Fire Resistance of the Load Bearing Structure of High Bay and Instrument Halls

Fire and Egress Safety Analysis of the Instrument Halls

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www.europeanspallationsource.se

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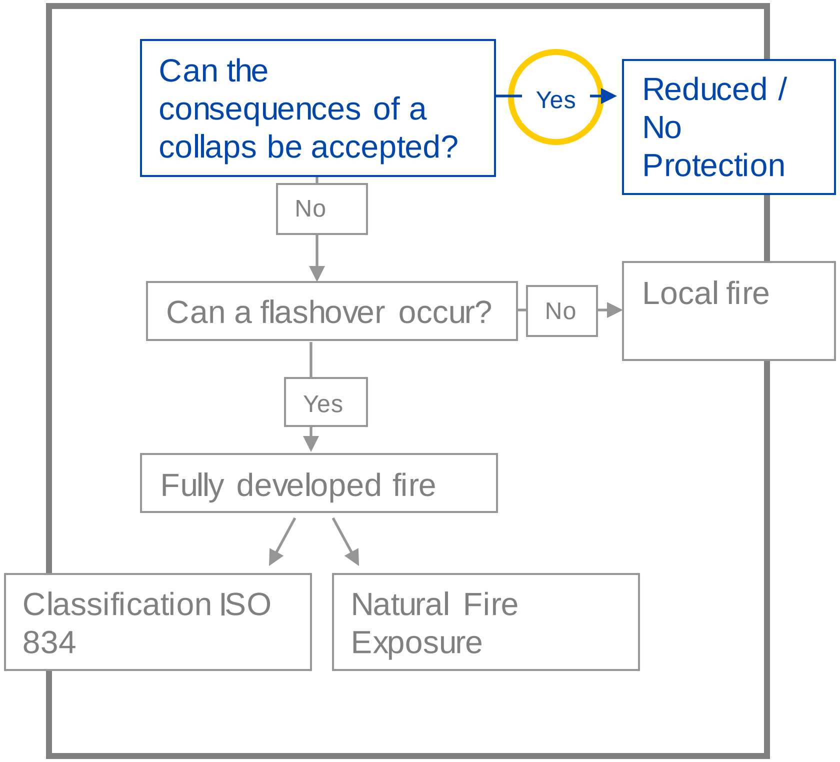
Aim and Objective

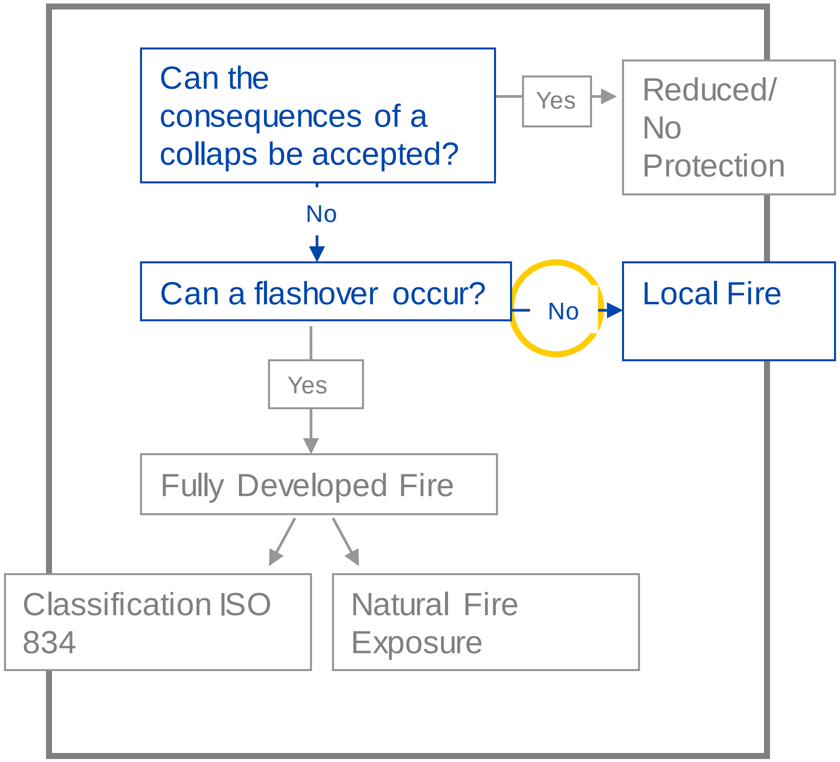
- **The aim of the analysis is to determine fire resistance of the structural elements in the High Bay and in the Instrumental Halls.**
- **This includes:**
  - Determining whether flashover might occur.
  - Measuring ceiling/local temperature from calculations and simulations of fires.
  - Determining safe distances and safe fire load to prevent flash over or local critical temperatures.

Reduced / no protection



Yes,… for some very rare cases. Not applicable for High Bay and Instrumental Halls.

Local Fire (Natural Fire Exposure)



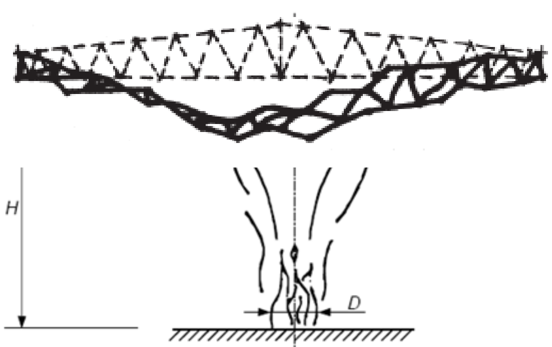
No, ….

EKS kap 1.1.2 7§ If it can be verified that a flashover cannot occur it is allowed to design the load bearing structure of the buidling according to the exposure from a local fire.

In the High Bay and the Instrument Halls this might be possible due to the large volume.

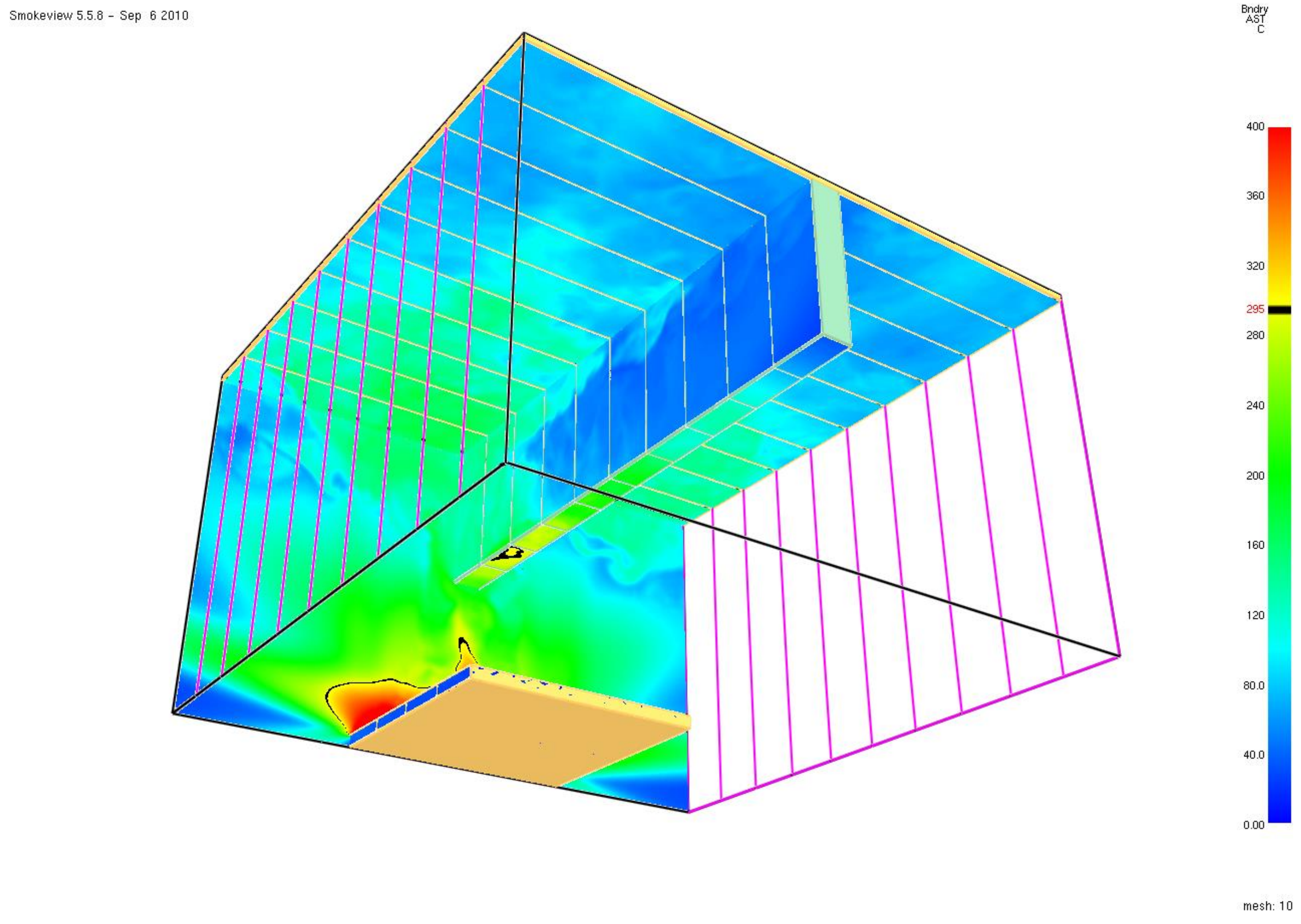
EKS 1.1.2 9 § The fire scenario and the heat production from the local fire shall be calculated due to the expected conditions in the building.

The hight and location of the fire load should be taken into account.

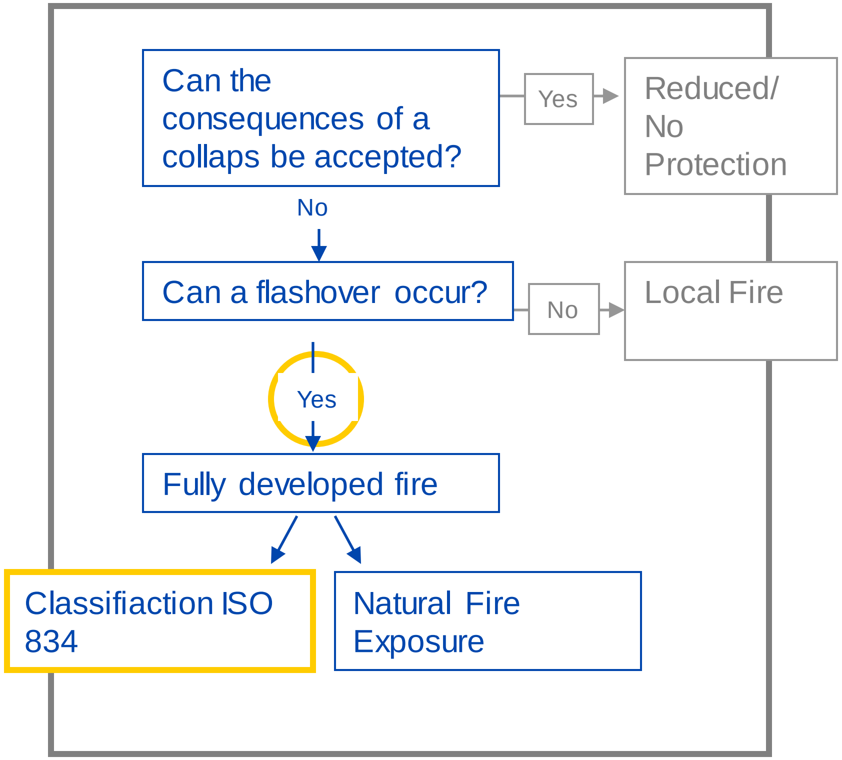


Do not forget the impact from flames

Local Fire


Smokeview 5.5.8 - Sep 6 2010
Bndry
AST
C
400
360
320
295
280
240
200
160
120
80.0
40.0
0.00
mesh: 10

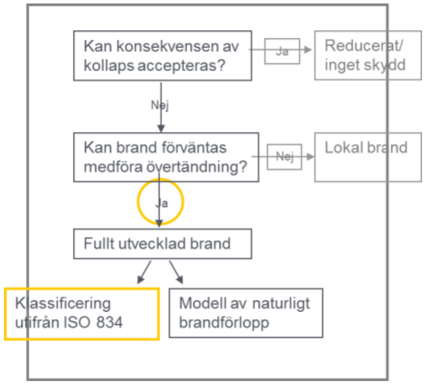
Klassificering utifrån ISO 834



EKS 1.2.3 §6 When designing according to classification (nominal temperature-time curves) structural elements shall be designed in a way that a collaps will not occur in a certain time period (according to table C-7).

- Tests according to SS-EN 13501-2 (ISO 834),
- Calculations based on the same nominal temperature-time curve, or
- A combination of tests and calculations above

Classification ISO 834



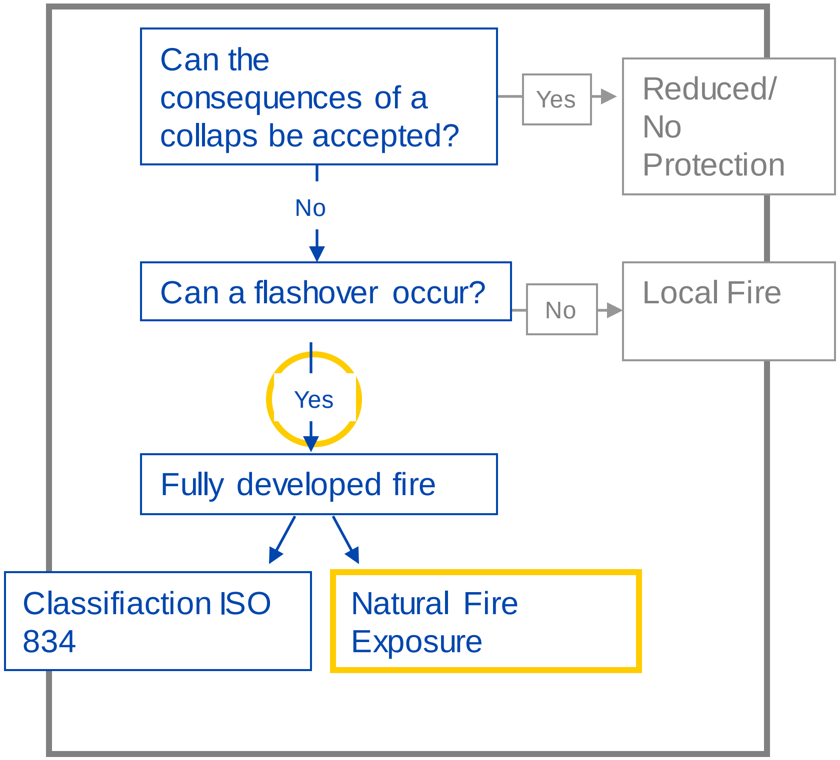
Tabell C-7 Brandteknisk klass i bärande avseende

Brandsäker-hetsklass	Brandteknisk klass vid brandbelastning f (MJ/m²)		
	f ≤ 800 MJ/m²	f ≤ 1600 MJ/m²	f >1600 MJ/m²
1	0	0	0
2	R15	R15	R15
3	R30	R30	R30
4	R60	R120 (R90*)	R180 (R120*)
5	R90 (R60*)	R180 (R120*)	R240 (R180*)

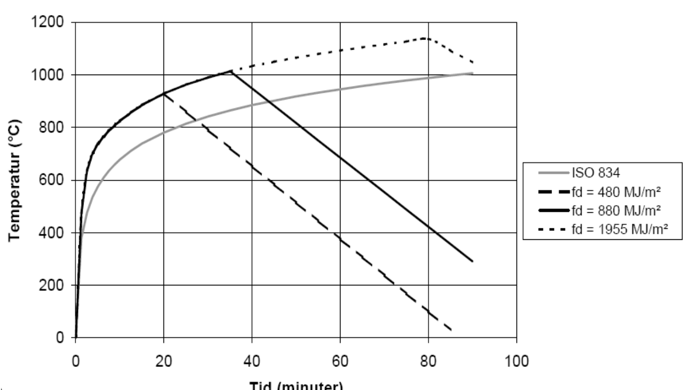
* Vid installation av automatisk vattensprinkleranläggning utförd enligt avsnitt 5:235 i Boverkets byggregler (2011:6).

(EKS kap 1.1.2 §6)

Natural Fire Exposure (fully delevoped fire)



EKS 1.1.2 §8 The temperature development shall be calculated by using energy and mass balance equations. The model described in i SS EN 1991-1-2, appendix A must be used.



$$\rho\left(\frac{\partial u_r}{\partial t}+u_r\frac{\partial u_r}{\partial r}+\frac{u_\theta}{r\sin(\phi)}\frac{\partial u_r}{\partial\theta}+\frac{u_\phi}{r}\frac{\partial u_r}{\partial\phi}-\frac{u_\theta^2+u_\phi^2}{r}\right)=-\frac{\partial p}{\partial r}+\rho g_r$$

$$\mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial u_r}{\partial r}\right)+\frac{1}{r^2\sin(\phi)^2}\frac{\partial^2 u_r}{\partial\theta^2}+\frac{1}{r^2\sin(\phi)}\frac{\partial}{\partial\phi}\left(\sin(\phi)\frac{\partial u_r}{\partial\phi}\right)-2\frac{u_r+\frac{\partial u_\phi}{\partial\phi}+u_\phi\cot(\phi)}{r^2}+\frac{2}{r^2\sin(\phi)}\frac{\partial u_\theta}{\partial\theta}\right]$$

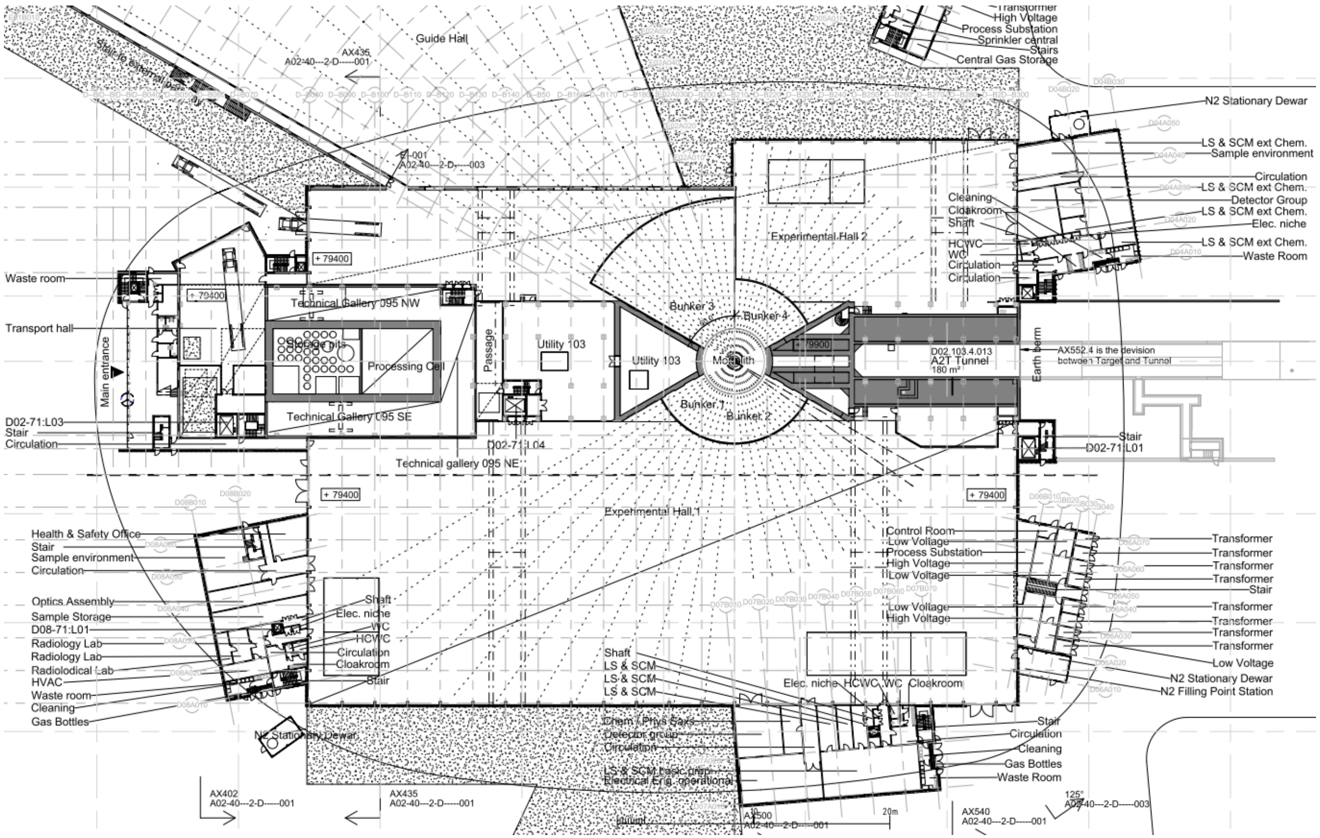
$$\rho\left(\frac{\partial u_\theta}{\partial t}+u_r\frac{\partial u_\theta}{\partial r}+\frac{u_\theta}{r\sin(\phi)}\frac{\partial u_\theta}{\partial\theta}+\frac{u_\phi}{r}\frac{\partial u_\theta}{\partial\phi}+\frac{u_r u_\theta+u_\theta u_\phi\cot(\phi)}{r}\right)=-\frac{1}{r\sin(\phi)}\frac{\partial p}{\partial\theta}+\rho g_\theta$$

$$\mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial u_\theta}{\partial r}\right)+\frac{1}{r^2\sin(\phi)^2}\frac{\partial^2 u_\theta}{\partial\theta^2}+\frac{1}{r^2\sin(\phi)}\frac{\partial}{\partial\phi}\left(\sin(\phi)\frac{\partial u_\theta}{\partial\phi}\right)+\frac{2\frac{\partial u_r}{\partial\theta}+2\cos(\phi)\frac{\partial u_\phi}{\partial\theta}-u_\theta}{r^2\sin(\phi)^2}\right]$$

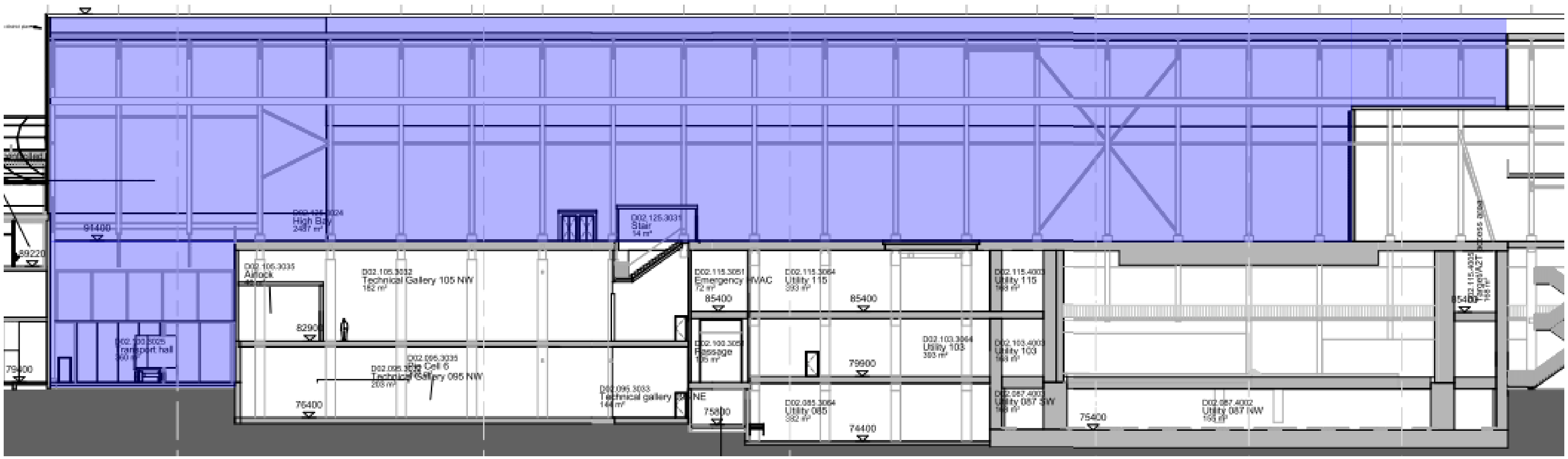
$$\rho\left(\frac{\partial u_\phi}{\partial t}+u_r\frac{\partial u_\phi}{\partial r}+\frac{u_\theta}{r\sin(\phi)}\frac{\partial u_\phi}{\partial\theta}+\frac{u_\phi}{r}\frac{\partial u_\phi}{\partial\phi}+\frac{u_r u_\phi-u_\theta^2\cot(\phi)}{r}\right)=-\frac{1}{r}\frac{\partial p}{\partial\phi}+\rho g_\phi$$

$$\mu\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial u_\phi}{\partial r}\right)+\frac{1}{r^2\sin(\phi)^2}\frac{\partial^2 u_\phi}{\partial\theta^2}+\frac{1}{r^2\sin(\phi)}\frac{\partial}{\partial\phi}\left(\sin(\phi)\frac{\partial u_\phi}{\partial\phi}\right)+\frac{2}{r^2}\frac{\partial u_r}{\partial\phi}-\frac{u_\phi+2\cos(\phi)\frac{\partial u_\theta}{\partial\theta}}{r^2\sin(\phi)^2}\right]$$

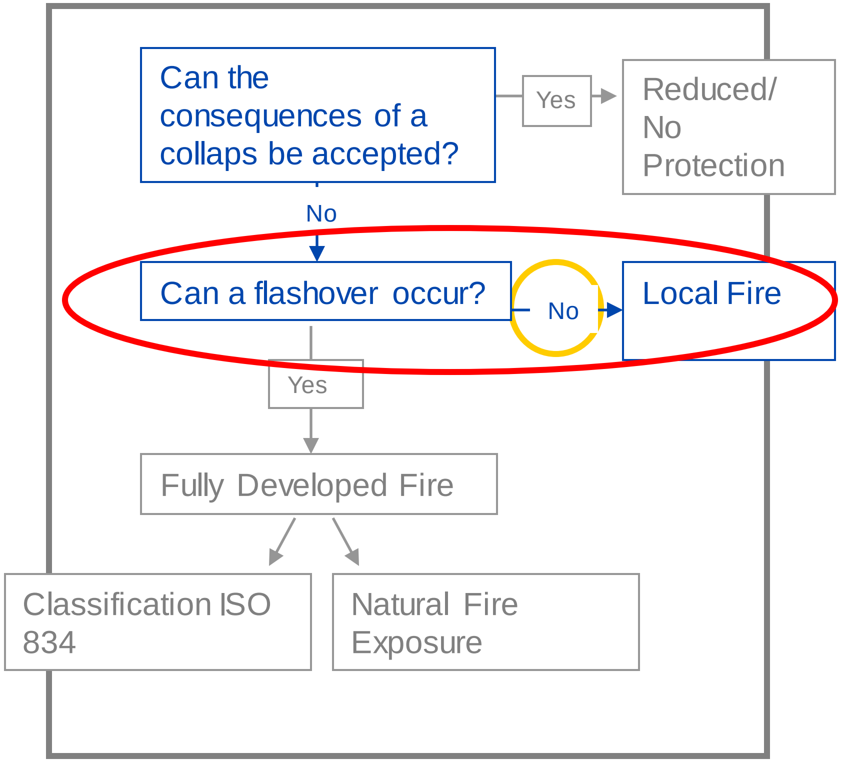
Experimental Halls



High Bay


91400
89220
D02.125.3024
High Bay
D02.125.3031
Stair
D02.105.3035
Airlock
D02.105.3032
Technical Gallery 105 NW
82900
D02.095.3035
Pig Cell 6
Technical Gallery 095 NW
79400
76400
D02.095.3033
Technical gallery
D02.115.3051
Emergency HVAC
85400
D02.115.3064
Utility 115
D02.100.3050
Passage
75800
D02.103.3064
Utility 103
79900
D02.085.3064
Utility 085
74400
D02.115.4003
Utility 115
D02.103.4003
Utility 103
D02.087.4003
Utility 087 SW
75400
D02.087.4002
Utility 087 NW

Local Fire (Natural Fire Exposure)



No, ….

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Flashover

Flashover is generally expected when the upper layer temperature is in the range of 500-600 °C.

Flashover criteria used: Temperature rise of 500 °C

Thus gives:

$$\dot{Q}_{FO} = 610(h_k A_T A_O \sqrt{H_O})^{1/2}$$

Critical Temperature of Hot Gas Layer

Flashover can be defined as the moment when incident radiation flux ($\dot{q}"$) on the floor is 20 kW/m².

$$\dot{q}" = \phi\varepsilon\sigma T^4$$

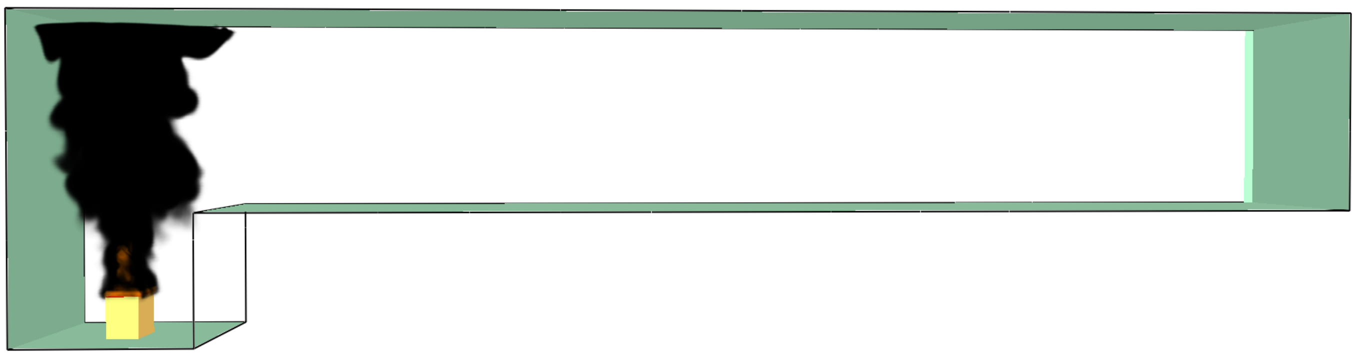
The hot gas layer temperature (T) where the incident radiation reaches this level is calculated with:

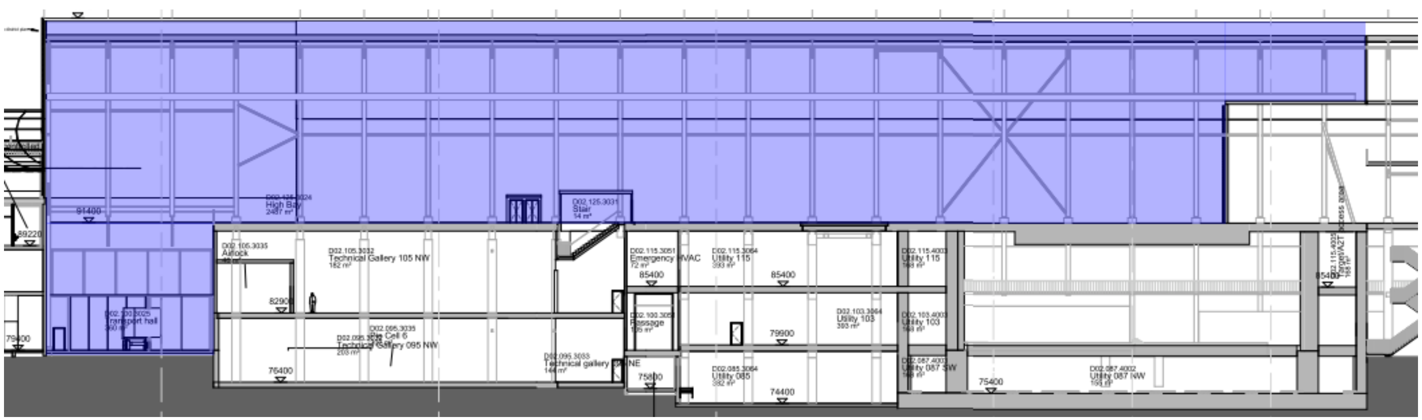
$$T = \sqrt[4]{\frac{\dot{q}"}{\phi\varepsilon\sigma}}$$

$$T = \sqrt[4]{\frac{20000\ W/m^2}{5{,}67 \cdot 10^{-8}\ W/m^2K^4}} = 771\ K = 498\ °C$$

Computational Fluid Dynamics

Fire Dynamics Simulator: High Bay Simulation (30 MW Truck fire)





Computational Fluid Dynamics

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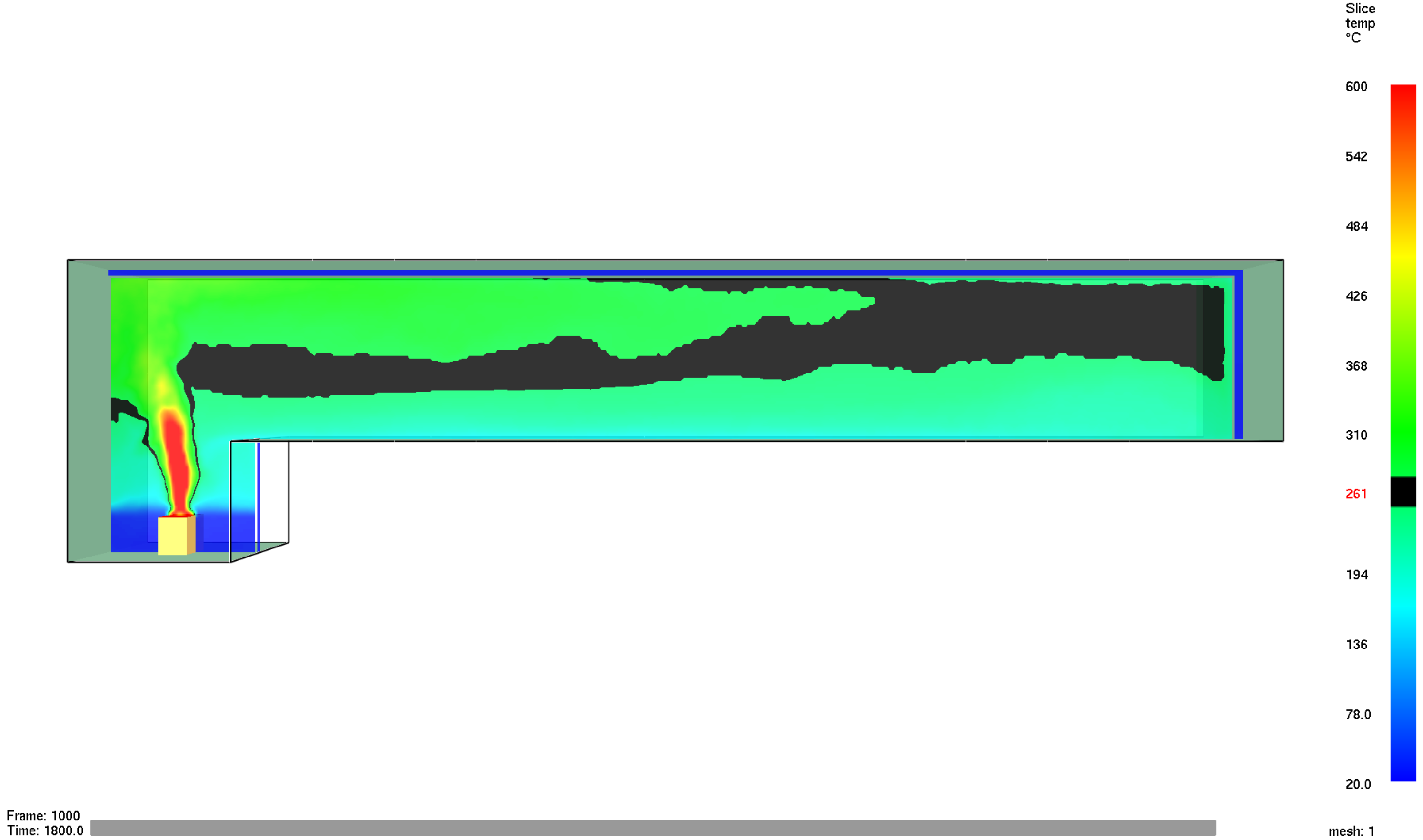

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Computational Fluid Dynamics

EUROPEAN SPALLATION SOURCE

Fire Dynamics Simulator: High Bay Simulation (30 MW Truck fire)

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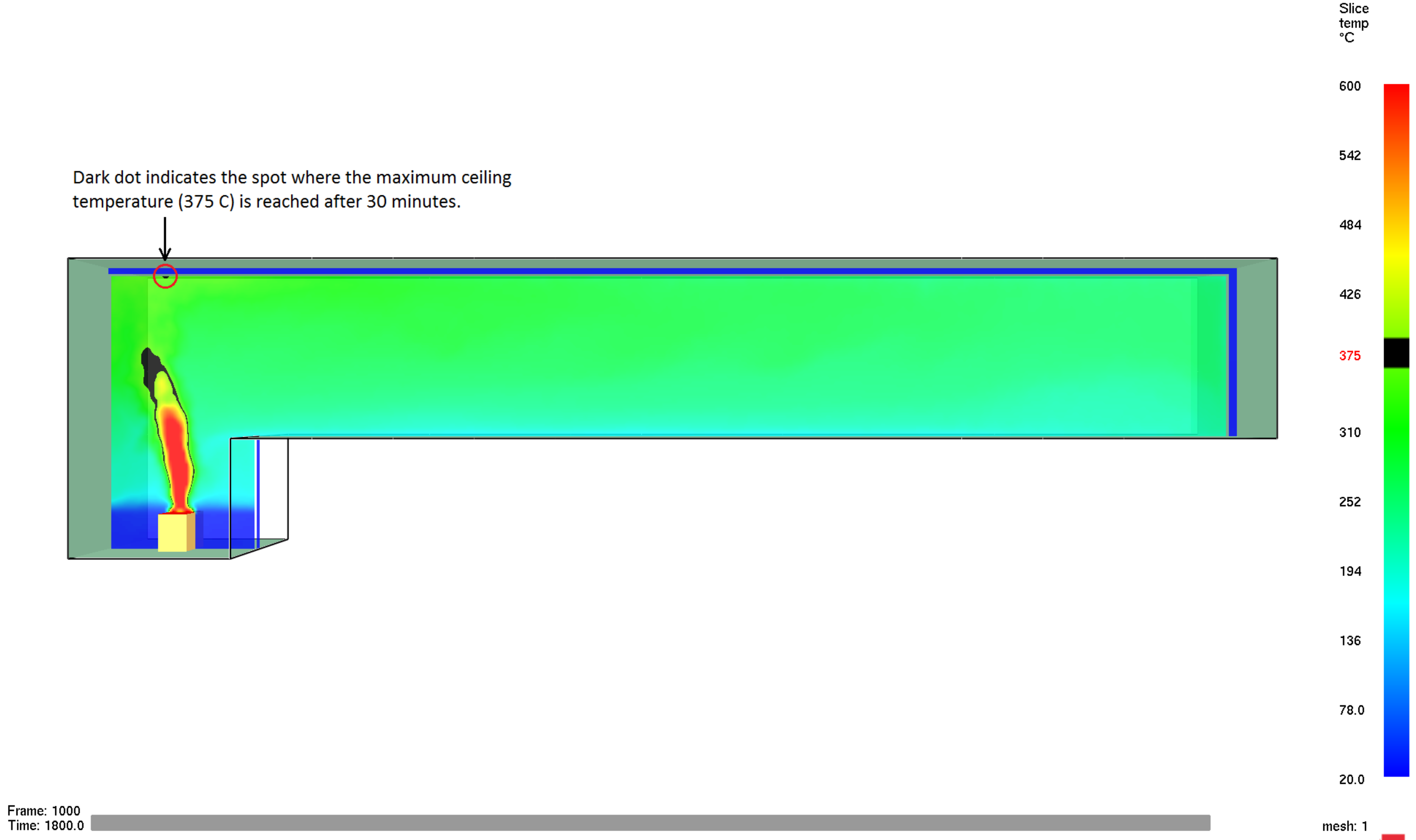

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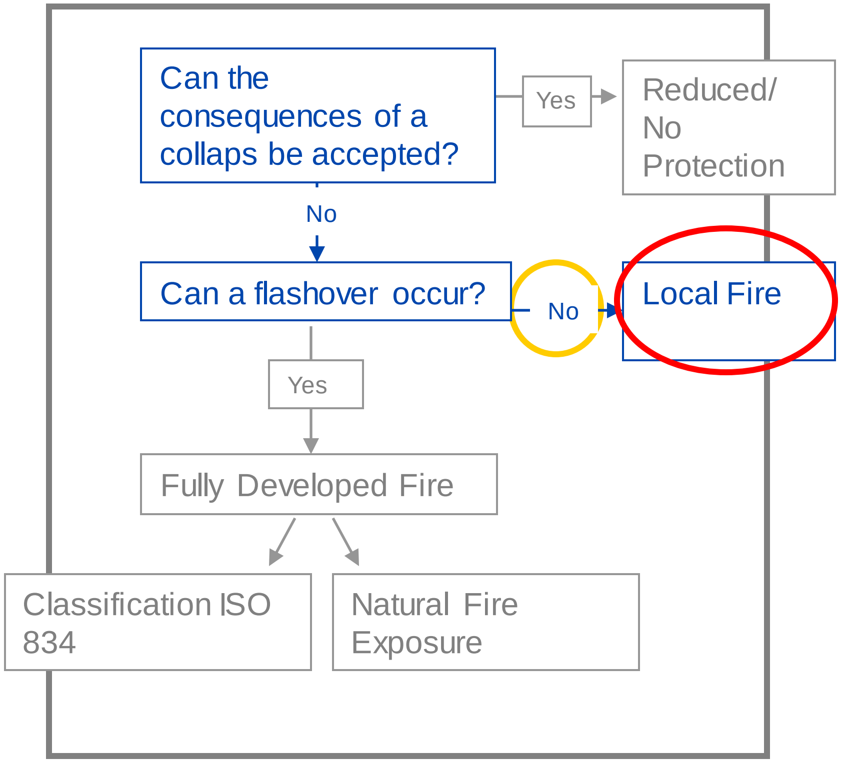
Local Fire (Natural Fire Exposure)



No, ….

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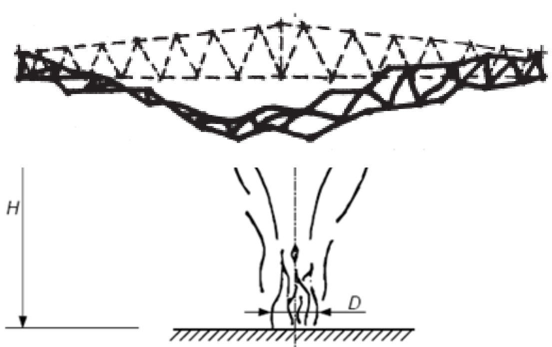


Include the impact from flames

Critical Steel Temperature

→ **Maximum load utilization for the steel structure : 80 %**

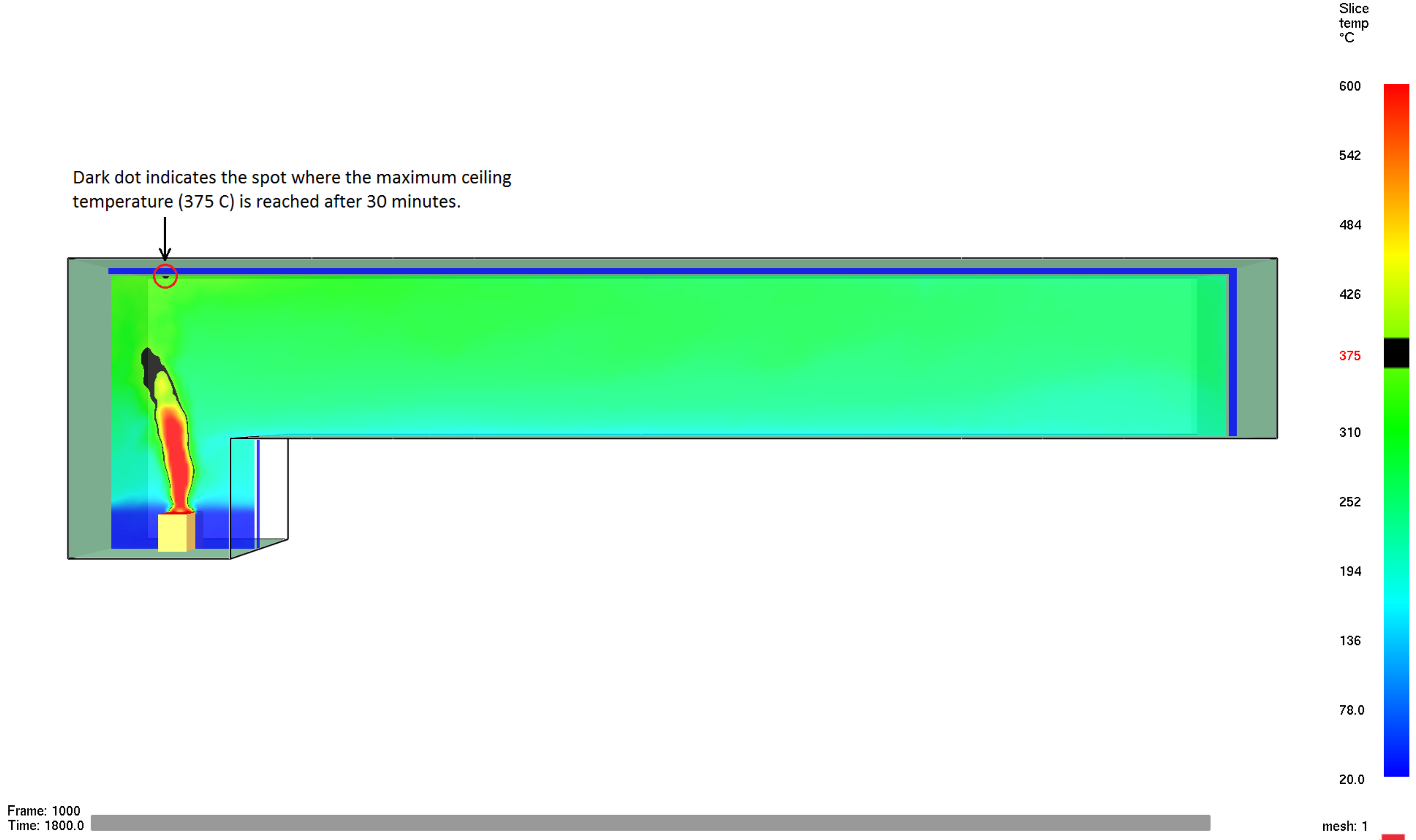
According to SS-EN 1993-1-2:2005 (table 4.1) this means:

→ **Critical steel temperature: 496 °C**

Computational Fluid Dynamics

EUROPEAN SPALLATION SOURCE

Fire Dynamics Simulator: High Bay Simulation (30 MW Truck fire)



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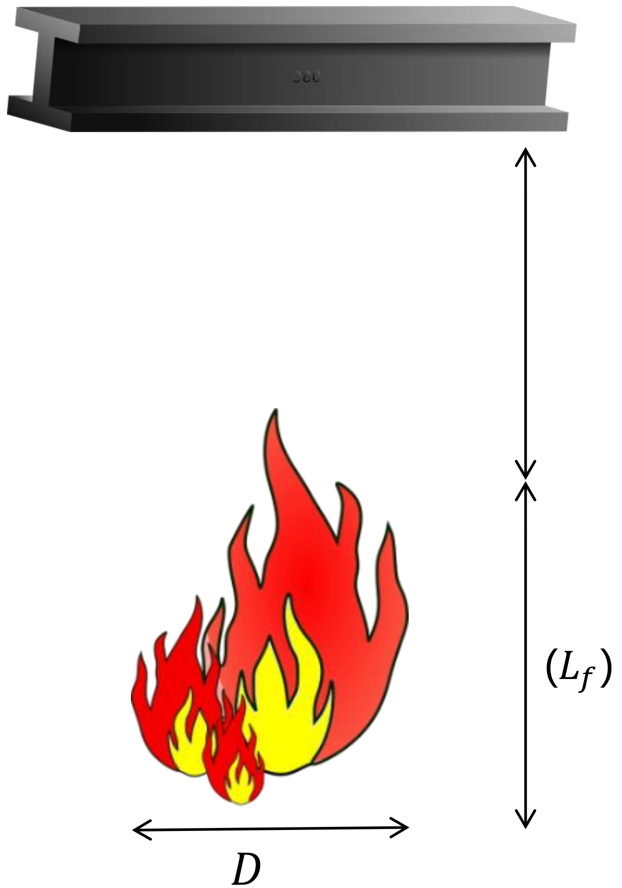
Safe distance from fire load

Local fire effect on supporting steel girders:



Mean flame height:

$$L_f = -1{,}02 \cdot D + 0{,}0148 \cdot Q^{2/5}$$

The height (z) at which the temperature (θ_z) in smoke plume reaches the critical steel temperature of 496 °C is calculated with:

$$\theta_z = 20 + 0{,}25 \cdot Q_c^{2/3}(z - z_0)^{-5/3}$$

$$z = \left(\frac{\theta_z - 20}{0{,}25 \cdot Q_c^{2/3}}\right)^{-3/5} + z_0$$

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Conclusions

- → **Flashover will not occur.**
- → **Design according to a local fire is acceptable.**
- → **Two main scenarios:**
  - Truck in the loading area
  - Cables in the High Bay
- → **The mean flame length in case of a truck fire is calculated to 6.6 m, which on top of a truck still leaves 18 m to the steel construction. The temperature of the smoke plume is calculated to 102 °C at the height of the steel beams (hand calculations).**
- → **In the case of a truck fire burning in steady-state with 30 MW, the highest temperature of the hot gas layer is achieved closest to the ceiling directly above the fire, where it reaches 375 °C. The mean temperature of the hot gas layer is around 260 °C at this time (CFD).**
- → **A fire in a cable tray is estimated to a HRR of 700 kW (200 kW/m2). The flame length of such a fire is calculated to 2.5 m, and the smoke plume reaches a temperature of 496 °C (the critical temperature of the steel beam) at 2.6 m above the fire source (i.e. close to the mean flame length).**

Conclusions

→ **Steel columns must be protected (R60)**

→ **Steel beams can be unprotected (R0)**

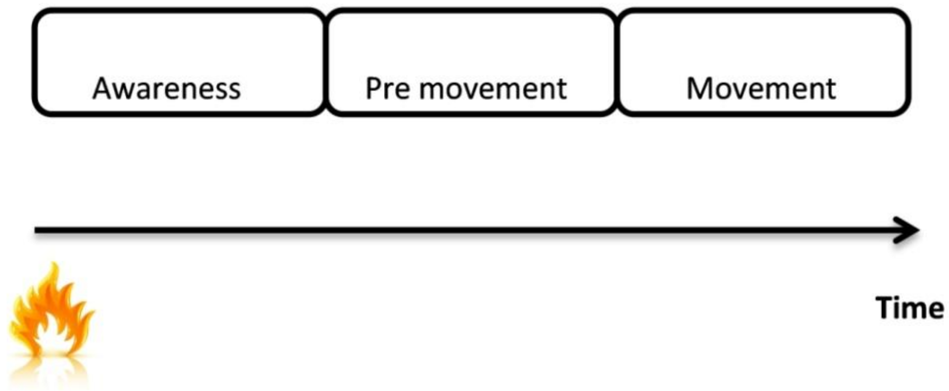
Fire and Egress Safety Analysis

The Swedish Building and Planning Authority (Boverket) "Guidelines on analytical design for fire protection of buildings" (BBRAD)

Objective:

Required Safe Egress Time **<** **Available** Safe Egress Time

Fire and Egress Safety Analysis



Total egress time (t_t):

$$t_t = t_a + t_p + t_m$$

t_a = time until people become aware of the fire
t_p = pre-movement time
t_m = movement time

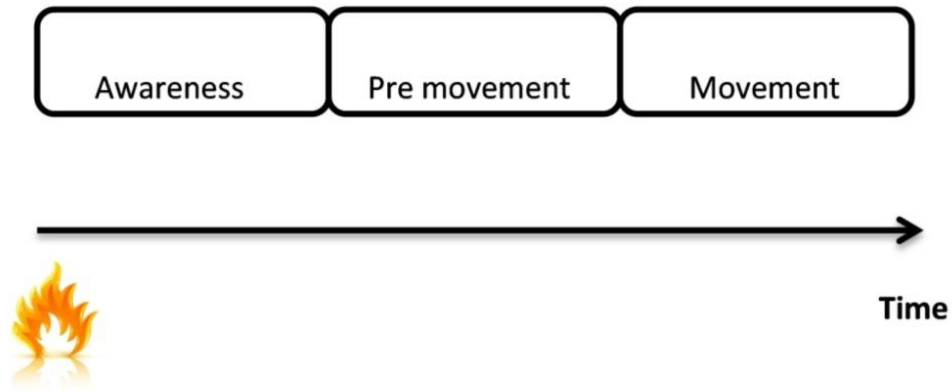
Fire and Egress Safety Analysis

1. Awareness time:

→ **Activated fire alarm?**

→ **Visible smoke?**

→ **Smell of smoke?**



2. Pre-movement time:

→ **Information seeking**

→ **Group behavior**

→ **Training**

→ **Perceived threat**

3. Movement time:

→ **Distance**

→ **Door width**

→ **Occupant density (queuing)**

→ **Familiarity with the building**

→ **Speed of movement (~1,5 m/s horizontally)**

Fire and Egress Safety Analysis

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Available Safe Egress Time:

- → **Smoke layer height**
- → **Visibility 2,0 metres above floor level**
- → **Toxicity 2,0 metres above floor level**
- → **Temperature**
- → **Heat radiation**

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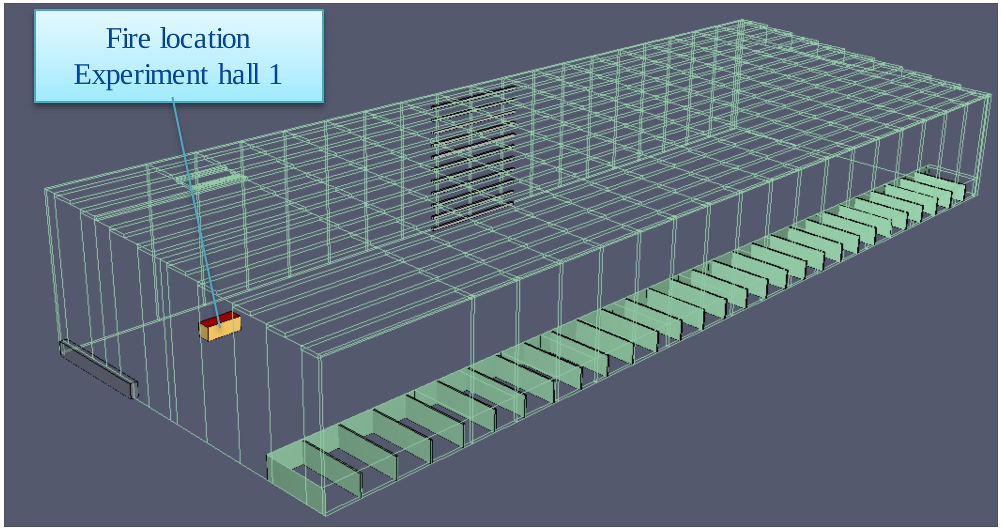
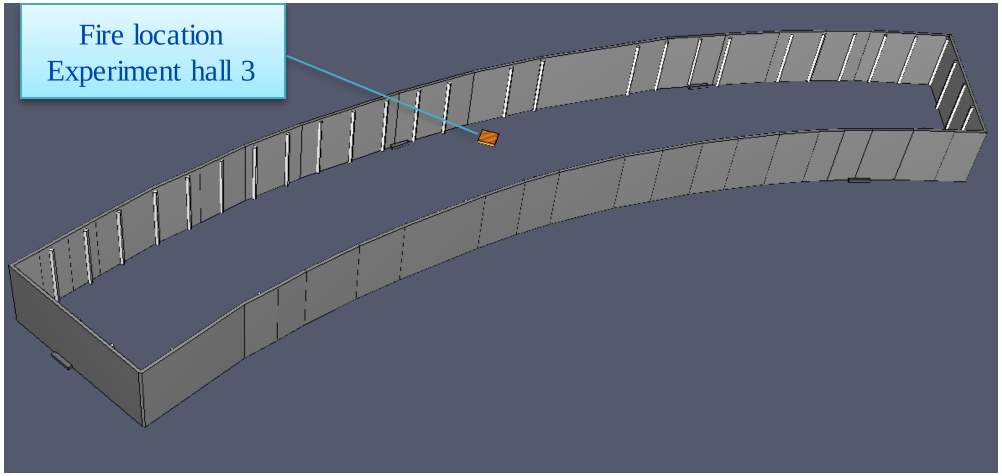
Fire and Egress Safety Analysis

→ **CFD-simulations to determine available safe egress time.**





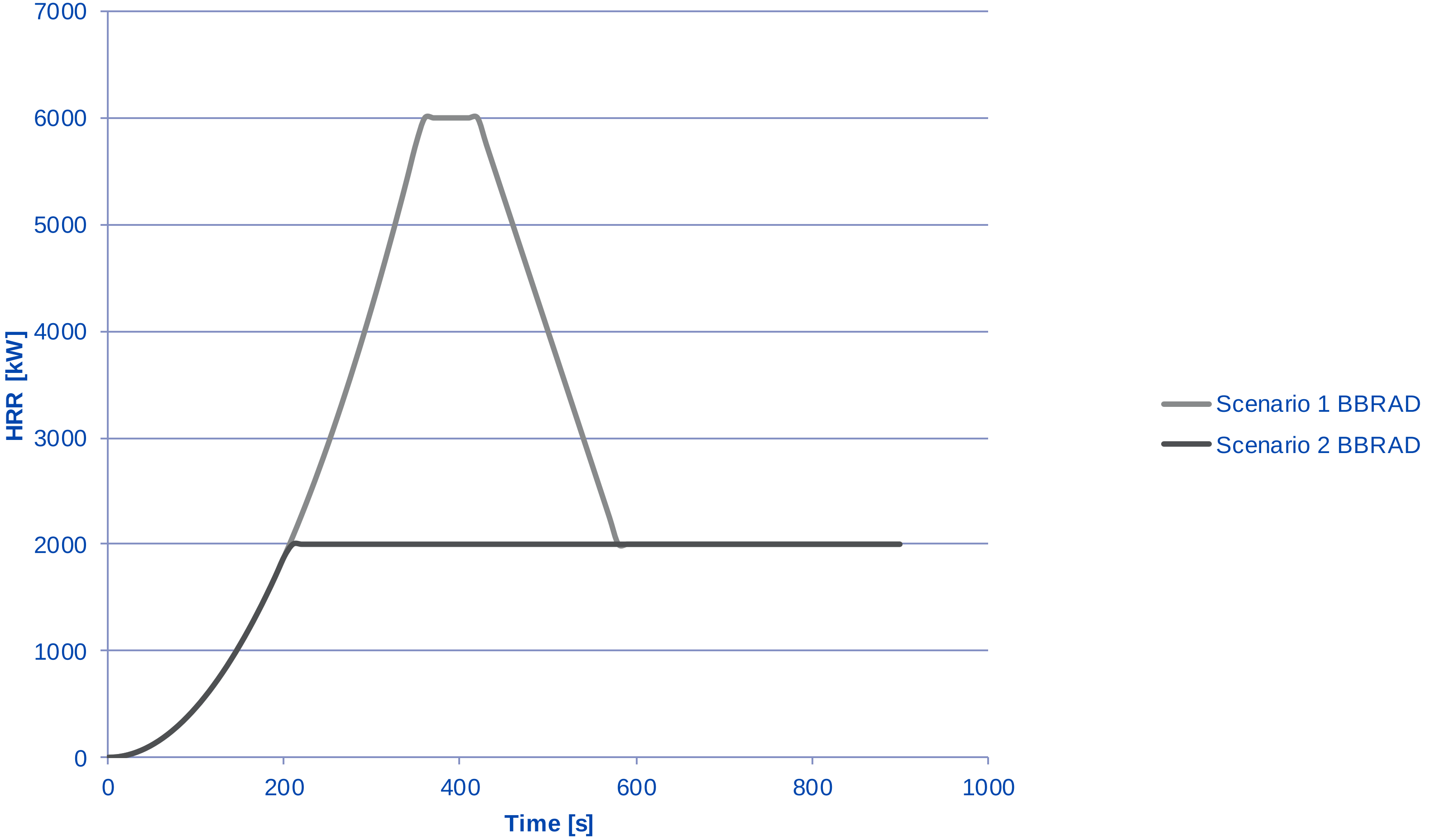
Fire and Egress Safety Analysis

→ **In accordance with BBRAD the following fire and egress scenarios should be analysed:**

1. Transient t-squared fire (high strain, all systems work). The sprinkler system is functional. After sprinkler activation the HRR is kept constant for one minute. Subsequently the HRR is decreased to one third linearly during the next minute.
2. Transient t-squared fire. Sprinkler is not operating. The HRR is kept growing until it reaches the maximum value of 2 MW and is subsequently kept constant at the maximum value.
3. The same scenario as scenario 1 with the exception that the evacuation alarm is not functional.

BBRAD does not give a clear indication of the maximum HRR for scenario 1 for the current type of facility.

Scenarios according to BBRAD

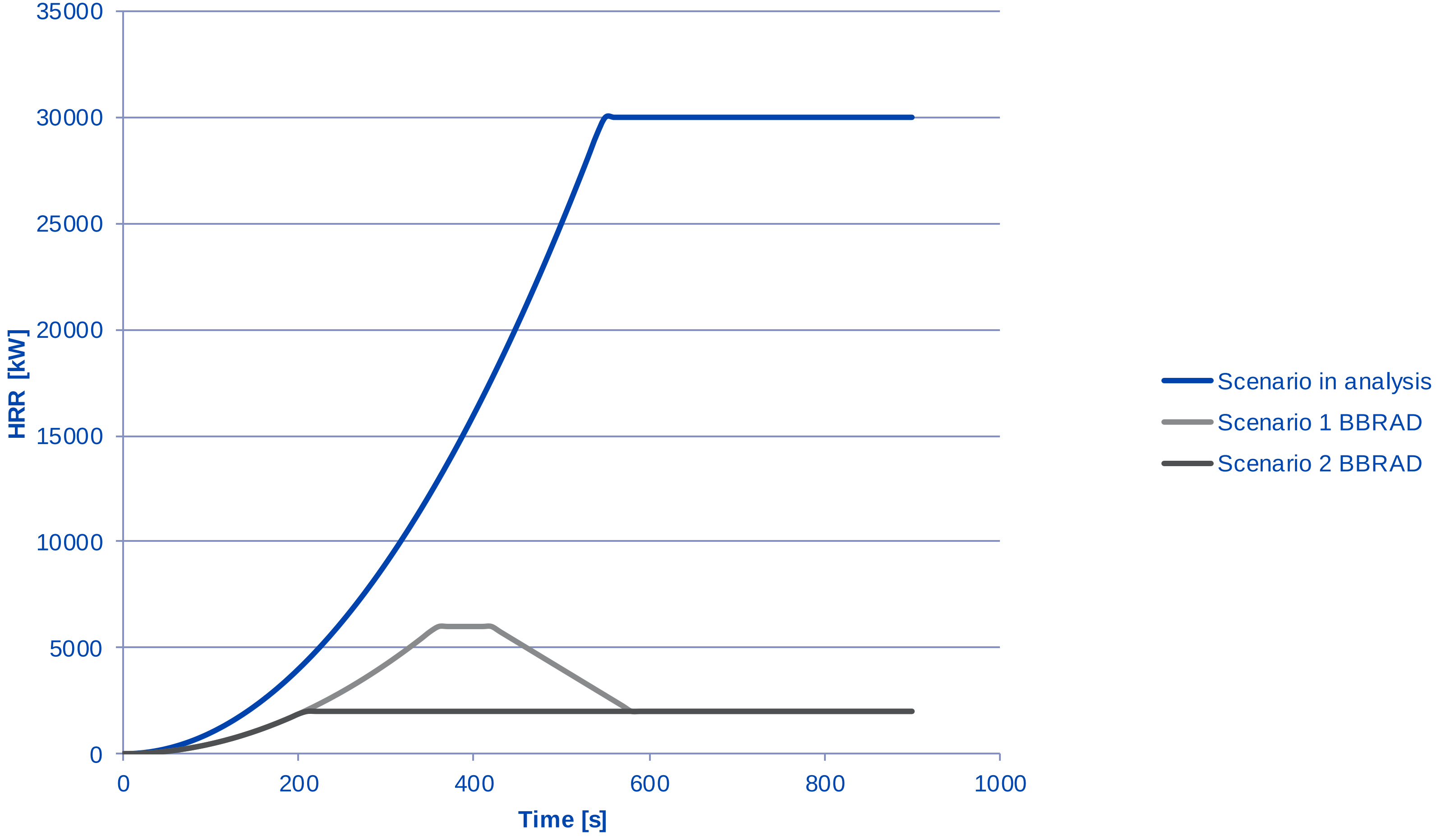


Fire and Egress Safety Analysis

In our analysis BBRAD has not been fully applied. Instead, conservative parameters have been used in the calculated scenarios:

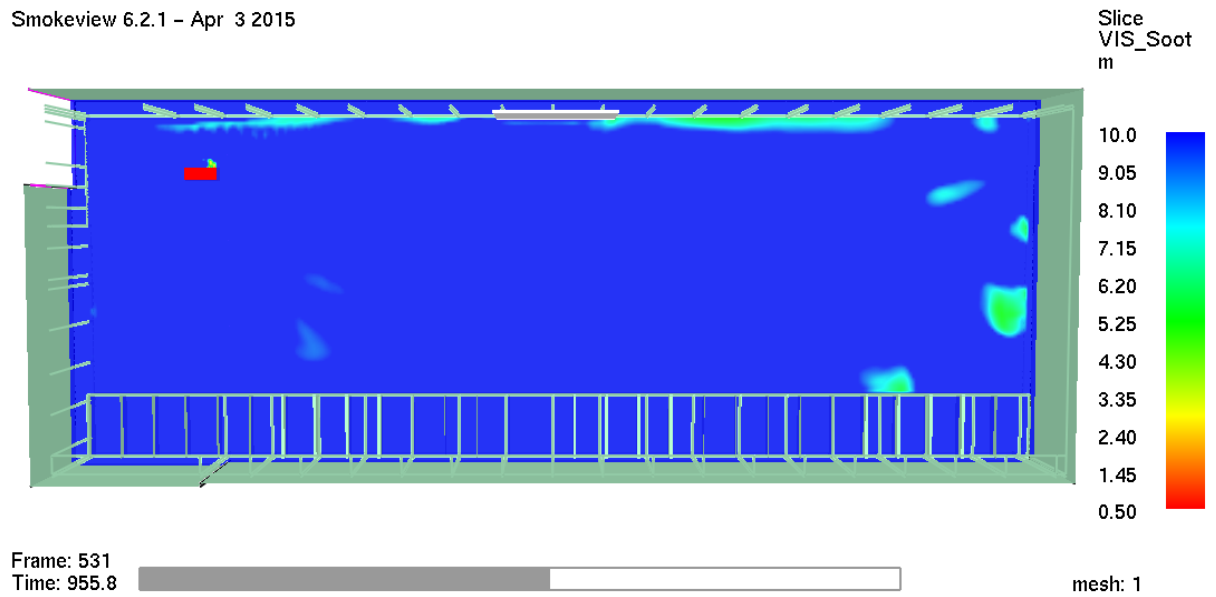
1. Transient t-squared fire. The sprinkler system is not taken into account in this design scenario, which is very conservative. In Experiment hall 1 och 2 maximum HRR is 30 MW representing a fire in a heavy goods vehicle.
2. The same scenario as scenario 1 with the expectance that the evacuation alarm is malfunctioning.

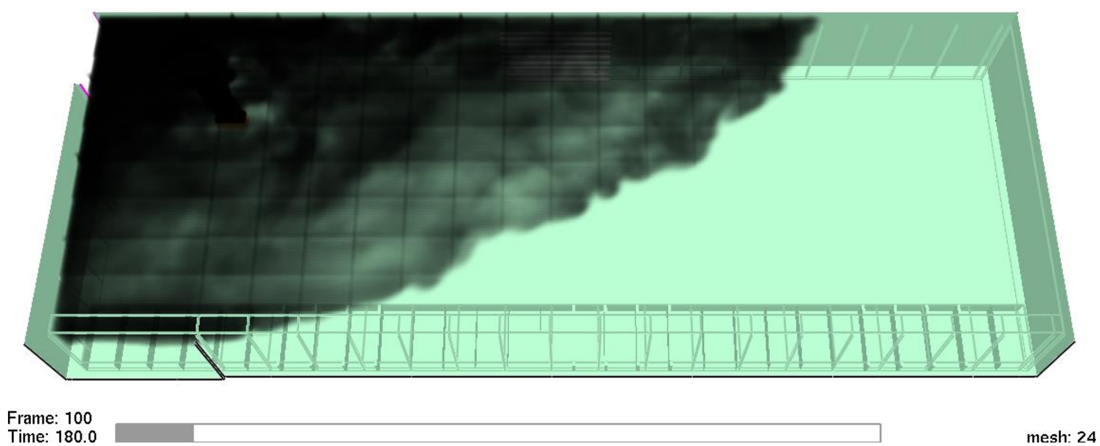
Scenario in the analysis



Fire and Egress Safety Analysis

- Is ***required*** safe egress time less than ***available*** safe egress time?





Fire and Egress Safety Analysis

Scenario	Fire alarm system working	Awareness time [s]	Pre movement time [s]	Movement time [s]	RSET [s]
Experiment hall 1	Yes	45	60	75	180
	No	180	60	75	315
Experiment hall 2	Yes	45	60	70	175
	No	180	60	70	310
Experiment hall 3	Yes	45	60	40	145
	No	140	60	40	240

Scenario	Fire alarm system working	RSET [s]	ASET [s]	The time margin for safe egress [s]
Experiment hall 1	Yes	180	955	775
	No	315	955	685
Experiment hall 2	Yes	175	955	320
	No	310	955	290
Experiment hall 3	Yes	145	500	355
	No	240	500	260