
CERN

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MSB
Myndigheten för samhällsskydd och beredskap
International Fire Instructors Conference 2018
Performance Based Design for Firefighter Safety
Firefighter Safety beyond prescriptive codes in complex facilities
Art Arnalich
CERN, European Organization for Nuclear Research
HSE
Fire Safety Engineering Team
PBD for Firefighter Safety
A. Arnalich, HSE-OHS-XP
Aug 2018 - EDMS 2011531v1
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ME Civil Engineering



3

ME Civil Engineering

**fire officer (BC)** at CEIS Guadalajara (Spain)

**fire instructor**



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ME Civil Engineering

**fire officer (BC)** at CEIS Guadalajara (Spain)

**fire instructor**

**fire officer (BC)** at CERN Fire Brigade (Swiss)

**fire safety engineer** at CERN

HSE
Fire Safety Engineering Team



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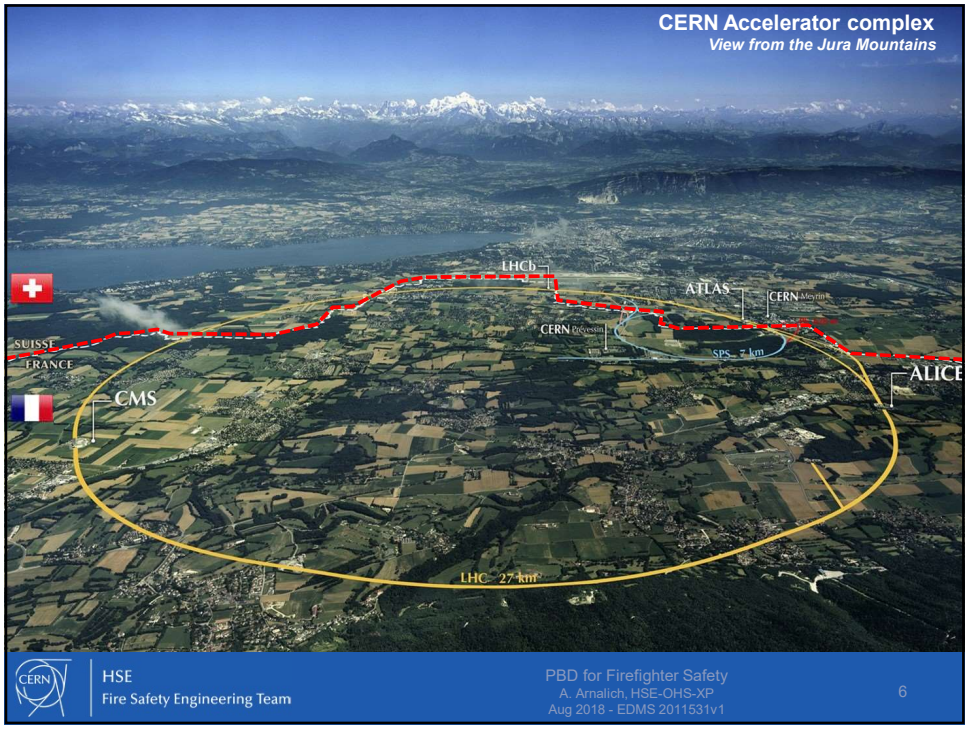




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Building 40
HSE
Fire Safety Engineering Team
PBD for Firefighter Safety
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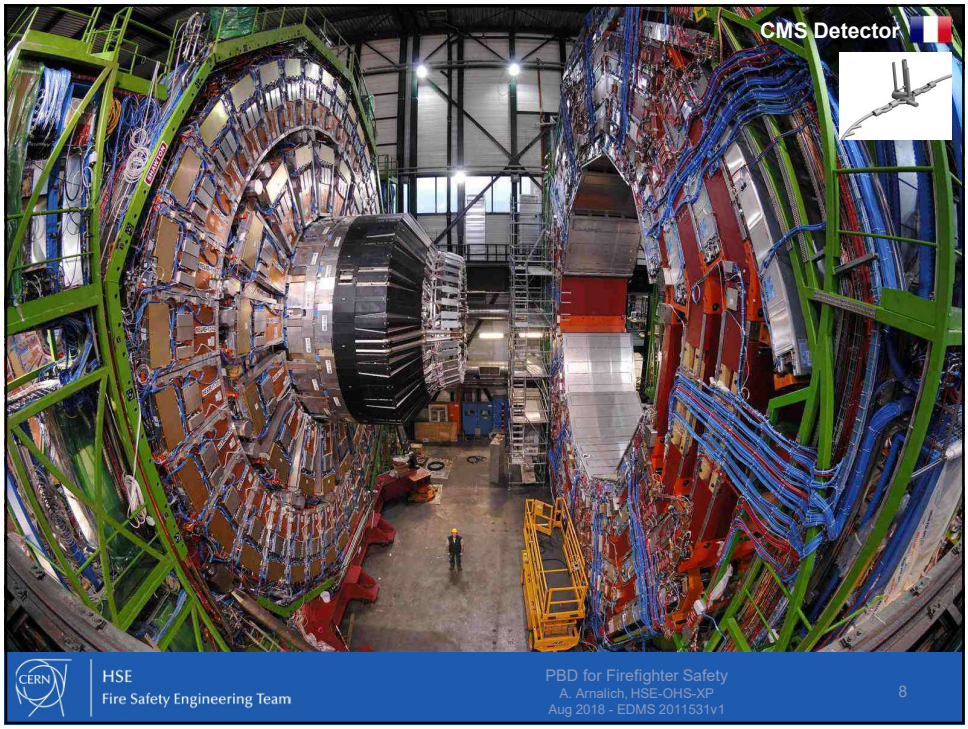
CMS Detector
HSE
Fire Safety Engineering Team
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**successful outcome**
in **fire safety** is
**team work** and **excellence**

10

**successful outcome**
in **fire safety** is
**team work** and **excellence**
in fire education,
fire research,
fire prevention,
fire protection,
fire codes and standards
fire safety engineering,
firefighter training,
firefighter safety,
....
and fire operations

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**how can we account for firefighter safety in the design of buildings?**



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how can we account for firefighter safety in the design of buildings?

**follow prescriptive codes**

let's design and prove it's safe using PBD
(Performance Based Design)



13

how can we account for firefighter safety in the design of buildings?

follow prescriptive codes

**let's design and prove it's safe using PBD**
(Performance Based Design)



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## goals

humble approach to **use performance based design for firefighter safety**

joint effort of fire department and fire engineering teams for complex non-standard fire scenarios

peer review and support from Fermilab, Lund University, ESS, …



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## evolution of society

LODD statistics, **increasing awareness**

cost for the community (social and economical)

## LODDs and injuries not acceptable



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LODDs and injuries not acceptable

**research on tactics**

**science based SOPs**




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LODDs and injuries not acceptable

research on tactics

**science based SOPs**

**engineered fire safety design for firefighter safety**



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urban
wildland
**industrial**

## complex fire scenarios anywhere



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what is a **complex scenario?**

safety critical aspects for firefighting

requires a complex analysis

requires non-standard tactics

requires special firefighting equipment



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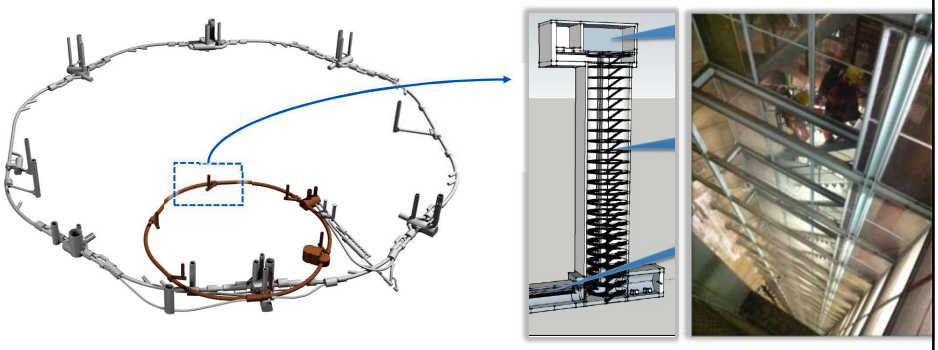
complex fire scenarios at CERN

## CERN Super Proton Synchrotron





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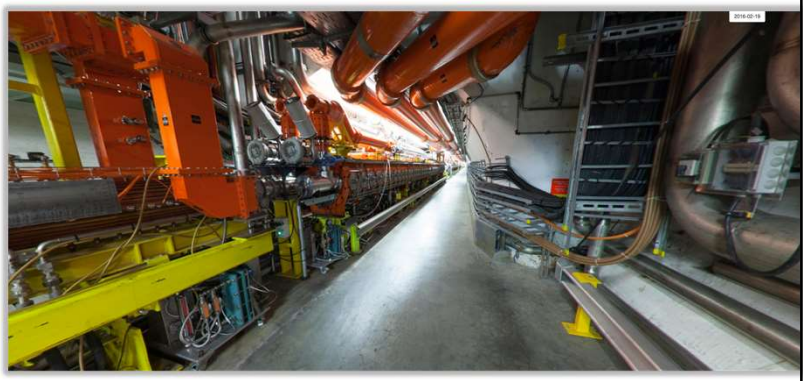
complex fire scenarios at CERN

## CERN Super Proton Synchrotron





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complex fire scenarios at CERN

## CERN Super Proton Synchrotron




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fire department

## fire department role in fire safety ?



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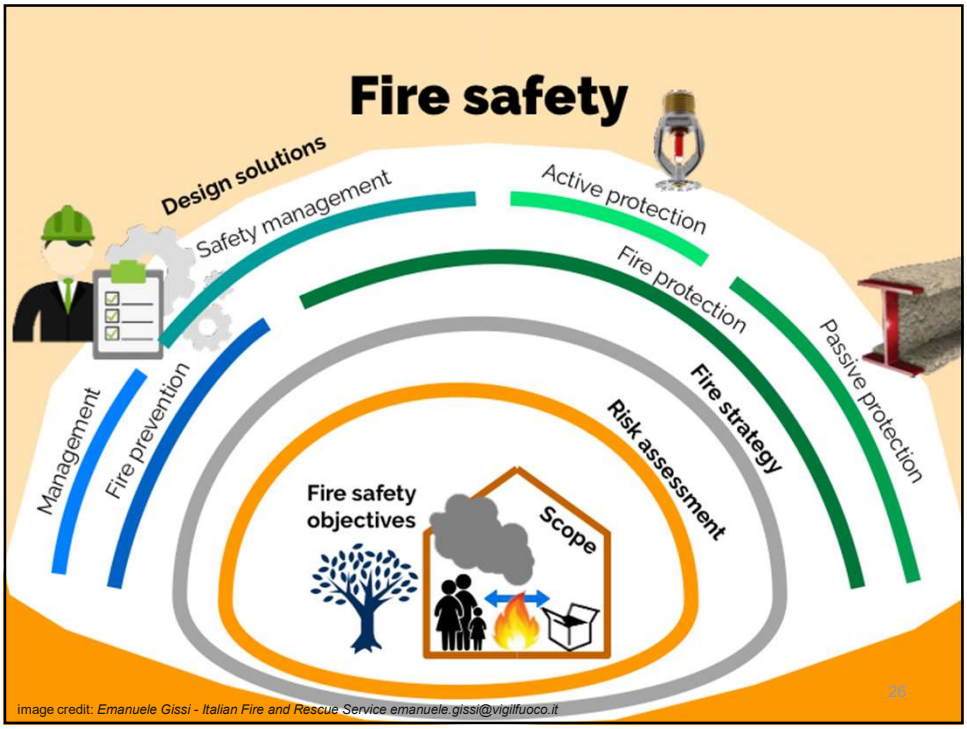


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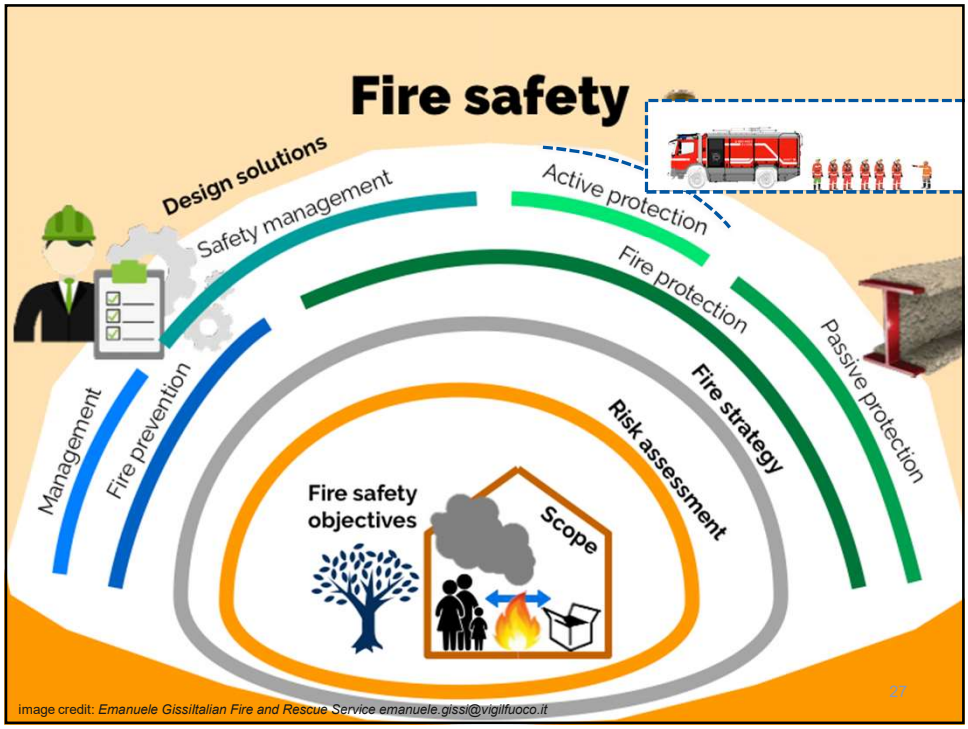


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fire department role in fire safety ?

**consequence reduction layer**



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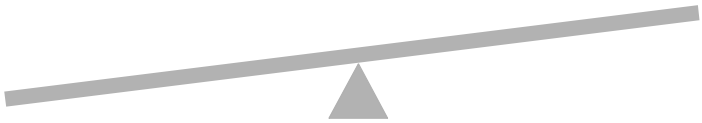
fire department as a consequence reduction layer

## balance risk vs benefit





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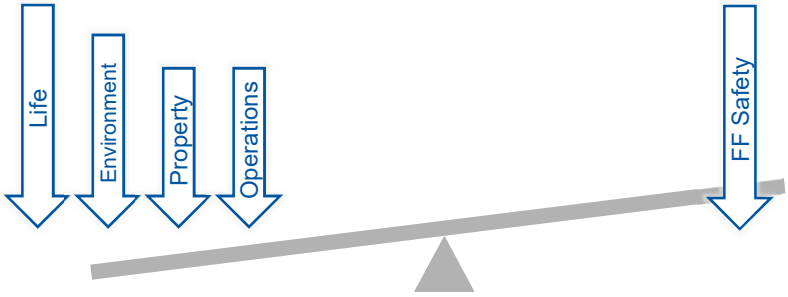
fire department as a consequence reduction layer

## balance risk vs benefit



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firefighter safety

codes, regulations: **prescriptive** approach

performance based: **engineering** approach



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firefighter safety in the codes

**prescriptive requirements**

**easy to apply**

**no risk analysis**



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## firefighter safety in the codes

*Code du Travail Art. 4216-2*: Les bâtiments et les locaux sont conçus et réalisés de manière à permettre en cas de sinistre : 1° L'évacuation rapide de la totalité des occupants ou leur évacuation différée, lorsque celle-ci est rendue nécessaire, dans des conditions de sécurité maximale ; 2° **L'accès de l'extérieur et l'intervention des services de secours et de lutte contre l'incendie** ;

*Norme de Protection Incendie AEAI*: « Les bâtiments et les autres ouvrages doivent être construits, exploités et entretenus de manière à: a garantir la sécurité des personnes et des animaux; e **permettre une lutte efficace contre le feu et garantir la sécurité des sapeurs pompiers.** »

*Construction Products Regulation 305/2011* « The construction works must be designed and built in such a way that in the event of an outbreak of fire: (d) occupants can leave the construction works or be rescued by other means; (e) **the safety of rescue teams is taken into consideration**."



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firefighter safety in the codes

**"…safety of rescue teams is taken into consideration"**

## how?

### what are de limits of safe firefighting?

(conditions, crew size, equipment, resources, engagement policy,…)



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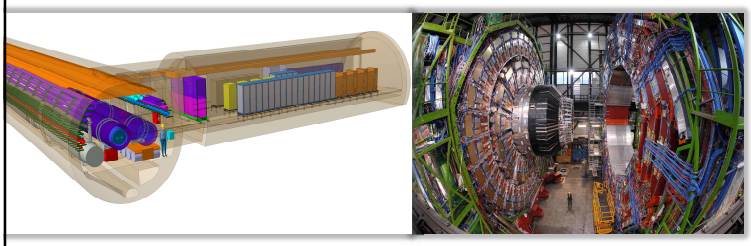
firefighter safety in the codes

scope of application

**what to do with non-standard scenarios?**





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**performance based design (PBD)**
**for firefighter safety in the codes**

engineering approach

**prove** the performance (firefighter safety)



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## performance based design (PBD) for firefighter safety in the codes

engineering approach

**prove** the performance (firefighter safety)




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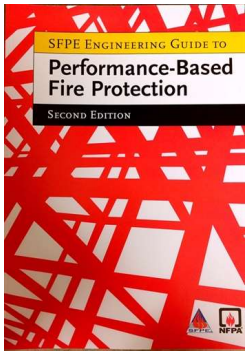
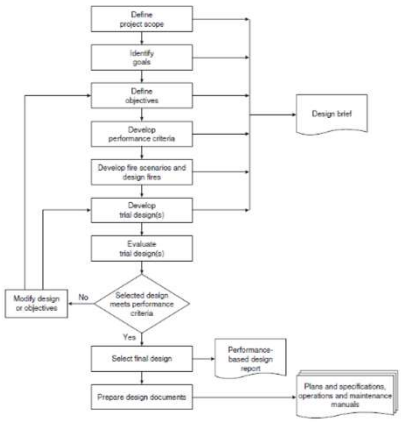
## performance based design (PBD)

**SFPE NFPA guide** for PBD as a base

common application for life, property loss

not so common for firefighting



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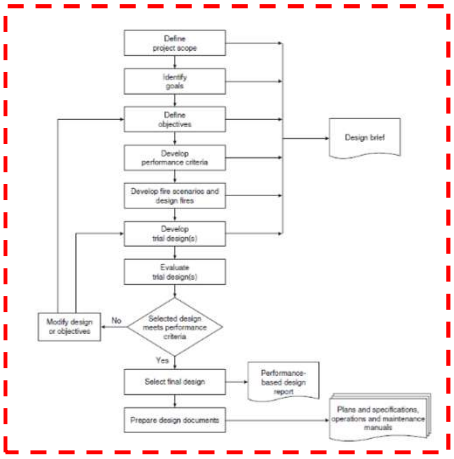
## performance based design (PBD) **process**



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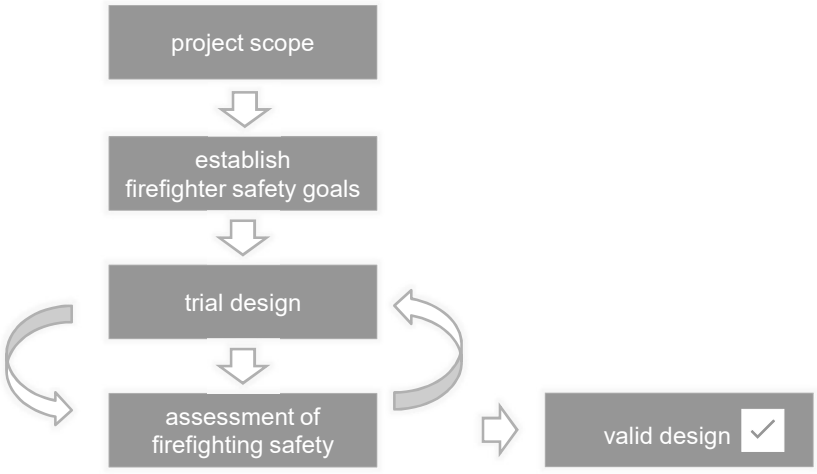
## performance based design (PBD) **process for FF safety**



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## performance based design (PBD) **process for FF safety**




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## performance based design (PBD) **process for FF safety**


**acceptance criteria**

criteria stated in engineering terms with which the adequacy of any developed trial designs will be judged acceptable

- building specifications
- exposure limits for FF



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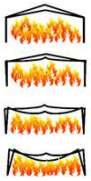
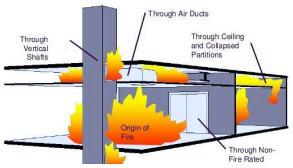
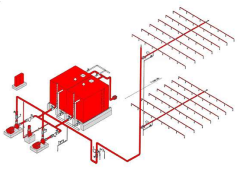
# building specifications

firefighter safety acceptance criteria expressed in building performance







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# building specifications

firefighter safety acceptance criteria expressed in building performance


Victorian Fire & Emergency Services Board
Community Safety Directorate
Guideline No: GL-17
GUIDELINE
Fire Brigade Intervention Model (FBIM)
General Provisions
MFB
Prepared By: MFB Community Safety Advisory Group
Authorised By: Director Community Safety
First Issued: 24 June 2003
Version No: 3
14 December 2010
Reviewed: 14 December 2016
Page 1 of 4
1. Purpose
To provide advice relative to when the Fire Brigade Intervention Model (FBIM) should be carried out and the information required to undertake the model. The model can be sourced via the Australasian Fire and Emergency Services Authorities Council (AFAC) website www.afac.com.au.
2. BCA Requirements
In 1996, a performance based building code[1] was introduced in Australia. To ensure that the Fire Brigades' functional role was maintained in the building code, a method of quantifying the Fire Brigades' role was required. In response to this issue, the Australasian Fire Authorities Council (AFAC) formed a Performance Based Fire Engineering Committee. This committee developed a model that determines the time taken by a Fire Brigade to undertake its activities at a fire scene.
In addition to the objectives and functional statements of the BCA, the following performance requirements are specific to Fire Brigade Intervention.
CP1 Structural stability during a fire.
CP2 Avoiding spread of fire.
CP9 Access provided to and around a building for fire brigade vehicles and personnel.
DP5 Fire isolated exits.
EP1.3 Fire hydrants.
EP1.5 Fire fighting equipment in a building under construction.
EP1.6 Facilities to co-ordinate fire brigade intervention.
EP2.2 Evacuation time of occupants.
EP3.2 Emergency lifts.
GP4.4 Fire safety system in an alpine area
3. What is FBIM and When Is It Required?
The 'Fire Brigade Intervention Model'[2] is an event-based methodology, which quantifies Fire Brigade activities employed during a fire from time of notification through to control and extinguishment. It has been primarily developed for use in fire engineering design in a performance-based regulatory environment so that the functional role of a Fire Brigade can be effectively incorporated into the building design process. It establishes a structured framework necessary to both determine and measure Fire Brigade activities on a time-line basis. It interacts with the outputs of other sub-systems which model such events as fire growth, smoke spread, fire spread, detection and suppression as well as occupant evacuation. The model has been developed for use on specific site characteristics and is applicable to most fire scenarios. As the
[1] Australian Building Codes Board (ABB) - The Building Code of Australia, Vol. 1 Class 2 to Class 9 Buildings - ECM Australia Limited
[2] Australasian Fire Authorities Council, 2004 - Fire Brigade Intervention Model - Version 2.3 - October 2004
THIS DOCUMENT IS UNCONTROLLED WHEN PRINTED
MFB COMMUNITY SAFETY DIRECTORATE
COMMUNITY SAFETY DIRECTORATE GUIDELINE

## Melbourne Metropolitan Fire Brigade

CP1 Structural stability during a fire.
CP2 Avoiding spread of fire.
CP9 Access provided to and around a building for fire brigade vehicles and personnel.

DP5 Fire isolated exits.

EP1.3 Fire hydrants.
EP1.5 Fire fighting equipment in a building under construction.
EP1.6 Facilities to co-ordinate fire brigade intervention.
EP2.2 Evacuation time of occupants.
EP3.2 Emergency lifts.

GP4.4 Fire safety system in an alpine area



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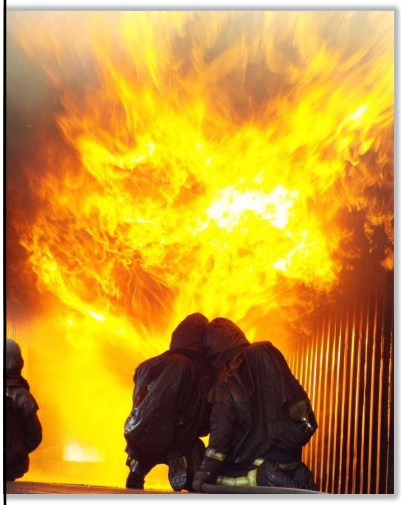
# exposure limits for firefighters

firefighter safety acceptance criteria based on fire dynamics





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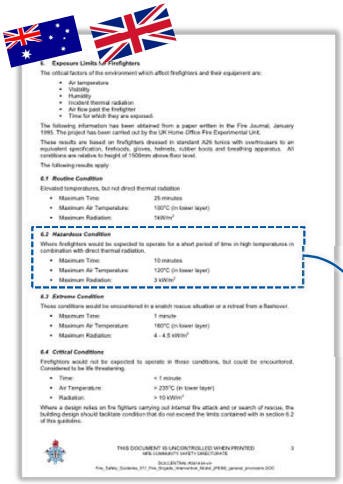
# exposure limits for firefighters

firefighter safety acceptance criteria based on fire dynamics



**Melbourne Metropolitan Fire Brigade**
**UK Home Office**

- Air temperature
- Visibility
- Humidity
- Incident thermal radiation
- Air flow past the firefighter
- Time for which they are exposed

*Example*
*Hazardous Condition*
- *Maximum Time: 25 minutes*
- *Maximum Air Temperature: 100°C (in lower layer)*
- *Maximum Radiation: 1kW/m2*

*" …building design should facilitate condition that do not exceed Hazardous Condition"*



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## hands on

CERN Super Proton Synchrotron



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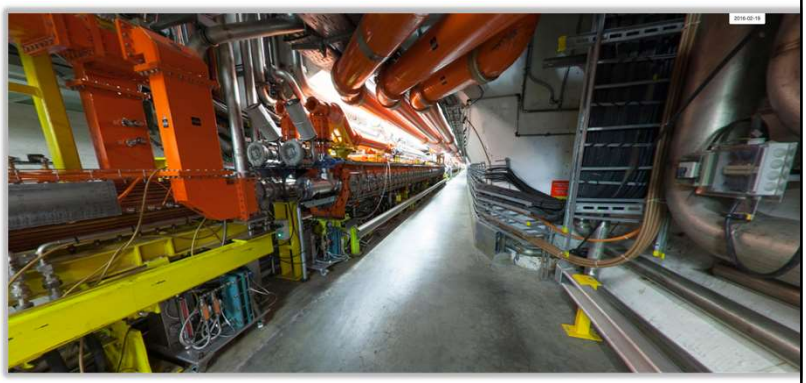
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

complex fire scenarios at CERN

## CERN Super Proton Synchrotron





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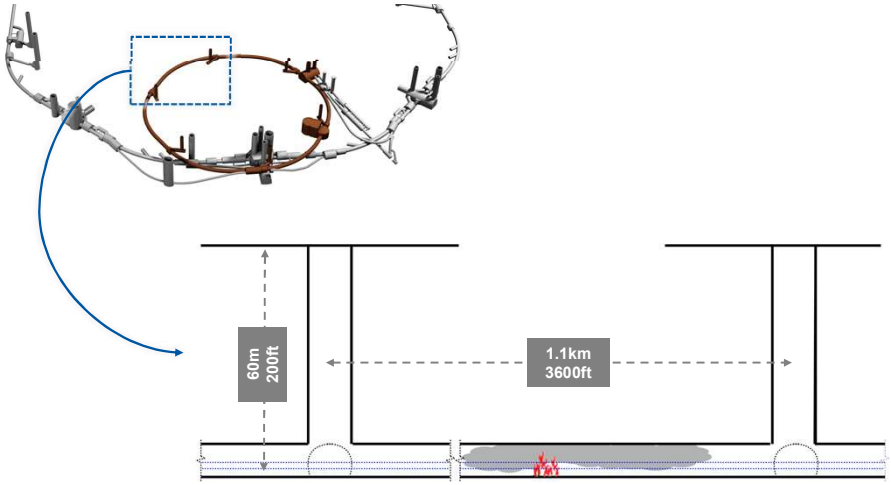
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design



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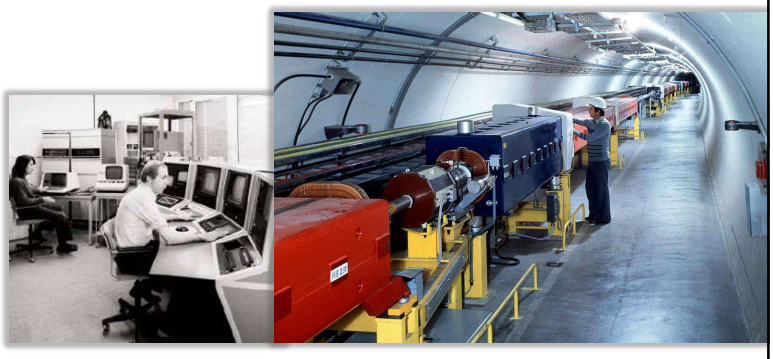
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

build 70's

**1970 fire safety standards**





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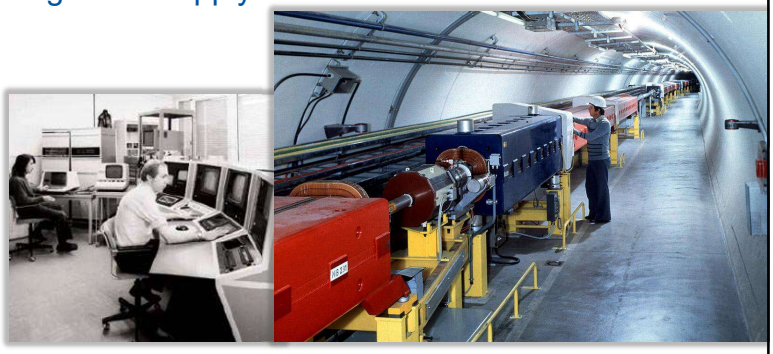
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

acceptable fire detection
limited fire suppression
no firefighting water supply





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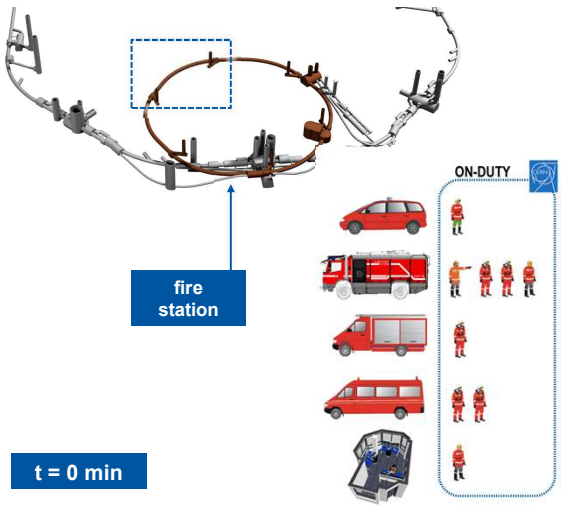
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design



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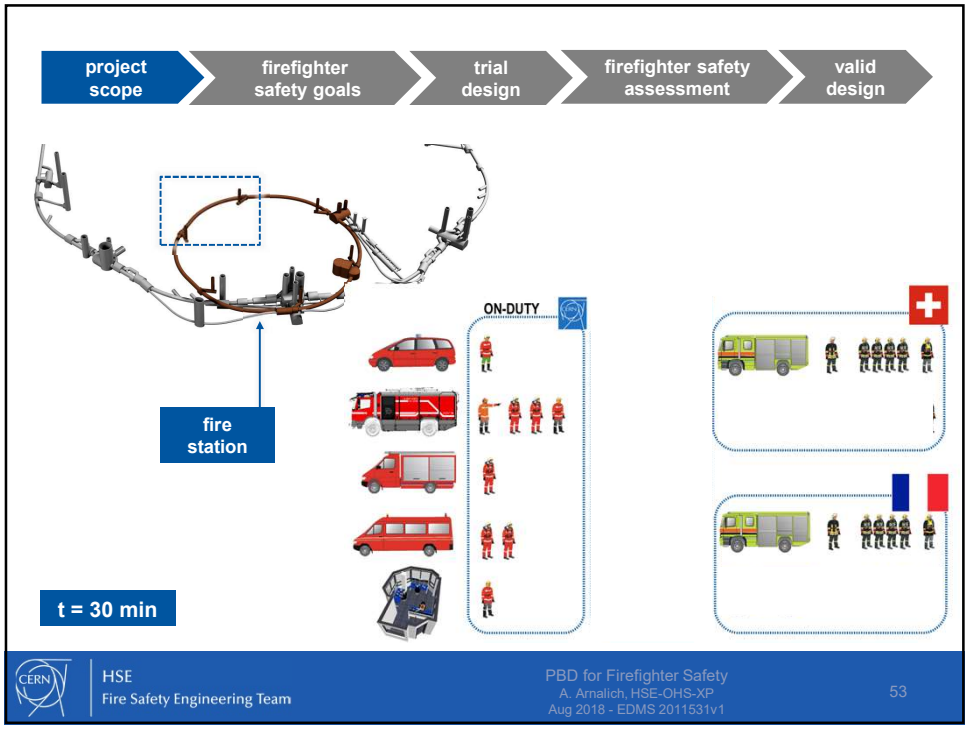
project scope
firefighter safety goals
trial design
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valid design
ON-DUTY
fire station
t = 30 min
HSE
Fire Safety Engineering Team
PBD for Firefighter Safety
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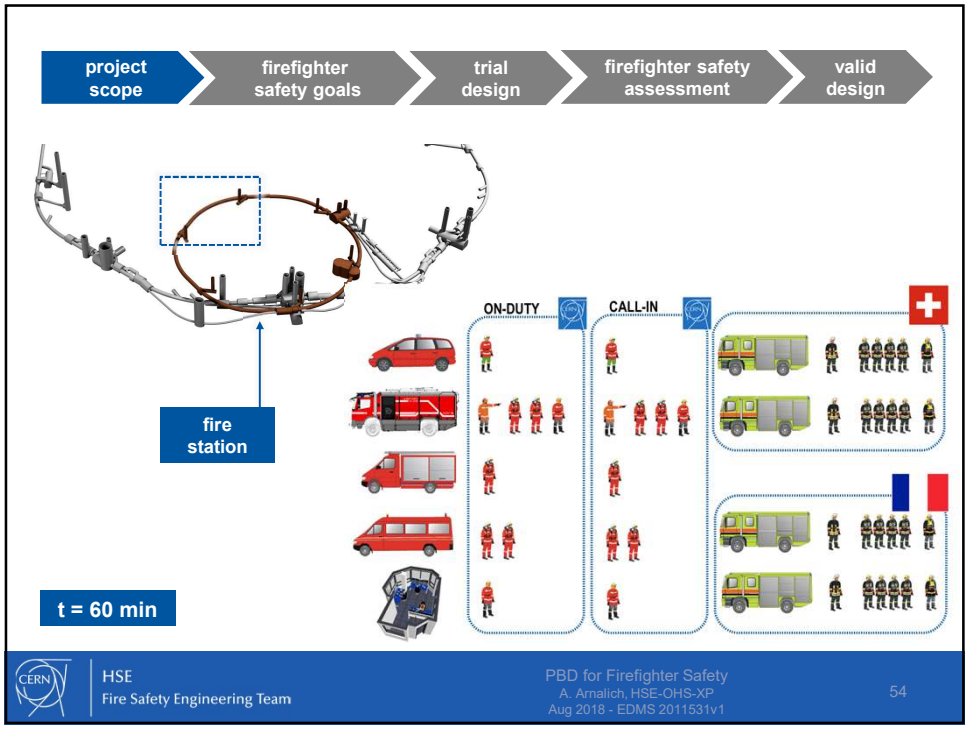
project scope
firefighter safety goals
trial design
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ON-DUTY
CALL-IN
fire station
t = 60 min
HSE
Fire Safety Engineering Team
PBD for Firefighter Safety
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project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

## safety objectives

| | Life | Environment | Property | Continuity of operation |
|---|---|---|---|---|
| | A | B | C | D |



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project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

## safety objectives

| | 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 [illegible] assured [illegible] case of [illegible] gas release and [illegible] 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 rele[illegible] the environment [illegible] incidents | An incident s[illegible] not cause other [illegible] tially dangerous a[illegible] ental 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



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project scope | **firefighter safety goals** | trial design | firefighter safety assessment | valid design

## acceptance criteria

criteria stated in engineering terms with which the adequacy of any developed trial designs will be judged acceptable

- building specifications
- exposure limits for FF

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



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project scope | **firefighter safety goals** | trial design | firefighter safety assessment | valid design

## acceptance criteria
## building specifications

**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

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



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project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

## acceptance criteria
## building specifications

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

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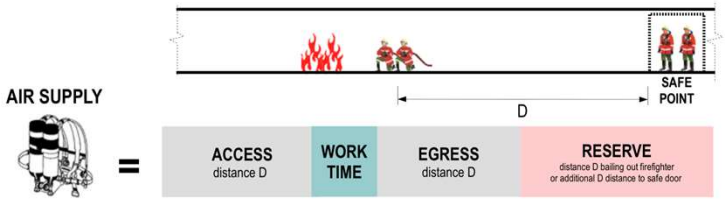
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

## 450m?
## firefighting limitations based on air supply



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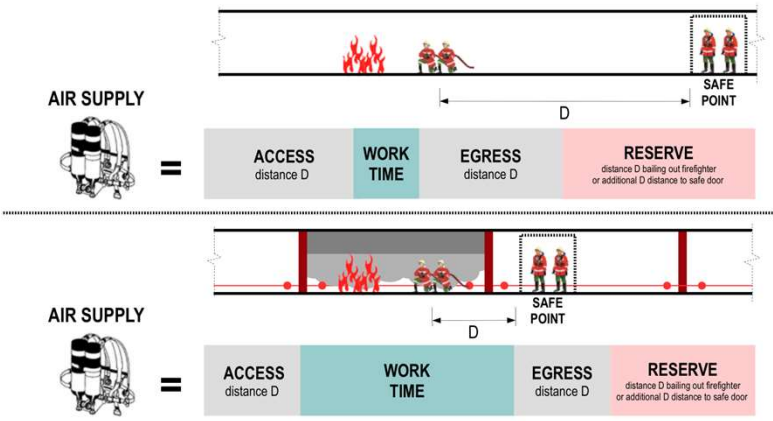
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

450m?

## firefighting limitations based on air supply



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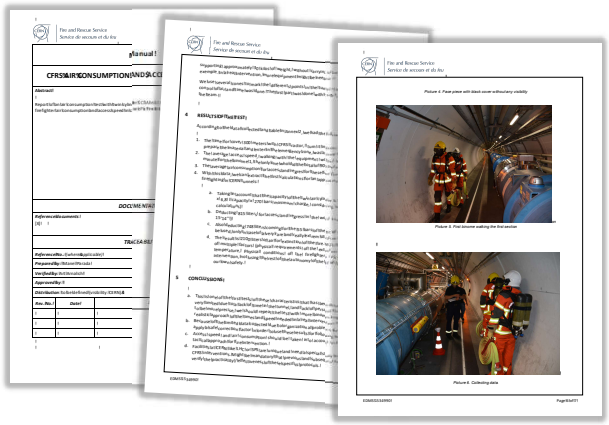
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

firefighting limitations based on air supply

## 450m = 20 minutes on the fire + safe egress





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project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design



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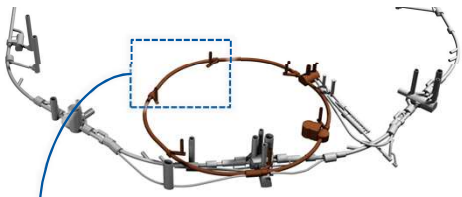
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design



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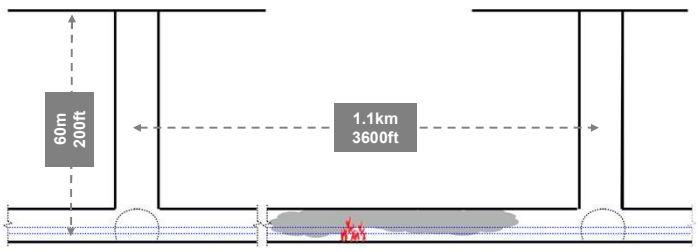




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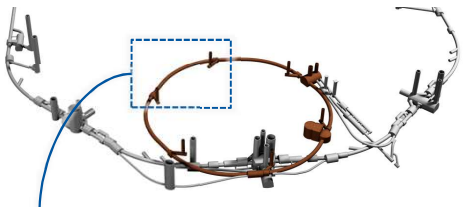
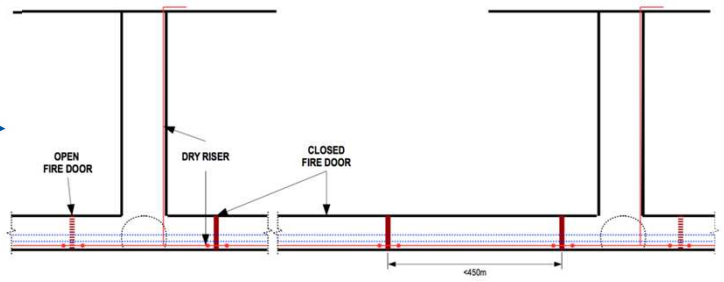
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design



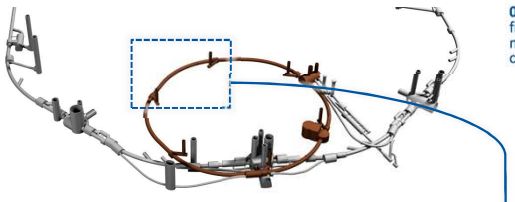
**04** Firefighter safety requires that closest **safe area** for firefighting (no imminent risk and no breathing apparatus needed) is **less than 450m away** from the door of the fire compartment.






65

project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design



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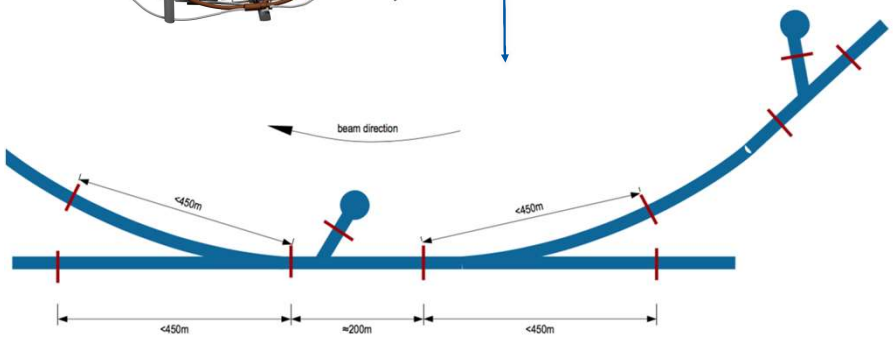
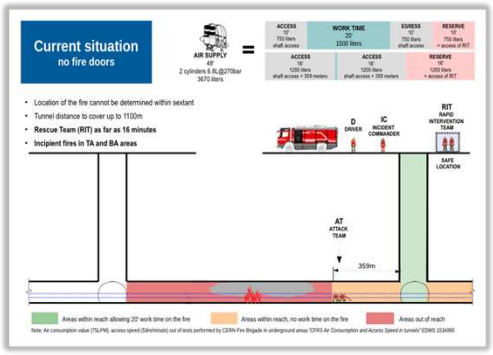





66

project scope | firefighter safety goals | **trial design** | firefighter safety assessment | valid design

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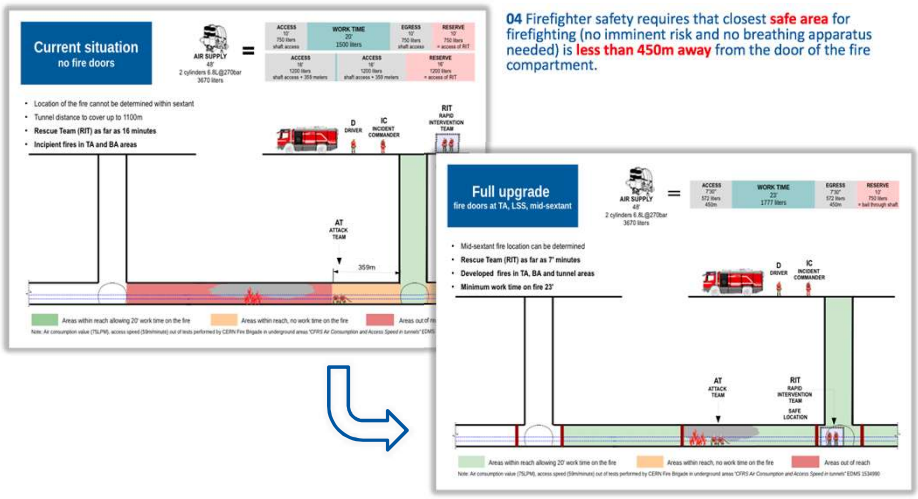
67

project scope | firefighter safety goals | **trial design** | firefighter safety assessment | valid design

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68

project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

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- 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.

extinguishing media
**matching fire scenario**

**big fire, big water**
**small fire, minimal damage**



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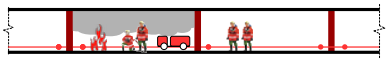
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

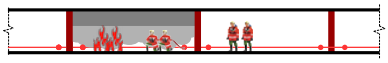
OFFENSIVE

**FIRE ATTACK EXTINGUISHERS**
<25kg fuel load

**FIRE ATTACK PORTABLE CAFS**
HRR <5MW + direct attack possible

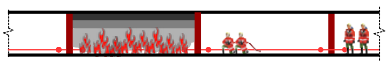


**FIRE ATTACK WATER DRY RISER**
HRR <20MW + direct attack possible



DEFENSIVE

**DOOR PROTECTION WATER DRY RISER**
HRR >20MW or direct attack not possible





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project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

portable CAFS
**medium fires (5MW)**
**test campaign**



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project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

**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:
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100L portable CAFS on trailer up to 5MW;
or 500LPM water hose line up to a maximum HRR of 20MW.

**big fire, big water**
**small fire, minimal damage**

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.



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project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design



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project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

## design fires





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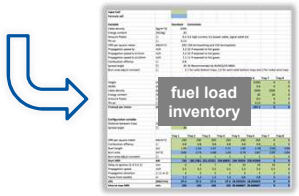
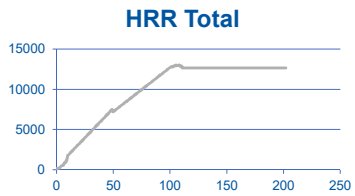
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

## design fires



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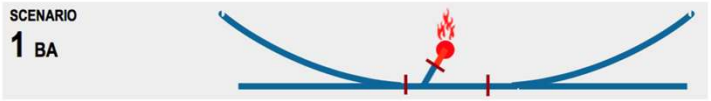
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

## seat of the fire, fire clusters and **fire scenarios**



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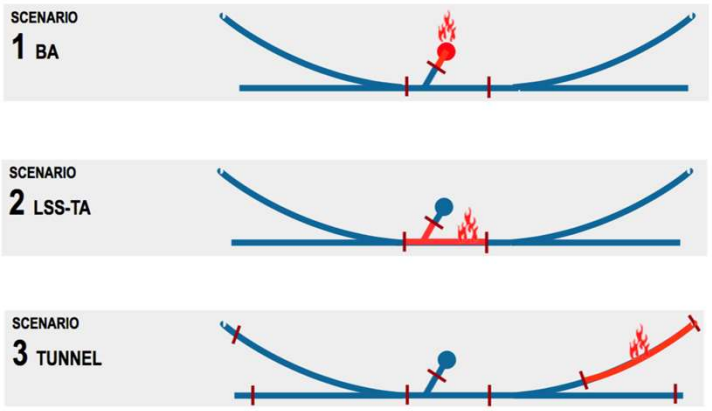
project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

seat of the fire, fire clusters
and **fire scenarios**



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project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

seat of the fire, fire clusters
**fire scenarios**

**what are the conditions?**
**what is the probability of success?**



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project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

what are the conditions?
what is the probability of success?

## FDS by NIST
Fire Dynamics Simulator

## FRPAM by CERN
Fire Response Probabilistic Analysis Model



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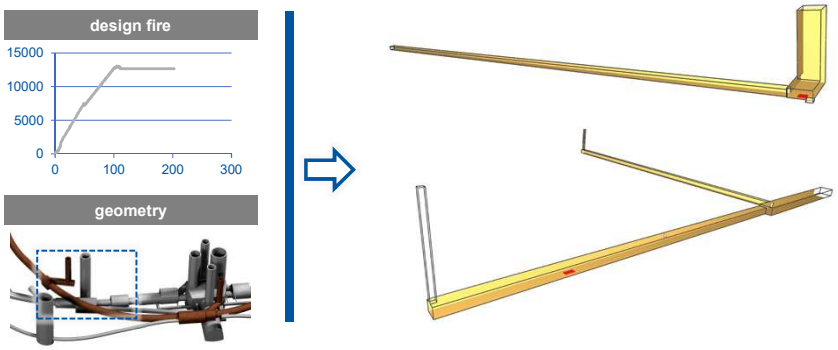
project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

## FDS by NIST
**input = fire scenario** (geometry and design fire)



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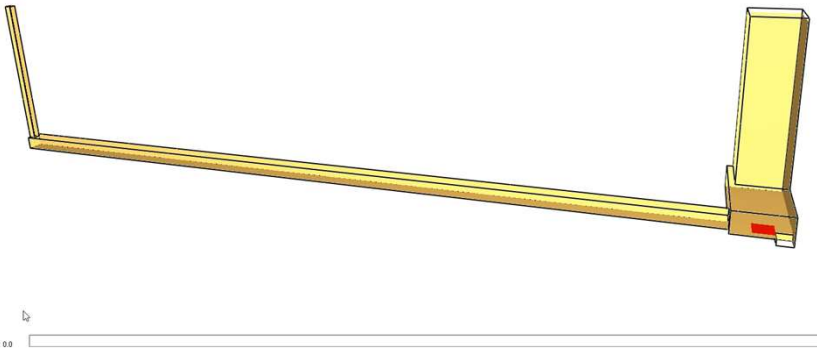
project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

## FDS by NIST

**output = firefighting conditions** (smoke spread, visibility, temperature, heat flux, …)





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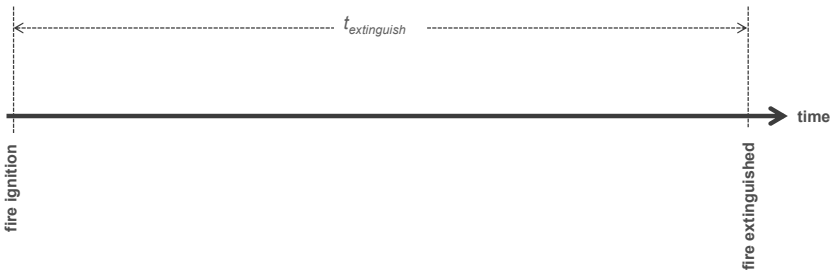
project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

## FRPAM by CERN

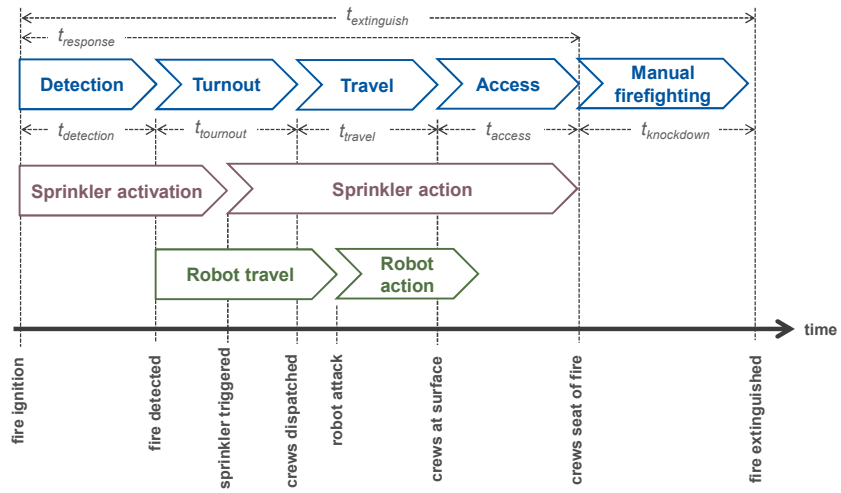
Fire Response Probabilistic Analysis Model






82

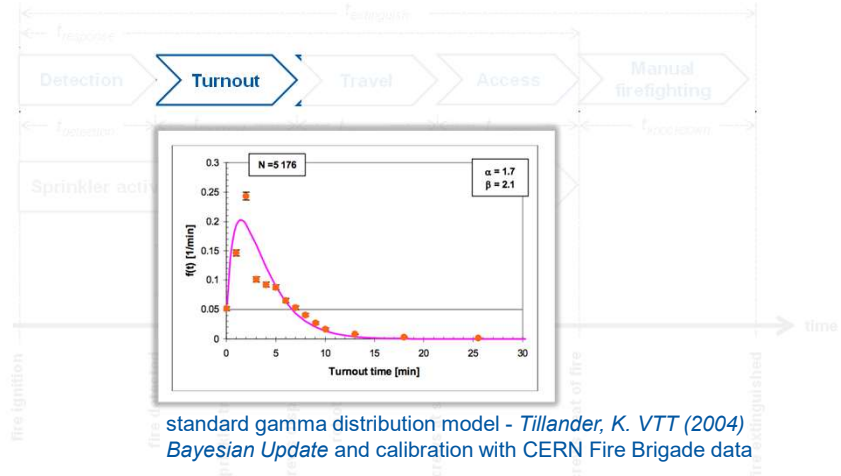
project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design






83

project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design




standard gamma distribution model - *Tillander, K. VTT (2004)*
*Bayesian Update* and calibration with CERN Fire Brigade data



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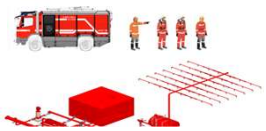
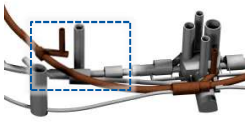
project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

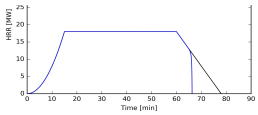
fire attack resources



geometry



design fire




**FRPAM**



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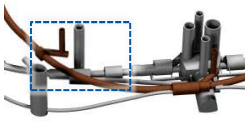
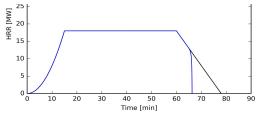
project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

fire attack resources

geometry

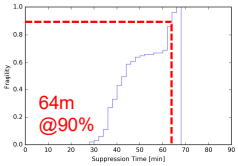


design fire

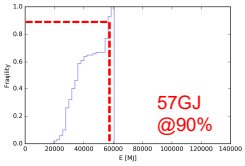



**FRPAM**

**extinguishing time**
cumulative distribution function




**energy release**
cumulative distribution function



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project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

fire attack resources

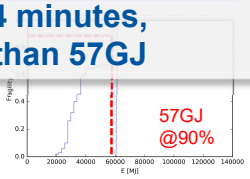
extinguishing time
cumulative distribution function

with a **90% probability,**

for the **given facility, design fire** and **fire attack resources**

**fire is put out in less than 64 minutes,**
**total energy release is less than 57GJ**

energy release
cumulative distribution function



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## performance based design (PBD) **process for FF safety**

project scope

establish firefighter safety goals

trial design

assessment of firefighting safety

valid design ✓



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project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design

## acceptance criteria

**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.

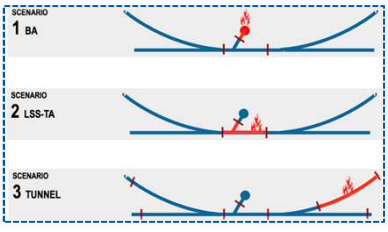
**06** Firefighter safety is only guaranteed if engaged teams remain in **communication** at all times with surface incident command post

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



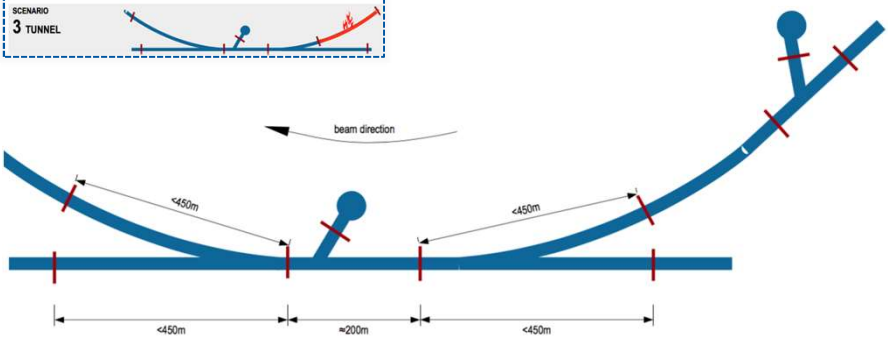
89

project scope | firefighter safety goals | trial design | firefighter safety assessment | valid design




**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.

✓ **acceptance criteria is achieved**






90

project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

## acceptance criteria

## trial design

**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. ✓

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**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 ✓

**back to a new trial design**



91

project scope | firefighter safety goals | trial design | **firefighter safety assessment** | valid design

## acceptance criteria

## trial design

**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. ✓

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**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 ✓

**valid design**



92

how can we account for firefighter safety in the design of buildings?

follow the codes

**let's design and prove it's safe using PBD**
(Performance Based Design)



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**successful outcome**
in **fire safety** is
**team work** and **excellence**
in fire education,
fire research,
fire prevention,
fire protection,
fire codes and standards
fire safety engineering,
firefighter training,
firefighter safety,
....
and fire operations

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## thanks for your attention


art.arnalich@cern.ch
CERN Fire Safety Engineering Team

**CERN, accelerating science**

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