FUTURE CIRCULAR COLLIDER

SAFETY CONCEPT OF THE FCC: OVERVIEW

A. Henriques, O. Rios
on behalf of the Safety WP team

Outline

- FCC Safety Work package
- Safety concept
  - Objectives and scope
  - Ten-years in the making: from conceptual to feasible
- Hazard registry: Standard Best Practices vs Performance-based
- Safety Systems
- Performance-based studies
- Consolidated safety design
- Next steps

FCC Safety Work package

Team

Thomas Otto
WP leader
Study coordination, hazard register, editor

Andre Henriques
Occupational health and safety

Oriol Rios
Fire Safety

Ghislain Roy
Operational safety, personnel safety systems

Guven Nergiz
Occupational health and safety
Numerical modelling

Pavol Vojtyla
Environmental impact of ionising radiation

Markus Widorski
Radiation protection

Giacomo Lavezzari
Radiation protection

Tomasz Ladzinski
Safety systems

Marc Nas
Emergency Preparedness and response

Acknowledgements: Contributions, exchanges from all TIWG

See “Implementation scenario Plenary”, J. Gutleber

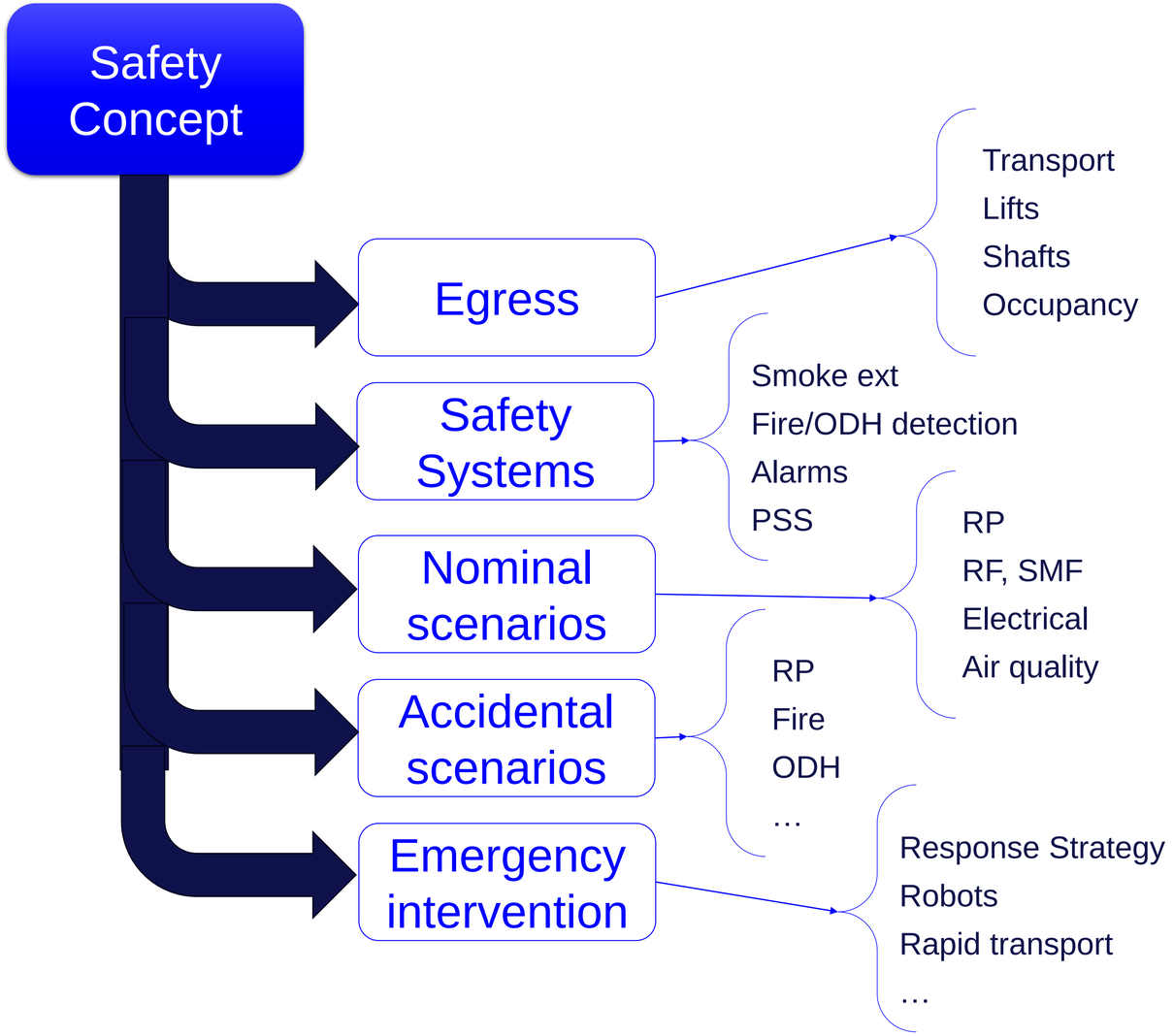
See “Civil Engineering Plenary”, T. Watson

Safety concept

Objective & Scope

Global repository for safety-related information for the FCC-ee feasibility study

- Focus on **Life Safety**
  - Environmental protection will be dealt in the Environmental Impact report - Initial State Analysis is ongoing and will be part of the feasibility study
  - Business continuity; asset protection: indirect impact; yet not quantified
- **3 phases**:
  - Civil Engineering construction
  - (machine) Installation
  - Operation
- Underground areas
  - Arc, caverns, galleries, alcoves
- Surface sites



Safety concept

Vol. 2: *Accelerators, Technical Infrastructures, Safety Concepts*

FUTURE CIRCULAR COLLIDER

FCC-EE SAFETY CONCPET

FCC-INF-RPT-00xx v.0.1
Date: 01/05/2024

Future Circular Collider

SAFETY CONCEPT

Safety Concept Report for FCC-ee

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Work package/unit:	Technical Infrastructures / Safety
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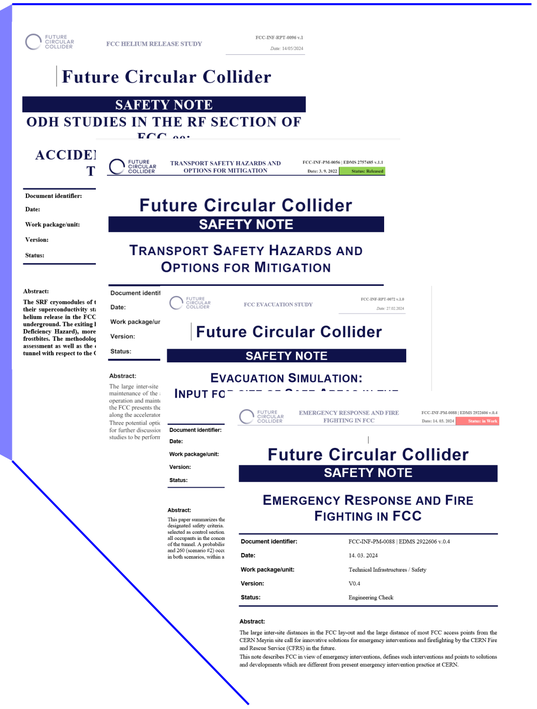
Status:	Draft

Abstract:

A first iteration of the safety concept for the FCC study was performed for the CDR. Following the advancements of the study and the feedback from the mid-term review, the Safety WP of the TIWG pillar worked on an update of the safety concept, developing more detailed assessments, including fire and ODH simulations as well as evacuation modelling. This report will provide the full overview of the Safety concept, tailored to FCC, serving as main reference for Safety Reviews and the Feasibility Study report.

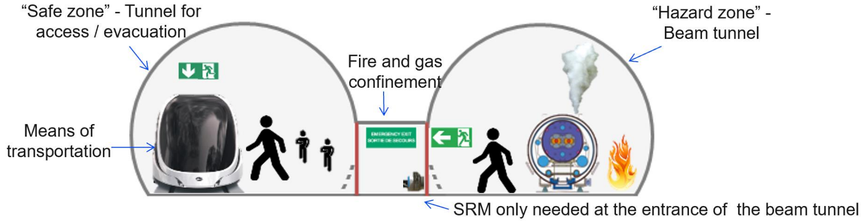
Individual detailed reports



See “FCC Feasibility Study statusFCC Feasibility Study status Plenary”, M. Benedikt

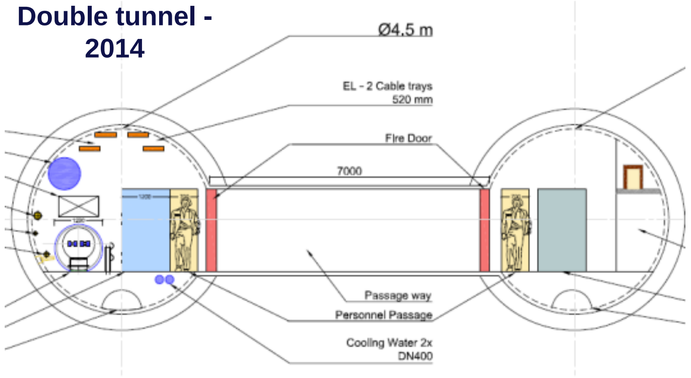
Safety concept

From conceptual to feasible

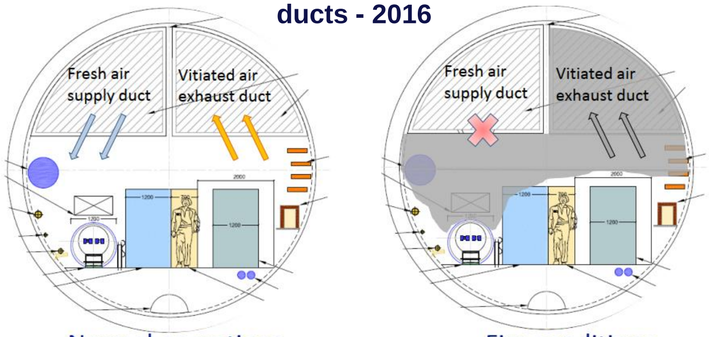


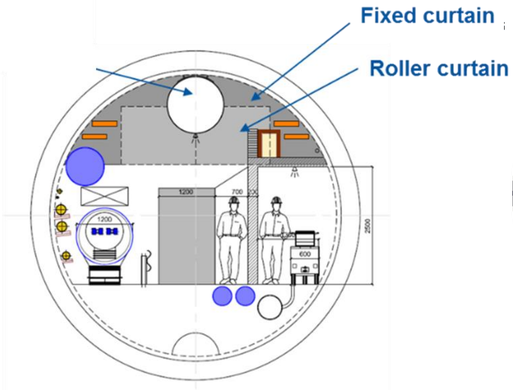
Double tunnel (sketch) - 2012

Double tunnel - 2014

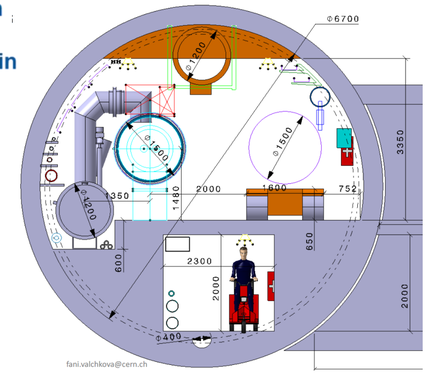


Smoke-ventilation ducts - 2016

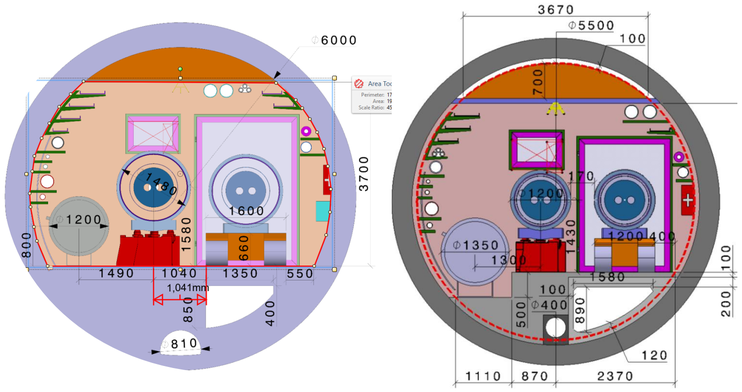




Lateral safe passage + smoke curtains - 2017

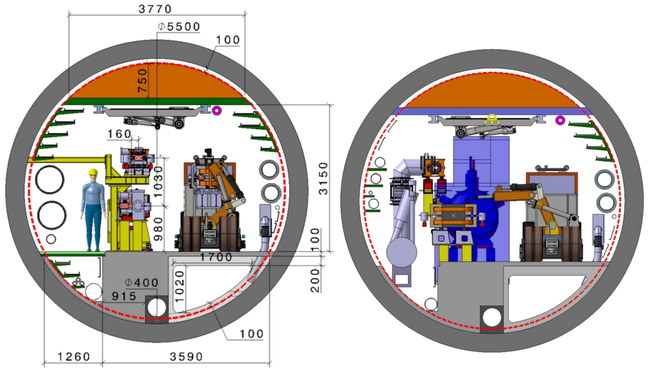


Underground passage - 2018



Fire compartments - 2018

Baseline - 2024



Hazard registry

Standard Best Practices vs Performance-based

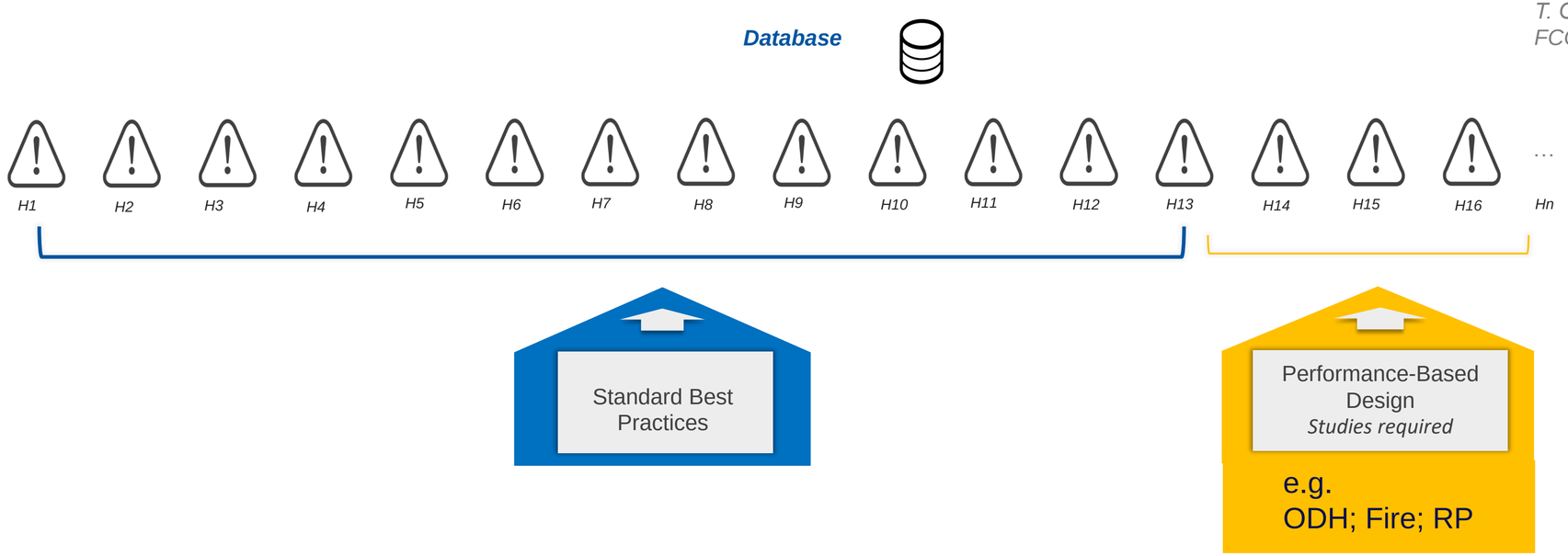
- Systematic collection of Hazards in the FCC facilities during different phases of its lifetime
- No assessment of probability or severity

A1	External Hazard to Facility
A2	Hazard to the Environment
B1	Physical Hazards
B2	Radiation, ionising
B3	Radiation, non-ionising
B4	Noxious Substances
B5	Fire Hazards
B6	Mechanical Hazards
B7	Electrical Hazards
C1	Working Environment
C2	Physiological Constraints
C3	Unexpected events
C4	Organisation
C5	Psychological Constraints

- Activation of ground
- Additional Traffic
- Noise (Environment)
- Release of pollutants: air
- Release of pollutants: solid
- Release of pollutants: water
- Release of radioactive liquid
- Release of radioactive solid
- Release of radioactivity by air

- Dangerous surface
- Fall of object from height
- Fluid under presure
- Uncontrolled object in motion
- Unprotected element in movement

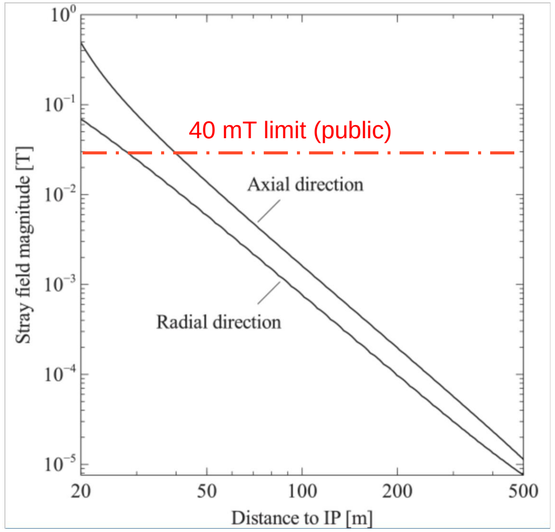
T. Otto, "FCC Safety Strategy for the Conceptual Design Report", FCC Week 2017, Berlin GE



See "Radiological studies for FCCee", G. Lavezzari

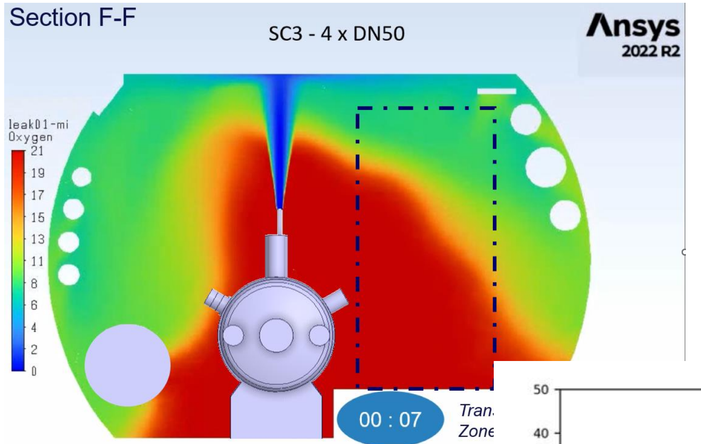
Hazard registry

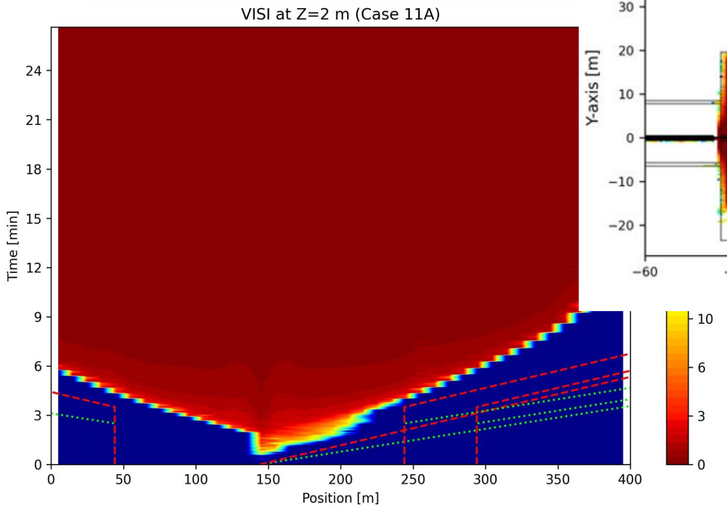
Standard Best Practices vs Performance-based (Safety studies)

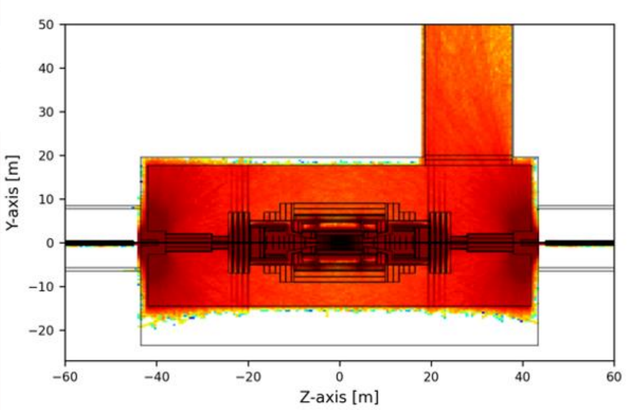


K. Hanke, "Residual magnetic field at surface of experimental points", FCC-INF-PM-0077 v.1

IP Rating







SAFETY SYSTEMS

Safety Systems

Integrated approach

Evacuation guidance system
(dynamic signage, RFID)

Hazard Detection
(ASD, Fiber Optics, Optical sensors)

Longitudinal compartments
(static confinement)

Horizonal & Vertical egress redundancy
(shafts, lifts)

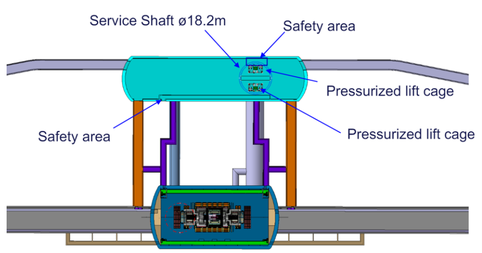
Emergency Response
(First Responders, Fire Fighting means, communication)

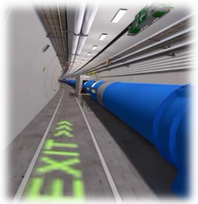
Control the access
(PSS, authorized personnel, safety training)

Air management
(dynamic confinement, smoke extraction)

Personnel Transportation
(vehicle driven egress)

https://www.cityexperiences.com/blog/golden-gate-viewpoints/





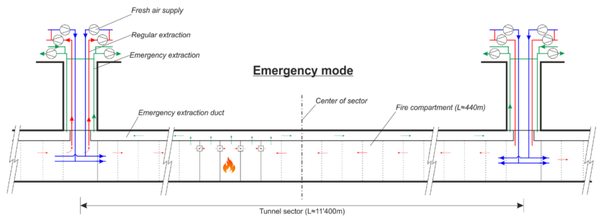
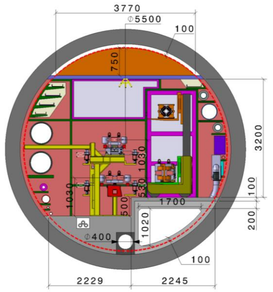
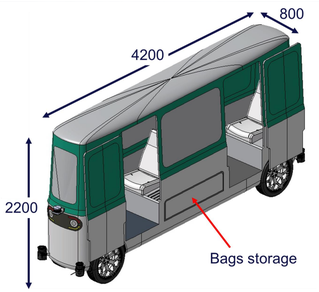


Figure 2.5 Illustration of the alternative tunnel ventilation concept without slab duct in emergency mode (deviation 4 in Table 2.1)

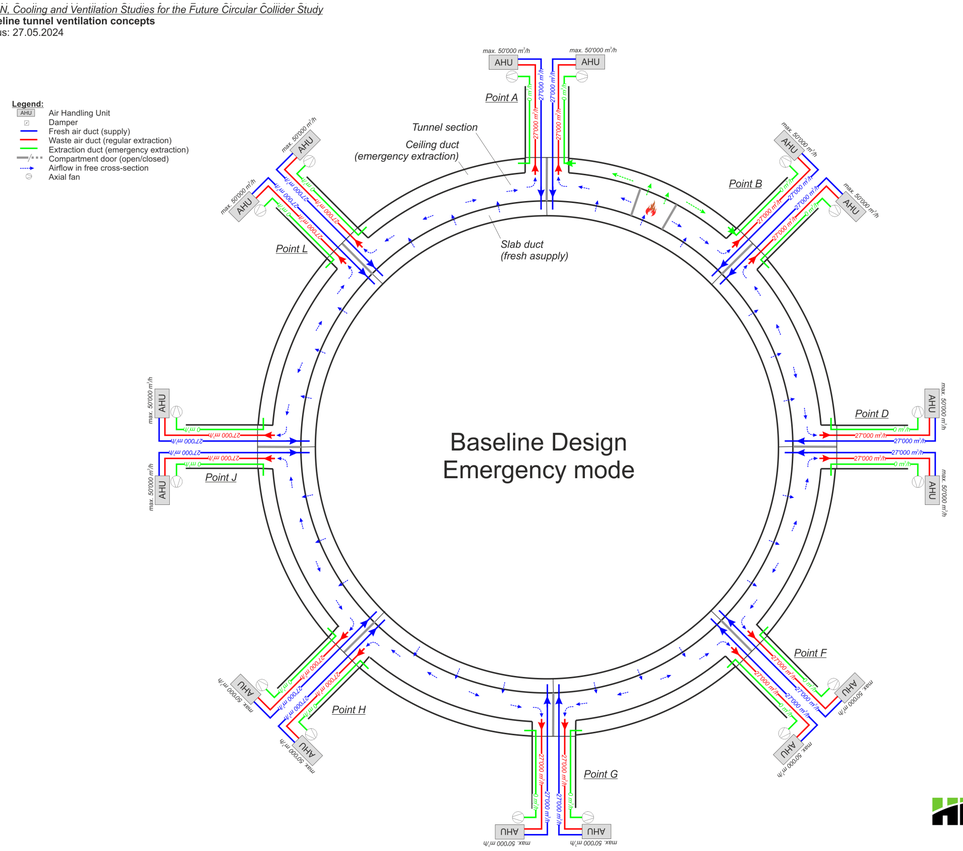




See “Ventilation strategy for the FCC”, I. Martin

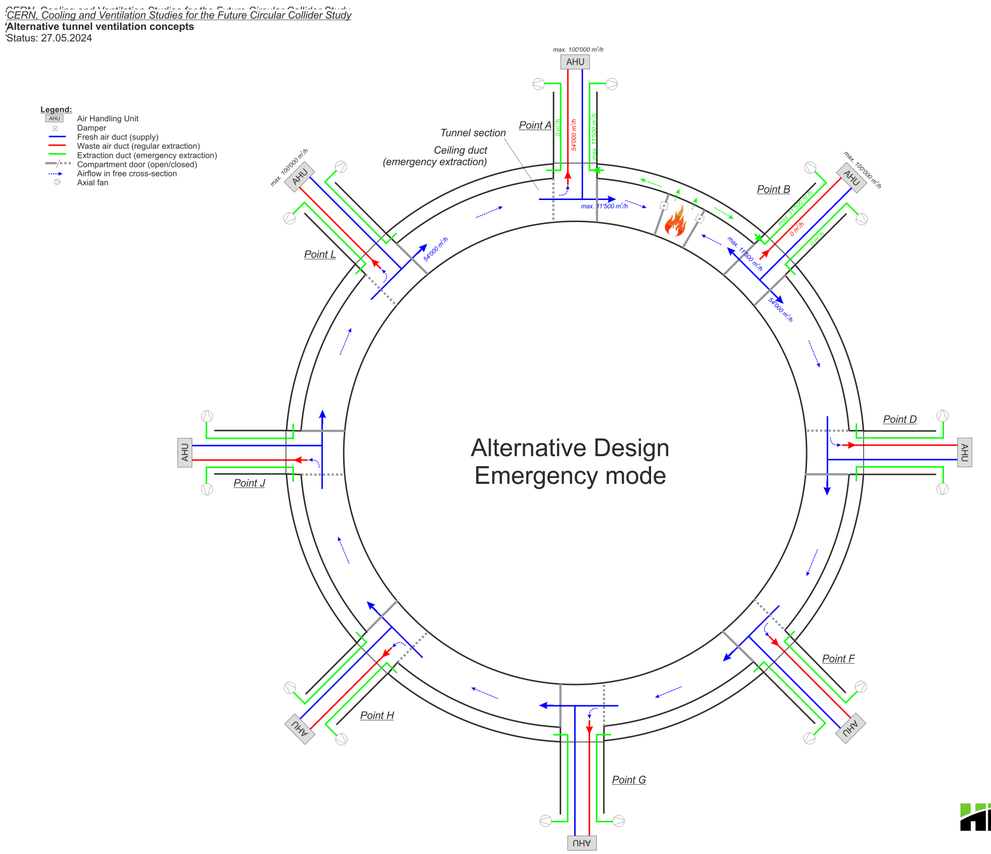
Safety Systems: Underground Air Management

Baseline strategy: Semi-transverse



HBI Haerter Consulting Engineers
Zürich · Bern · Heidenheim · Sydney

Possible Optimization strategy: Longitudinal (cyclic)



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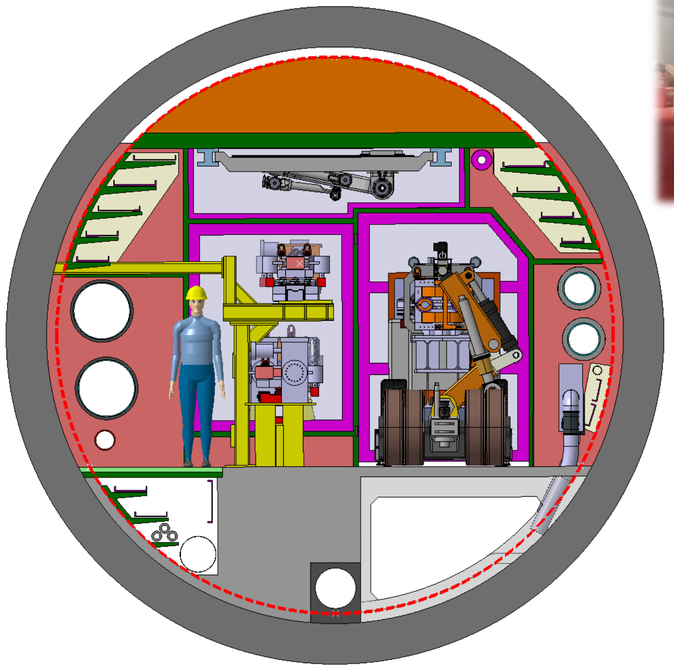
Emergency Mode

Safety Systems: Tunnel Compartments

Objectives:

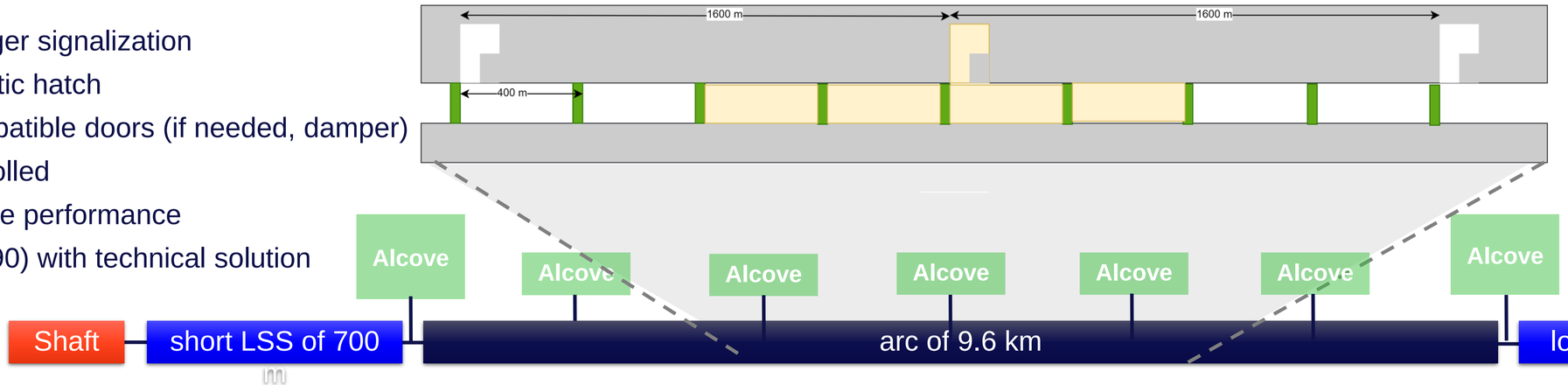
- Safe egress:
  - Allows safe evacuation for occupants
  - Allows static and dynamic smoke confinement
- Search & Rescue from Fire Brigade
  - Enables faster and safer intervention
  - Reduces the smoke diving (air supply)
- Reduces asset loss
  - Limits the propagation and damage to the accelerator and equipment



Example in SPS

Main Features

- Every 400 m there is a tunnel enclosure
- Length compatible with cell length
- Smoke tight
- Dynamic Danger signalization
- Robot automatic hatch
- Pressure compatible doors (if needed, damper)
- Position controlled
- Fire Resistance performance (tbd, EI30/60/90) with technical solution



Alcoves
- 5 + 2 / sector

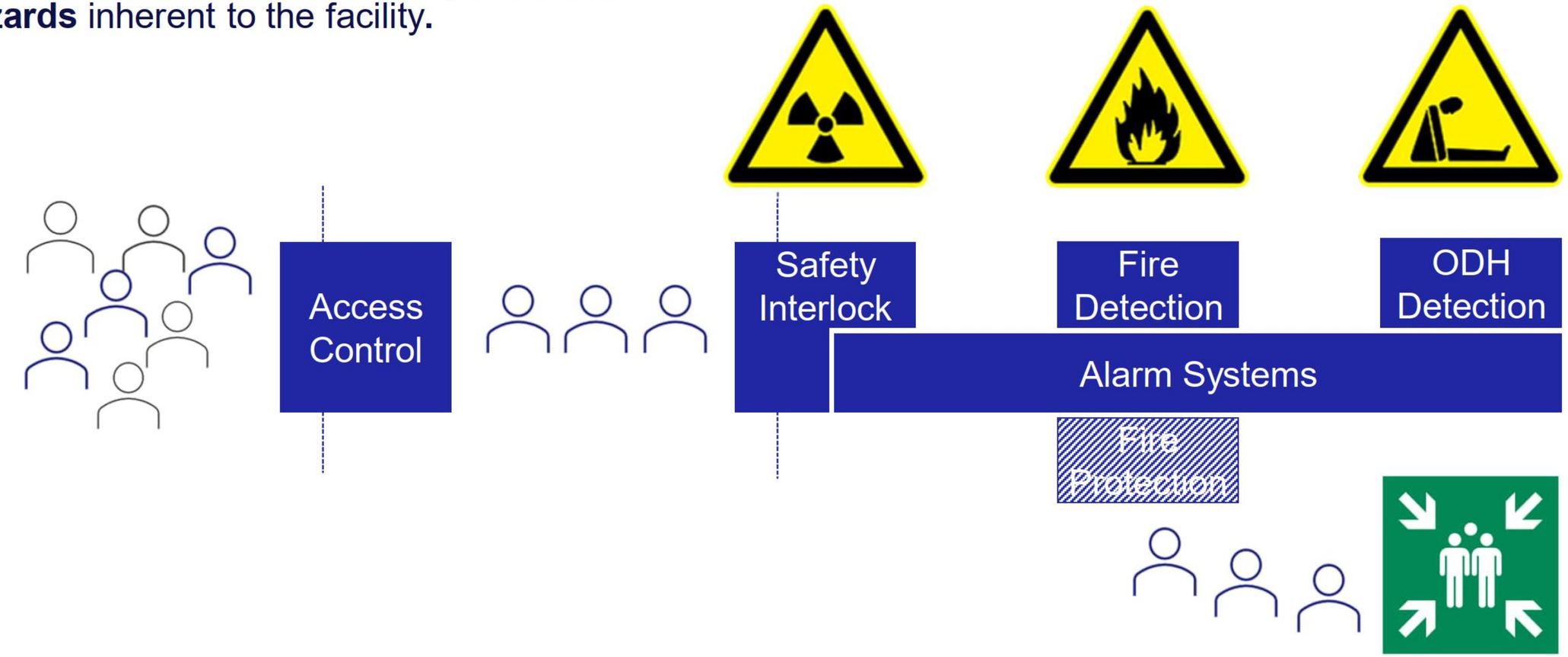
Fire compartments:
- 28 / sector

Safety Systems Personnel Safety Systems

(incl. access control, hazard detection, alarms)

See “Personnel Safety Systems”, T. Ladzinski

Systems installed to protect the **personnel** from **hazards** inherent to the facility.



See “Transport concept for personnel (Normal and evacuation)”, R. Rinaldesi

See “Update on magnet and people transport vehicles and logistics simulation study”, B. Müller

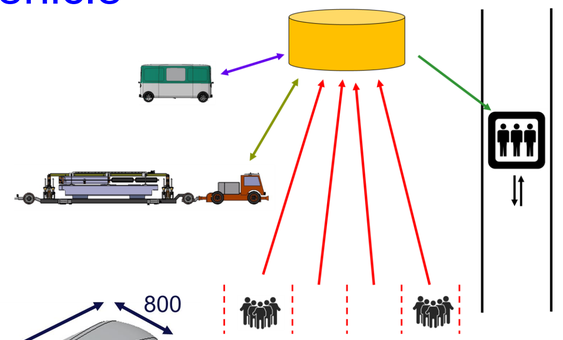
Safety systems Evacuation

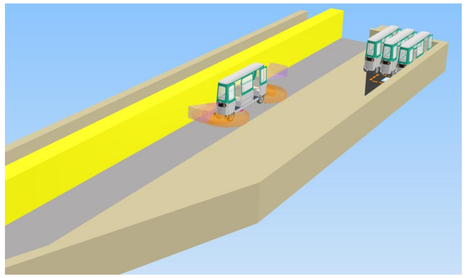
11 km evacuation distance: shall be assisted by other (mechanical) means

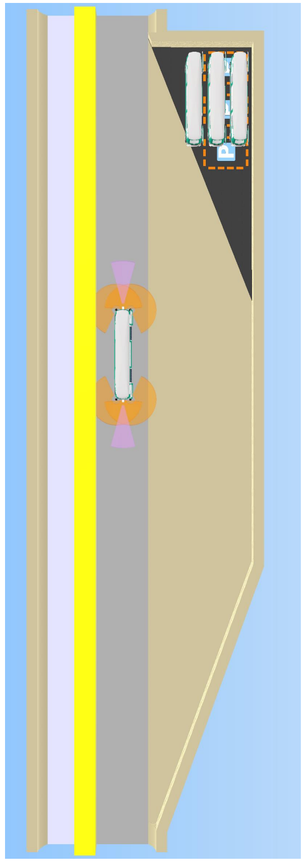
Nominal Strategy: Always available motorized vehicle

Logic

- Go to workplace with vehicle
- Vehicle parked in adjacent area (short intervention, near-by-stand-by)
- In case evac. Walk to vehicle and leave
- Cross-over possible
- Symmetrical vehicle. Reversing direction

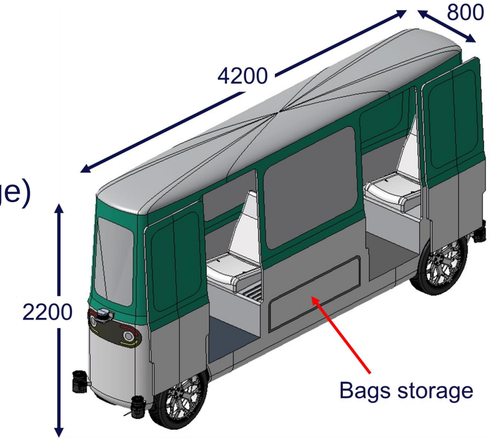






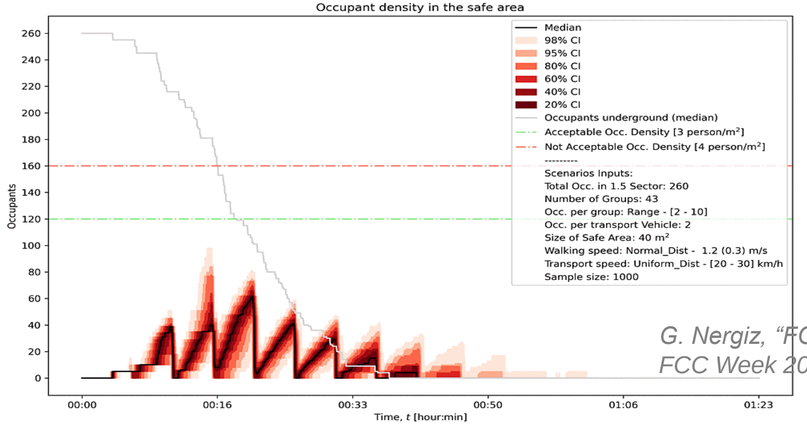
Main Features

- Autonomous driving
- 4 seats + 4 bags (size equivalent to cabin luggage)
- Max speed: 30 km/h
- Battery driven; autonomy of 150-200 km
- Weight (fully loaded): 1500 kg
- Line guidance
- Equipped with LIDAR sensors and laser scanners
- Equipped with First Aid and first intervention material



No rescue refuges but Safe Areas

- Safe waiting are connected to shaft
- Over pressurized and fire rated
- Occupational crowding and size study. 40m^2



G. Nergiz, “FCC Evacuation modelling, FCC Week 2023, London UK

Degraded Strategy: emergency + vehicle down

- Alternative vehicle (communication)
- Ultimate manual transportation in alcove (bike, tricycle, scooter)

PERFORMANCE-BASED STUDIES

Update since FCC Week 2023

See “Radiological studies for FCCee”, G. Lavezzari

Oxygen Deficiency Hazard in RF section

Input data

Ref: From Cryo SRF Task Force

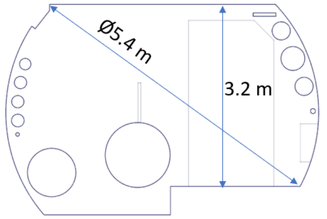
Class/Case	Risk Situation	Mass Flow	Pressure Reached [bar]	Discharge Diameter
1	Static losses on cryomodule insulated from cryogenic plant	7.3 g/s	~ 1.7	1 SV of DN < 20mm
2	**Sustained RF quench**	**2.9 Kg/s**	**~ 2**	**Min 4x48mm BD**
3	I… vac…			…mm …0)
4	Beam vacuum break (100 mm aperture)	9.2 Kg/s	~ 12	4 x DN80 BD not sufficient to contain the pressure build up

* Preliminary values scaled from LHC cryomodules. New simulations running with updated figures (FCC-related)

Assumption: Same discharge area from the LHC risk assessment

Scenario	Number of Release points per cryomodule	Release Diameter (each point) [mm]	Release Rate (each point) [kg/s]
1	1	100	2.9
2	2	100*	1.45 (2.9 / 2)
3	4	50	0.725 (2.9 / 4)

*It should be 71 mm in reality, but slightly more conservative



Version: 06.2023
FCC Tunnel Point H – RF Section

Helium Release conditions:

- @400 MHz Cryomodule;
- Inventory: **900 L**
- Mass flow rate **2.9 kg/s** * @ 2 bar
- Total Helium inventory = 107 kg
- Total release time = **37 seconds**
- Additional **20 s** after helium release **cut-off** (57 s in total)

Ventilation Conditions:

- Semi-Transverse ventilation concept **27000 m³/h**
- Tunnel ventilation inlet **25140 m³/h**
- Fresh air inlets **4 x 465 m³/h**

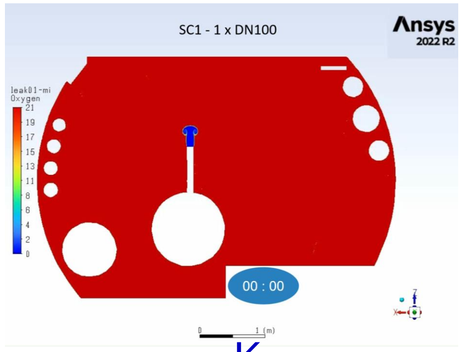
Objectives:

- Observe the turbulent effects near the release point(s)
- Extent of the ODH risk (O2 < 18%)
- Cloud propagation
- Impact on the cross-section geometry

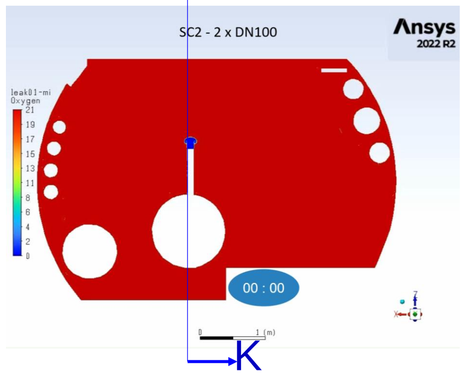
Oxygen Deficiency Hazard in RF section

Release Point mid-section (-1.25 m)

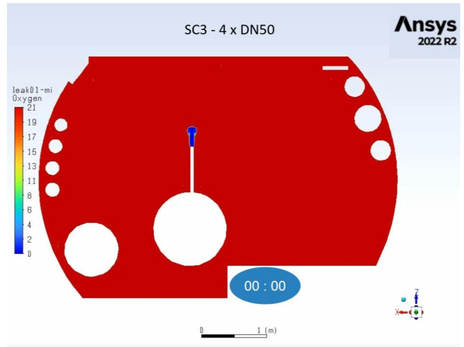
SC1
1xDN100



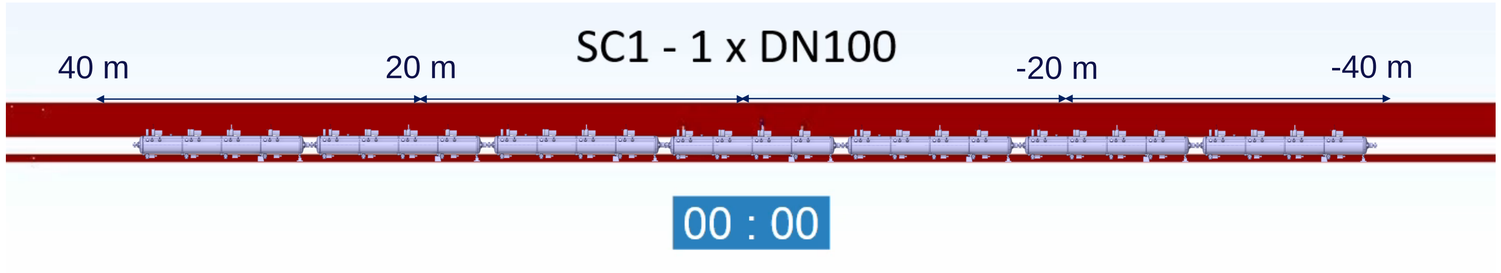
SC2
2xDN100

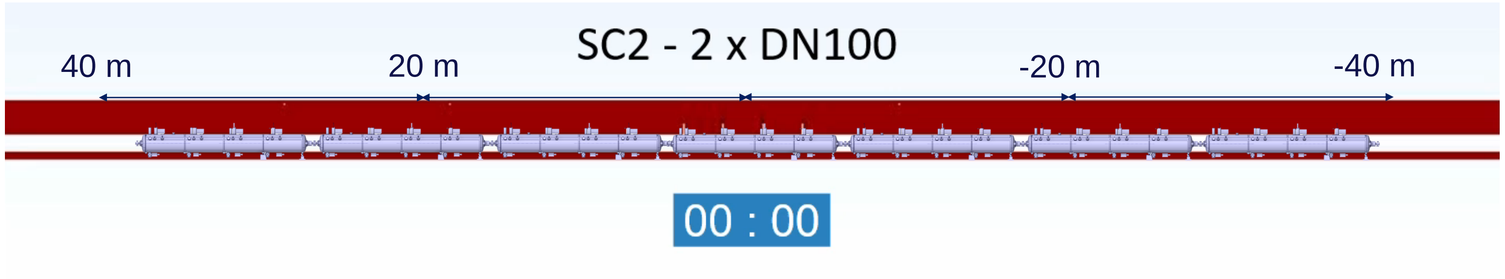


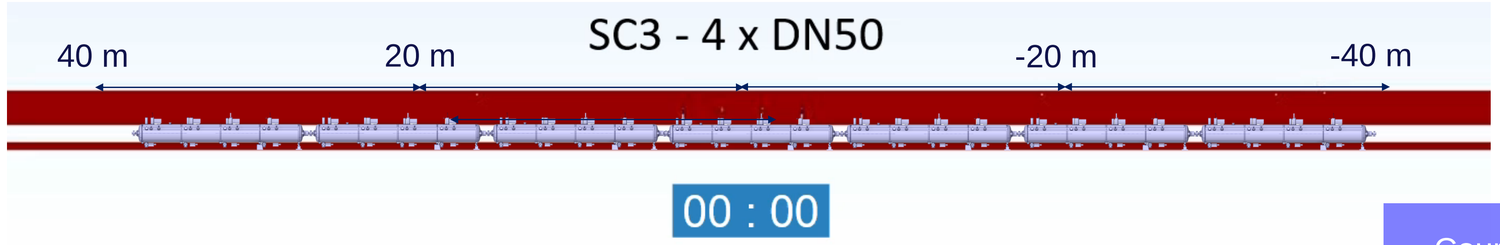
SC3
4xDN50



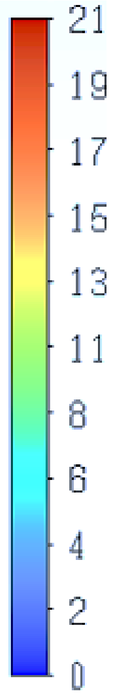
Section K – K







Oxygen Level [%]

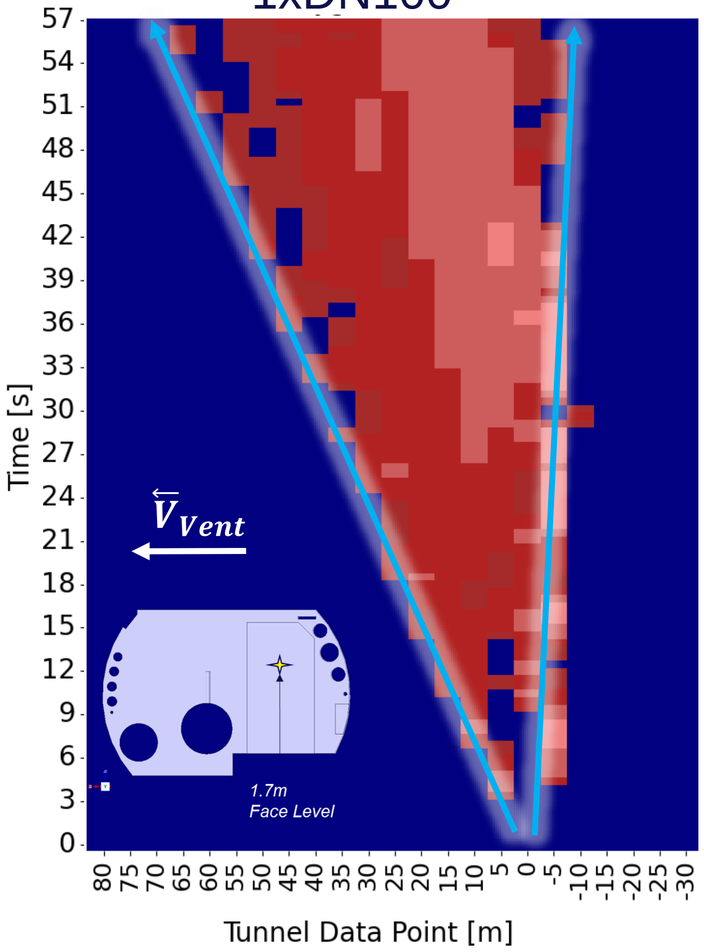


Courtesy G. Nergiz

Oxygen Deficiency Hazard in RF section

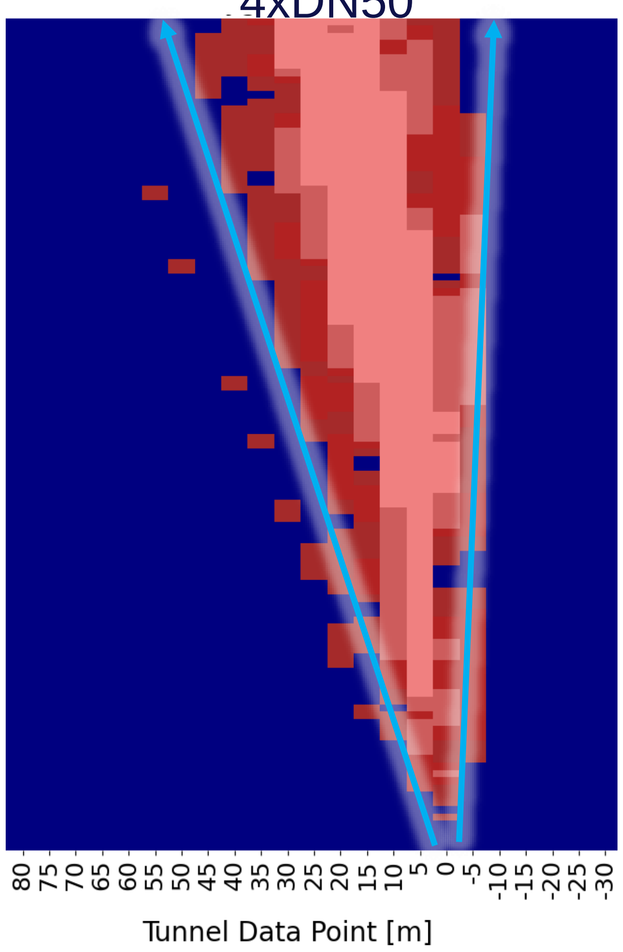
SC1

1xDN100



SC3

4xDN50



Propagation speed and plug size

SC	Cloud front [m/s]	He Plug (< 37s) [m/s]	He Plug (≥ 37s) [m/s]	Plug size [m]
1	~1.52	~0.66	~0.58	~32.3
2	~1.33	~0.57	~0.7	~29.4
3	~1.66	~0.63	~0.81	~34.6

Conclusions:

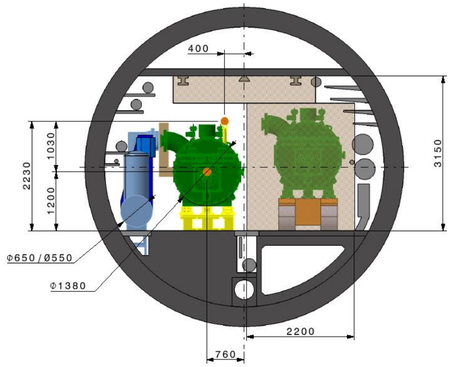
- Turbulent effects near the release point(s) is confirmed
- O2 < %18 in 10 seconds
- He plug formed and for up to 35 m

Oxygen Deficiency Hazard in RF section

Next Steps – More simulations

- New simulations with updated cryomodule thermo-hydraulic and mechanical design
  - Updated risk assessment, tailored to FCC SRF
  - Significantly higher flow rates (↑ cavity surface areas)

- New simulations with
  - Updated Cross-section
  - Use of emergency extraction system (effect on the He plug)



Helium safety and PRDs

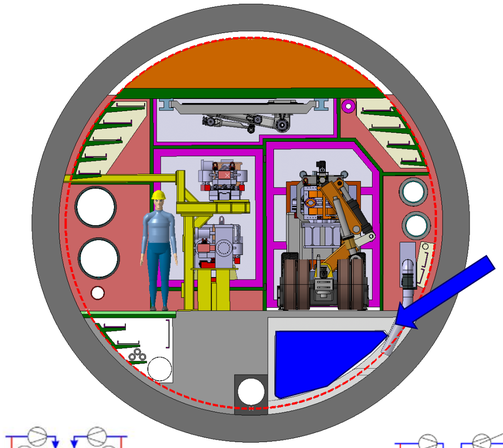
CM/ Case	Risk Situation	Heat load	Mass flow	T	Pressure reached (bar)	Discharge diameter	Comments
400MHz – Risk case scenario 3	Beam vacuum break (100 mm aperture)	380 kW	**19.57 Kg/s**	4.99K	~ 1.95 bara	**$Ø_{min}$= 130.5mm** **1 x BD DN150** **or** **2 x BD DN100** (each one taking half of the flow rate)	HL calculated considering the wet surface of the cavities (9.5m^2) without protection (4 W/cm^2). Exceptional case. Mitigation measures are needed to contain the probability of this event (e.g. orifice limiting bellows protections, no mech. work with liquid inventory).
800MHz – Risk case scenario 3	Beam vacuum break (100 mm aperture)	195 kW	**10.3 Kg/s**	4.99K	~ 1.95 bara	**$Ø_{min}$= 95mm** **1 x BD DN125** **or** **2 x BD DN80** (each one taking half of the flow rate)	HL calculated considering the wet surface of the cavities (4.96m^2) without protection (4 W/cm^2). Mitigation measures are needed to contain the probability of this event (e.g. orifice limiting bellows protections, no mech. work with liquid inventory).

See “SRF system integration - cryomodule functional specifications and design of the 400MHz”, K. Canderan

Smoke extraction and **Life Safety: PBD Study**

Aim and Scope

- ✓ Validate smoke extraction + compartment baseline
- ✓ Explore longitudinal alternative proposal
- ✓ Compare safety level
- ✓ Study degraded modes



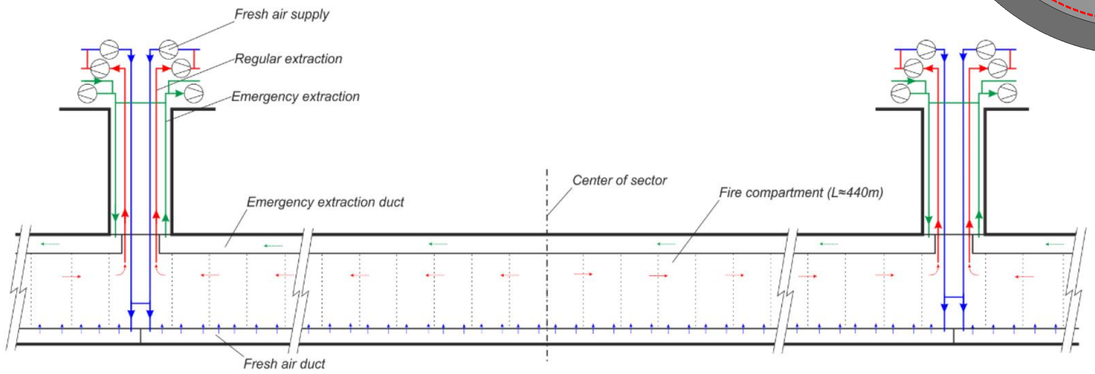
Fresh-air duct

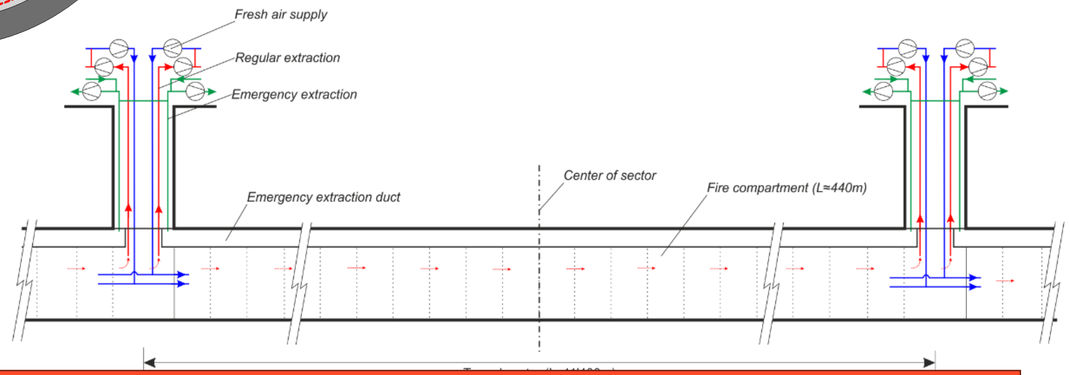
For semi-transverse only

Semi-Transverse

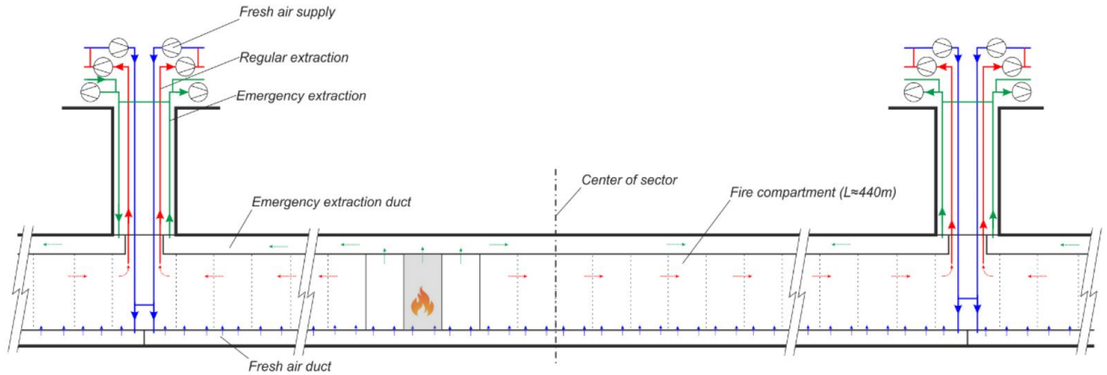
Longitudinal

Run/Access

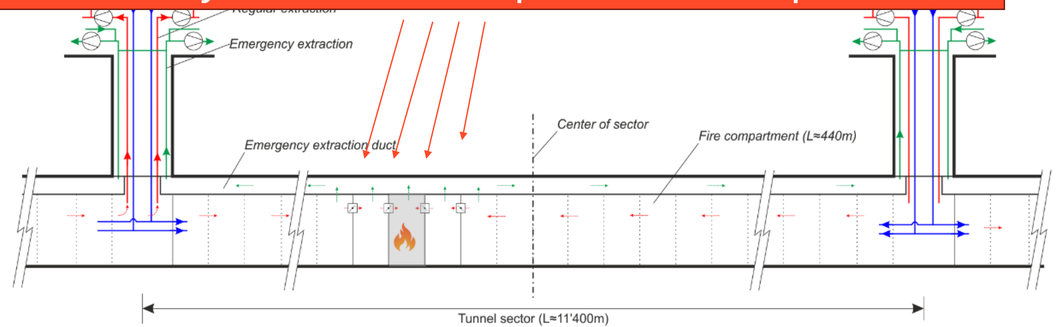




Emergency



Mechanically controlled dampers in all compartments

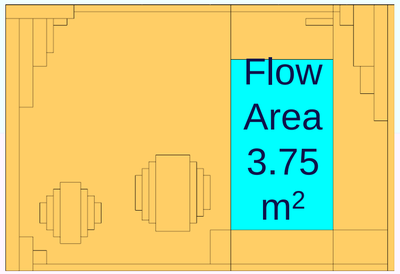


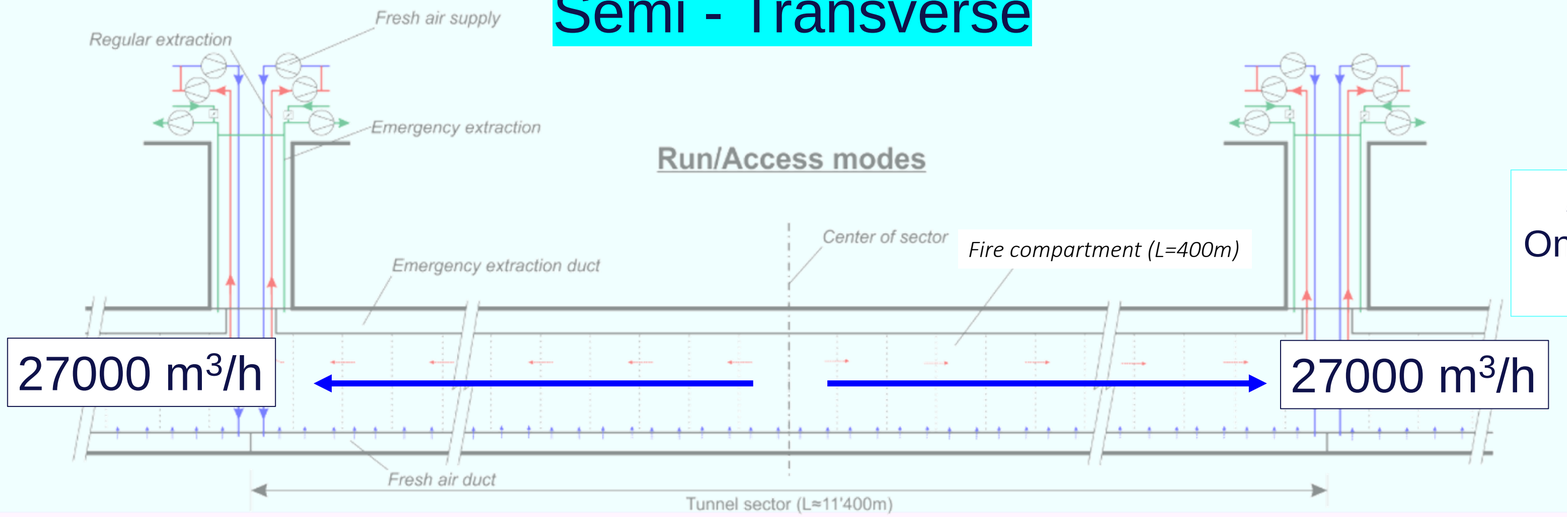
Global Picture Comparison Between Concepts

Semi - Transverse

S-T Worst Case
The Last Compartment
The Last Door

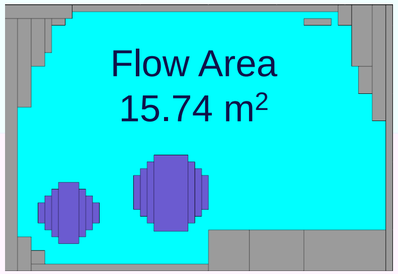
Avg. Max. Flow Velocity
On the Door
2 m/s





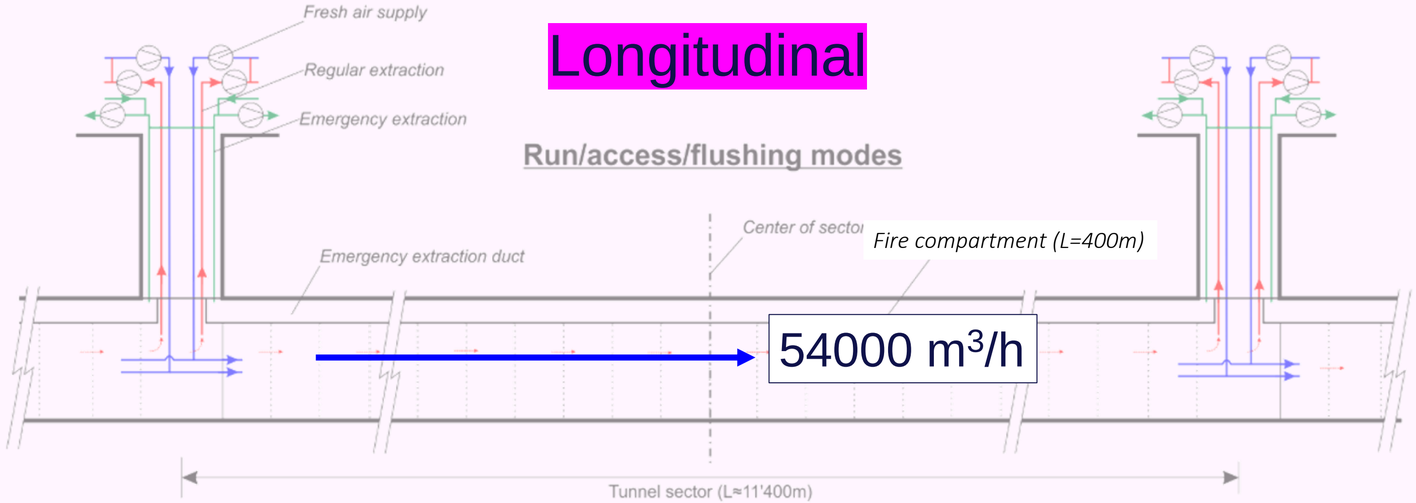
S-T Worst Case
The Last Compartment
The Last Door

Avg. Max. Flow Velocity
On the Tunnel Cross-Section
0.5 m/s



Longitudinal

Avg. Max. Flow Velocity
On the Door
4 m/s
(reduced with dampers)

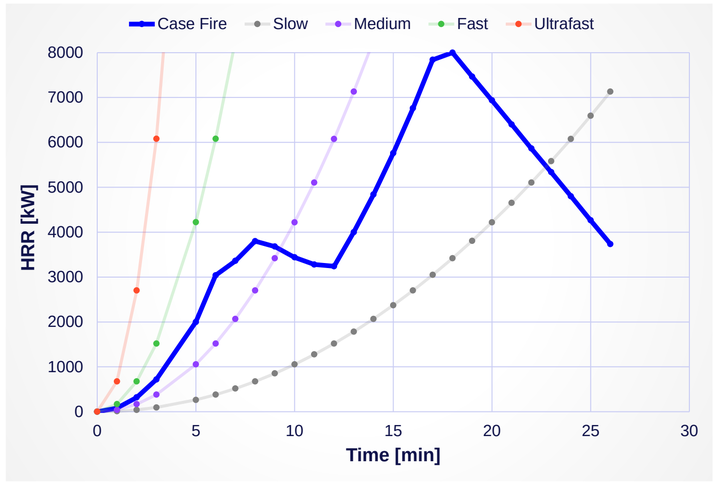


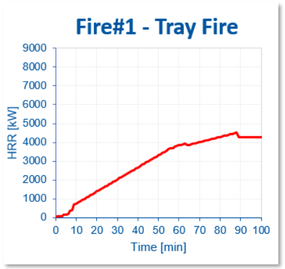
Avg. Max. Flow Velocity
On the Tunnel Cross-Section
1 m/s

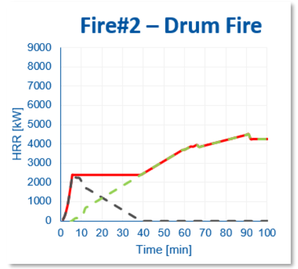
Longitudinal Worst Case
The First Compartment
The First Door

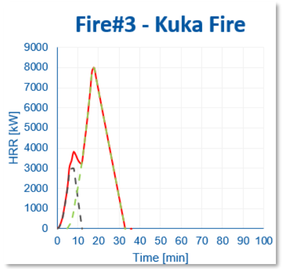
Longitudinal Worst Case
The First Compartment
The First Door

Smoke extraction and **Life Safety:** Criteria









Acceptability criteria	Criteria (after fire start)
Visibility	>10 m at height of 2m
Occupants exp. FED	< 0.3
Occupants' exp. Temperature	< 60 C

ASET
(Available Safe Evacuation Time)

Comparative criteria	Criteria (after fire start)
Time to FED	Time to FED = 0.3 and FED = 1.0
Time to lose Visibility	Time to reach 10m visibility at height of 2m
Exposed Occupants	Exposed by smoke or not (decreased visibility)
Smoke Travelling Speed	Avg. speed of smoke (smoke travelling speed from fire point to the long end of the tunnel)
Air Velocity at Fire Doors	Avg. air velocity on the fire door's cross-section

For Comparison, also degraded modes are studied

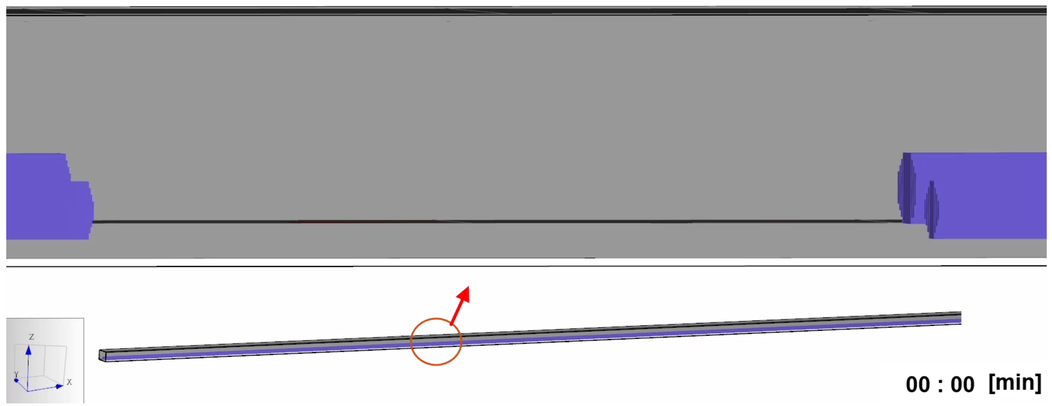
- Smoke extraction fails
- Fire Detection fails
- Smoke extraction delayed
- Make-up air fails

+ parametric exploration on optimal smoke extraction flow

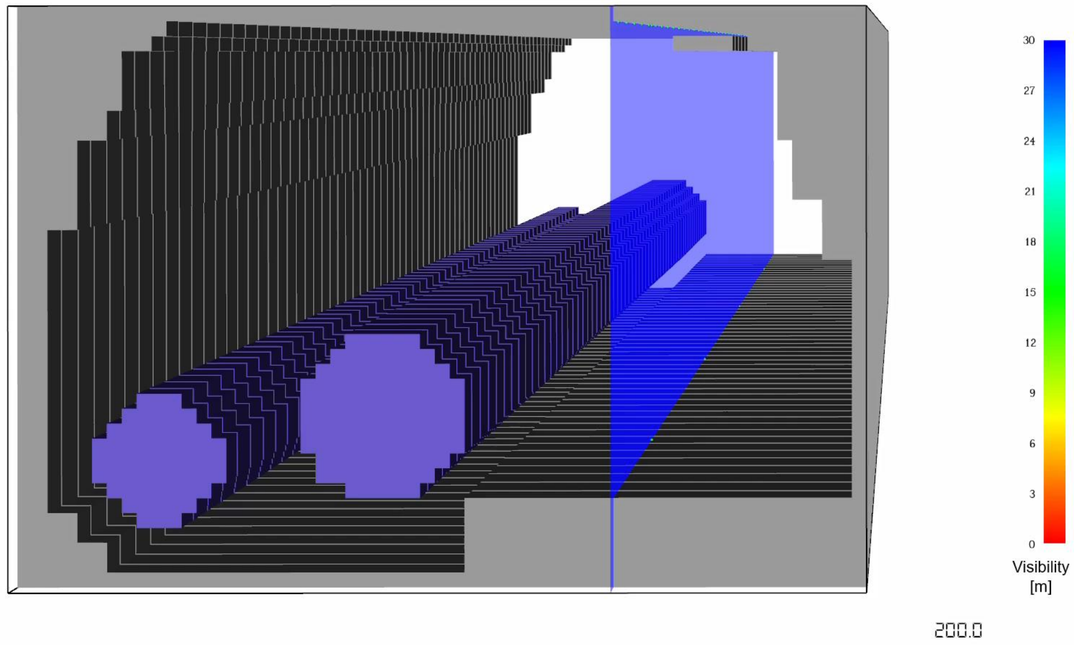
7.000 m^3/h – 14.000 m^3/h – 20.000 m^3/h – 28.000 m^3/h

Smoke extraction and **Life Safety: Results**

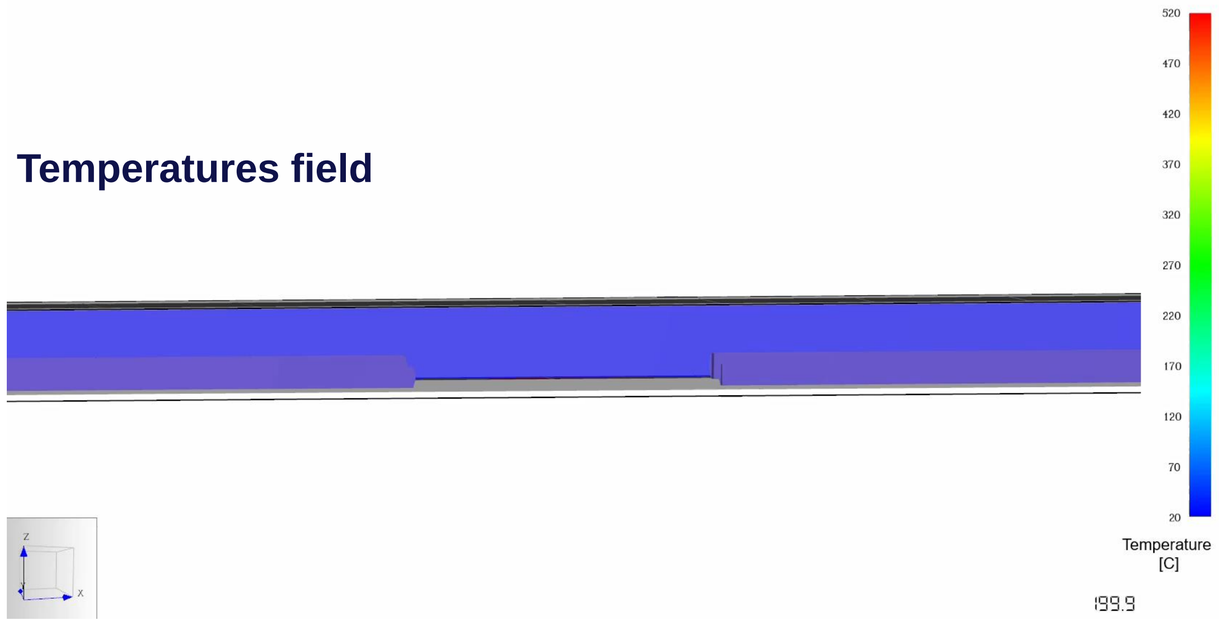
HRR + visibility + temperature
Horizontal velocity



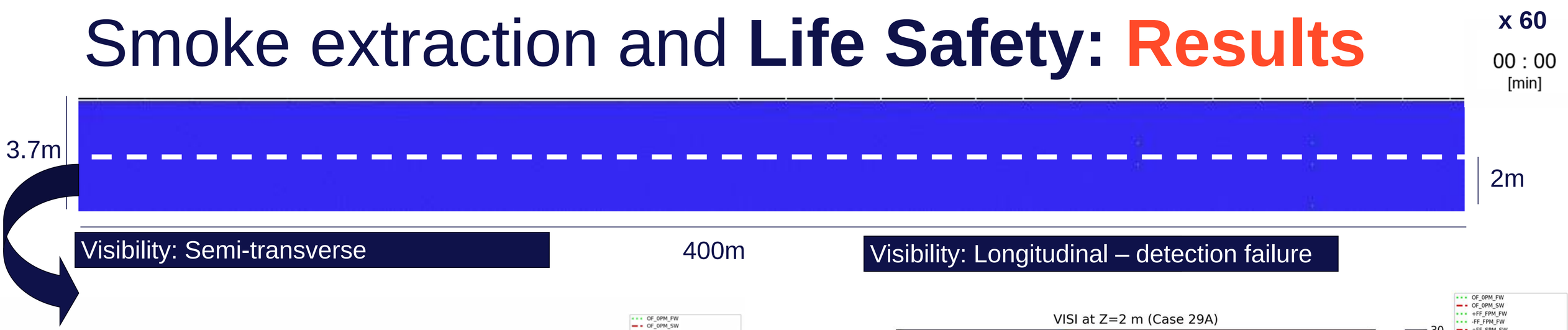
Smoke + visibility



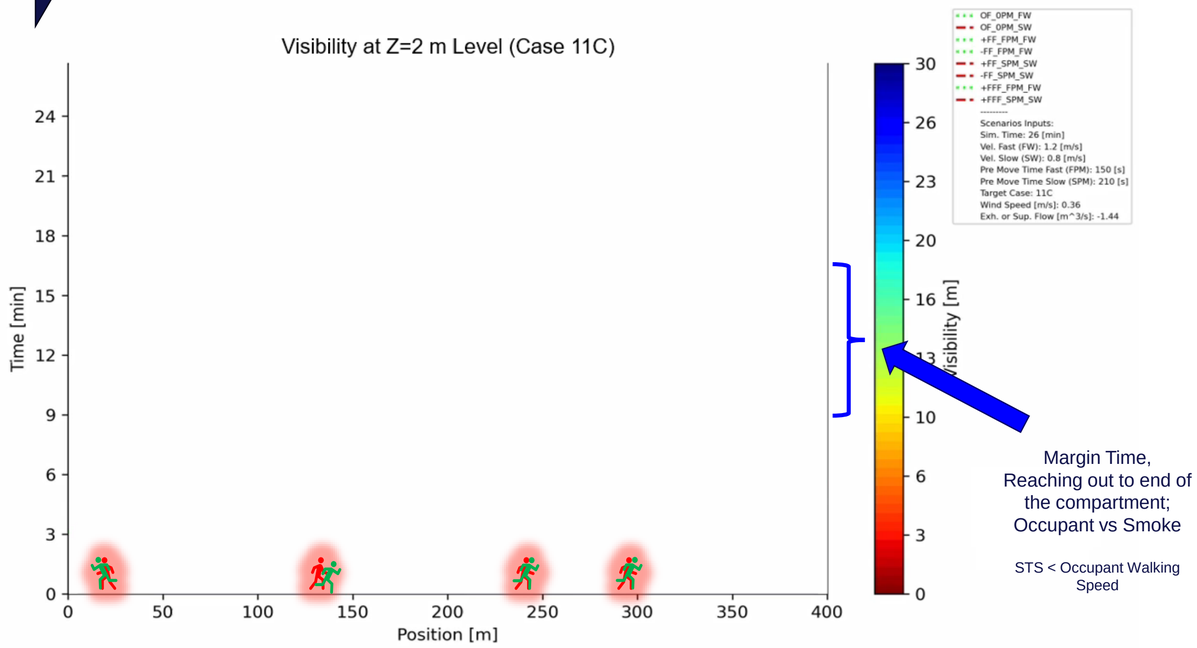
Temperatures field



Smoke extraction and **Life Safety: Results**



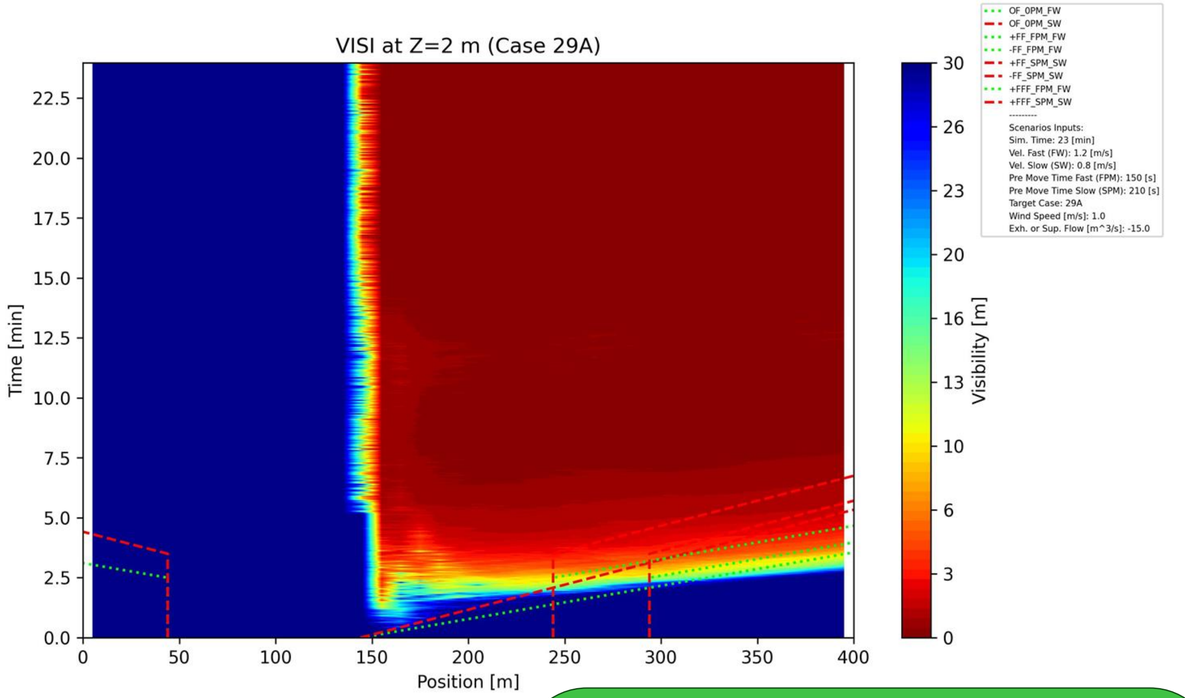
Visibility: Semi-transverse



Margin Time,
Reaching out to end of the compartment;
Occupant vs Smoke

STS < Occupant Walking Speed

Visibility: Longitudinal – detection failure



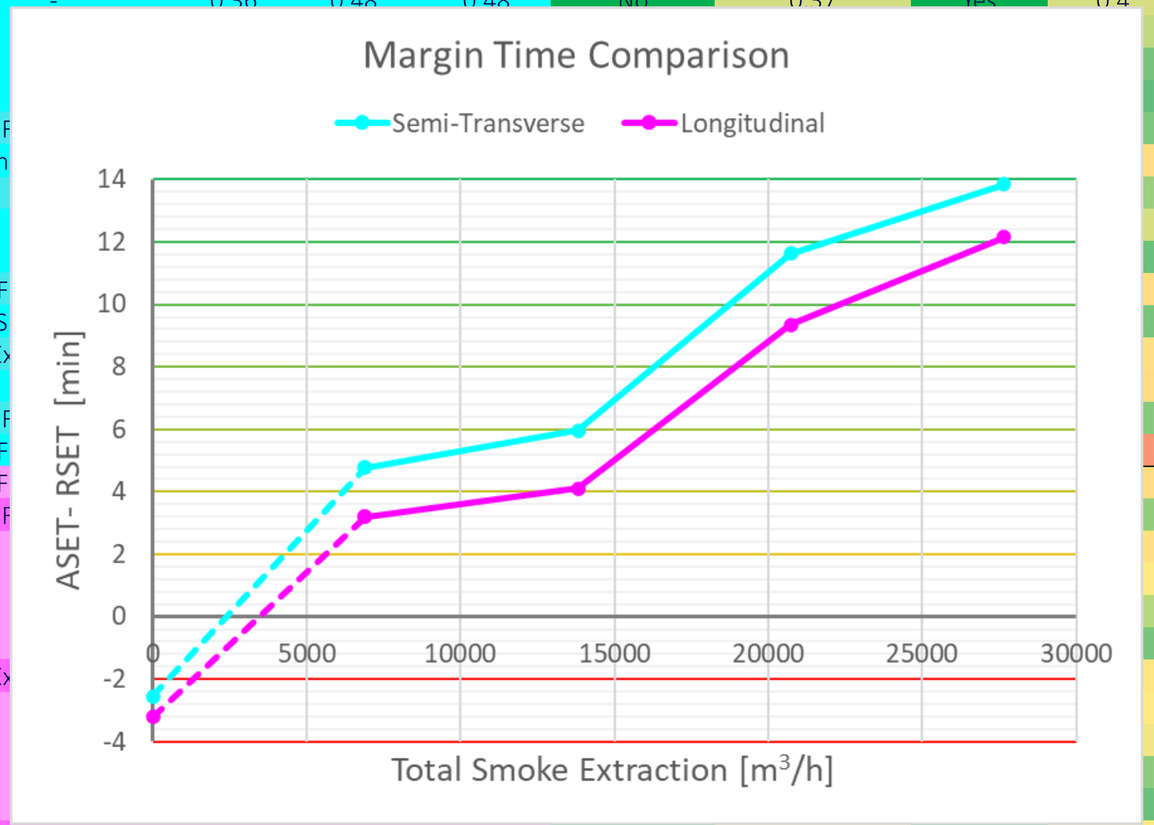
Pre movement time: 0s, 150s, 260s
Walking speed: 0.8 m/s – 1.2 m/s

Margin time = ASET - RSET

>30 CFD runs

Smoke extraction and **Life Safety: Results**

Case Name	Ventilation Type	Failure Type	Failure Explanation	LBFV* [m/s]	Supply Rate [m^3/s]	Exhaust Rate [m^3/s]	Occupant Exposed or Not	Smoke Travelling Speed [m/s]	STS < Walking Speed	Speed margin [m/s]	Margin Time [min]	Time to FED 0.3 [min]	Time to FED 0.3 long end [min]	Time to FED 0.3 short end [min]	Time to FED 1.0 [min]	Air Velocity at Door > 3 m/s (critical)
1.1A	Semi-T.	-	-	0.36	0.48	0.48	No	0.37	Yes	0.4	4.7	16	24	18	22	-
1.1B	Semi-T.	-									5.7	16.5	26	18.5	24	-
1.1C	Semi-T.	-									11.2	17	>26	19.5	>26	-
1.1D	Semi-T.	-									13.7	18	>26	20.5	>26	-
1.5A	Semi-T.	Delay	60s F								10.2	17	>26	19	>26	-
1.6A	Semi-T.	Delay, 4	60s Fan								1.2	17	23	19	24	No
1.7A	Semi-T.	-									7.7	17	>26	19	25.5	-
1.2A	Semi-T.	-									4.7	16	24	25	22	-
1.2B	Semi-T.	-									12.7	19	>26	21	>26	-
1.8A	Semi-T.	1	No F								1.2	13	16	18.5	20	No
1.9A	Semi-T.	2	S								11.2	15.5	22.5	17.5	21.5	No
1.10A	Semi-T.	3	Ex								1.7	16	22	17.5	23.5	No
1.11A	Semi-T.	4									1.2	16.5	23	19	24	No
1.12A	Semi-T.	Delay	60s F								9.7	17	17	19	>26	No
1.13A	Semi-T.	1	No F								-2.8	18	21	>26	18	Yes (10)
2.1A	Long.	1	No F								1.2	16.5	19.5	17	21	No
2.2A	Long.	Delay	60s F								8.2	14.5	>26	16.5	21.5	-
2.3A	Long.	4									1.7	13.5	19.5	16	20.5	No
2.3B	Long.	4									3.2	15.5	23	18	21.5	No
2.3C	Long.	4									6.2	16	>26	18	21.5	No
2.3D	Long.	4									11.2	16	>26	18	22	No
2.4A	Long.	3	Ex								2.2	16	23	18.5	19	-
2.5A	Long.	-									3.2	15	23	17	20	-
2.5B	Long.	-									3.7	14.5	>26	16.5	21	-
2.5C	Long.	-									9.2	14.5	>26	16.5	22	-
2.5D	Long.	-									12.2	15	>26	17	22	-
2.6A	Long.	-	-	0.36	-	0.768	No	0.43	Yes	0.4	3.2	16.5	>26	18.5	20	-
2.7C	Long.	1	No Fire Detection	1	-	CLOSED	Yes	0.66	No	0.1	-0.3	16	20	19	22	No
2.7D	Long.	1	No Fire Detection	2	-	CLOSED	Yes	0.74	No	0.1	-1	13.5	18	22	22	Yes (4.35)
2.8A	Long.	Delay, 4	60s Fan Delay, Door Fail	0.36	-	1.44	Yes	0.36	Yes	0.4	5.2	16	>26	18	22	No
2.9A	Long.	1	No Fire Detection	1	15	CLOSED	Yes	1.42	No	-0.6	-3.8	>26	>26	>26	>26	Yes (21.2)



Smoke extraction and **Life Safety: Conclusion**

- Both **semi-transverse** and **longitudinal** normal ventilation mode **meet safety criteria IF nominal conditions are considered** (not degraded mode).
- **Semi-transverse** strategy performs better at the end of the compartment (larger safety margin), longitudinal case adds **efficient pressure confinement**.
- **Longitudinal** case becomes **unacceptable in case of failure to detect** (high speeds downwind).
- **Delay** in the **fan starting times** and/or door closing time leads to an increase in the smoke travelling speed, but, in nominal modes there is still margin.
- Exhaust Fan Failure and No Fire Detection simulations show that **prompt detection and active smoke extraction plays an important role for occupant safety in case of accidental fire.**

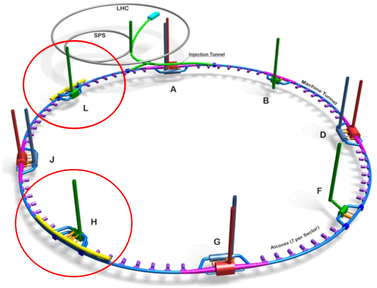
Longitudinal mode remarks:
- In case of door closing, pressure to open door needs to be assessed (and trapping solved)
- Dampers to be sized and integrated in cross section (in fire-walls)
- Passive infrastructure (slab-duct) to be replace by active system (fire-wall reversible damper)

CONSOLIDATED SAFETY DESIGN

Other underground areas

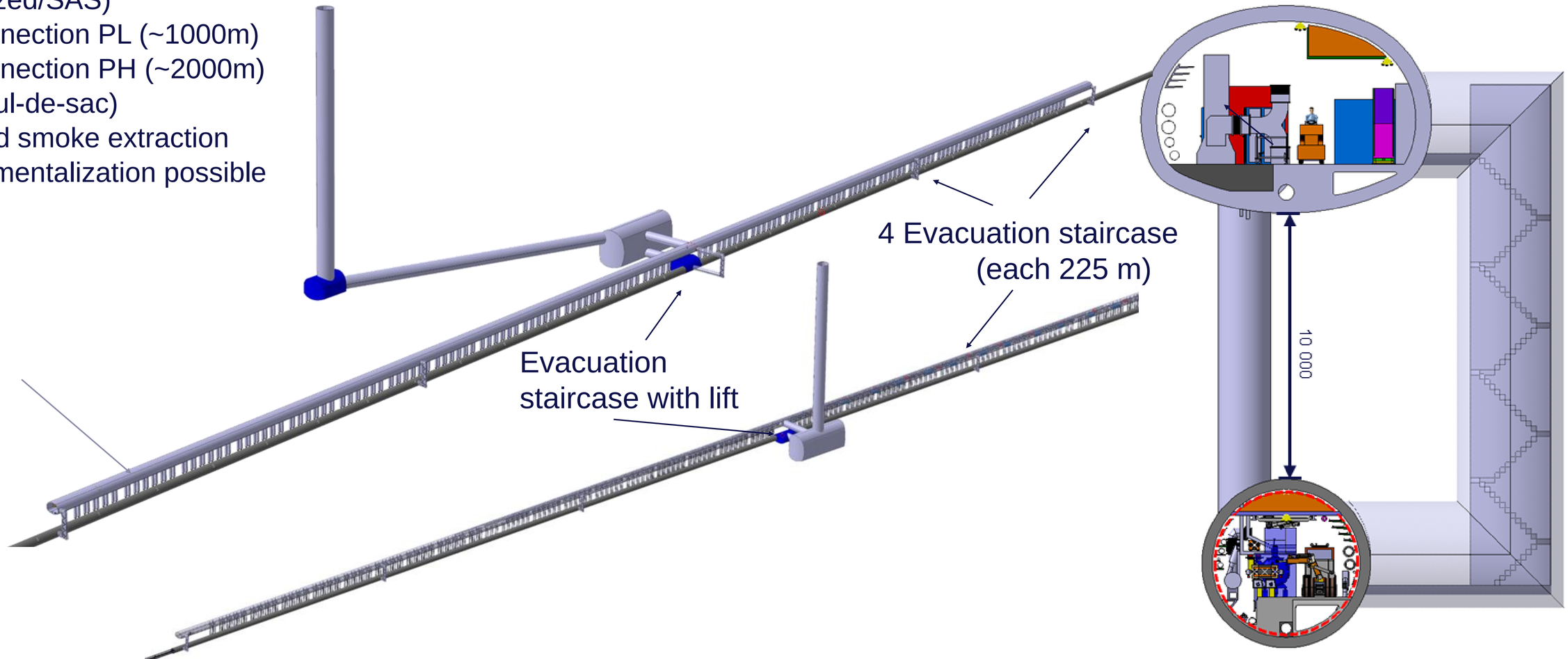
See “Radiological studies for FCCee”, G. Lavezzari

Klystron gallery

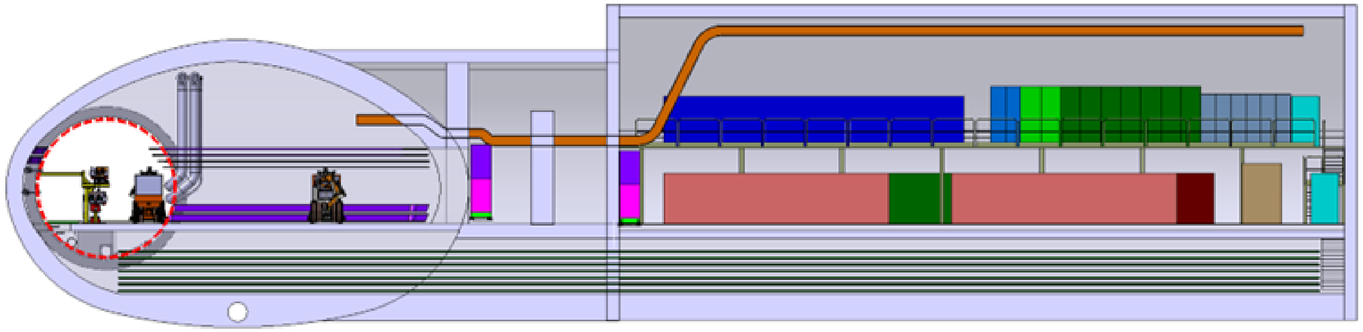


Point H and L

- Klystrons galleries are high fire load + ignition risk areas
- Dedicated emergency connection staircase: (pressurized/SAS)
  - 4 connection PL (~1000m)
  - 8 connection PH (~2000m)
  - (no cul-de-sac)
- Dedicated smoke extraction
- Compartmentalization possible



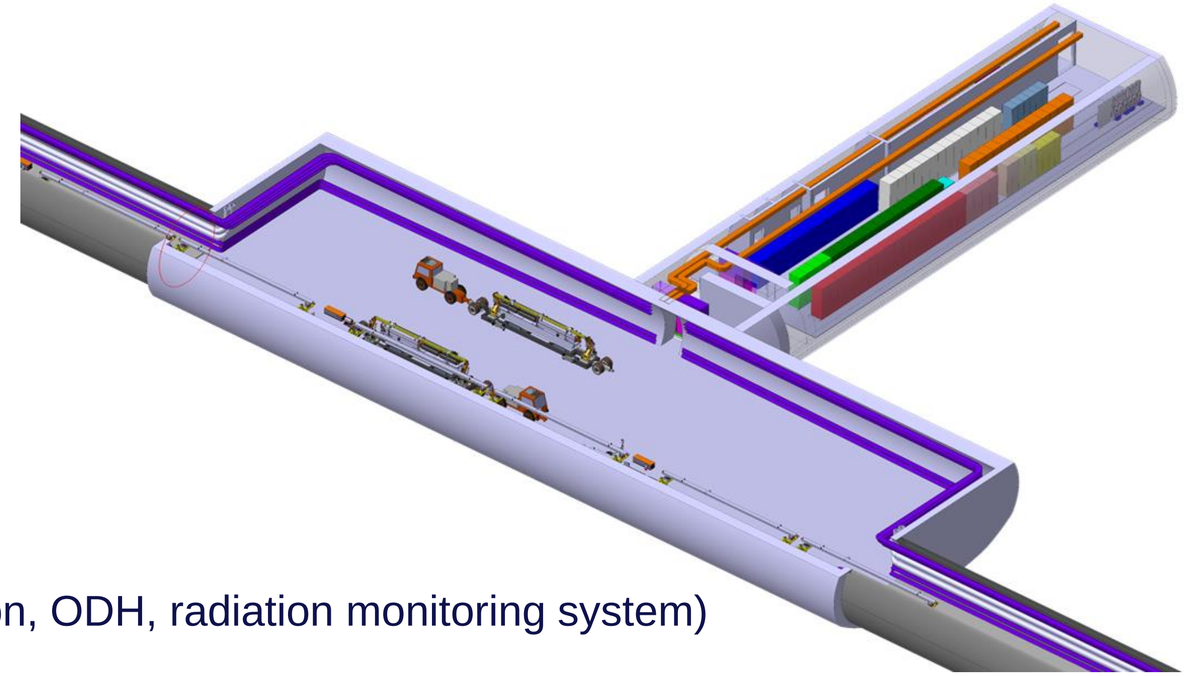
Alcoves



Key: Alcoves are NOT a safety refuge

Safety features

- Fire compartment
- Smoke extraction system
- Detection system
- Limited depth to 40 m cul-de-sac

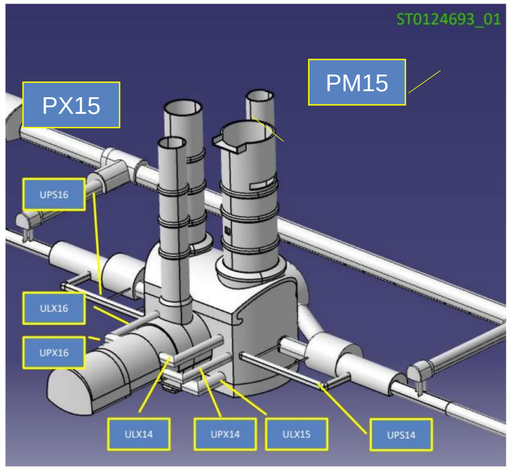


Safety features

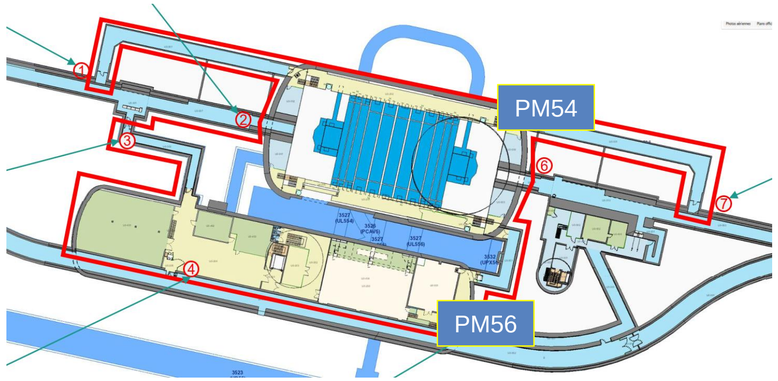
- First-aid and rescue equipment
- Command post (every other alcove)
- Additional PPE (e.g. oxygen masks)
- Other equipment (e.g. fire extinguishers, stretchers, etc)
- Electronic racks for control of safety systems (e.g. Fire detection, ODH, radiation monitoring system)
- Lay-by area for parking vehicles

Experimental / Service Cavern @ IPs

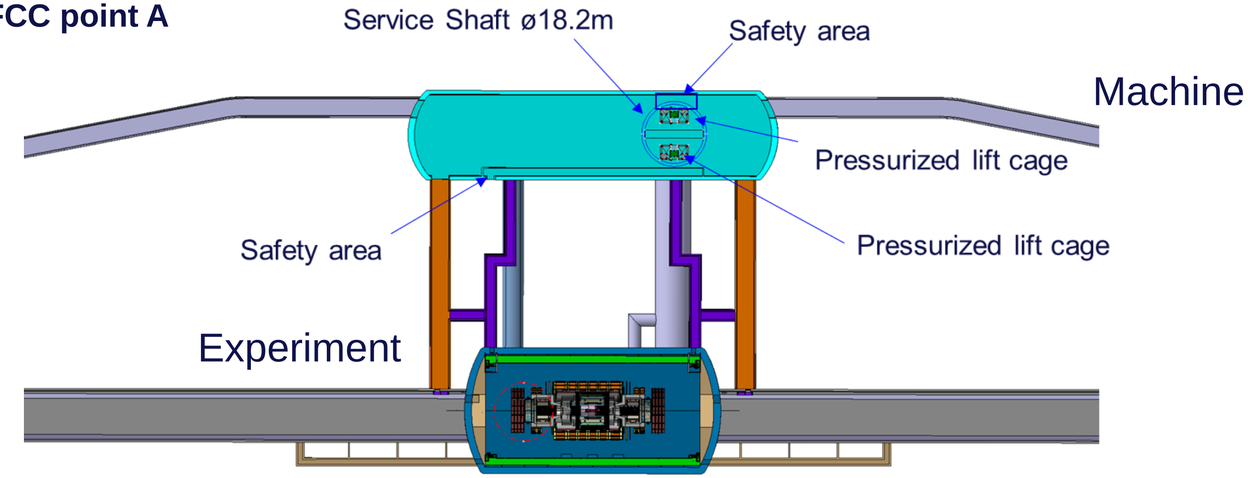
ATLAS underground



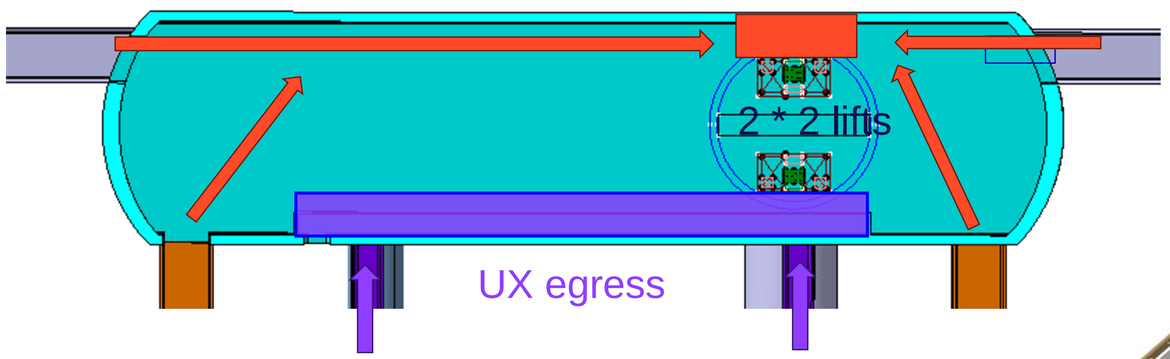
CMS underground

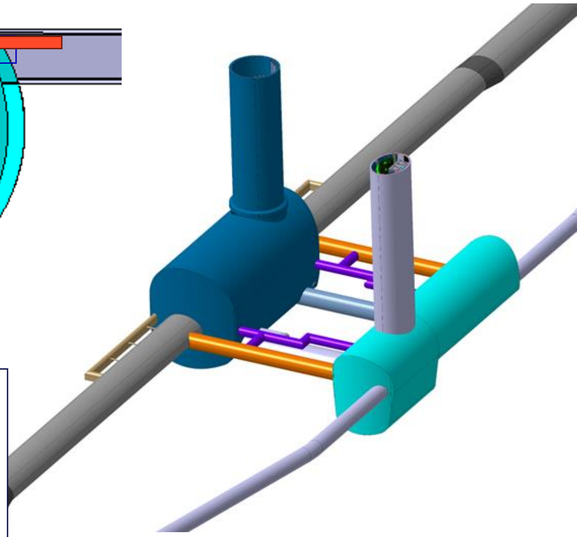


FCC point A



FCC machine egress

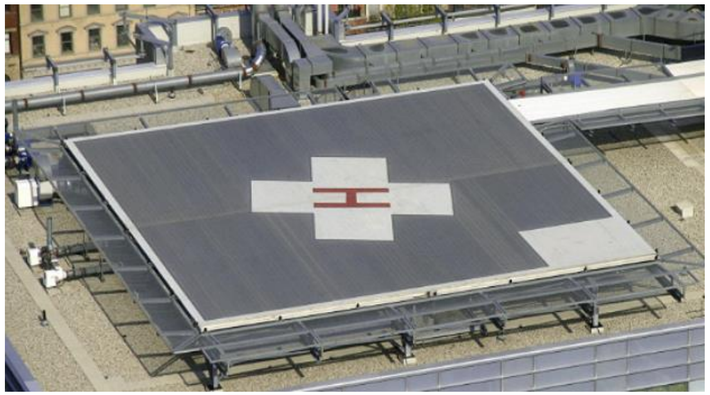




- Single personnel shaft
- Independent safe path from machine and experiment
- 2 independent lift shafts (2 x 2 lifts)
- Several safe connections between exp-service caverns

Surface Buildings

Credits: afvoil, multibrief.

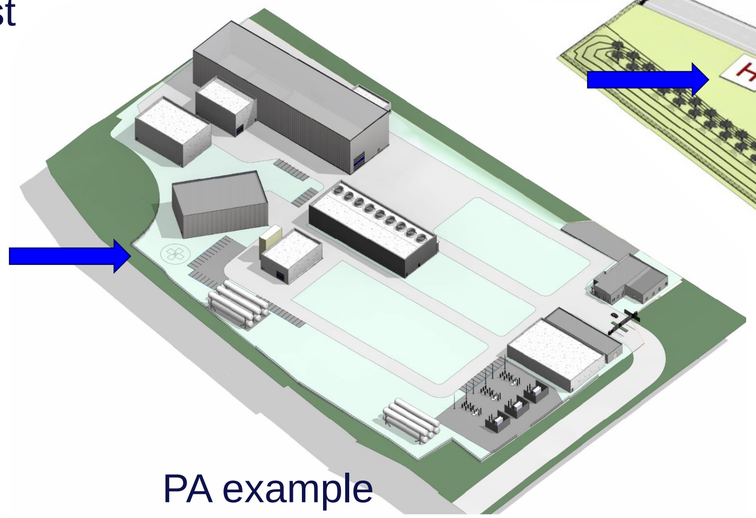


Safety of surface buildings:

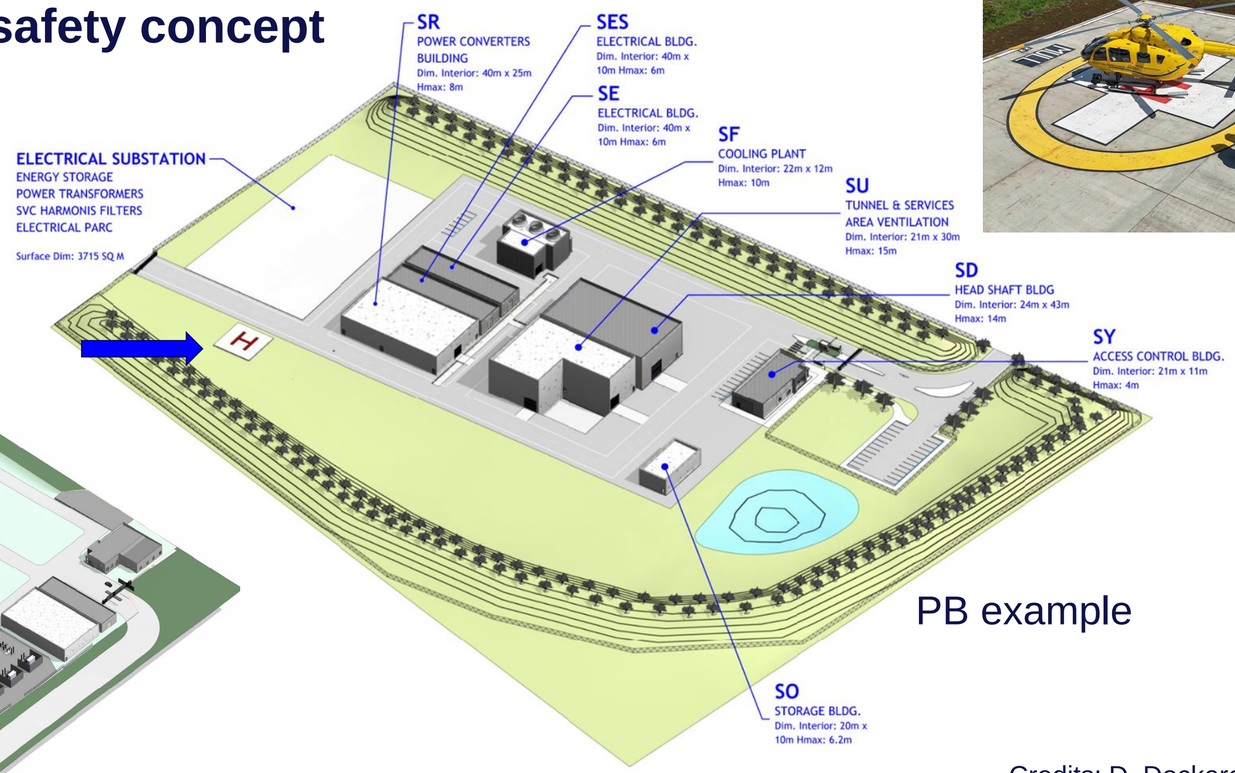
Safety Concept = Prescriptive approach (standard HS safety level)

Surface points also important for global safety concept

- Helipad
- Fire Fighting equipment
- Infirmary/waiting room/temp. fire-medical station
  - (depending on point type)
- Advance command post



PA example



PB example

Credits: D. Dockerey, et al. FNAL, 2023

See “FCC Robotic system for safety”, H. Gamper.

Intervention Concept

FCC intervention concept ≠ 4 x LHC’s

0. Self-sufficient workers in FCC (minimize exposure)

1. Intervention before evac: Trained workers on site

- 1st Response to emergency (medical, fire, damage control)

2. Emergency response robots

- Establish Situational Awareness
- 1st Intervention (Firefighting, Search and Rescue?)

3. Professional human responders

- Verify SA
- 2nd Intervention
  (Finalize SAR, Finalize FF, specific damage control)

defense.gov.au/

https://mobilityforesights.com/

Construction phase → Contractor + CFRS !
Installation Phase → CFRS + Special plan (degraded)
Operation (run/stops) → CRRS + Firs Aiders + Local

Key aspects

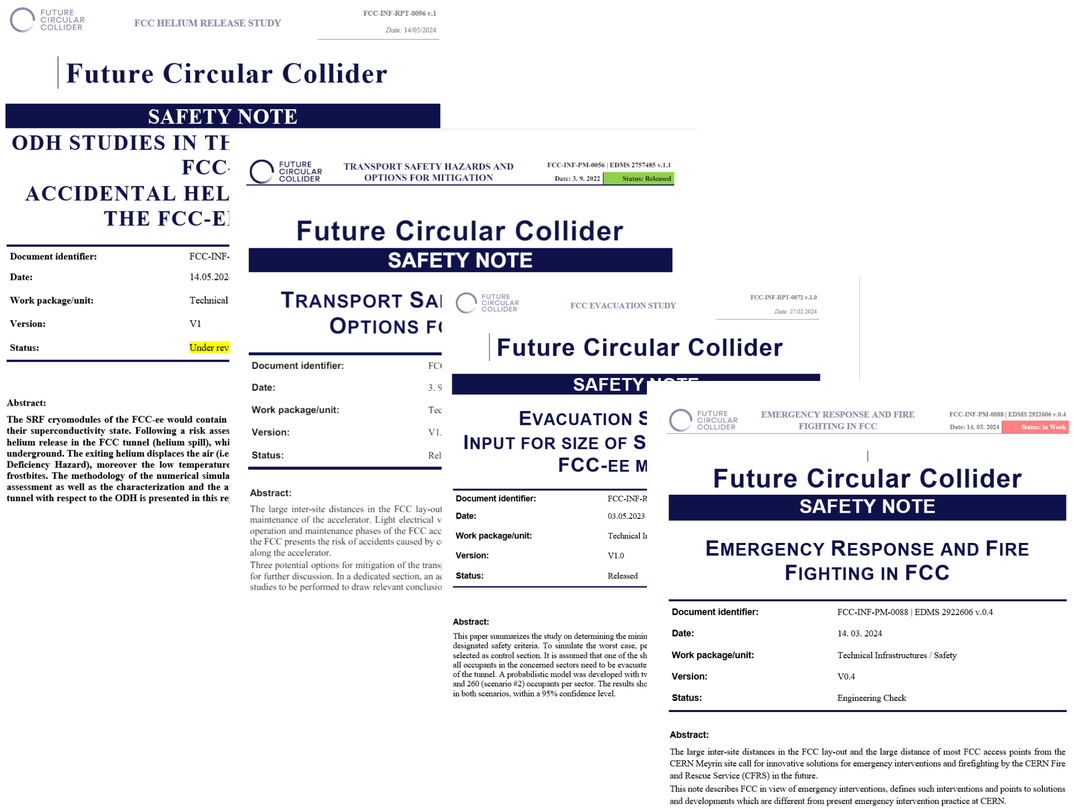
- **Safety by design** and focus on **prevention**
- A **trained workforce** that can do **first emergency intervention**
- A **strong collaboration** and interoperability with various local **HS** Emergency Services
- The positioning of several **autonomous emergency response robots** that support **information gathering** and **intervention**
- The positioning of ‘**CFRS equipment hubs**’: Fire Engine/Rapid Intervention Vehicles, sub-command posts, support for air transport, casualty care and HS support
- A **CFRS roadmap** from current operations (2020) to FCC operations (2040)

Courtesy: M. Nas

NEXT STEPS

Next Steps …… FCC Feasibility Report

- ❑ Complete the safety studies
- ❑ Start editing the ‘Safety Concept’ report as **main deliverable for the Feasibility Study**



- ❑ Third party review of HSE’s contribution to the FCC study
- ❑ By consultant expert in large underground infrastructure projects
- ❑ Review of the concept as a whole and not individual safety systems or assumptions
- ❑ … make sure we are not missing something important (namely in the construction and installation phases)