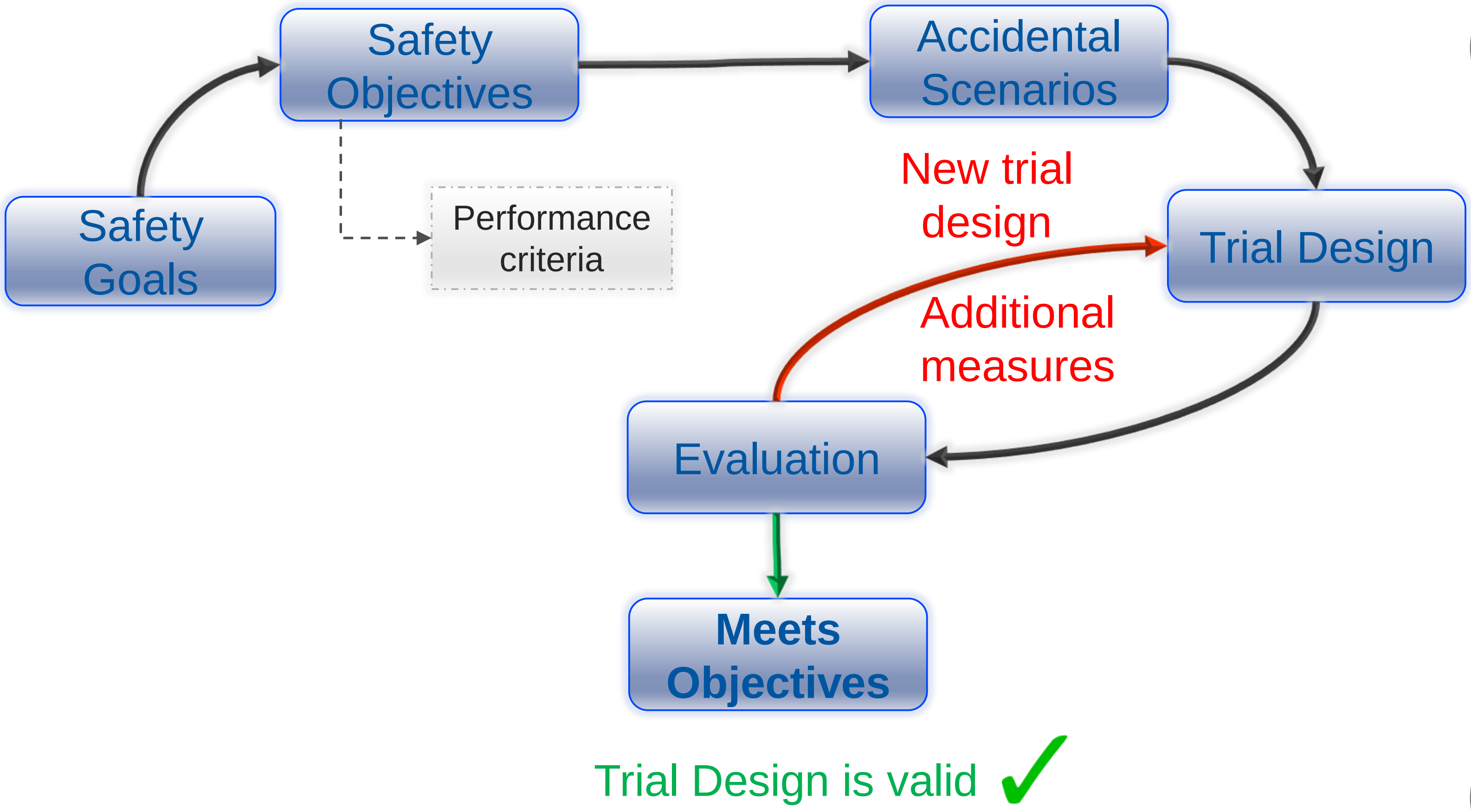
Probabilistic — Consequences and probabilities of scenarios are quantified and their combination evaluated in a risk matrix

Full Probabilistic — Every scenario is evaluated through risk profiles and other risk indicators.

CDR

TDR

Performance Based Design



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Cryogenic Safety studies – FCC-hh

Based on contributions from the FCC PBD Working Group

Input Data

+ LHC studies

M.Nonis, G. Peon, L. Tavian

- 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***

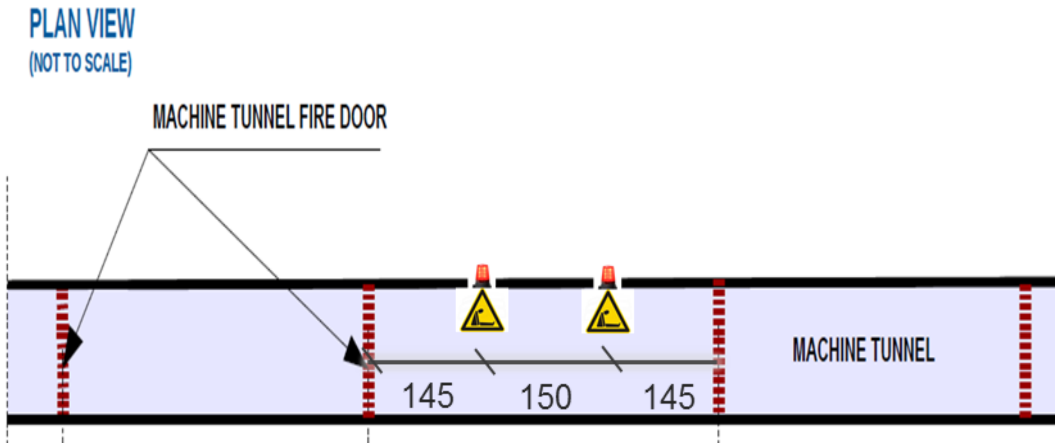
- Helium sectorisation:
  - Superconducting magnets: **220 m** (corresponding to 1 cell)
  - Cryogenic ring line (QRL): **8400 m** (corresponding to sub-sector)

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

** header E*

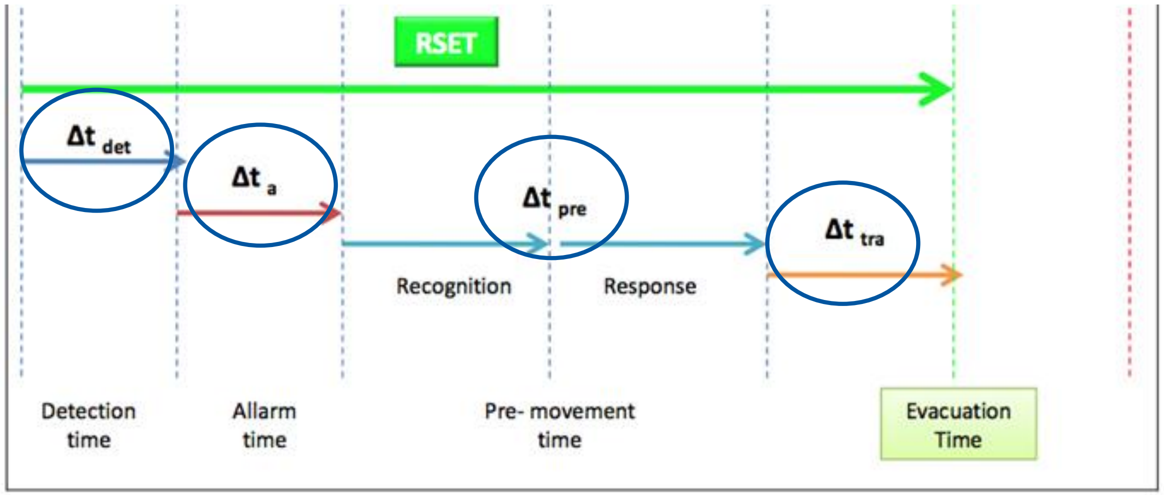
Input Data

- 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):



- ➢ Δt_{det} = distance to ODH detector / He cloud prop. velocity
- ➢ Δt_{a} = 5s
- ➢ **Δt_{pre} = 30 s ***
- ➢ Δt_{tra} = walking speed x 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

Based on
LHC data

Note: No detailed studies yet made for FCC cryostats

a. MCI* (design) → ~ 30 kg/s

b. Relief plate release → ~ 1 kg/s

c. Small leak → ~ 300 g/s

d. Minor leak → ~ 100 g/s

**Maximum Credible Incident*

Accidental scenarios

Scenario	Description
Cryo1	1 kg/s ; 5 m from release point
Cryo2	1 kg/s ; 5 m from release point; emergency extraction ON
Cryo3	1 kg/s ; 200 m from release point
Cryo4	0.3 kg/s; 150 m from release point
Cryo5	0.1 kg/s; 5 m from release point
Cryo6	32 kg/s during operation

Varying the relief mass flow & distance to the release

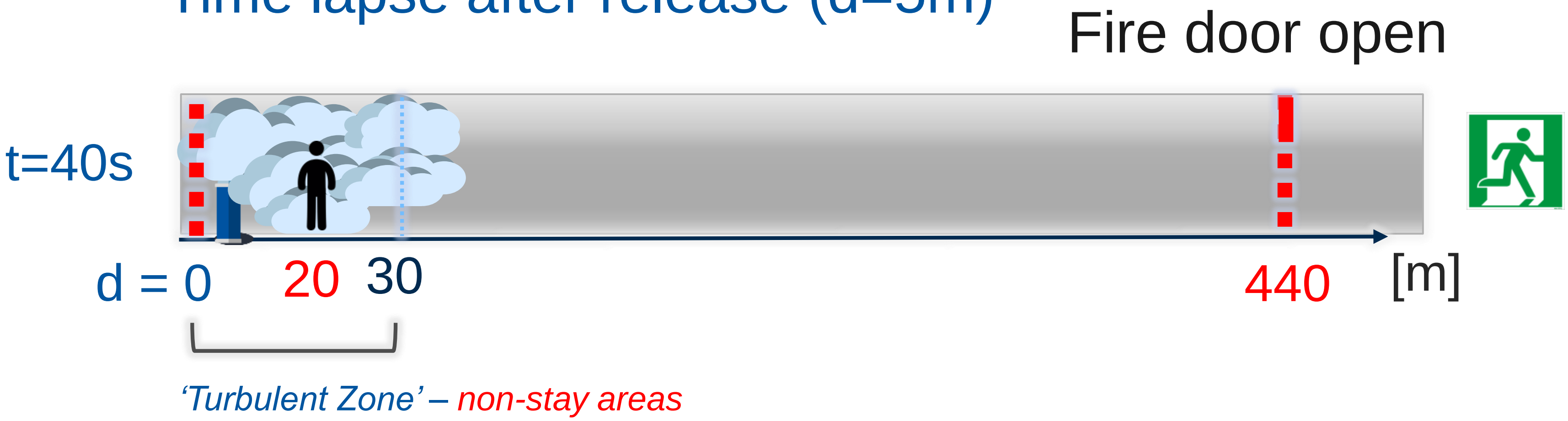
Evaluation of the Trial Design

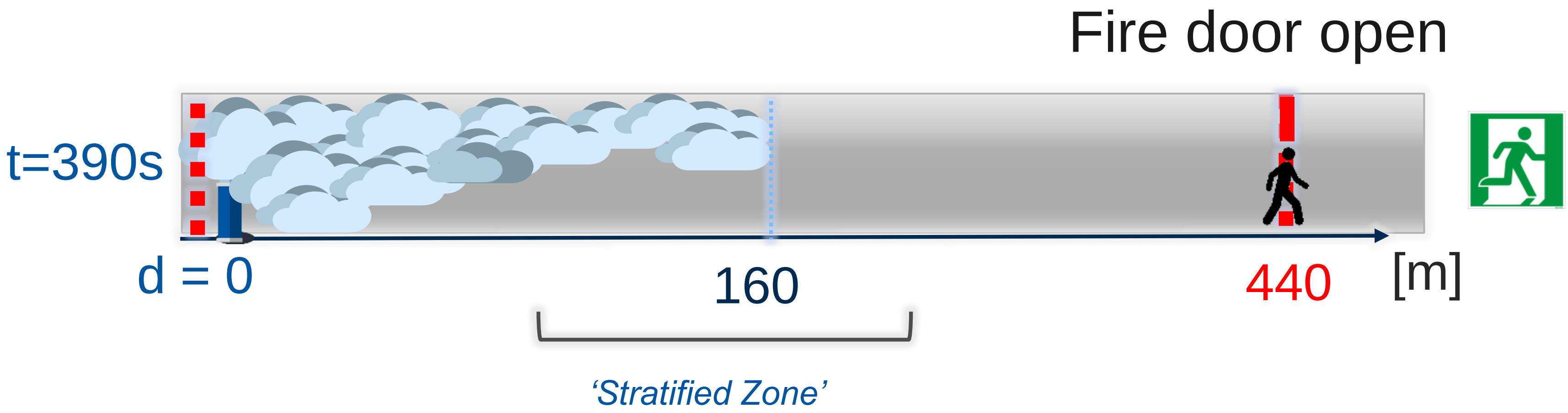
Summary

Based on
simplified model

Cryo1: 1 kg/s ; 5 m from release point

- Time lapse after release (d=5m)

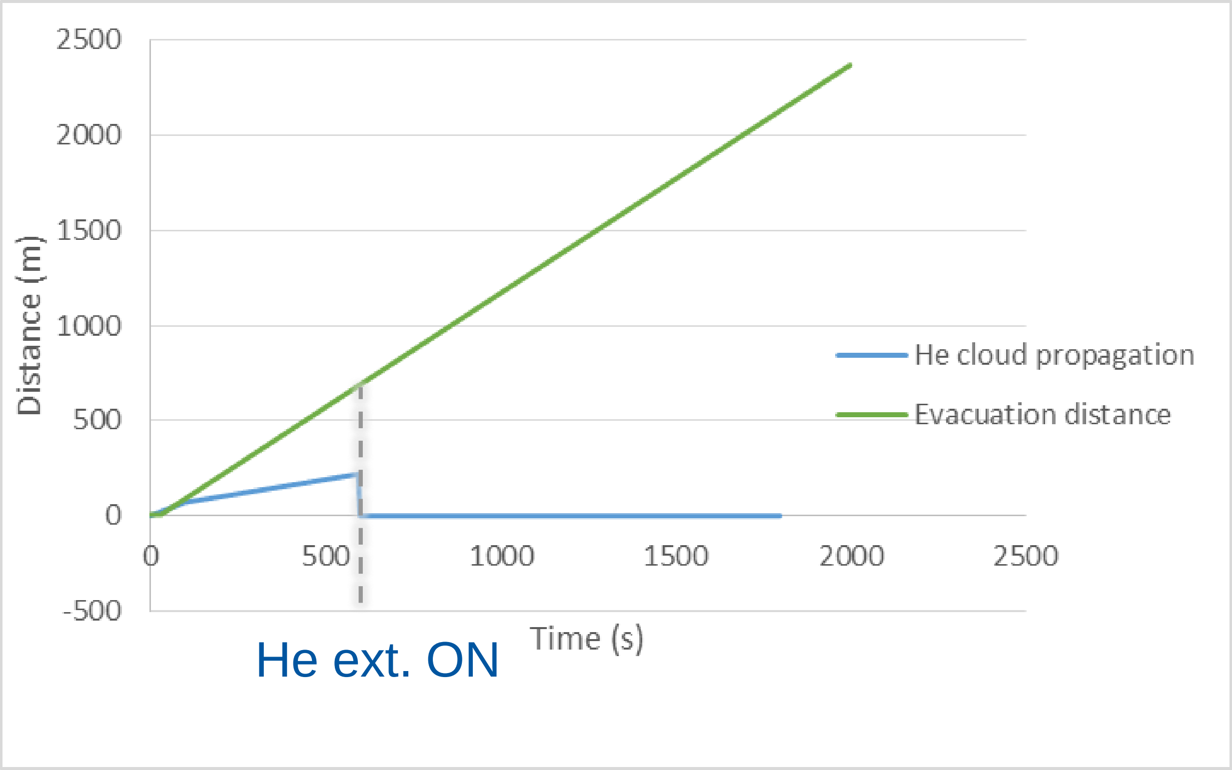




Critical distance in the 'Turbulent zone'

Illustrations are not to scale

Cryo2: 1 kg/s ; 5 m from release point; extraction ON



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

After passing 2 fire doors (880m) is considered 'safe' to wait for transportation

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

Cryo4: 0.3 kg/s ; 150 m from release point

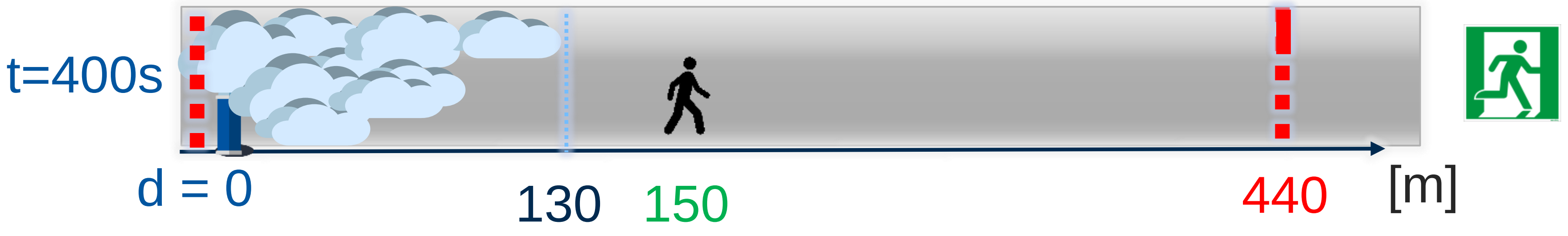
- Time lapse after release (d=150m)

Less mass flow = smaller GHe layer → t.b.c via CFD

Illustrations are not to scale

Cryo4: 0.3 kg/s ; 150 m from release point

- Time lapse after release (d=150m)



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									
Accidental Scenarios	Health & Safety of personnel			Environmental protection		Property protection			Continuity of operations
	A1	A2	A3	B1	B2	C1	C2	C3	D1
Cryo1	X	X	X(?)	✓	✓	✓	✓	✓	✓
Cryo2	X (?)	X	✓ (?)	✓	✓	✓	✓	✓	✓
Cryo3	✓	X	X(?)	✓	✓	✓	✓	✓	✓
Cryo4	✓	X (?)	✓	✓	✓	✓	✓	✓	✓
Cryo5	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cryo6	X	X	X	✓	✓	✓	X	X	X

Evaluation of Trial design - FCC

Trial design #1									
Accidental Scenarios	Health & Safety of personnel			Environmental protection		Property protection			Continuity of operations
	A1	A2	A3	B1	B2	C1	C2	C3	D1
Cryo1	X	X	X(?)	✓	✓	✓	✓	✓	✓
Cryo2	X (?)	X	✓ (?)	✓	✓	✓	✓	✓	✓
Cryo3	✓	X	X(?)	✓	✓	✓	✓	✓	✓
Cryo4	✓	X (?)	✓	✓	✓	✓	✓	✓	✓
Cryo5	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cryo6	X	X	X	✓	✓	✓	X	X	X

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

Evaluation of Trial design - FCC

Full Report EDMS N. 1818330

Trial design #1									
Accidental Scenarios	Health & Safety of personnel			Environmental protection		Property protection			Continuity of operations
	A1	A2	A3	B1	B2	C1	C2	C3	D1
Cryo1	X	X	X(?)	✓	✓	✓	✓	✓	✓
Cryo2	X (?)	X	✓ (?)	✓	✓	✓	✓	✓	✓
Cryo3	✓	X	X(?)	✓	✓	✓	✓	✓	✓
Cryo4	✓	X (?)	✓	✓	✓	✓	✓	✓	✓
Cryo5	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cryo6	X	X	X	✓	✓	✓	X	X	X

(?) → 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:

S. La Mendola, V. Mertens, T. Otto, S. Marsh, M. Nonis, O. Rios, J. Osborne, L. Tavian, S. Grau, G. Lindell, G. Peon, M. Widorski, FCC I&O WG memebrs

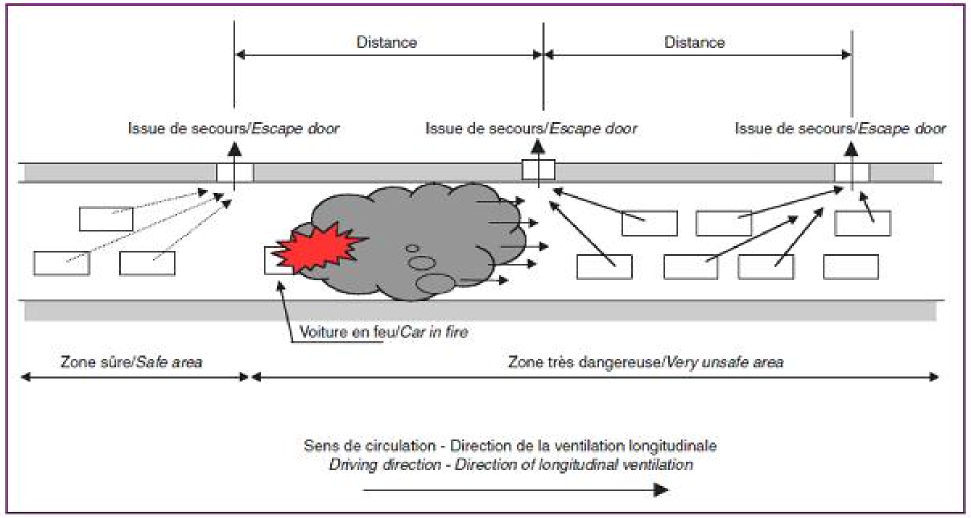
CERN

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.”



Manuel AIPCR des tunnels routiers

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 Estimate_cost * Poisson_prob [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 ($f > 10^{-6}/y$).

Frequency ▶ / Consequence ▼	Beyond extremely unlikely $f \leq 10^{-6} yr^{-1}$	Extremely unlikely $10^{-4} \geq f > 10^{-5} yr^{-1}$	Unlikely $10^{-2} \geq f > 10^{-4} yr^{-1}$	Anticipated $f > 10^{-2} yr^{-1}$
High	10	7	4	1
Moderate		8	5	2
Low		9	6	3
Negligible	11	12		

Key

High Risk | Moderate Risk | Low Risk | Negligible risk

★ The star indicates the position of the scenario (example)

Courtesy of S. La Mendola

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

Ignition due to hot work $P(I_{HW})$

Extinction by Occupants (E)	Fire Detection (D)	Sound Alarm (A)	Ventilation stops (V)	Scenario ID	Prob. / y	Consequence [kCHF]	Expected cost [kCHF/y]
$P(E \mid I_{HW})$				1	…	…	…
			$P(V \mid A \cap D \cap \bar{E} \cap I_{HW})$	2	10^{-x}	y	y * 10^{-x}
		$P(A \mid D \cap \bar{E} \cap I_{HW})$					
			$P(V \mid A \cap D \cap \bar{E} \cap I_{HW})$	3	…	…	…
	$P(D \mid \bar{E} \cap I_{HW})$						
			$P(V \mid \bar{A} \cap D \cap \bar{E} \cap I_{HW})$	4	…	…	…
		$P(\bar{A} \mid D \cap \bar{E} \cap I_{HW})$					
$P(\bar{E} \mid I_{HW})$			$P(\bar{V} \mid \bar{A} \cap D \cap \bar{E} \cap I_{HW})$	5	…	…	…
	$P(\bar{D} \mid \bar{E} \cap I_{HW})$			6	…	…	…

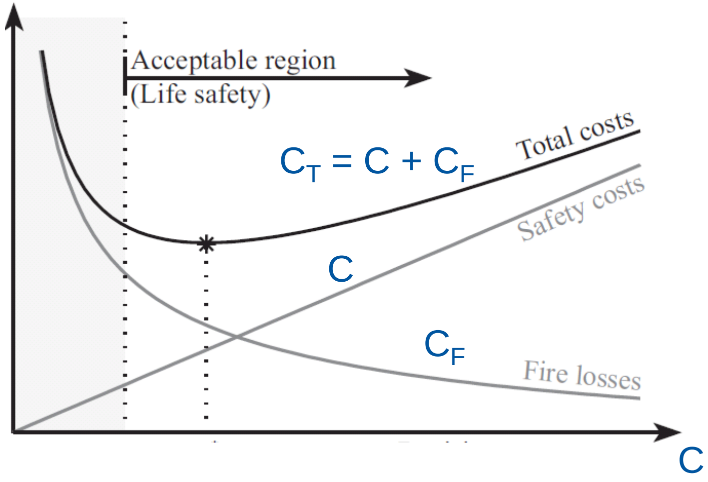
Courtesy of S. La Mendola

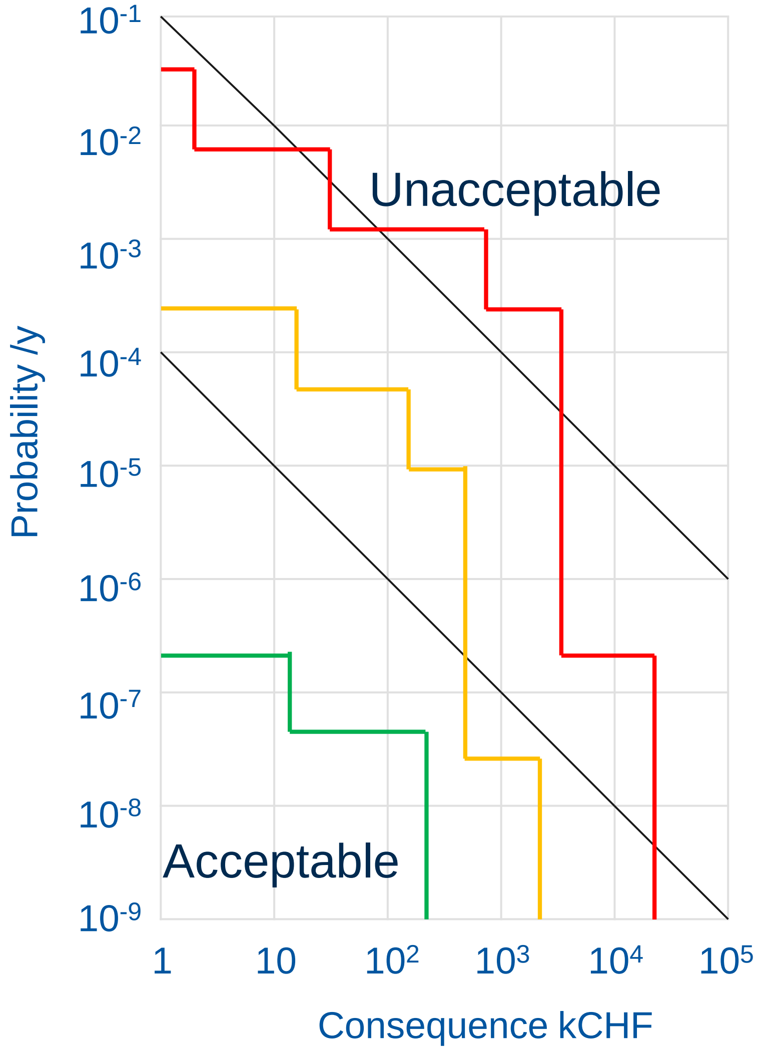
Case study: fire in the arc of a generic accelerator tunnel during a long shutdown. **Full probabilistic** evaluation.

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:
$C_T = C + C_F$

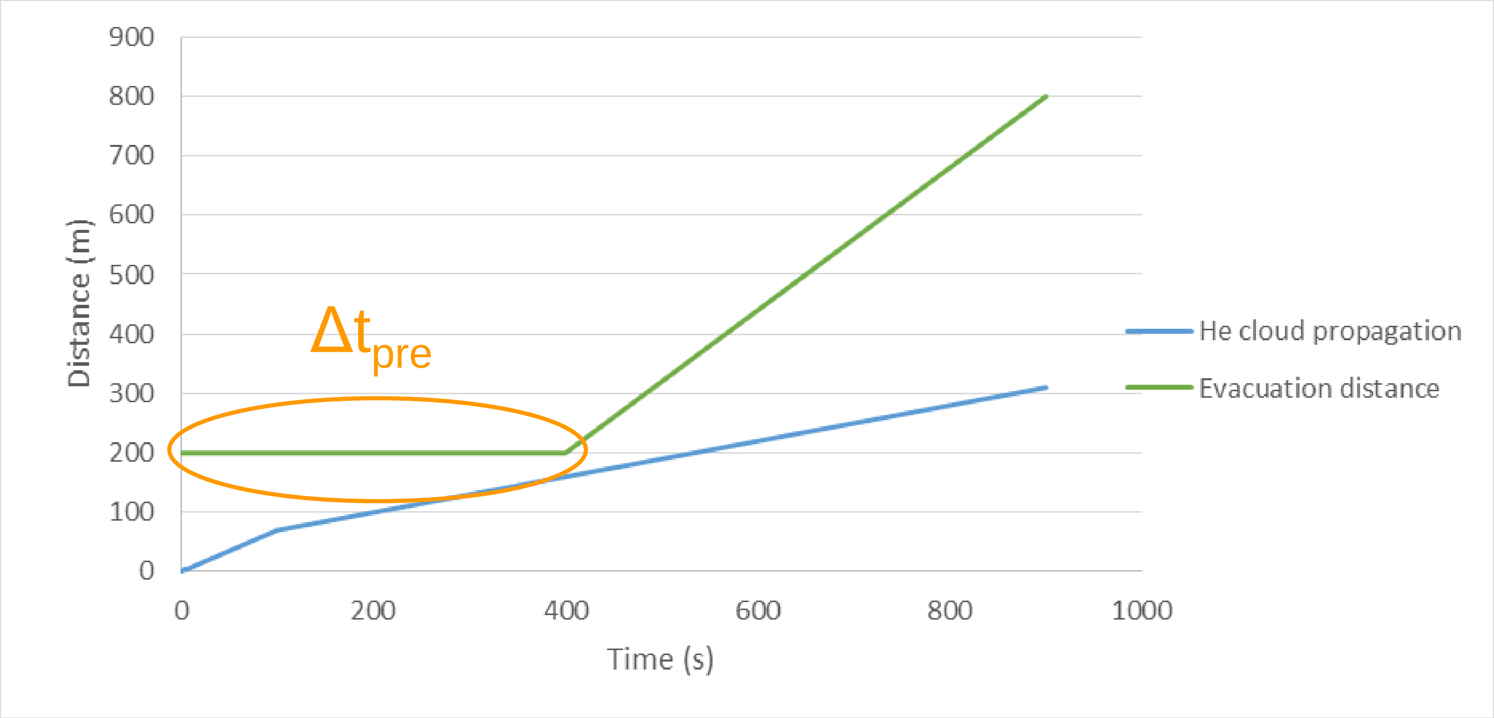




Courtesy of S. La Mendola

Cryo3: 1 kg/s ; 200 m from release point

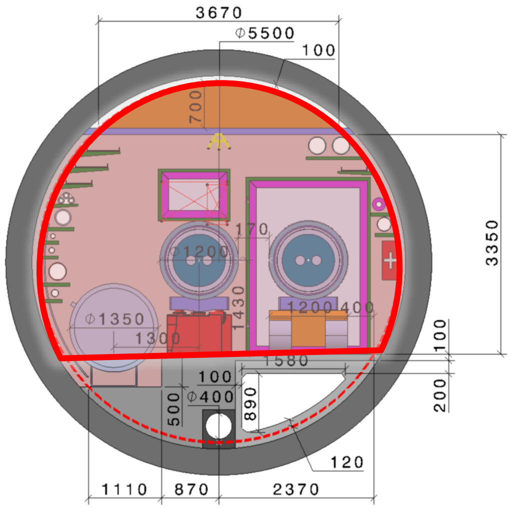
- Propagation of He cloud and evacuation distance



- Occupant is always 'ahead' the He cloud

L. Tavian

Cryo6: : 32 kg/s during operation



5.5 m Ø : 15 m2

- 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

Property protection

- Loss of one compartment & 1 cell

Downtime

- 1 year of operation

5.5 m Ø → 7000 m^3 of air + 5 600 m^3 GHe

→ **1300 mbar** pressure increase → With doors closed

CFD calculation needed… ← With doors open