



Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Fire Protection for Underground Research Facilities

James Priest, PhD Fire Strategist/Researcher/Pyroscientist
May 5, 2015

Soudan Underground Laboratory



Soudan Continued



Foam in Underground Laboratory



Underground Fire Command



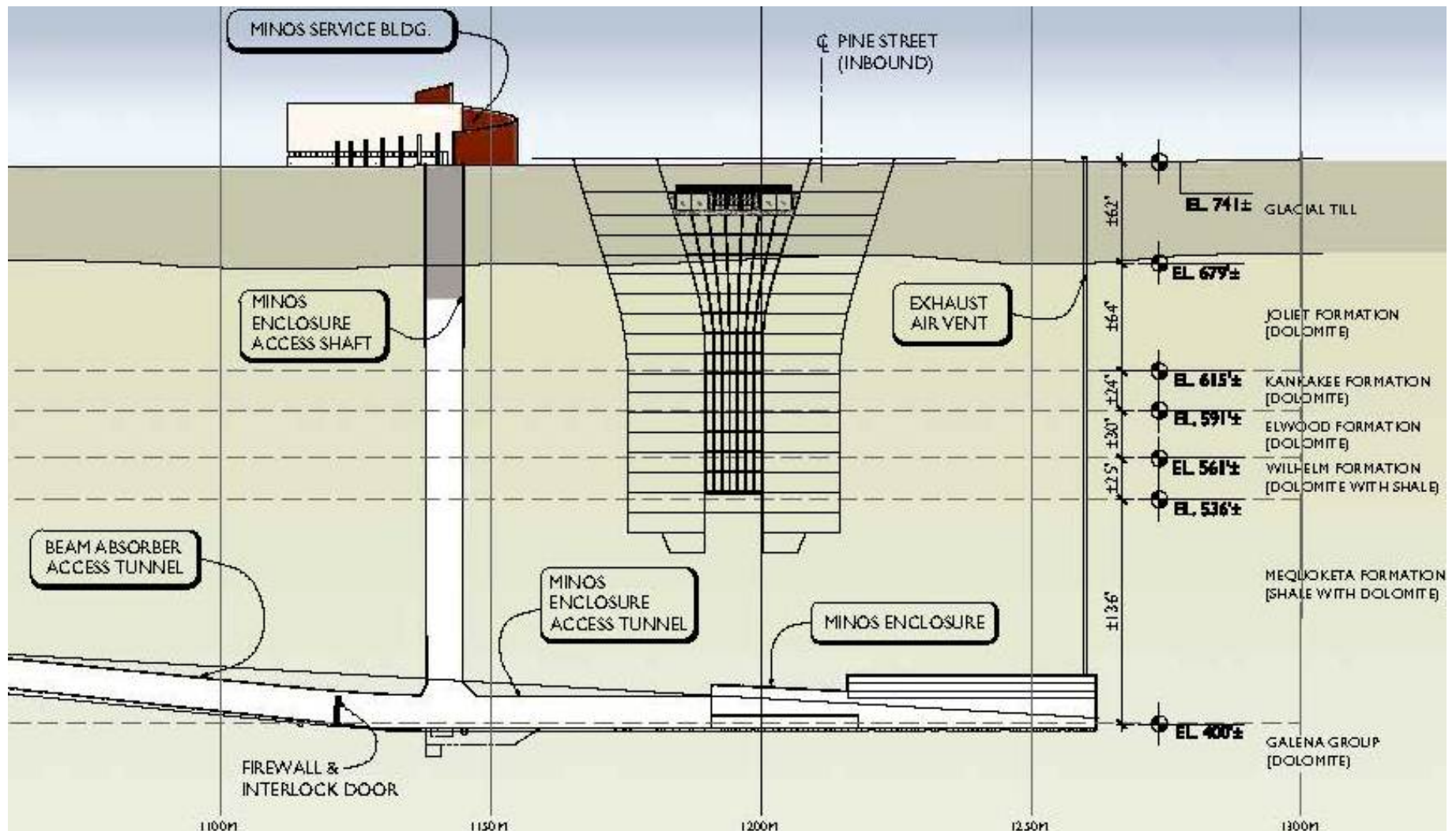
Soudan & Fire Service Response



Guess Where the Grill is?



Upside Down High Rise Building



Issues

- NFPA 520 does not apply to all underground facilities
- NFPA 520 covers subsurface facilities that are accessed horizontally via a portal
- NFPA 520 is not intended to apply to facilities that can only be accessed vertically (by hoists or elevators)
- Underground Facilities which, by DOE Order 420.1C is required to comply with both NFPA 101 and the local building code
- When does MSHA apply? or can be applied?

Overview

- The Sub-Surface Working Group (SWG) was formed from the May 15, 2012 Fire Safety Committee Meeting to deal with design and Life Safety issues in US DOE's Unique Facilities not addressed in the codes and standards
 - National Fire Protection Association and International Building Code
 - NFPA 520, *Standard on Subterranean Spaces*
 - Mine Safety and Health Administration (MSHA) (non working mines)
- *A DRAFT report was sent to DOE, January 2014*

SWG Members

- James Priest (FERMI Lead)
- Jim Bisker (DOE-HQ, Lead)
- Sherman Butler (WIPP)
- Peter Feng (NNSA-AC)
- Brian Fiscus (NNSA-NV)
- John Kubicek (NTS)
- Kevin Levy (DOE-CH)
- James Niehoff (FERMI)
- John Saidi (DOE-CA)

SWG Objective

- **To assist in the development of a consistent set fire protection criteria in National consensus standards or, where necessary, to augment such criteria for DOE Sub-Surface facilities.**

SWG Activities

- NFPA 520 Members
 - Jim Priest (FERMI) Principal
 - John Kubicek (NTS) Alternate
 - Solicited participation and information from the NFPA 520 Technical Committee
- Identify existing US DOE Sub-Surfaces Facilities
 - 19 Active and 14 inactive
- Identify DOE regulations associated with Sub-Surface Facilities
 - 10 CFR 851, Worker Safety and Health Program
 - 10 CFR 830, Nuclear Safety Management
 - 10 CFR 835, Occupational Radiation Protection
 - DOE Order 420.1C, Facility Safety
 - DOE-STD-1066-2012, Fire Protection
 - DOE O 420.2C, Safety of Accelerator Facilities

DOE Underground Facilities

Facility	Location	Date	Hazard	Depth	Exits	Self Exiting Y/N	Limits on Number of People	Fire Suppression System	MSHA 57.1 or NFPA 520
Waste Isolation Pilot Plant (WIPP)	Chihuahuan Desert, outside Carlsbad, N.M.	March 26, 1999	transuranic (TRU) waste	2150 ft	3: Salt Handling Shaft, Air intake Shaft, & Waste Shaft	No	145	Protect vehicles with dry chemicals, Alarms, fire brigades, shafts.	MSHA:
Yucca Mountain nuclear waste repository	Nye County, Nevada	Not yet	spent nuclear reactor fuel and other high level radioactive waste	1,000 feet beneath the surface and 1,000 feet above the water table	4 The North Portal, designated ventilation intake shafts, South Portal, North Construction Portal.	N/A	N/A	Automatic (sprinkler), refuge stations, Rescue, Firewater, Fire suppression, Fire detection, Fire alarm, Fire notification, Explosion protection, Fire barriers	MSHA: NFPA 520: No
SLAC Linac tunnel	Menlo Park, CA	1967 (date of first linac beam)	Prompt radiation High intensity electron beam line for research purposes.	25 feet	Ladders every 333 feet (total of 15). Three stairwells to surface. Exit to grade at west end.	Yes	During long downs, no more than 100 people in linac tunnels.	Air sampling smoke detection, wall mounted CO2 portable fire extinguishers. Fire hydrants at surface. Two cross-tunnel fire barriers.	MSHA-no. NFPA 520-no.
SLAC Beam Switch Yard (BSY)	Menlo Park, CA	1967	Prompt radiation from high intensity electron beam for research purposes	0 - 30 feet	One grade level exit, two ladders to surface, 5 exits through other tunnel spaces.	Yes	50 employees maximum during long downs.	Combination of spot-type smoke detection and air sampling detection. Wheeled and portable CO2 fire extinguishers.	MSHA – No. NFPA 520—under review.
SLAC LCLS	Menlo Park, CA	2007 (first beam)	Prompt radiation from electron and x-ray beam pulses used for research.	0 – 70 feet	One grade exit, two stairwells, one ramp up to grade	Yes	Varies, but no more than 60 employees in any one fire area	Sprinklers, wall-mounted CO2 fire extinguishers, spot type/beam type/VESDA smoke detection (varies by area)	MSHA—no. NFPA 520-no.
Fermilab- NuMI	outside Batavia, Illinois , near Chicago	November 21, 1967 (as National Accelerator Laboratory)	neutrino beam generated MI-65 Target Hall and MINOS Detector Hall)	150 ft to 350 ft	2-hour fire rated, 44-in width pressurized passageway, stair, & egress elevator	Yes	50 Occupants	Emergency voice fire alarm system, heat & smoke detection, sprinklers	MSHA 57.1: n/a NFPA 520: Yes

Fermilab- ILC	outside Batavia, Illinois , near Chicago	Future	International Linear Collider Conceptual Design Phase only. Currently this project is unfunded	350 ft	2 & refuge areas with 2 hour fire barriers, stairs > 44 in. Wide, and doors > 36 in. wide.	Yes	<50 Occupants	fire alarm system, heat & smoke detection, sprinklers	MSHA 57.1: n/a NFPA 520: Yes
Fermilab - LBNE	outside Batavia, Illinois, near Chicago	November 21, 1967 (as National Accelerator Laboratory	Long baseline neutrino experiment – Conceptual Design Phase	320 ft	2-hour fire rated, 44-in width pressurized passageway, stair, & egress elevator	Yes	50 Occupants	Emergency voice fire alarm system, heat & smoke detection, sprinklers	
University of Minnesota – Soudan Underground Laboratory	Near Ely Minnesota	1900-est. mine 1980- est. lab	Several Experiments (MINOS long baseline neutrino experiment receives a beam of neutrinos from Fermilab).	2,340 ft	Fire Rated Single Shaft Elevator		average -11; maximum- 36	fire alarm system, heat & smoke detection, Automated suppressant system- sprinklers, Extinguishers, and 1 escape chamber (shafts), ventilation	
Sanford Underground Research Facility SURF (Deep Underground Science and Engineering Laboratory, DUSEL)	Homestake, SD	2002	Experiments LUX- the most sensitive detector yet to search for dark matter cryogens and other hazardous materials	4850 ft below ground	2: Primary and secondary	Yes		**two means of access/egress will be provided Notification of an emergency “stench gas” system	MSHA 57.1: Yes NFPA 520: Yes
Nevada National Security Site	Nye County, NV	1950s	8 active & 14 inactive facilities; hazards vary by facility but may include explosives, radioactive materials, wood, paper, oils, etc.	Varies from hundreds to thousands of ft	Shafts and portals depending upon the facility	Yes and no, varies by facility. One facility has 3 shafts and the others have portals	Varies by facility and by activity	Varies by facility: Portable fire extinguishers, fire alarm systems, squawk boxes, miners cap lamps & emergency lighting, refuge stations, no automatic suppression.	No & No**
Ultra Low Background Counting Laboratory 3425 Building PNNL 16	Richland, WA	2010	R&D Lab with some hazardous materials, cryogens	40 ft	2 exits – one at each end of the building	Yes	30 – typically less than 10		N/A This is a building built per IBC and NFPA 101

National Consensus Standard - Definitions

- NFPA 520, *Standard on Subterranean Spaces*
 - Subterranean Space. A cavern resulting from the extraction of subsurface-located material from underground areas in a manner that the surface area of the property is not disturbed except in the vicinity of the entrances and ventilation openings
 - Developed Space. An area of the subterranean space that has been altered for the use of advanced industrial capability, technological sophistication, or economic productivity.
 - Common Space. The area of the developed subterranean space other than buildings, including but not limited to roadways, railways, loading docks and entrances.
 - Undeveloped Space. Subterranean space that has been mined but has not been altered for the use of advanced industrial capability, technological sophistication, or economic productivity.

National Consensus Standards – Definitions Continued

- **NFPA 101, Life Safety Code**
 - Underground Structure. A structure or portions of a structure in which the floor level is below the level of exit discharge.
 - Not to be confused with a basement which is defined as “any story of a building wholly or partly below grade plane that is not considered the first story above grade plane”
 - Requirements for underground spaces are located in section 42.7.4 of NFPA 101
- **International Building Code**
 - Underground Buildings (Section 405). The provisions of this section apply to building spaces having a floor level used for human occupancy more than 30 feet (9144 mm) below the lowest level of exit discharge.

SWG Definition

- Sub-Surface Facility: A space (including tunnels, or networks of drifts) resulting from the extraction of material below grade where the footprint of the excavated space extends beyond the footprint of any connected above grade structures. Such a facility may include the following components:
 - Developed Space: Areas that have been altered for the performance of mission-oriented process operations or experiments. This space includes the underground infrastructure, such as escapeways, refuge stations, ordinary-hazard supporting-activity areas, and inactive, legacy process operation/experiment areas.
 - Undeveloped Space: Areas that are either currently being mined or have already been mined, including the installation of Sub-Surface support features, but has not been altered for the performance of mission-oriented process operations or experiments. Undeveloped space may also include non DOE mined spaces bordering DOE subsurface facilities.
 - Process Operation/Experiment Space: Areas in which high-hazard material is staged or used that is separated from other areas by fire-resistive construction.

US DOE Sub-Surface Facilities

- Basically two types:
 - Storage – Mainly long-term radiological waste storage sites
 - Laboratory -physics research (particle detectors and accelerators) or weapon component testing activities
- Sub-Surface Storage:
 - Waste Isolation Pilot Plant – A shaft accessed facility
References the Mine Safety and Health Administration (MSHA) through Public Law 102-597
 - Yucca Mountain – A tunnel accessed facility MSHA became incorporated under DOE/RW-0586, *Subsurface Safety and Health Requirements Document*

SWG Recommendation 1

- **The DOE should incorporate key provisions of 30 CFR 57 into DOE's Worker Health and Safety Rule addressing DOE Sub-Surface facilities such as:**
 - Employee training and equipment;
 - Background radiation (Radon) levels;
 - Air quality and redundancy;
 - Illumination minimums based on the Sub-Surface facility components;
 - Occupant sound levels based on the Sub-Surface facility components; and
 - Other Sub-Surface protection features that are not addressed by OSHA

SWG Recommendation 2

- **The DOE should establish guidelines for coordinating DOE O 420.1C design requirements into DOE Sub-Surface facilities.**

SWG Recommendation 3

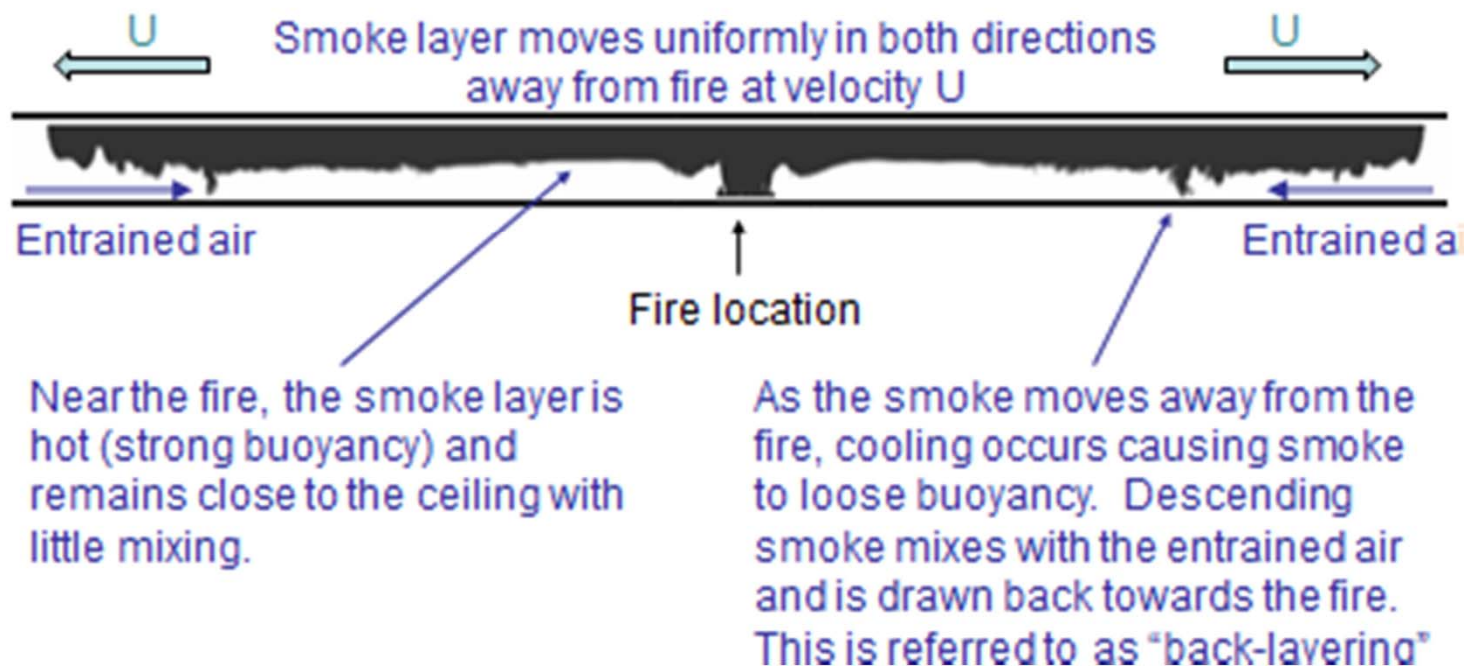
- **The DOE should establish guidelines for Mine Rescue or Emergency Responder teams.**

FERMI – ILC FDS Computer Model Studies

- Fire and Egress Analysis for the International Linear Collider conducted by Hughes Associates, Inc.
 - Computer model simulations for tunnel diameters
 - 4.5m, 5.0m, and 6.5m
 - Present results/effects
 - Smoke movement
 - Fire size
 - Fire location (tunnel or cavern)
 - Sprinklers
 - Determine time required to evacuate
 - Determine maximum fire size

Tunnel Fire Dynamics

- Smoke movement in level, naturally ventilated tunnels



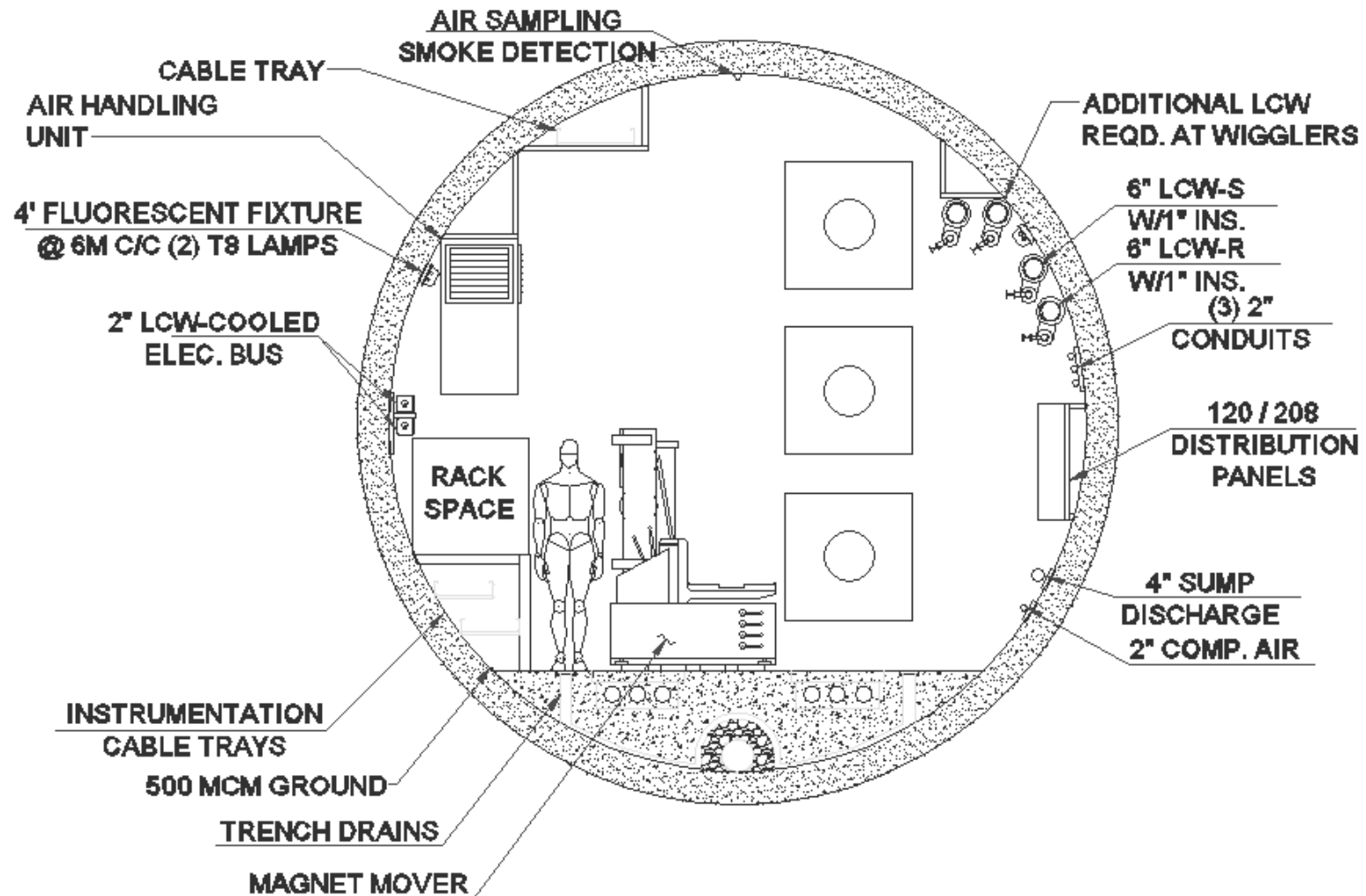
Tunnel Fire Dynamics Continued

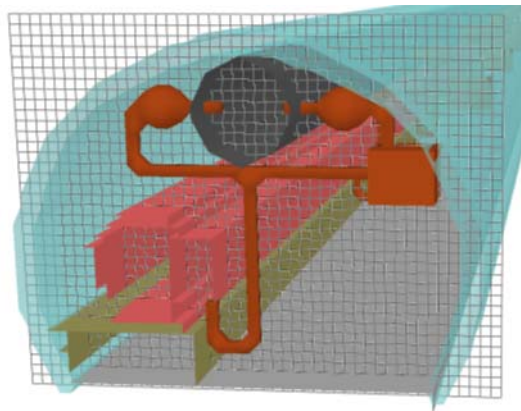
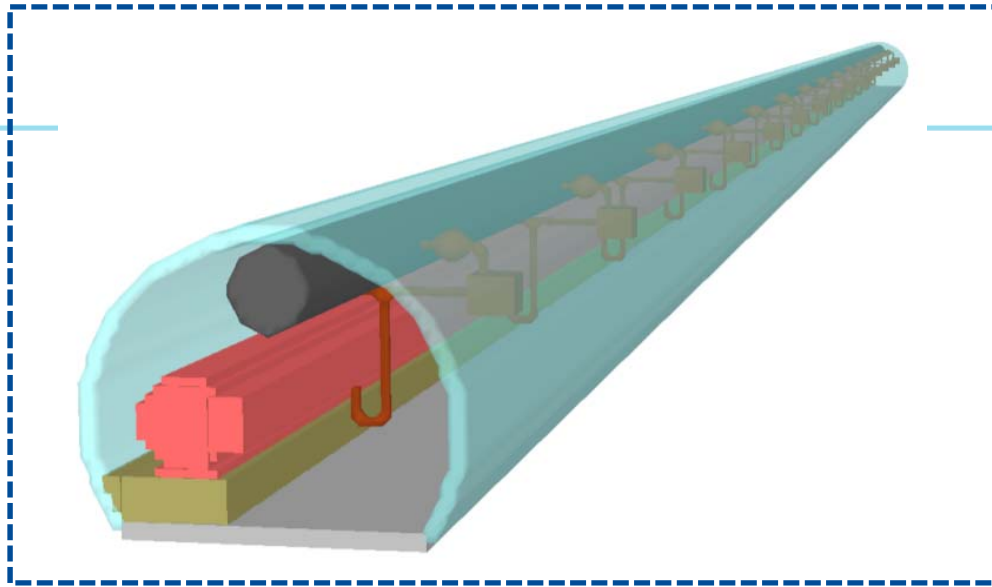
- The speed of the smoke layer (ceiling jet) is a maximum near the fire and decreases moving outward
- For naturally ventilated tunnels, the smoke layer will continue to propagate outward over long distances
 - The distance between vertical shafts in the International Linear Collider (ILC) is over 2,000 meters
 - It is not feasible to create models of this entire length due to limitations in maximum number of cells versus run time.
 - Sufficient resolution needed to obtain accurate results

Potential Fire Scenarios

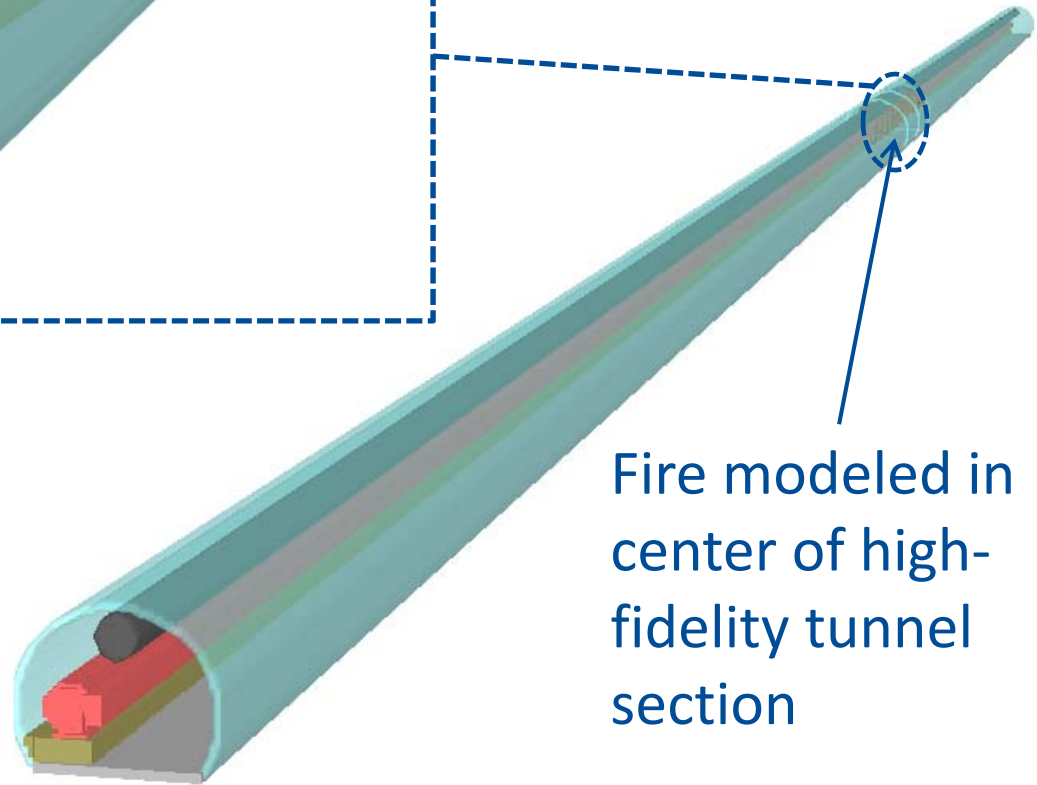
- Cable Tray Fires
 - Low cable loadings
 - Cables embedded under concrete floors or encased in rigid conduit
- Miscellaneous Combustibles
 - Trash
 - Other combustibles
- Pool / spill fires
 - Rapid growth
 - Primary fuel present is transformer oil (mineral oil)
 - Multiple components in ILC tunnel and base cavern contain oil
 - One 76 meter section of tunnel may contain up to 470 gallons of oil
 - Largest quantity of oil in single component is a 100 gallon tank housed in a step down transformer
- **Pool / spill fires represent the most demanding fire scenarios**

Typical ILC Accelerator Tunnel





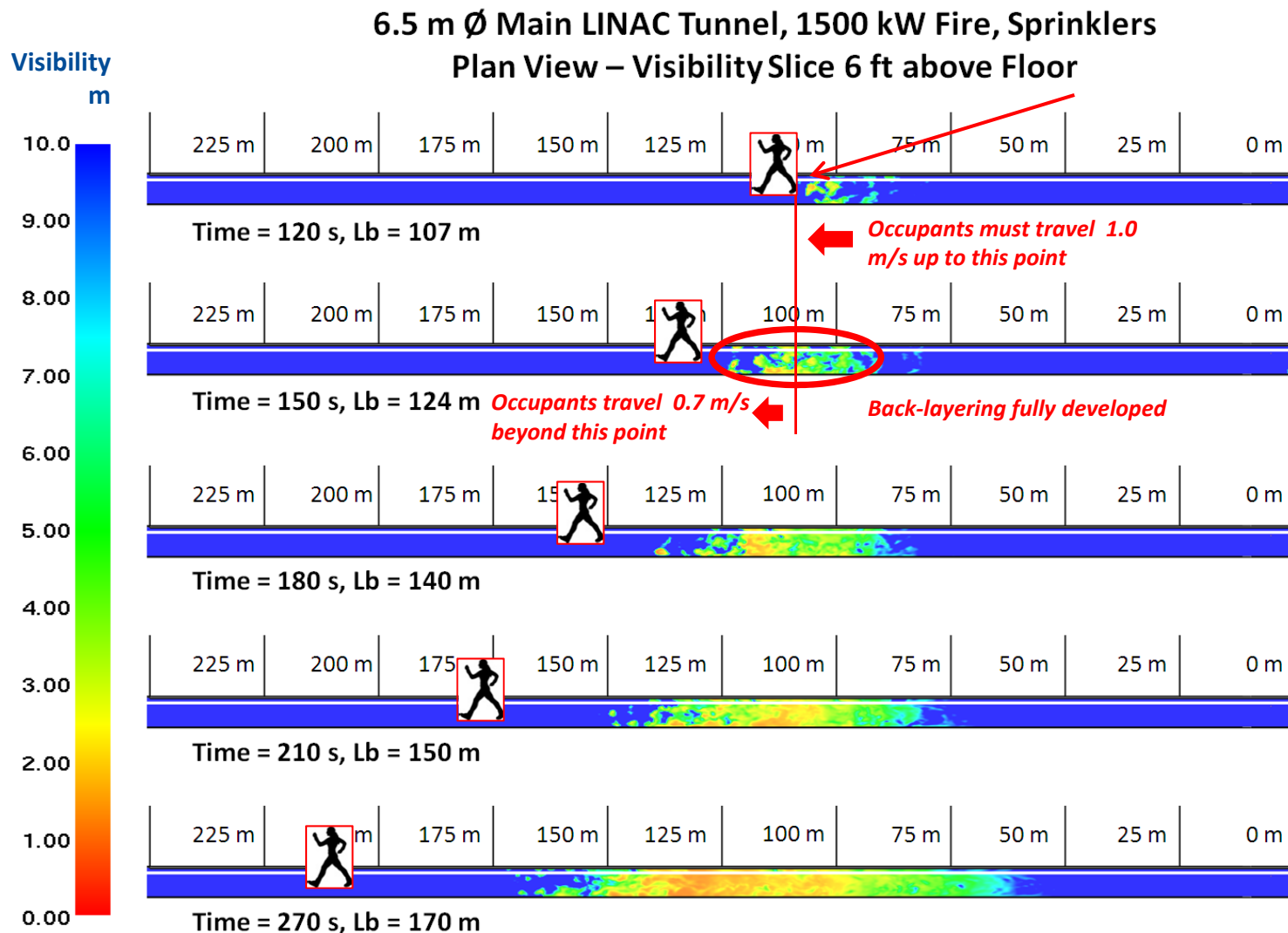
5 inch cells –
isometric view
showing grid



400 m long tunnel
section.

Fire modeled in
center of high-
fidelity tunnel
section

Tunnel Fire Results



Travel speed required to outrun back-layering = 1.03 m/s

Travel speed required to stay ahead of smoke layer = 0.63 m/s

Results Continued

- Given the low occupancy load in the tunnel:
 - Queuing (congestion) would not occur in tunnel during an emergency
 - Occupant travel speeds would be consistent with normal “walking speeds” on uncongested, level pathways
- Visibility is the critical tenability criterion (i.e. visibility is lost before other tenability criteria are exceeded)
 - Results presented in terms of visibility

Criteria	Limit
Temperature	< 76 °C (168 °F)
CO Concentration	< 1,200 ppm
O ₂ Concentration	> 17% by volume
Visibility	> 10 m (30 ft)

-
- Workshop on Fire Protection at Research Facilities
 - Partnership of 17 European Nations committed to the goal of collectively building and operating the world's leading facility for research using neutrons by the second quarter of the 21st Century

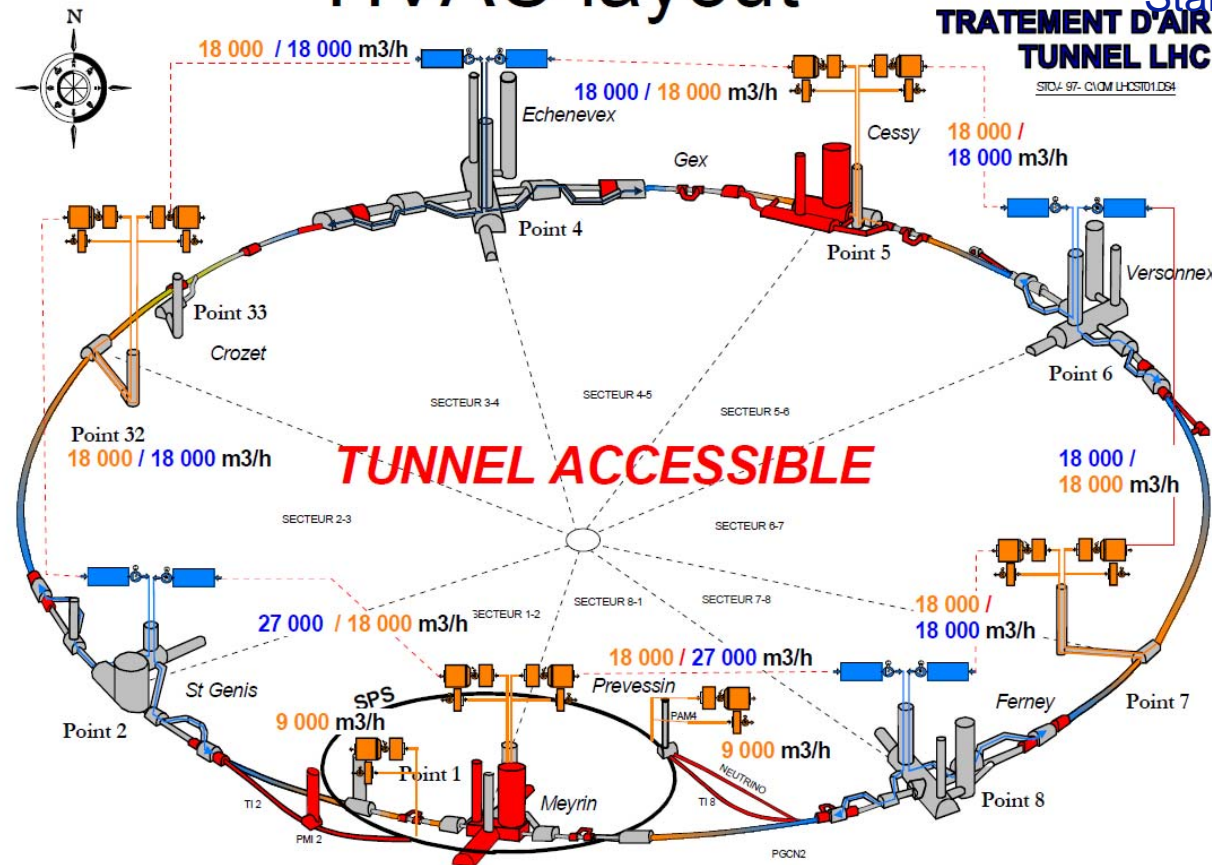
pathfinder, FDS + EVAC, Exodus and SmartFire

<https://www.youtube.com/watch?v=gmPOIriMiyU>

LHC air management

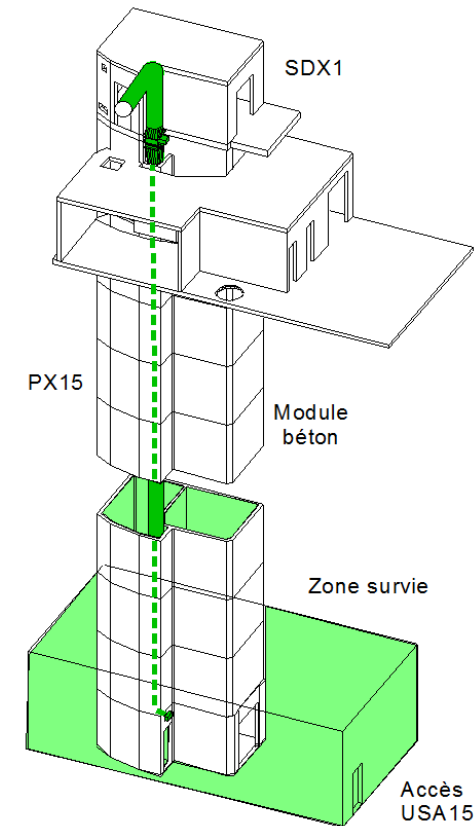
In the LHC, fresh air is injected in even points while vitiated air is extracted at odd points.

HVAC layout



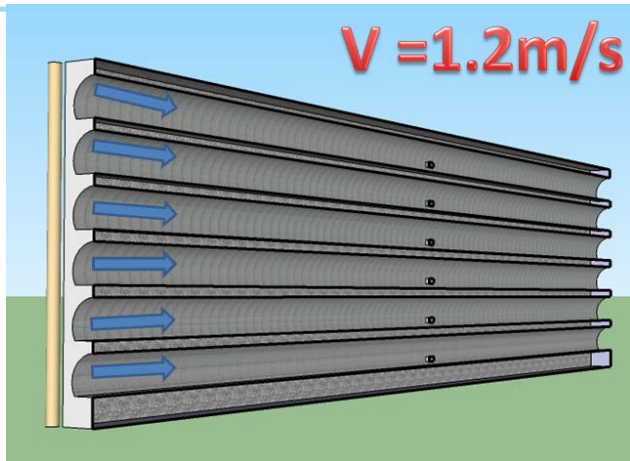
Pressurized safe zones are located at the bottom of the shafts.

Staircases are pressurised as well.

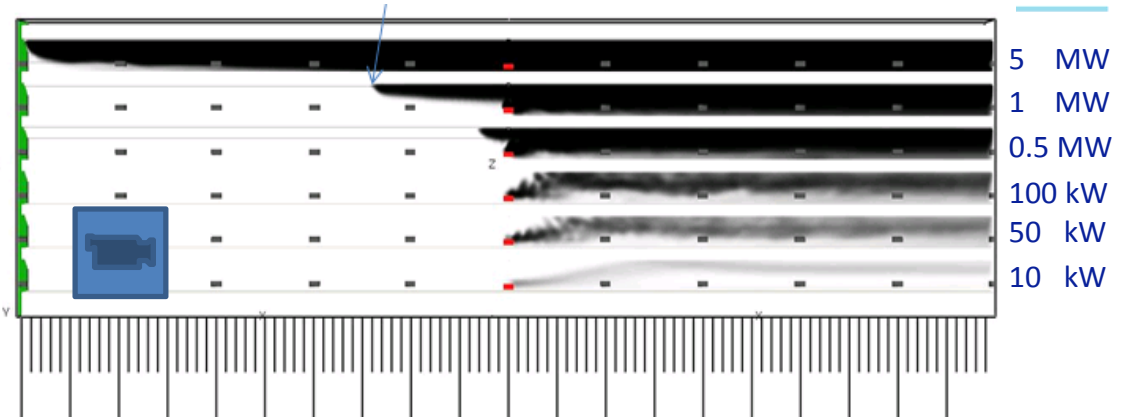


In the LHC, the evacuation takes place through the lifts

Characterization of fire hazard in tunnels

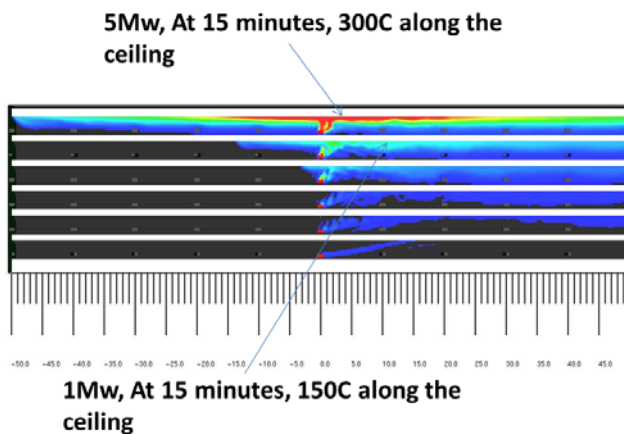


1.2m/s Smoke temperature



Main results

- Back layering reaches an equilibrium distance;
- Stratification downstream is lost very early;
- Velocity downstream initially high, tends to slow down close to ventilation speed ;
- The average gas temperature reaches a maximum of almost 300°C for a 5 MW fire, but after 200 m it goes down to a bit more than 50°C ;
- Decrease of visibility to almost zero in smokes;
- Presence of CO and HCN;
- O_2 concentration goes down to 16.5 % and CO_2 goes up to 3.2% both for a 5 MW fire.



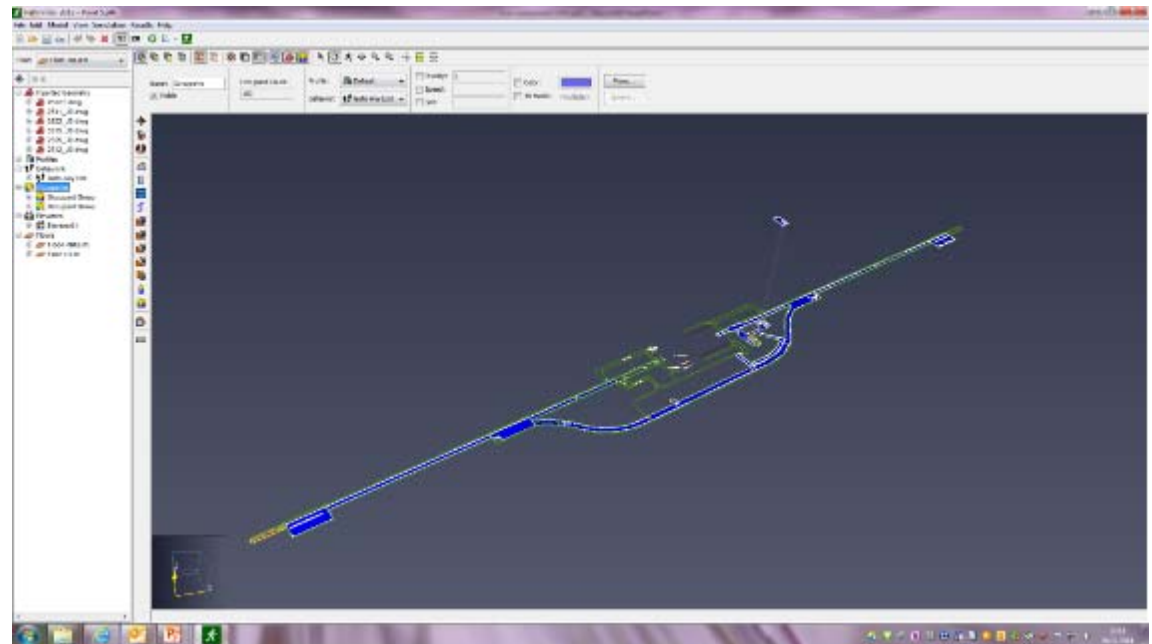
A further development: Avatar – based evacuation model

Bypass, Long Straight Sections and
CMS experiment model

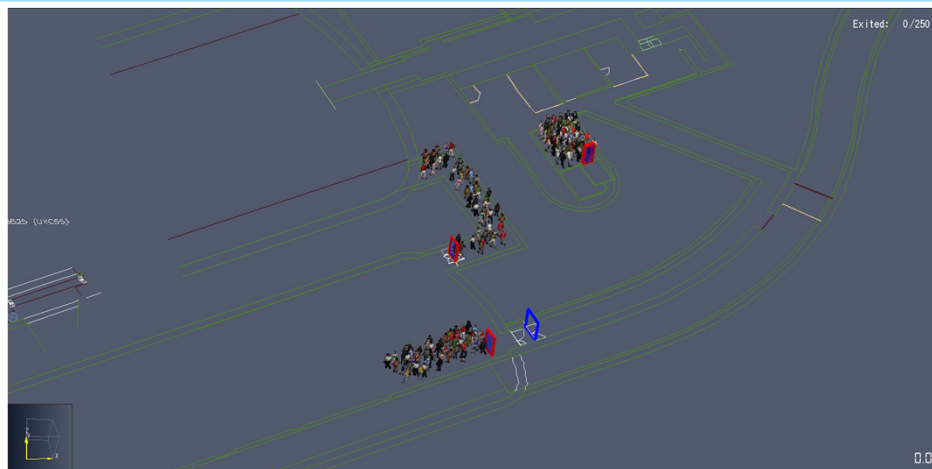


[Users Guide for Pathfinder](#)

[Technical Reference Manual for Pathfinder](#)

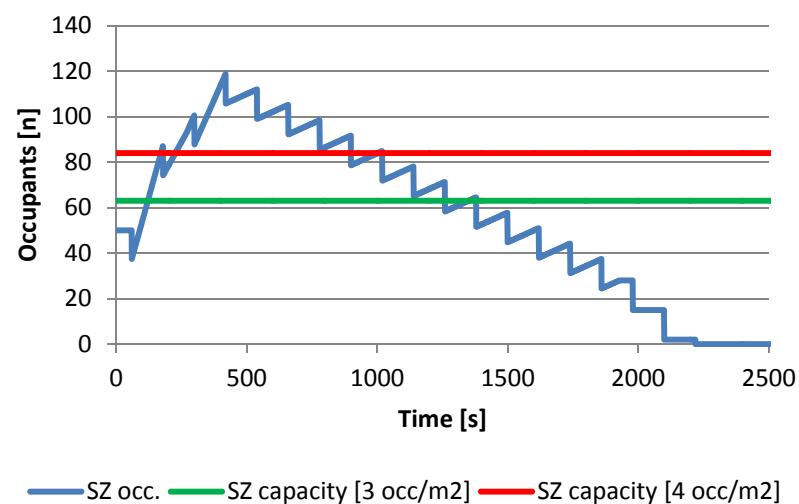
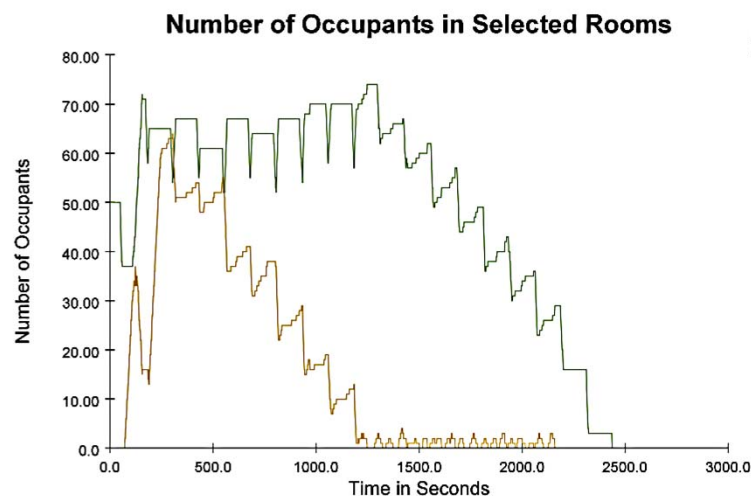


Tunnel bypass, LSS and Experiment - output data



Key results

- Maximum occupancy of US 56: 74 persons $\Rightarrow 3.5 \text{ occ/m}^2$
- **Max n. Of people waiting outside the safe zone: 64**
- As expected, occ. density does not increase indefinitely in the avatar-based model



Intervention of rescue teams

The possible interference between the rescue teams and the evacuees is evaluated.

CERN Fire and Rescue Services (CFRS) response strategy: to descend into the LHC tunnel always upstream of fire.

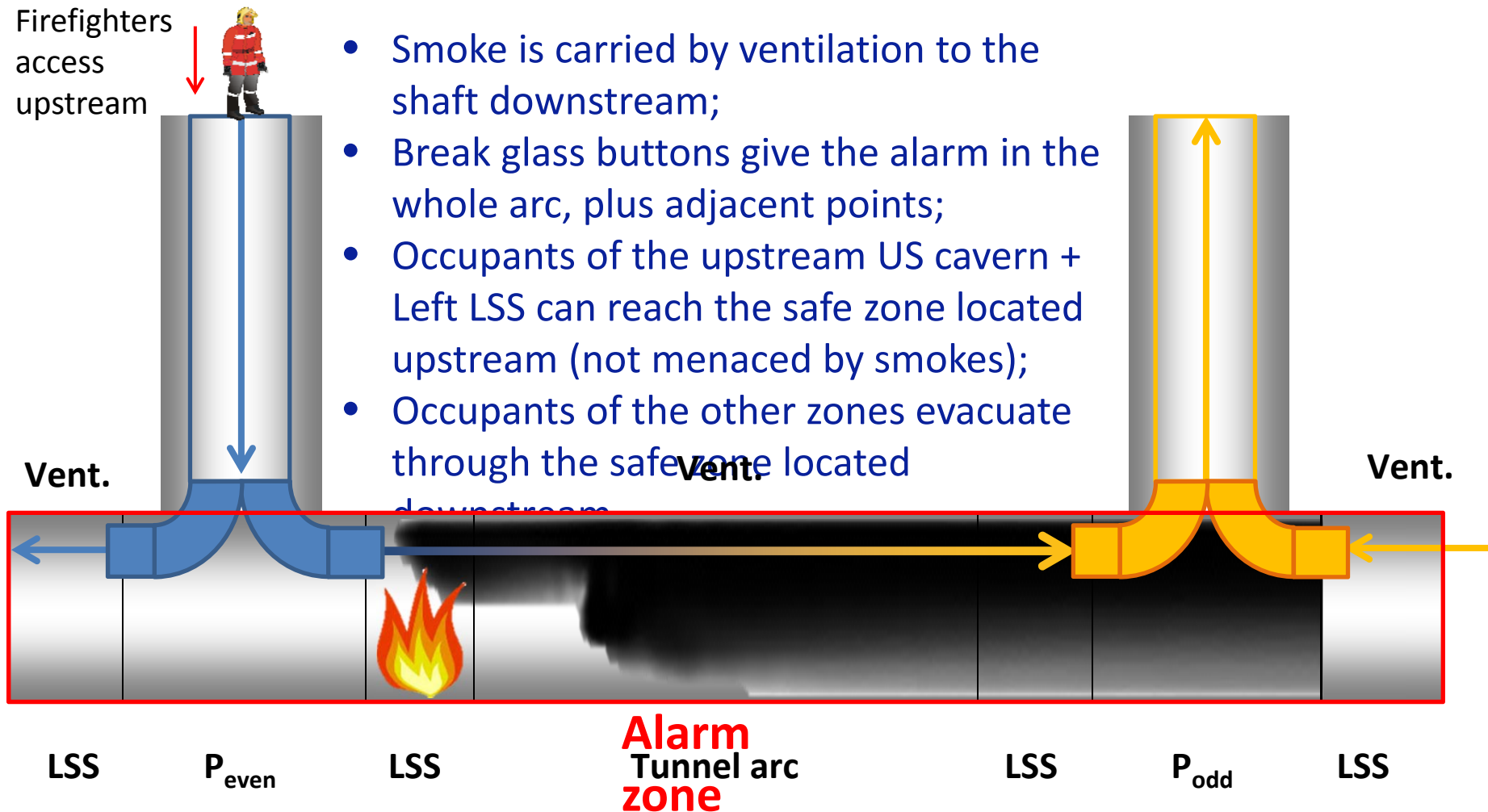
However, when a fire is reported close to a Long Straight Section (LSS) or to an Underground Service Cavern (US cavern) the CFRS access from the nearest shaft, regardless of the ventilation direction.



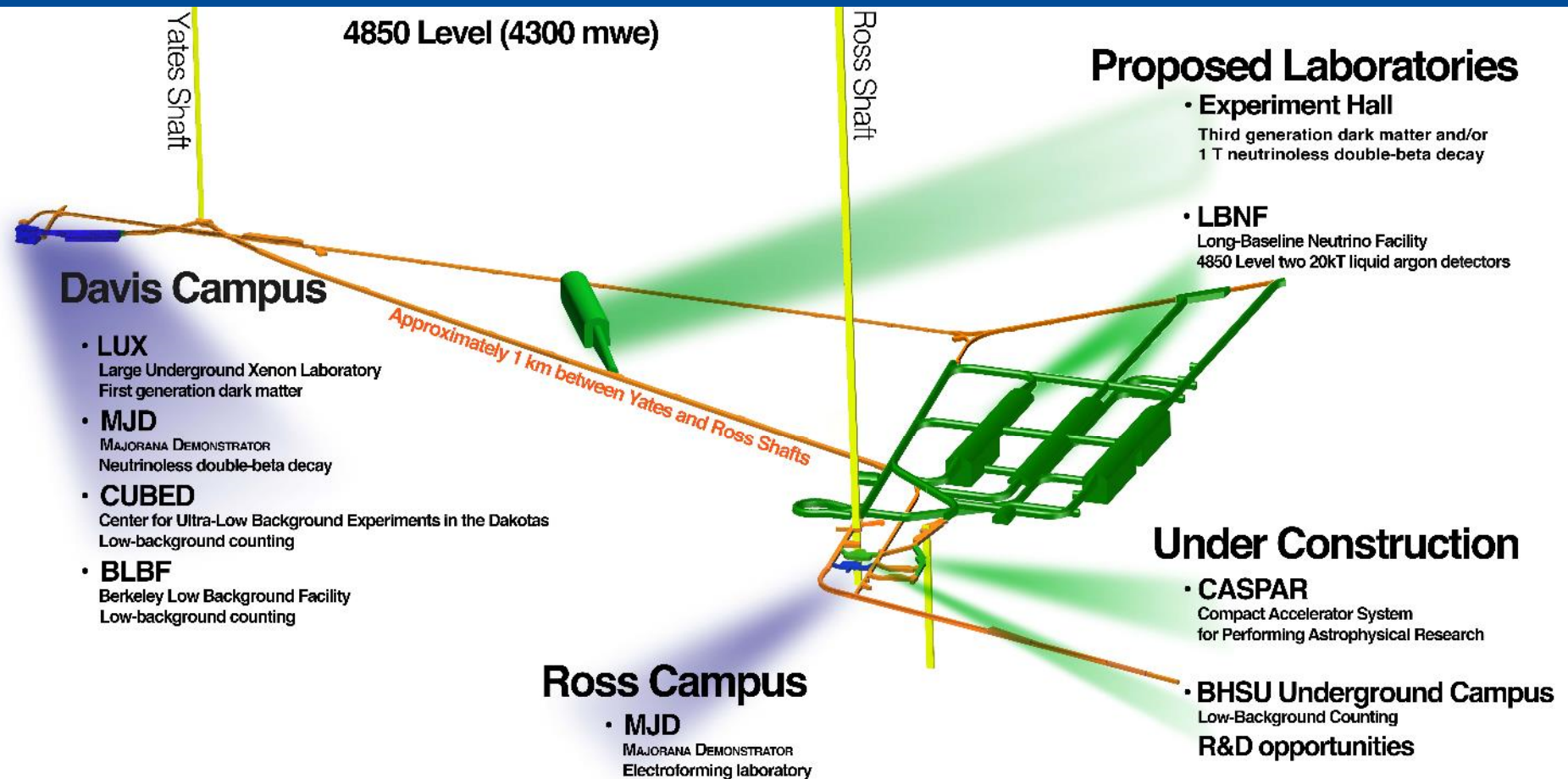
Critical interference occur when evacuees and firefighters meet in presence of smoke.

The fire scenarios considered in this study take into account the place where the fire starts w.r.t. the ventilation direction as well as the alarm zone and the firefighters access points.

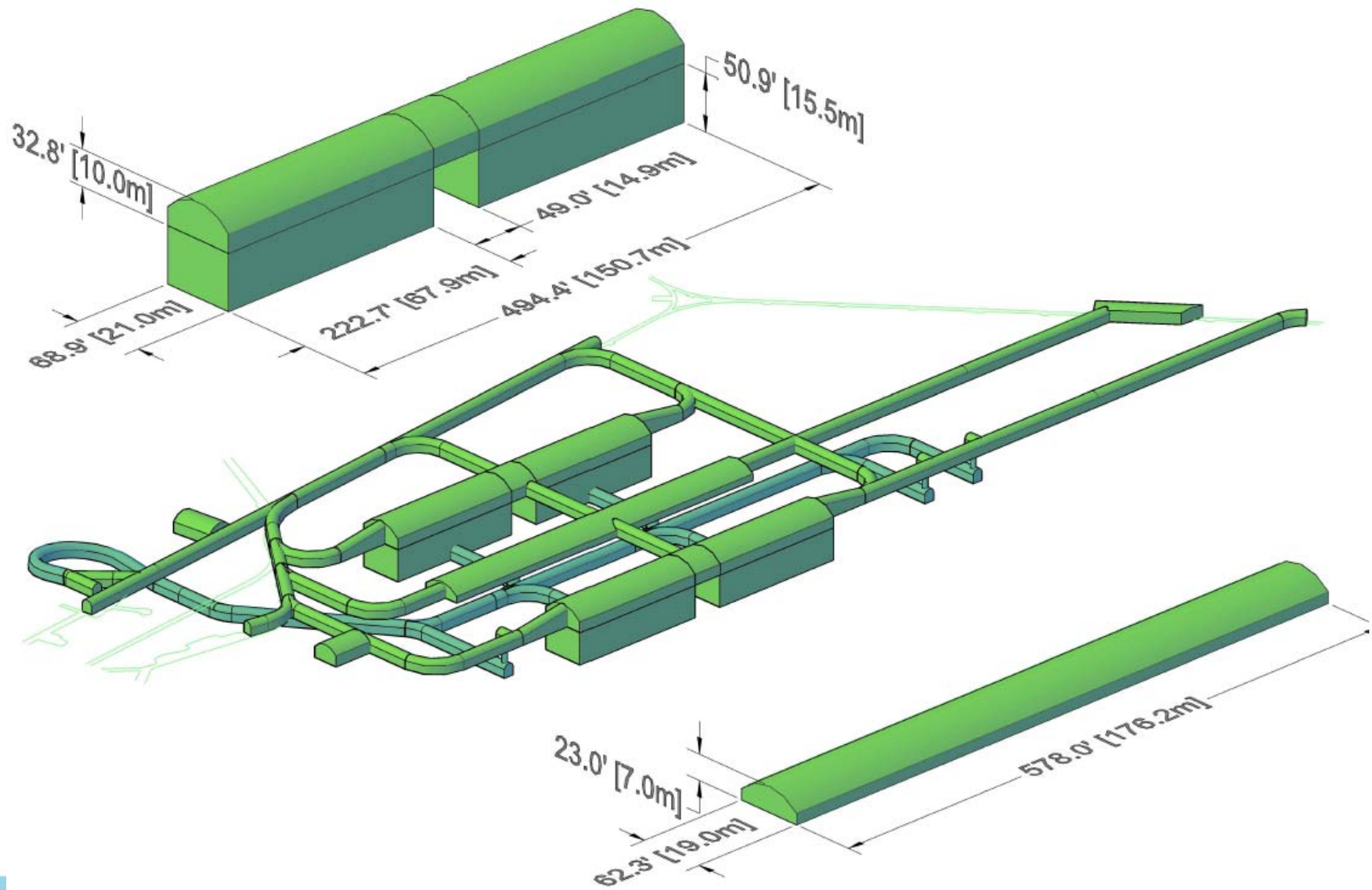
Scenario 2: fire in the upstream right LSS



The Long-Baseline Neutrino Facility Project



Cavern Sizes



N2 Spill Test

