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RISFIM - Risk-based simplified fire models and methods

21.11.2023 ESRA seminar, Stavanger

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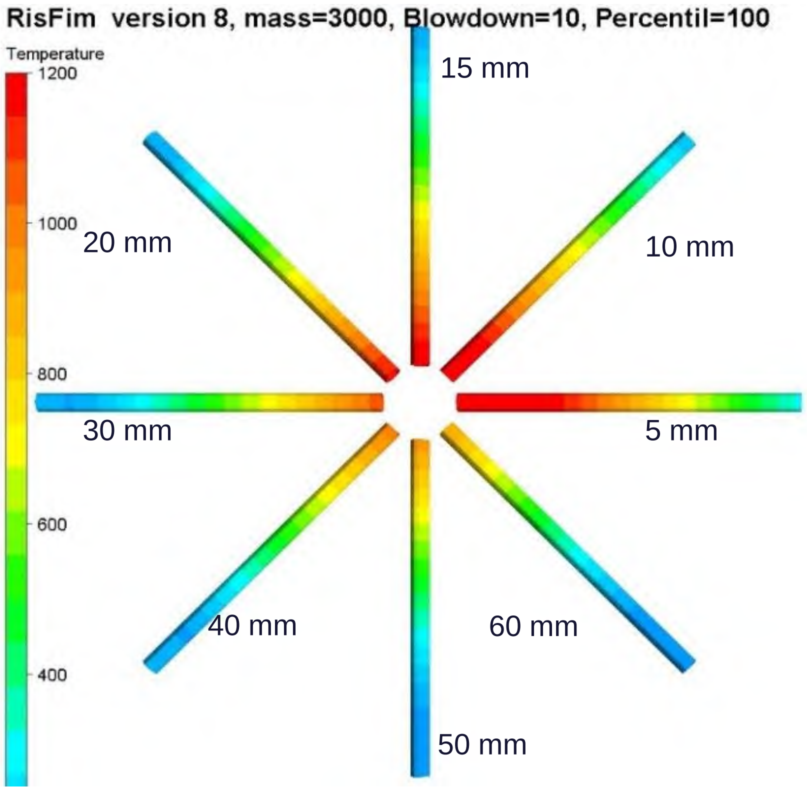
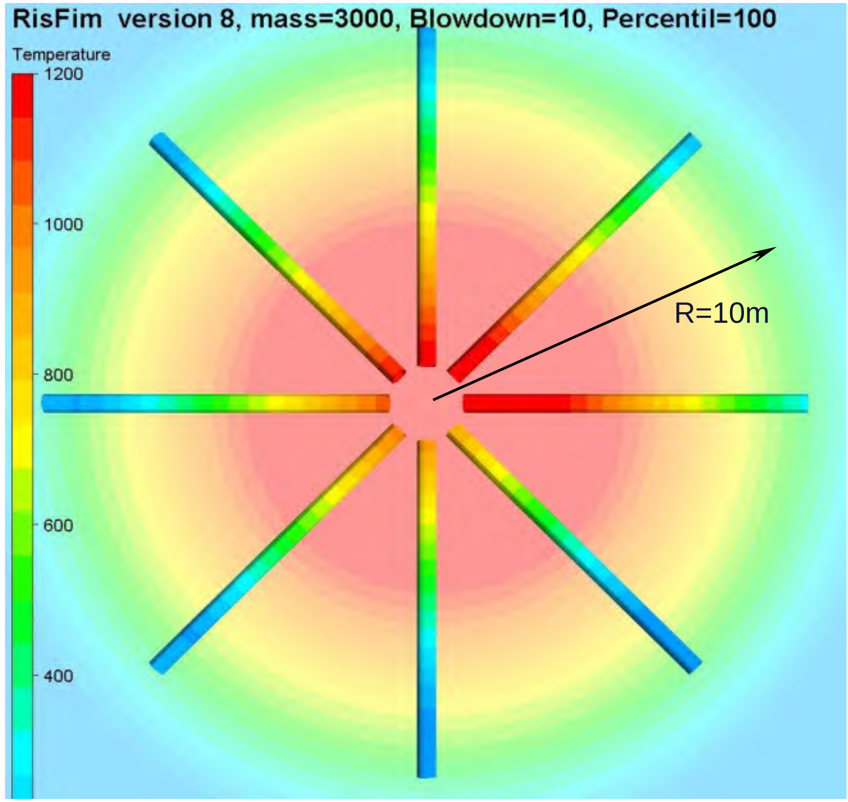
Temperature as a measuring stick!





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RISFIM Innovation project funded by RCN

- RISFIM
  - Risk-Based Simplified Fire Models and Methods
  - innovation project for the industrial sector funded by the The Research Council of Norway, Safetec, DNV, Equinor Energy AS, Vår Energi AS, Aker BP ASA, ConocoPhillips Skandinavia AS, Lundin Energy Norway AS and Wintershall Dea Norge AS
  - Project owned and managed by Safetec
  - Started July 2021 - closed August 2023
- Objective
  - to develop of a fully coupled risk-based methodology for derivation of design accidental fire loads and fire events for complex industrial facilities
- Activities
  - Finalize conceptual CFD based numerical model in KFX for investigation of fire loads incorporating heat transfer to structures – model denoted VISTemp
  - Execute numerical experiments with the VISTemp model
  - Develop simplified empirical model based on numerical experiments
  - Develop Guidelines
- Used as reference for determination of fire loads in the revised version of NORSOK Z-013

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RISFIM Deliverables

Models

- **VISTemp** – numerical CFD-based model implemented in KFX describing the damage potential for given design in terms of a volume-temperature distribution. The work included implementation of enhanced pool fire model in KFX to reflect the full transient behaviour of liquid fires.
- **Temperature ball** – simple empirical model that replicate the VISTemp volume-temperature distribution for typical designs.
- **RISFIM Fire frequency model** - used in the development process to determine the residual fire risk when applying the RISFIM methodology

Guidelines

- General guidelines for fire resistant structures
- Guidelines for secondary structures
- Guidelines for main load bearing structures
- Guidelines heat loads for pressurized systems exposed to fire
  - Probabilistic method for estimation of peak local incident heat flux based on VISTemp
  - Probabilistic method for global average heat load based on KFX simulations

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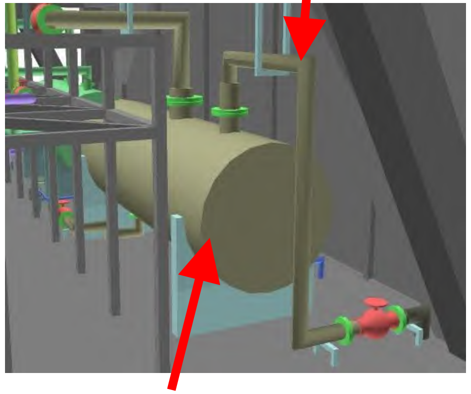
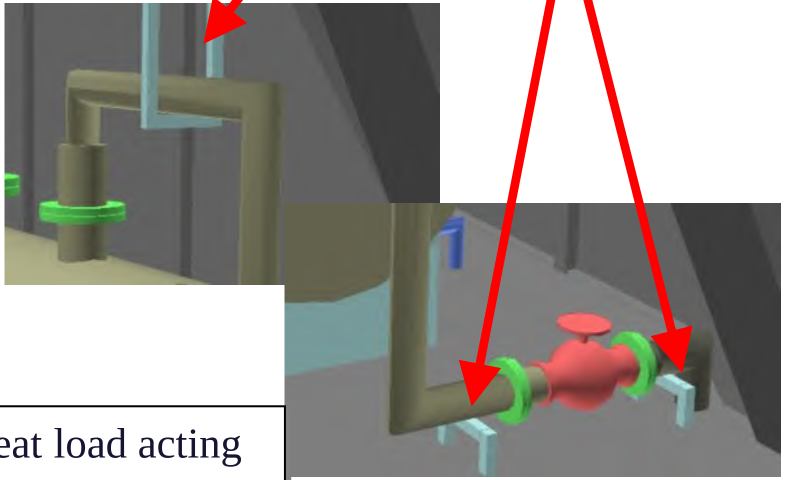
Key fire safety design aspect addressed by RISFIM

What is the local heat load acting on process equipment?

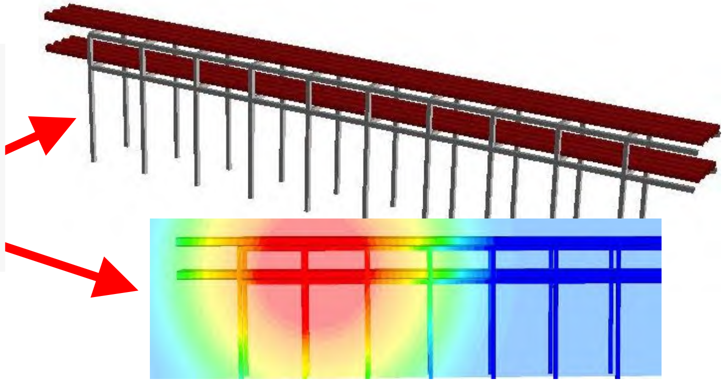


What happens if the pipe supports become weak in a fire scenario? Is passive fire protection (PFP) needed to avoid rupture of the process system?

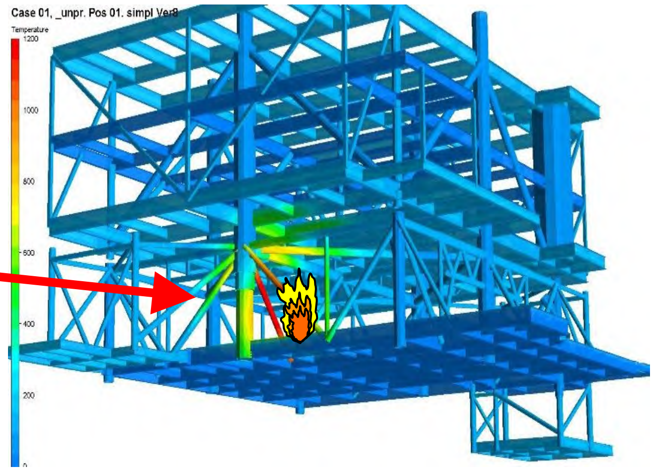


What is the global heat load acting on process equipment?

Does this pipe rack need PFP when exposed to realistic fires?



How does early project phase decisions, such as conceptual design of load carrying structures and requirements to process safety systems, potentially affect inherent fire integrity of facility?



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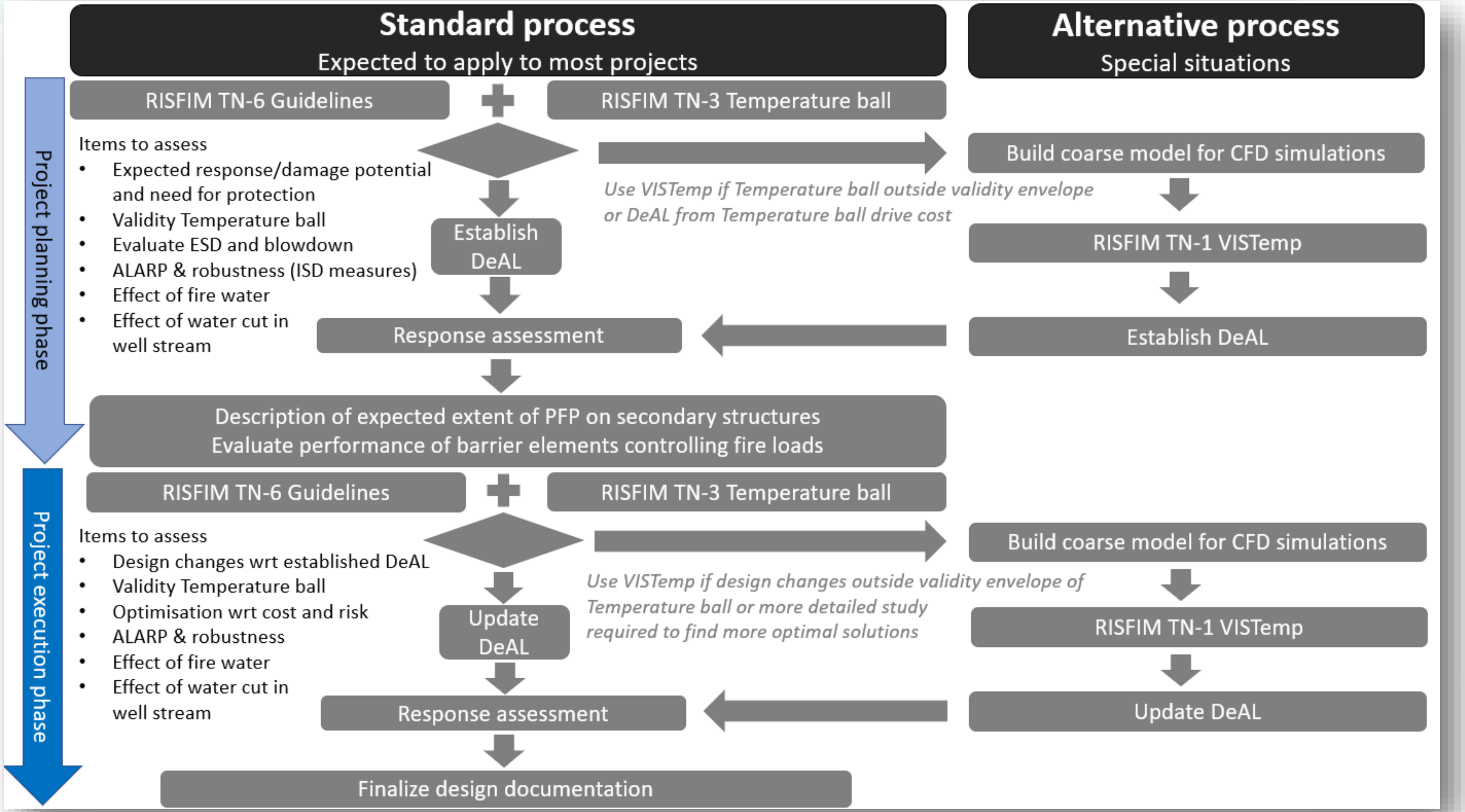
RISFIM methodology for secondary structures

Typical secondary structures

- Pipe systems including pipe supports
- Pipe racks including pipes
- Access platforms

- Objective that
  - standard process is applicable in most cases
  - Temperature ball set in planning phase is applicable throughout project execution phase unless a design change requires update



Standard process
Expected to apply to most projects

Alternative process
Special situations

Project planning phase

RISFIM TN-6 Guidelines + RISFIM TN-3 Temperature ball

Items to assess
- Expected response/damage potential and need for protection
- Validity Temperature ball
- Evaluate ESD and blowdown
- ALARP & robustness (ISD measures)
- Effect of fire water
- Effect of water cut in well stream

Establish DeAL

Response assessment

Use VISTemp if Temperature ball outside validity envelope or DeAL from Temperature ball drive cost

Build coarse model for CFD simulations

RISFIM TN-1 VISTemp

Establish DeAL

Description of expected extent of PFP on secondary structures
Evaluate performance of barrier elements controlling fire loads

Project execution phase

RISFIM TN-6 Guidelines + RISFIM TN-3 Temperature ball

Items to assess
- Design changes wrt established DeAL
- Validity Temperature ball
- Optimisation wrt cost and risk
- ALARP & robustness
- Effect of fire water
- Effect of water cut in well stream

Update DeAL

Response assessment

Use VISTemp if design changes outside validity envelope of Temperature ball or more detailed study required to find more optimal solutions

Build coarse model for CFD simulations

RISFIM TN-1 VISTemp

Update DeAL

Finalize design documentation

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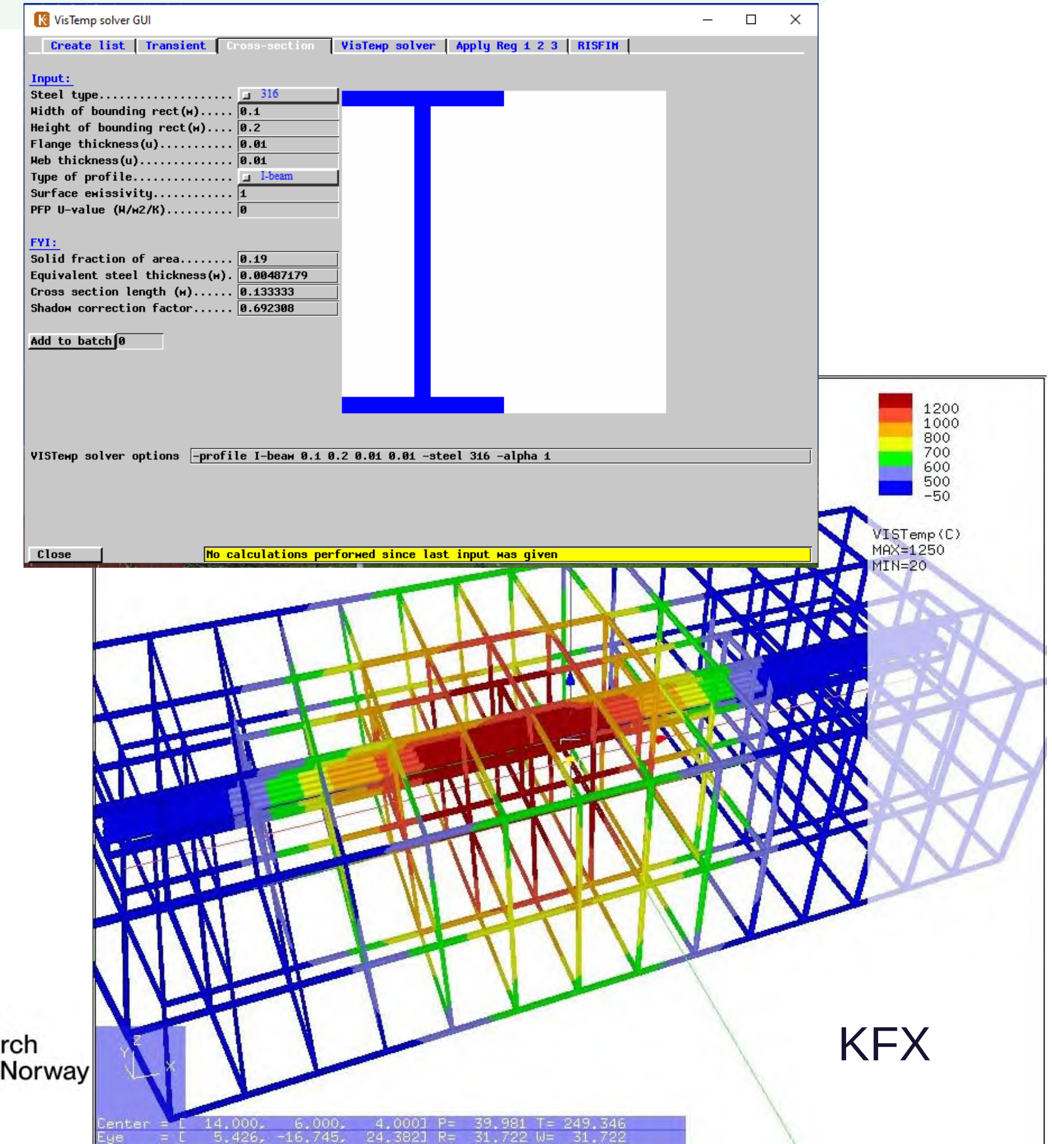
VISTemp – Virtual Structural Temperature

- Aim is to capture the unique characteristics of the time-dependent fires based on state-of-the-art CFD simulation techniques in KFX and at the same time reduce the required number of scenarios analyzed to derive a dimensioning fire load in compliance with regulatory and company requirements.
- The key feature of the methodology is post-processing of the **temperature response** of a virtual structural network fitted within the area of interest. This virtual network can be thought of as a high-density network of temperature sensors ensuring that the hottest area/volume is captured
- The initial step is to perform CFD simulations for a range of transient scenarios based on a geometrical model with acceptable quality
- The objective is to find the leak rate that result in the most severe fire exposure. Hence, the method is in line with the WCPF methodology used to find the worst fire exposure acting on load bearing structures
- **The result is a realistic reusable measure of the worst credible damage potential caused by the worst credible fires within the area of interest**
- VISTemp is sensitive to the leak scenario properties, the process and safety system properties as well as the properties of the exposed virtual component



Input:
Steel type.................... 316
Width of bounding rect(m)..... 0.1
Height of bounding rect(m).... 0.2
Flange thickness(u)........... 0.01
Web thickness(u).............. 0.01
Type of profile............... I-beam
Surface emissivity............ 1
PFP U-value (W/m2/K).......... 0

FYI:
Solid fraction of area........ 0.19
Equivalent steel thickness(m). 0.00487179
Cross section length (m)...... 0.133333
Shadow correction factor...... 0.692308

Add to batch 0

VISTemp solver options -profile I-beam 0.1 0.2 0.01 0.01 -steel 316 -alpha 1

No calculations performed since last input was given

VISTemp(C)
MAX=1250
MIN=20

```
Center = [   14.000,    6.000,    4.000] P=  39.981 T= 249.346
Eye    = [    5.426,  -16.745,   24.382] R=  31.722 W=  31.722
```

KFX

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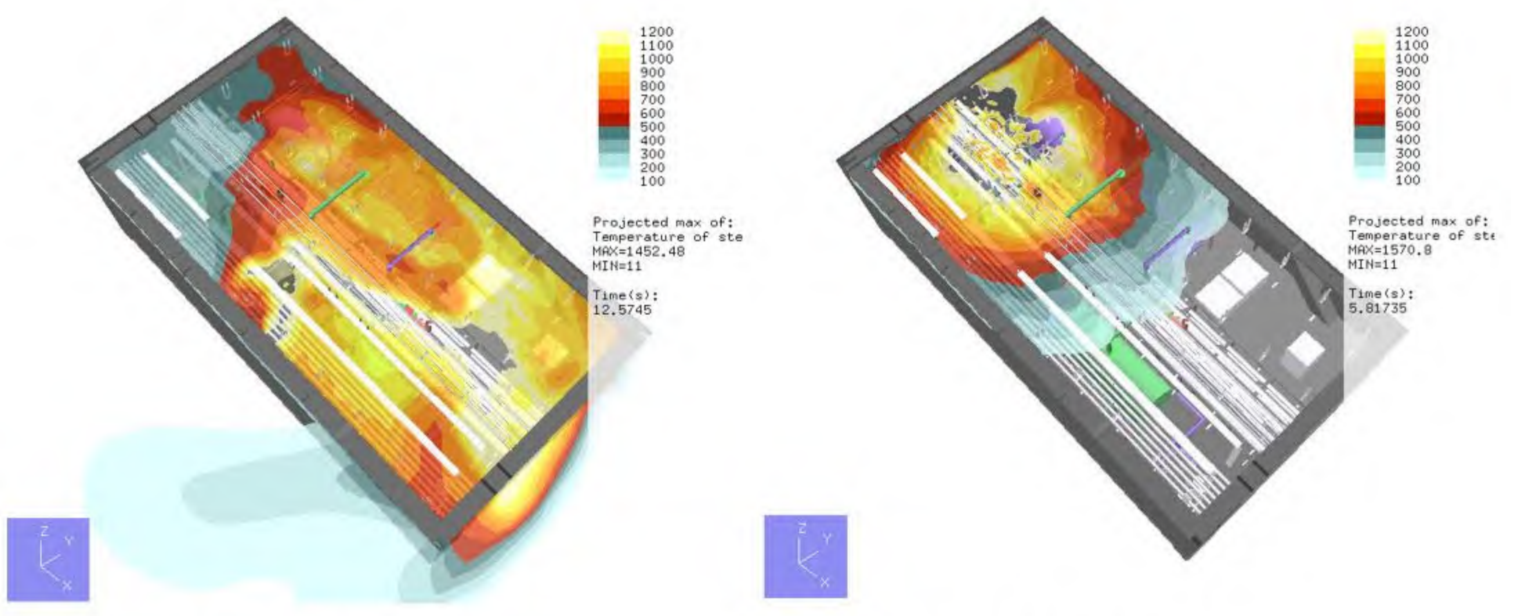
VISTemp – Virtual Structural Temperature 2/3

The actual heat distribution in space follows the time-dependendant dynamics of the fire, but, VISTemp extract the all time high temperature at all points in space – which adds conservatism to the method

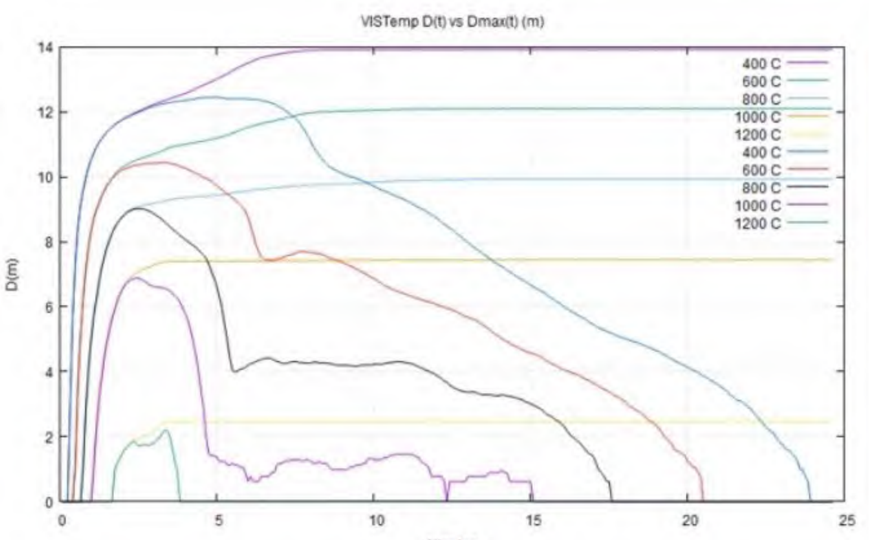


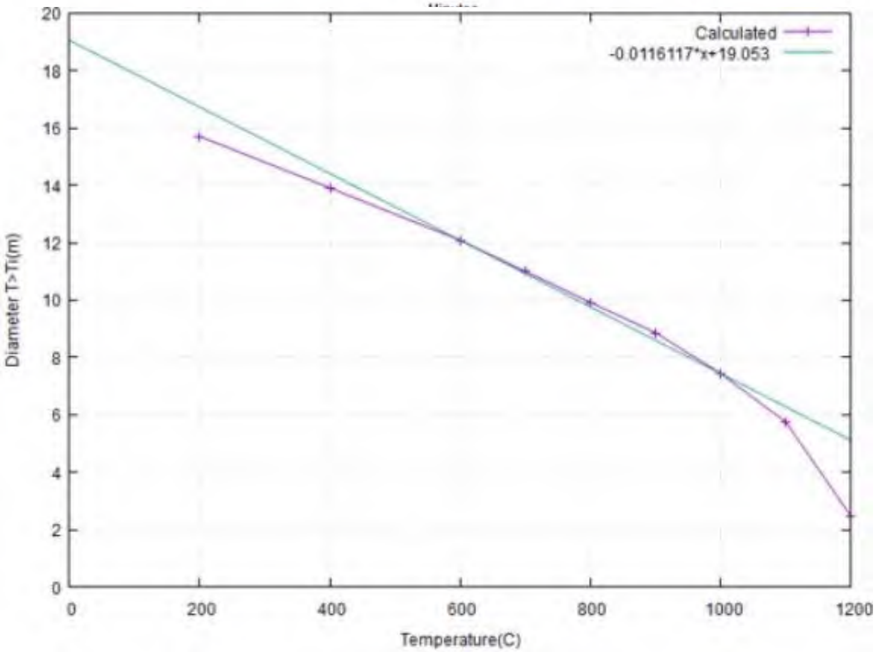
20 seconds into the fire

3 minutes into the fire

Figure 5.21: Visualization gas temperature in the fire at various points in time (note that the time in the plot is incorrect)

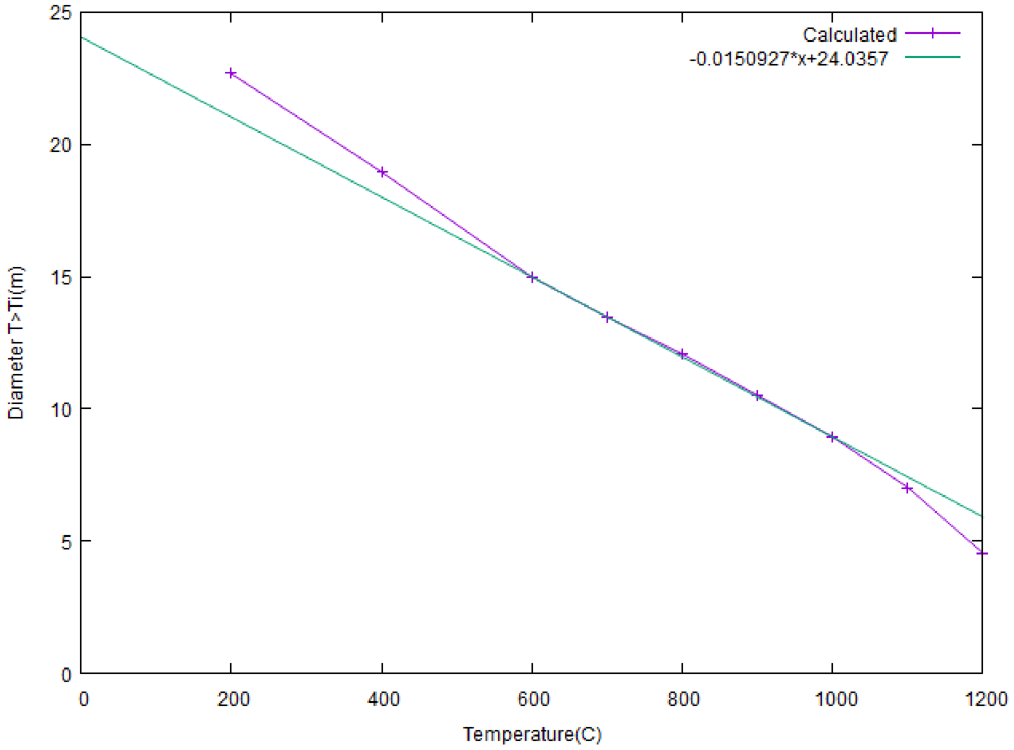
ay

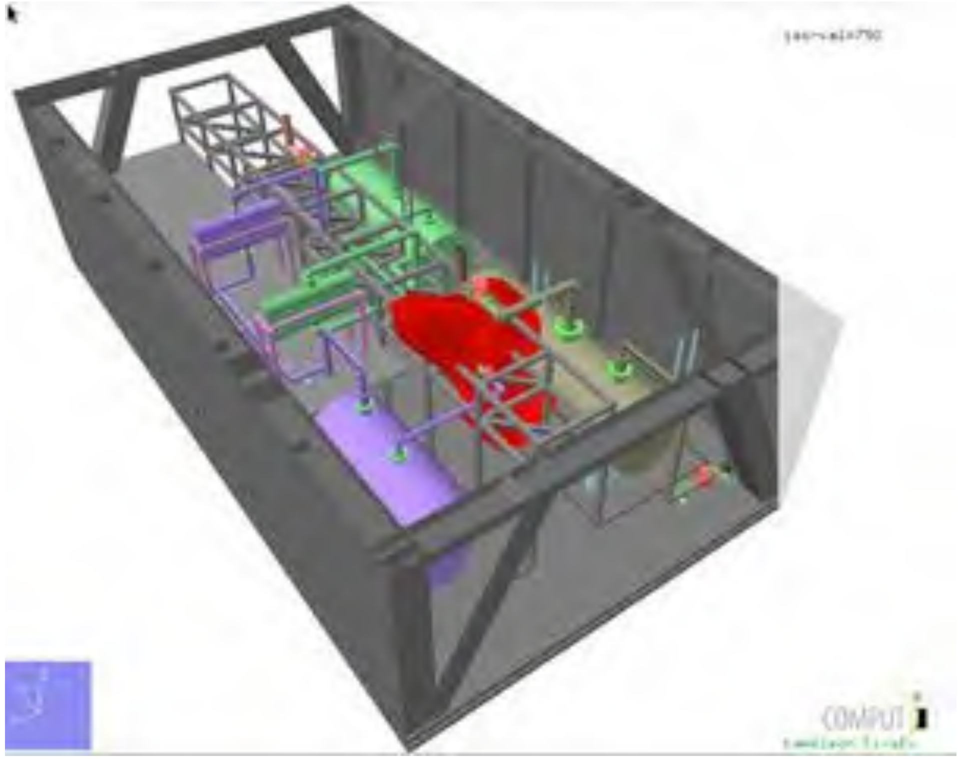




VISTemp – Virtual Structural Temperature 3/3

- The resulting volumetric temperature response can be approximated by a sphere, which forms an effective basis for making a simple model that can replicate the response in a real fire





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VISTemp temperature calculations

- Heat balance on a thin steel slab:

$$q = k_{sh} \cdot (\varepsilon(q_{in} - \sigma T_s^4) + h_c(T_{amb} - T_s))$$

- Time development of temperature:

$$T_{t+\Delta t} = T_t + \frac{q}{\rho C_p(T)\delta} \Delta t$$

δ is average steel thickness per unit exposed surface area

- Shadow factor (Eurocode 3 1-2):
  - I-profile: $k_{sh} = 0.9 \cdot A_{br}/A_c$
  - Other concave profiles: $k_{sh} = A_{br}/A_c$
  - Convex profiles: $k_{sh} = 1$
- A_{br} is the surface area per unit length of the smallest rectangle that the profile fits into, and A_c is the surface area per unit length of the beam.
- In the VISTemp calculator, the shadow factor is baked into an equivalent δ

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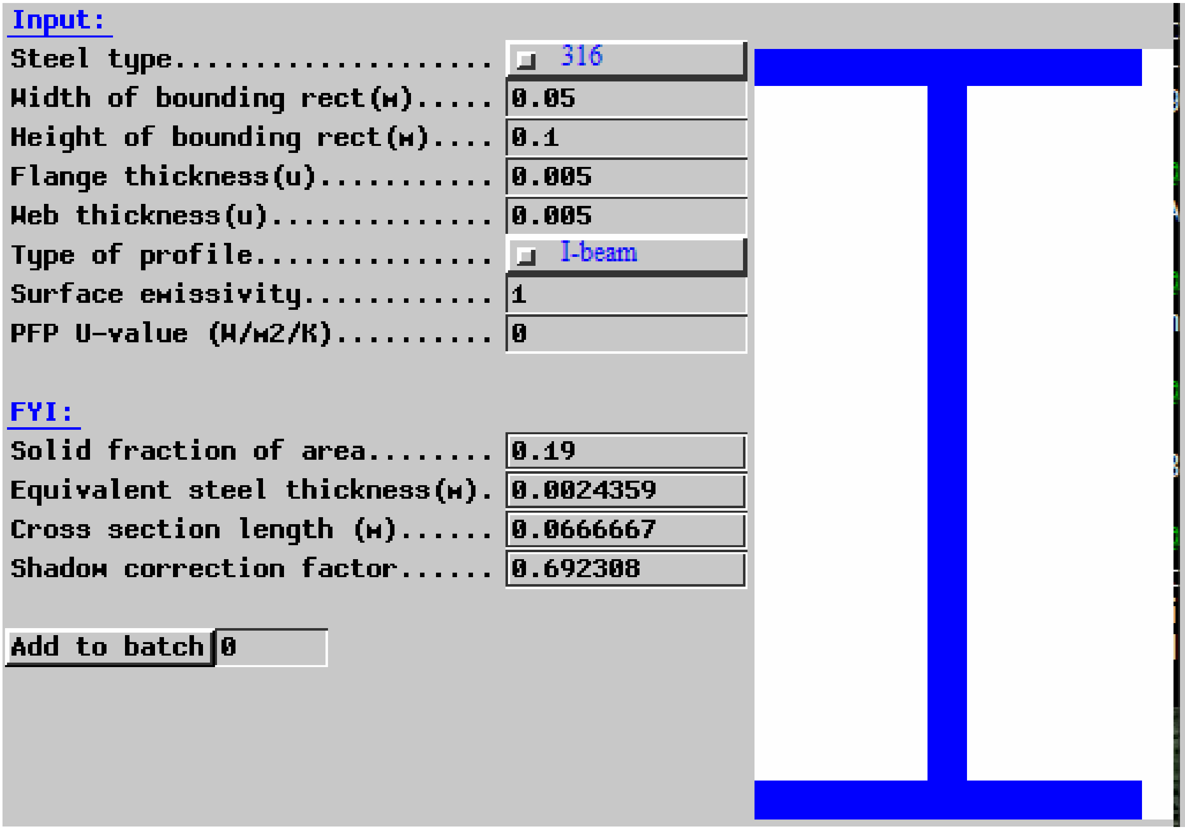
Shadow correction factor integrated in the VISTemp GUI

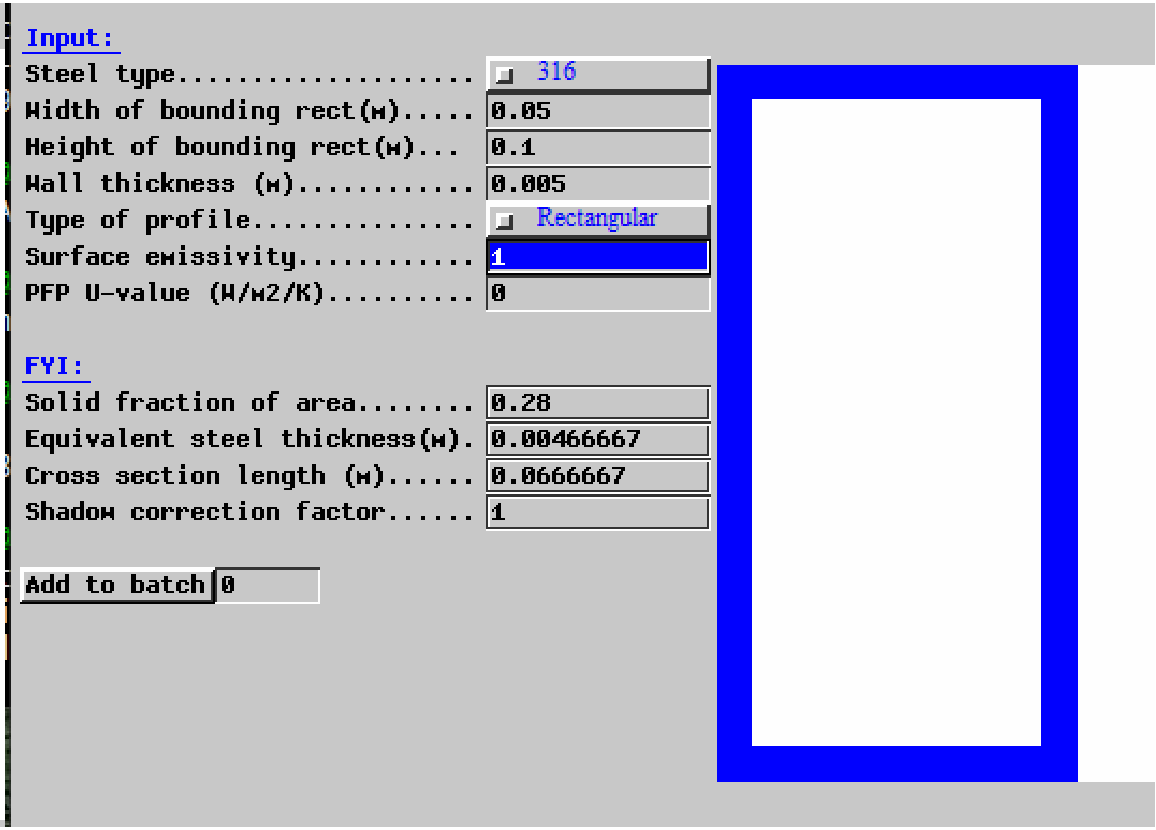


Input:

Steel type....................	316
Width of bounding rect(m).....	0.05
Height of bounding rect(m)....	0.1
Flange thickness(u)...........	0.005
Web thickness(u)..............	0.005
Type of profile...............	I-beam
Surface emissivity............	1
PFP U-value (W/m2/K)..........	0

FYI:

Solid fraction of area........	0.19
Equivalent steel thickness(m).	0.0024359
Cross section length (m)......	0.0666667
Shadow correction factor......	0.692308



Input:

Steel type....................	316
Width of bounding rect(m).....	0.05
Height of bounding rect(m)...	0.1
Wall thickness (m)............	0.005
Type of profile...............	Rectangular
Surface emissivity............	1
PFP U-value (W/m2/K)..........	0

FYI:

Solid fraction of area........	0.28
Equivalent steel thickness(m).	0.00466667
Cross section length (m)......	0.0666667
Shadow correction factor......	1

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Linear temperature decay as a function of diameter How is that possible?

- In the point source model, the heat radiation flux is a function of the distance (r) from a point:

$$Q(r) = \frac{Q_{kw}}{4\pi r^2}$$

- Substituting $Q(r)$ with $\sigma T(r)^4$ gives equilibrium (steady state) temperature as a function of radius for a point source:

$$T_k(r) = \left(\frac{Q(r)}{\sigma}\right)^{0.25} = \left(\frac{Q_{kw}}{\sigma 4\pi r^2}\right)^{0.25} = \left(\frac{1}{r^2}\right)^{0.25}\left(\frac{Q_{kw}}{\sigma 4\pi}\right)^{0.25} = \left(\frac{Q_{kw}}{\sigma 4\pi}\right)^{0.25}\frac{1}{\sqrt{r}}$$

- Simple numerical transient temperature calculations using $Q(r) = \frac{Q_{kw}}{4\pi r^2}$ as heat load, show nearly linear variation of temperature with distance to the center point in the most interesting temperature interval for loss of strength for steel. One important reason for this is that time to reach equilibrium temperature increase with decreasing heat load.

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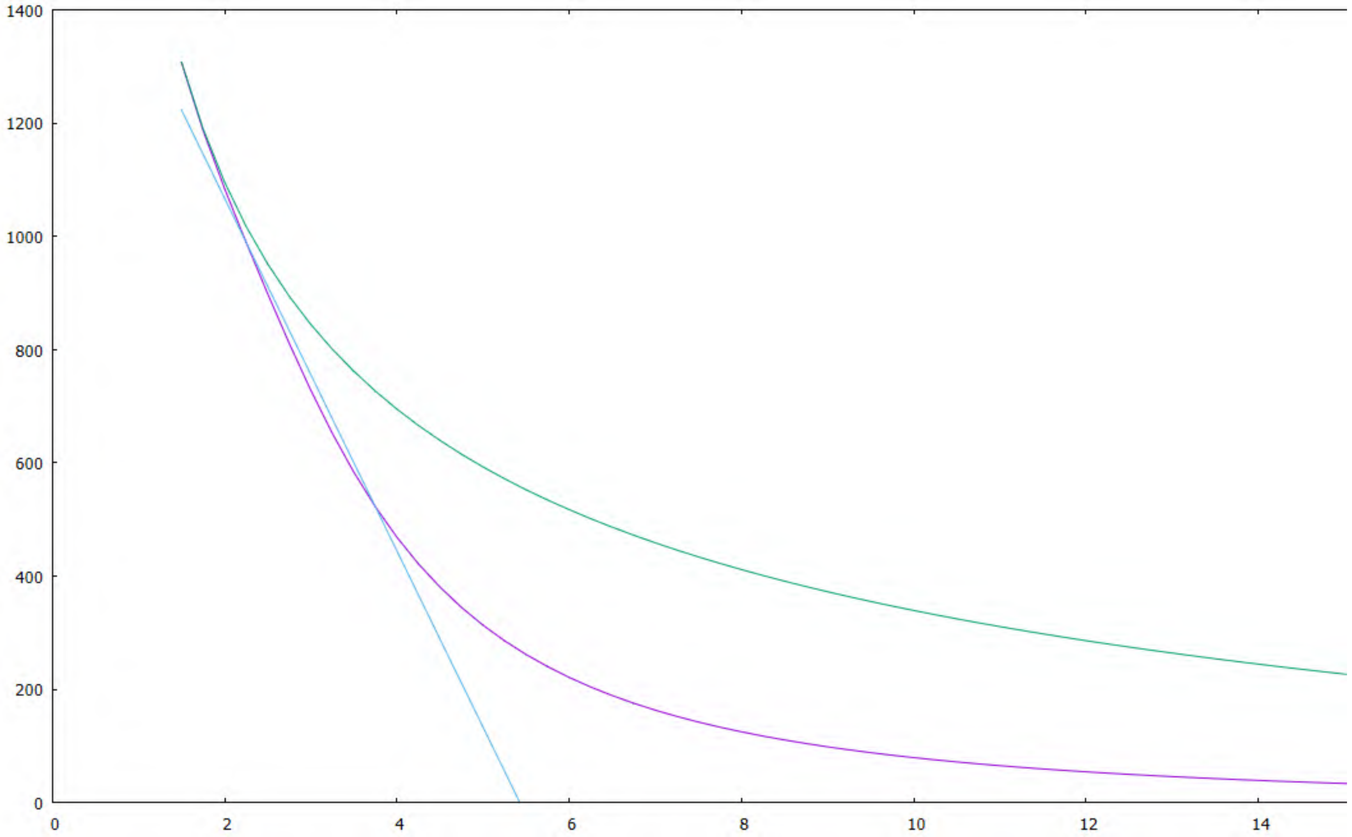
Difference between equilibrium temperature and time dependent temperature after a few minutes for the point source heat load



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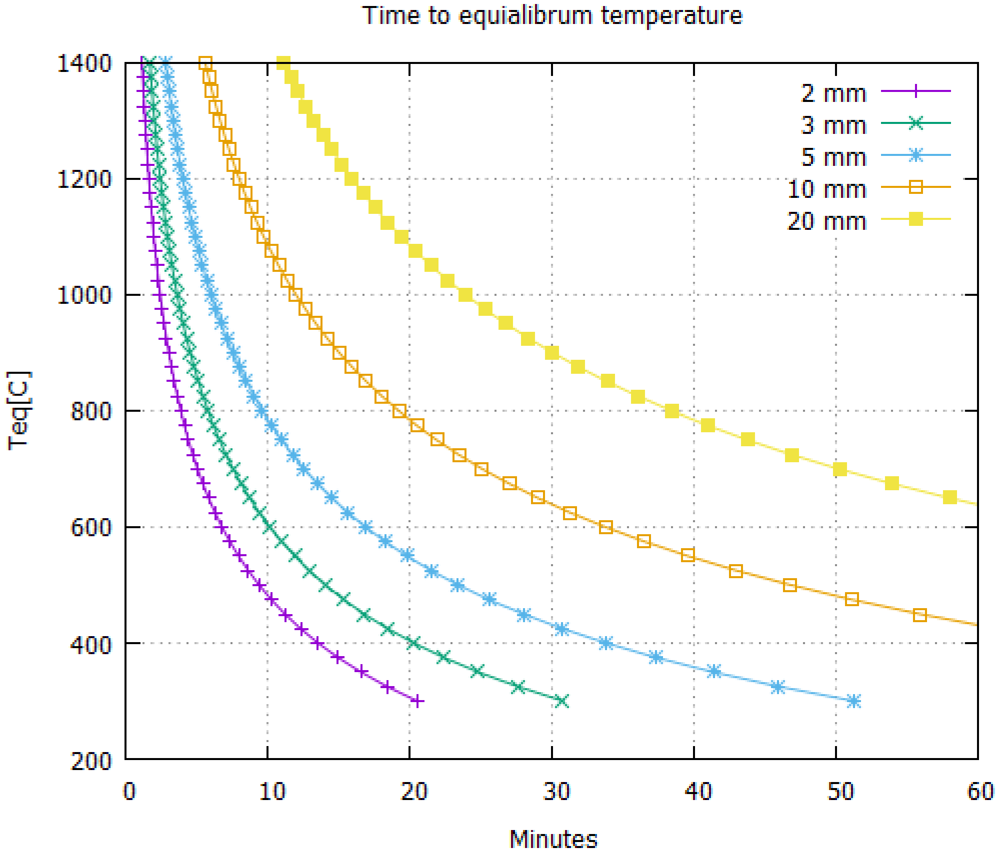
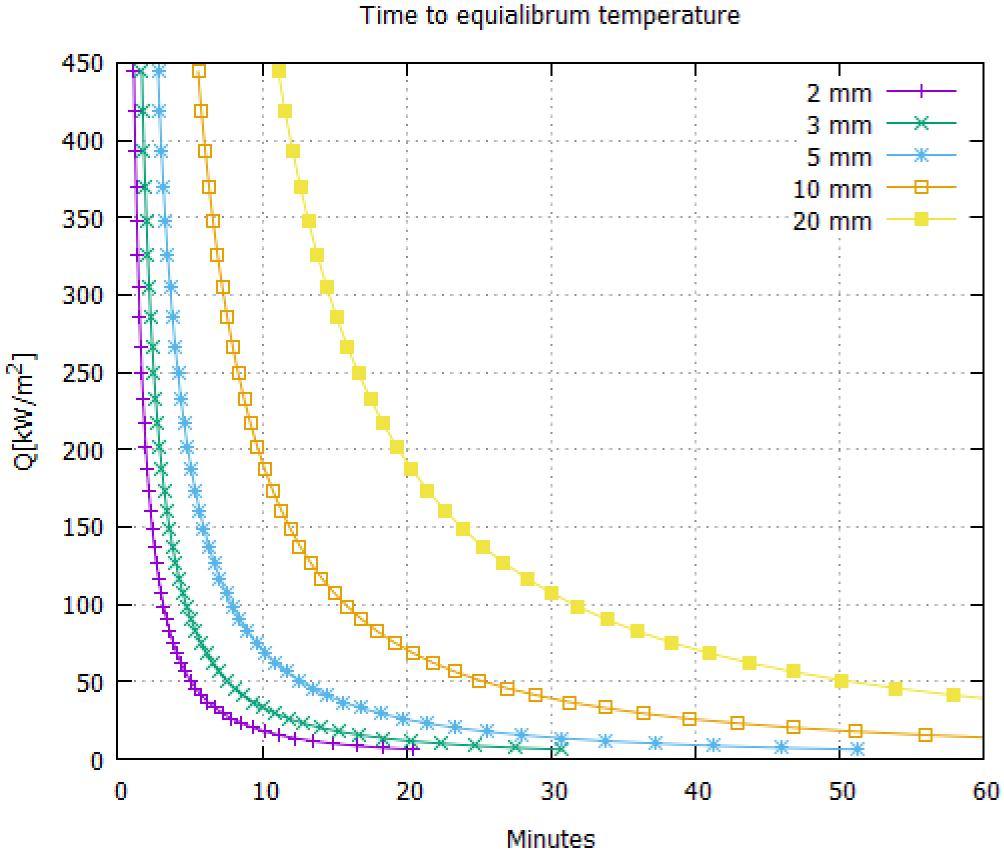
Time to reach equilibrium temperature depends on heat load and steel thickness


Time to equialibrum temperature


Time to equialibrum temperature

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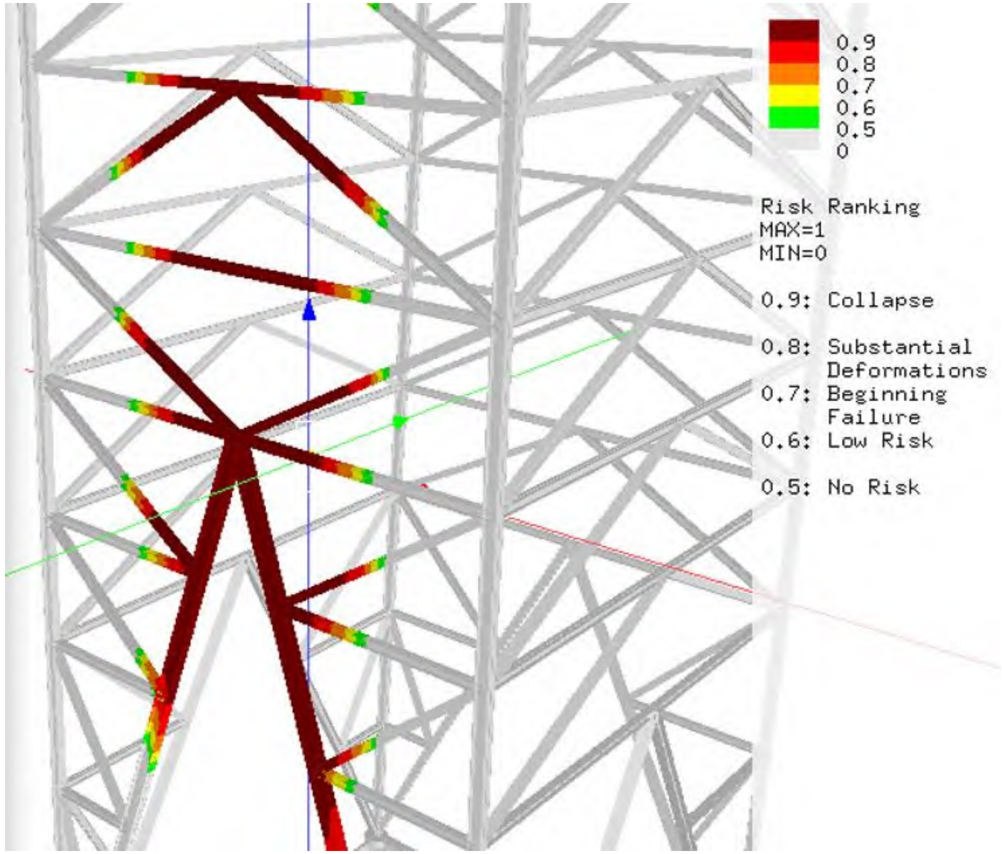
Temperature vs risk of damage



		<--------Risk--------->		
Temperature[C]	Degrade	Material	Beam	Column
0.0	1.000	0.000	0.00	0.00
400.0	1.000	0.000	0.00	0.00
500.0	0.780	0.220	0.15	0.30
600.0	0.470	0.530	0.40	0.60
700.0	0.230	0.770	0.55	0.80
800.0	0.110	0.890	0.70	0.90
900.0	0.060	0.940	0.80	0.95
1000.0	0.040	0.960	0.90	0.98
1100.0	0.020	0.980	0.95	0.99
1200.0	0.005	0.995	0.99	1.00

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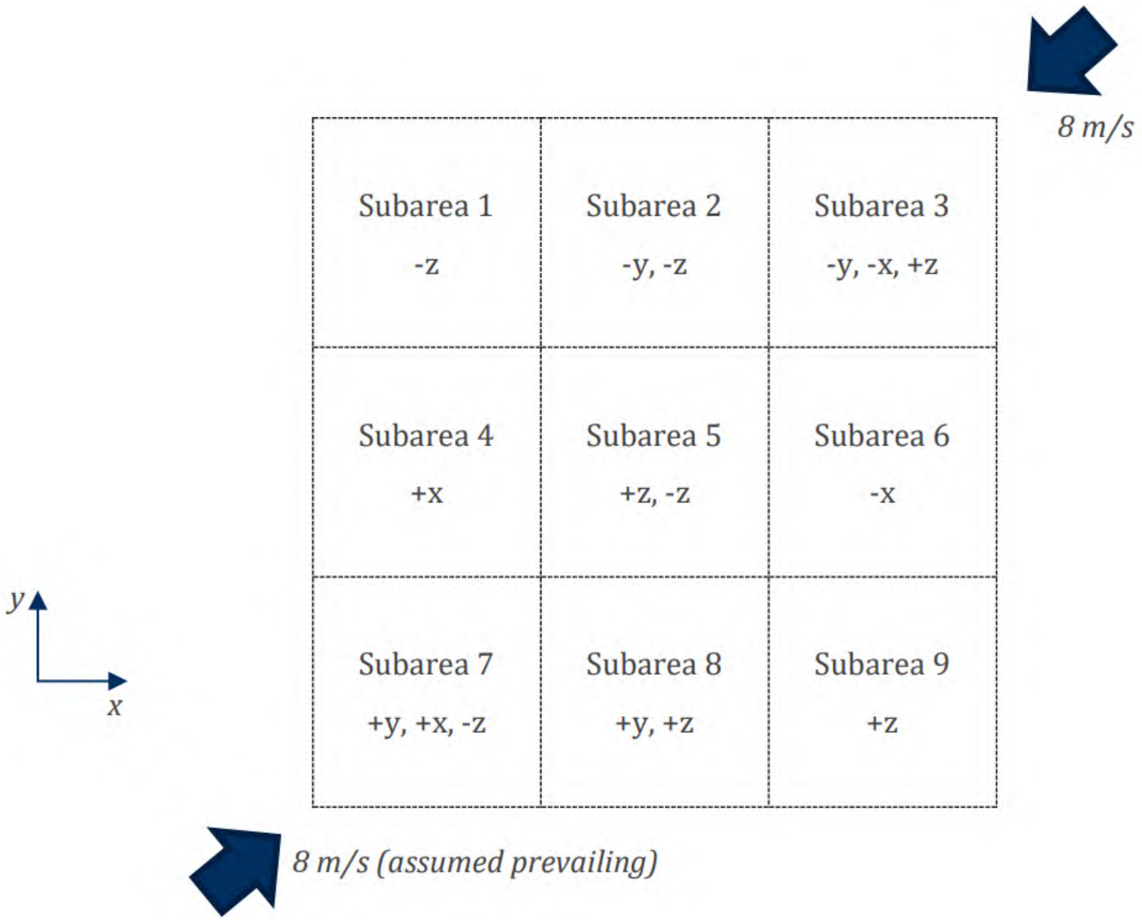
Time for a live demo

- How to prepare a dataset for VISTemp calculations is explained in TN-1
- It takes longer to prepare and run KFX to generate a data set for VISTemp calculation than we have for this demo ☺
- We run usually 16 mass flows from each leak point and leak direction to construct transients.
- For each run we collect a data set that contains the field values we need for calculating heat load on virtual structures
- When this is done, we can go on doing parameter variations with the VISTemp calculator. Each VISTemp run takes only a minute or so when the data set from KFX is available.
- Preparing KFX simulations takes only a few minutes for to prepare for each leak point, but the simulations takes a few hours each, so the real time to perform the CFD calculations depends on how many CPUs are available
- **DEMO BREAK**



8 m/s

Subarea 1 -z	Subarea 2 -y, -z	Subarea 3 -y, -x, +z
Subarea 4 +x	Subarea 5 +z, -z	Subarea 6 -x
Subarea 7 +y, +x, -z	Subarea 8 +y, +z	Subarea 9 +z

8 m/s (assumed prevailing)

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Pool and Spray fires

- Liquid leaks from pressurized vessels cause sprays.
- Pool fires can be caused by rain out from liquid sprays.
- In most cases, high pressure leak stems from high vapor pressure in the liquid so that flashing occur when expanded to atmospheric pressure
- Spray fires behaves quite like gas jet fires
- Pool fires typically dominates the fire picture after the pressure inside segments has dropped to a level where the leak is gravity driven
- Typically, a liquid hydrocarbon fire will start as a spray fire that is time dependent based on ESD and depressurization, and then later when the pressure has dropped leads to pool fires.
- The traditional way of simulating pool fires by using a lookup table (e.g. Fabig TN-13) to calculate the evaporation rate of the pool fire in a process area in CFD simulations sometimes leads to questionable results, since the evaporation is to a high degree controlled by radiation feedback to the pool surface.
- Radiation feedback depends on location of fire in relation to obstructions

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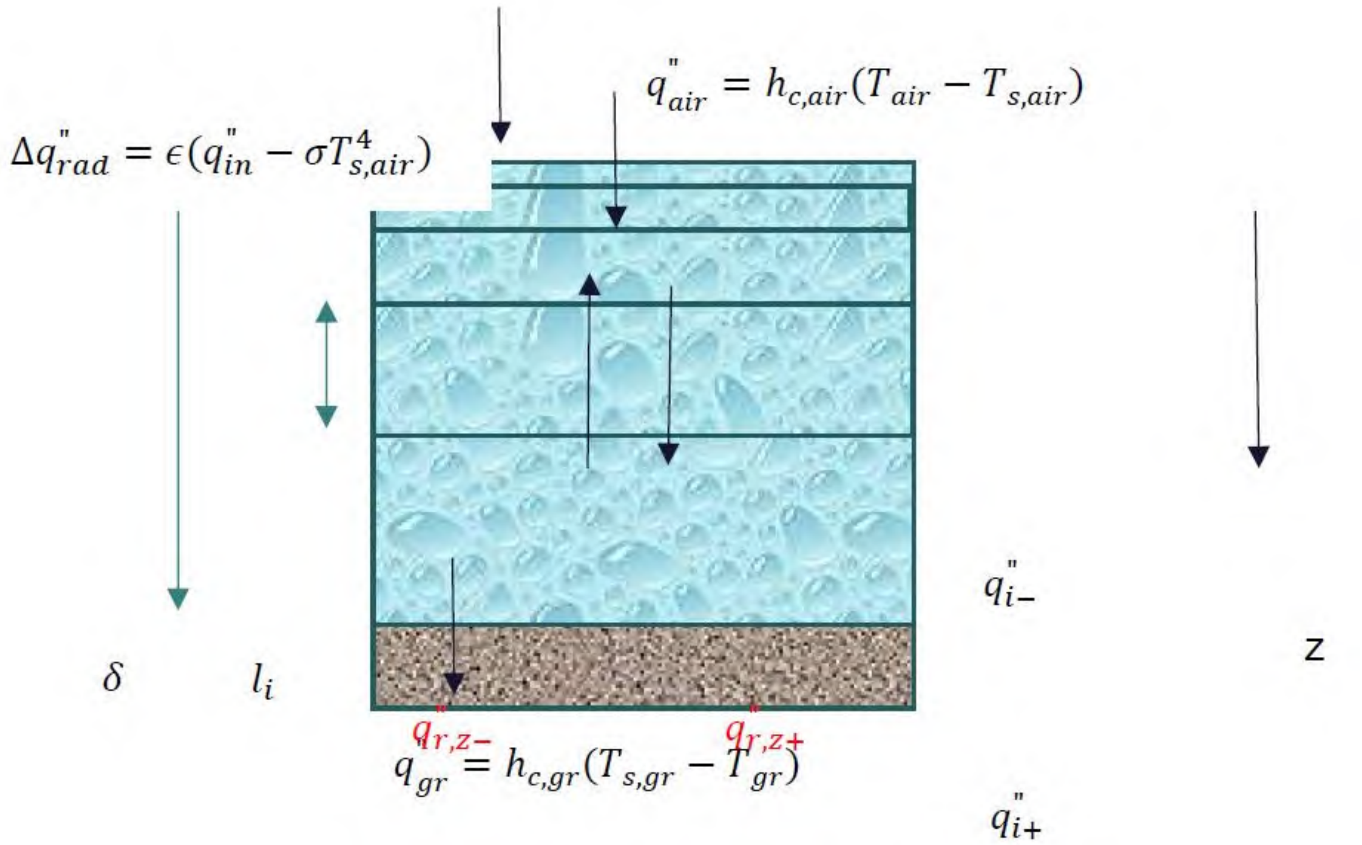
Pool fire improvements in the RISFIM project

- Better treatment of mixtures (TN-2)
- Vertical 1-D calculation of temperature gradient in pool
- Sloped floor
- Inclusion of drains

The temperature layer model



Thermal inertia

- The effect of warm solid surfaces is possible to calculate in KFX given that:
    1. All thermal response properties for all solid surfaces in the simulated facility are known and specified as input to the study
    2. The full fire is simulated in real time
- Both these requirements are very costly to implement.
- We tested out several strategies to emulate the thermal inertia when combining steady state fires to construct transient heat loads.
    - Assuming all surfaces iso-thermal is not conservative
    - Assuming all surfaces adiabatic (reaching equilibrium temperature) gives far too much heating when compared with solving transient leaks with realistic thermal properties
    - **A middle ground that showed to be quite reasonable doing spot checks was to use isothermal temperatures with emissivity of 0.5 for all surfaces**

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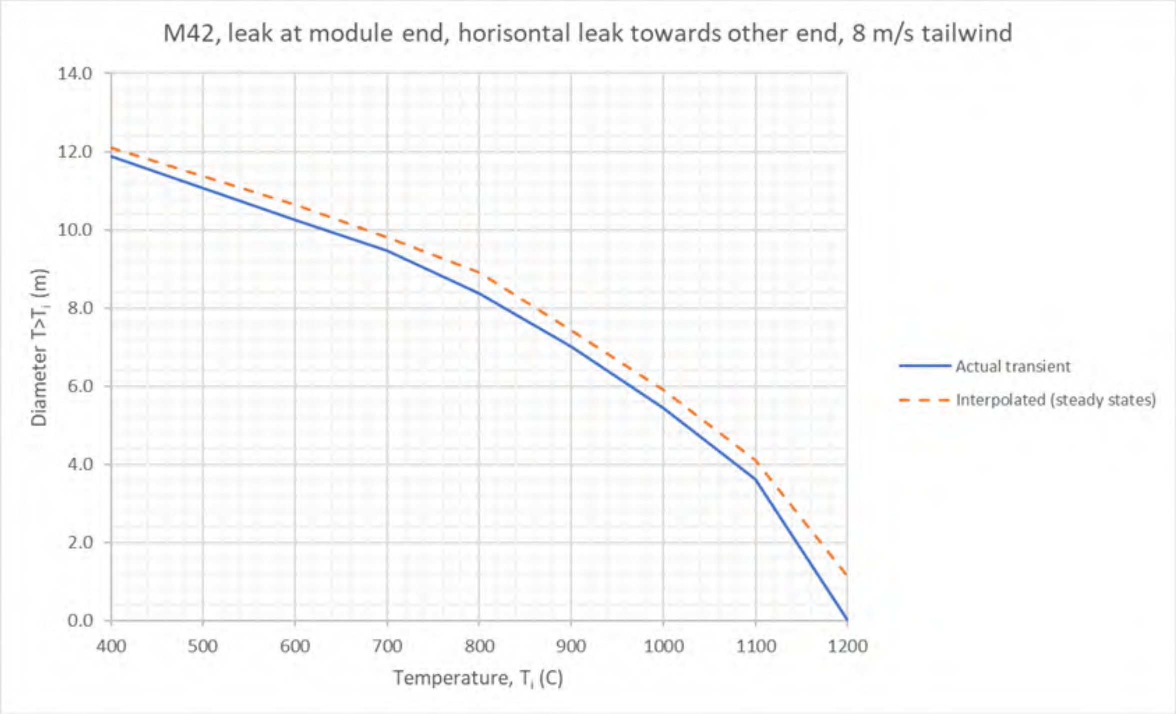
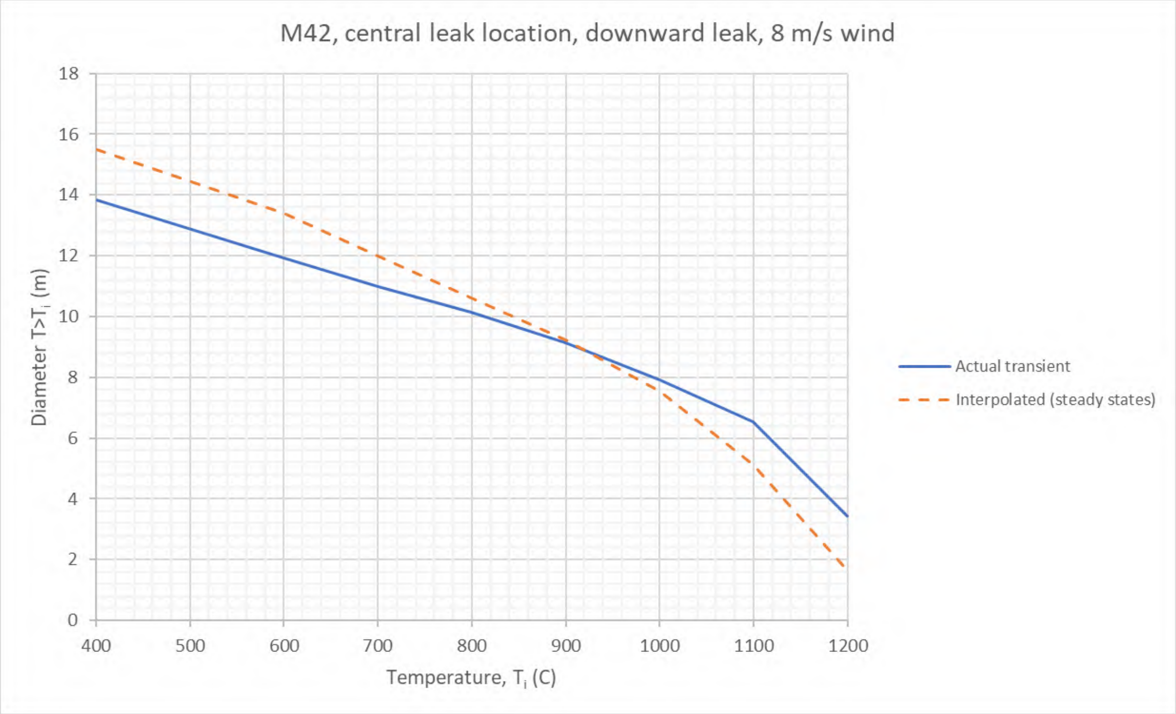
Thermal inertia – comparison with actual transient

- Conclusion: VISTemp method for setting boundary conditions for steady state simulations gives acceptable representation of actual transient leak


M42, leak at module end, horisontal leak towards other end, 8 m/s tailwind


M42, central leak location, downward leak, 8 m/s wind

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RISFIM methodology for secondary structures

Typical secondary structures

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- Pipe racks including pipes
- Access platforms

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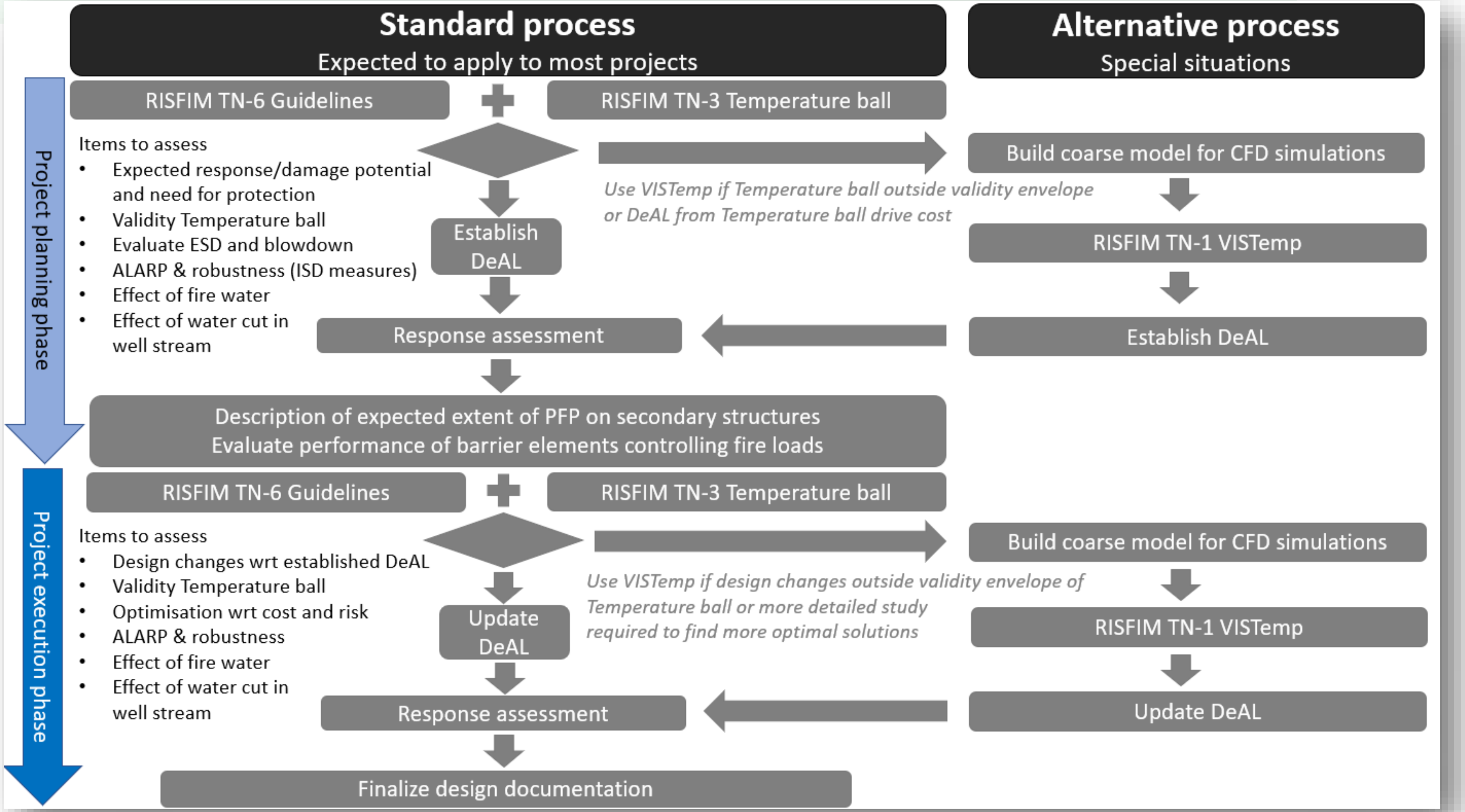

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Project execution phase

RISFIM TN-6 Guidelines + RISFIM TN-3 Temperature ball

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Build coarse model for CFD simulations

RISFIM TN-1 VISTemp

Update DeAL

Finalize design documentation

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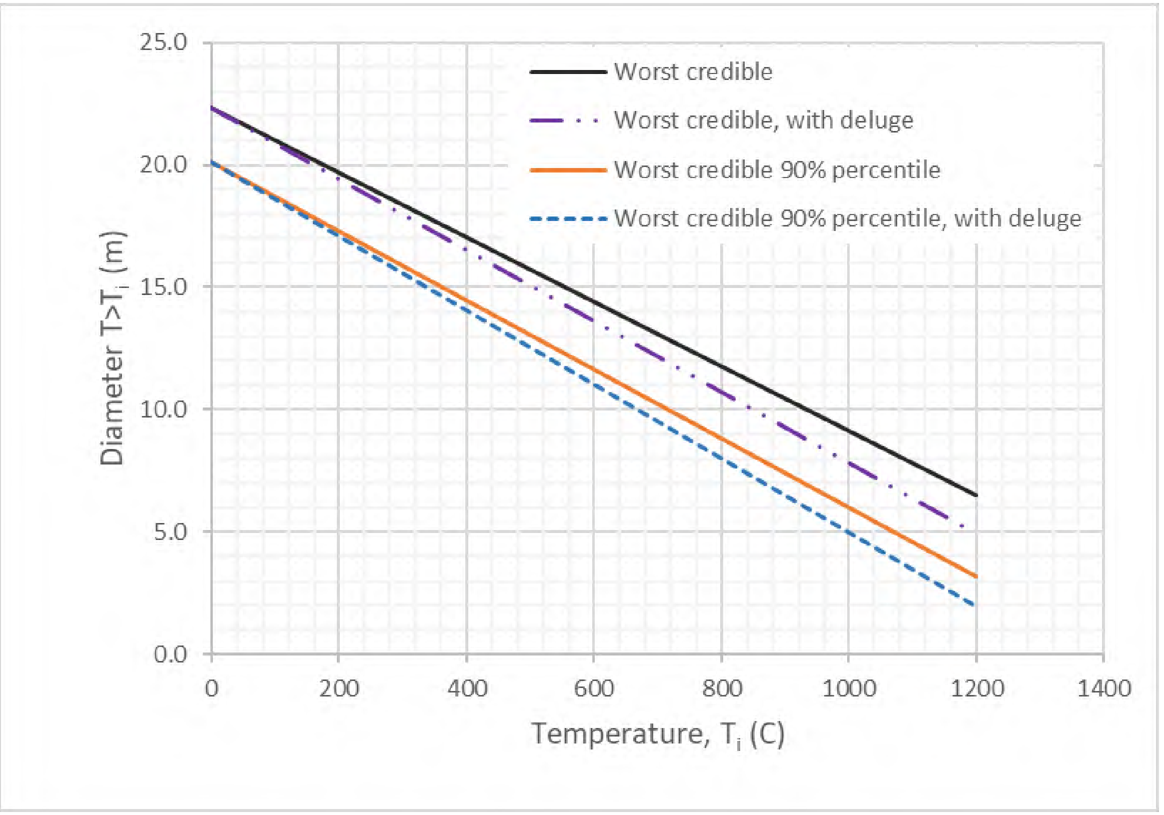
Temperature ball for O&G facilities

Openness	Fraction of module walls, roof and deck open for free flow
Depressurisation capacity	Time to 6.9 barg
Max segment mass	Largest gas inventory Largest liquid inventory
Equivalent profile thickness	Profile type and thickness
Module size	Gross volume of module
Time to ESD and BD	Time to ESD valve closed BD delay after ESD
100% or 90% percentile	Worst credible (100%) 10^{-5} per year residual risk
Deluge	NORSOK S-001 capacity Only for screening



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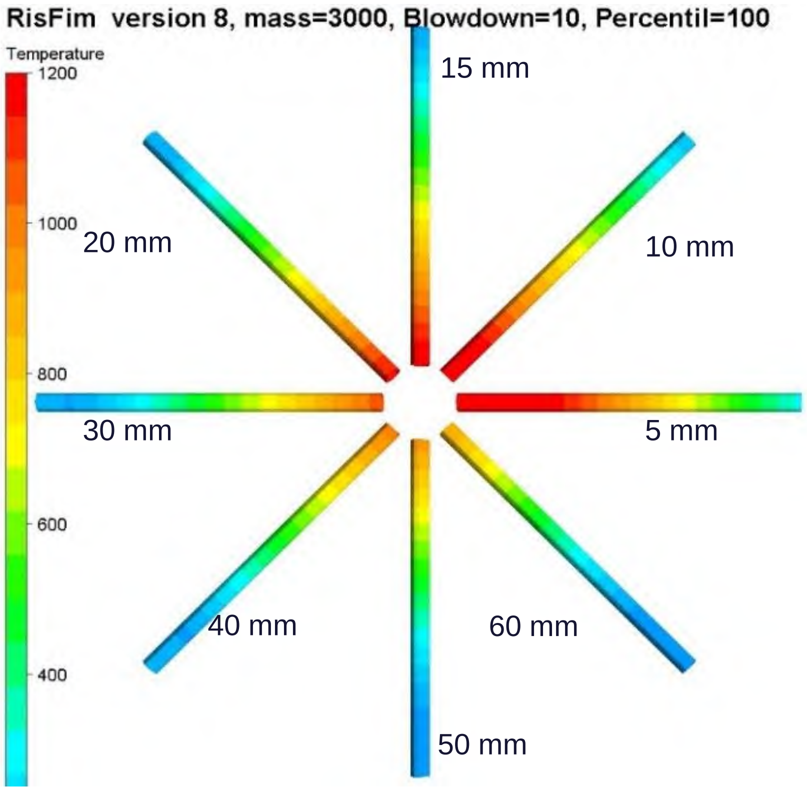

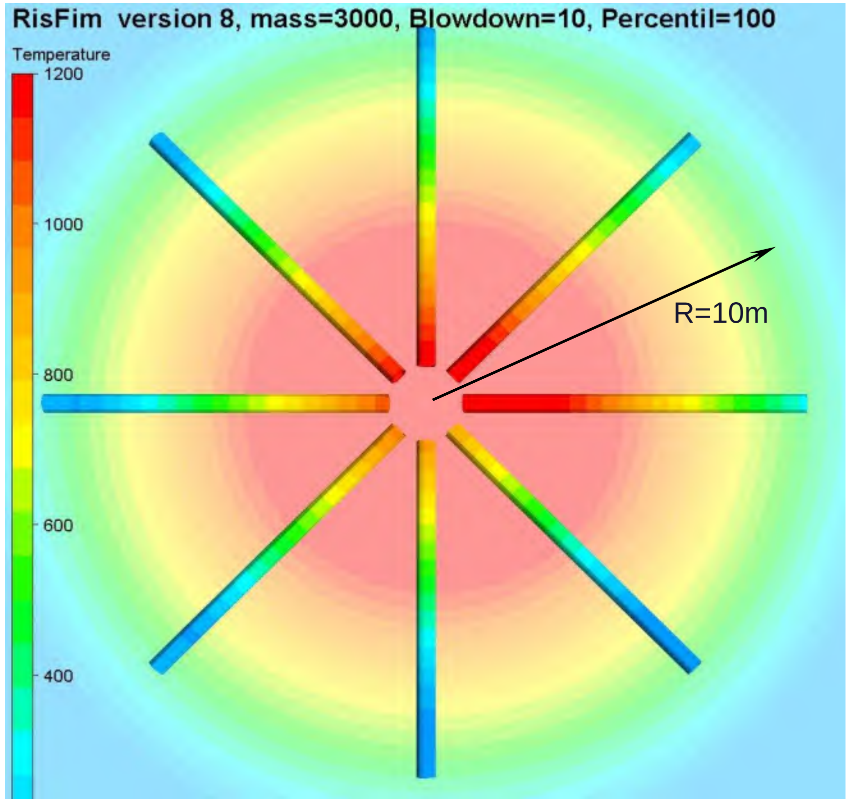

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Effect on Temperature ball

Openness	• Fraction of module open	Effect: Diameter increase with increasing opennes Driving factor: Larger flame volume
Depressurisation capacity	• Time to 6.9 barg	Effect: Diameter increase with increasing time to 6.9 barg Driving factor: More mass fed to fire with time
Max segment mass	• Largest gas inventory • Largest liquid inventory	Effect: Diameter increase with increasing mass Driving factor: More mass fed to fire with time
Equivalent profile thickness	• Profile type and thickness • The most sensitive param.	Effect: Diameter increase steeply with decreasing thickness Driving factor: Less heat transfer needed to elevate temperature
Module size	• Gross volume of module	Effect: Diameter increase with increasing volume Driving factor: Larger flame volume
Time to ESD and BD	• Time to ESD valve closed • BD delay after ESD	Effect: Diameter increase with increasing mass Driving factor: more mass fed to fire with time

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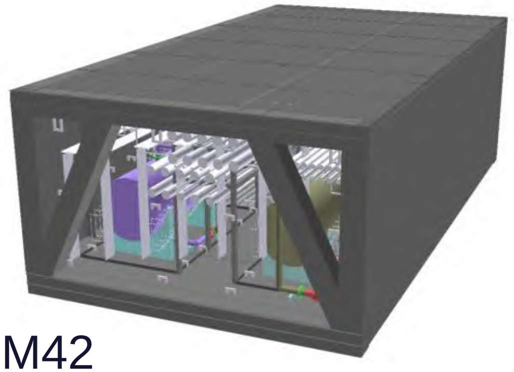
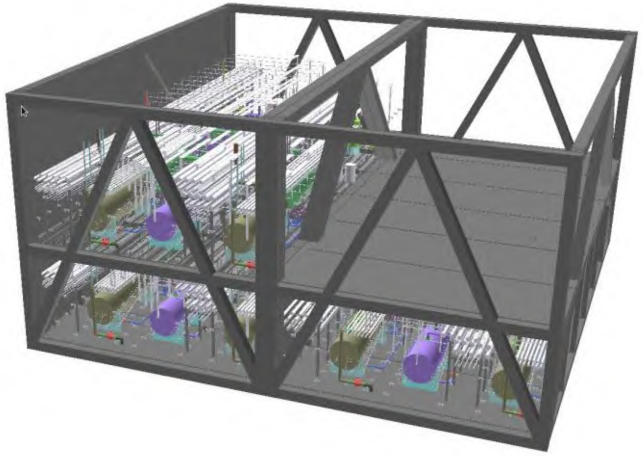
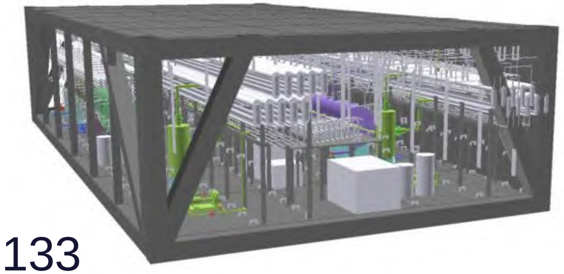
Parameterisation – empirical data

- 8 generic offshore modules have been established for systematic investigation of the geometrical design parameters affecting resulting heat loads
  - Varying size (4000 to 40000 m^3)
  - Varying ventilation conditions (poorly ventilated to open)
  - Varying length to width ratio
- Gas jet fire simulations
  - 450 fire simulations per module
  - 40 000 temperature response simulations with VISTemp per module
  - altogether **300 000 temperature response simulations**
- Spray/pool fire simulations
  - 12 fully coupled spray/pool fire simulations in one module


M42


M404


M133

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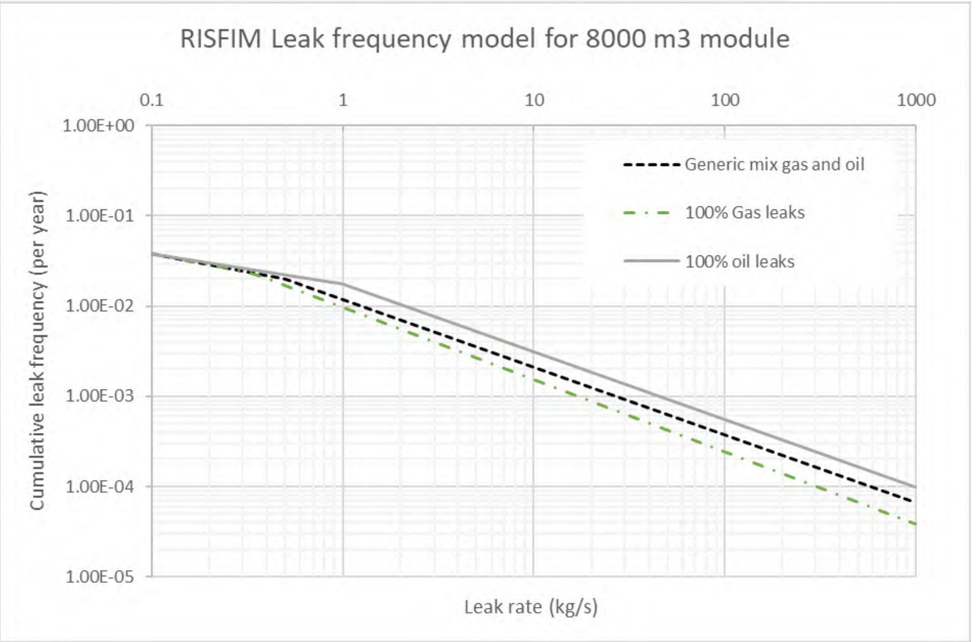
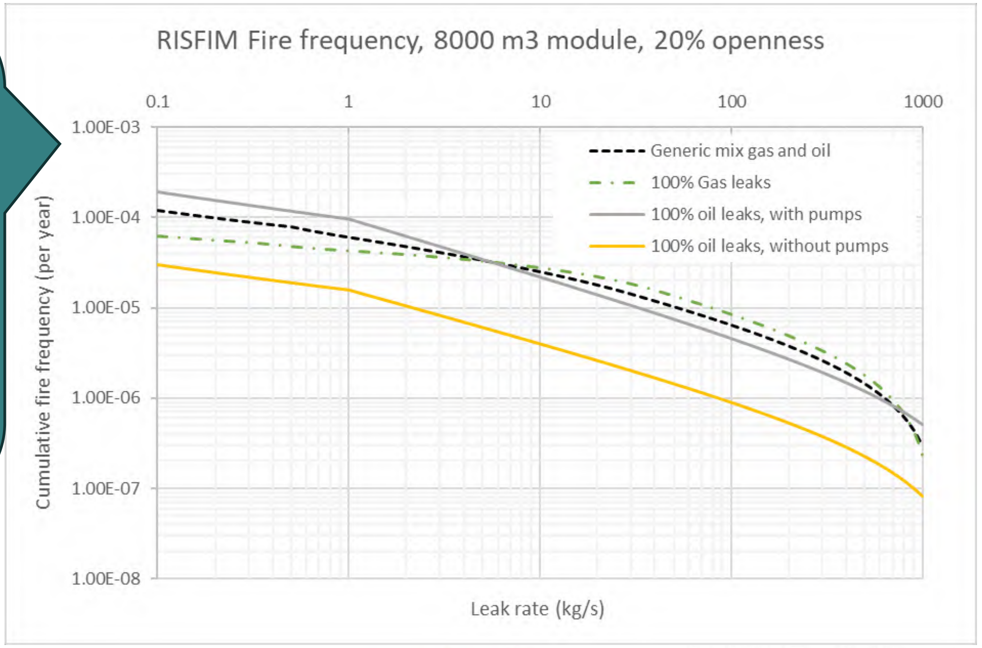
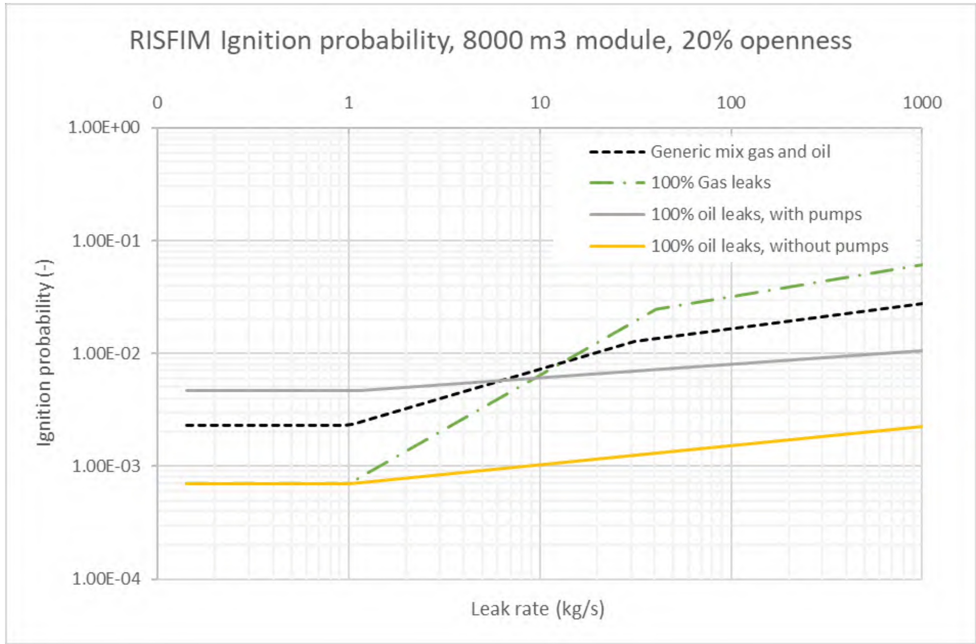
RISFIM Fire frequency model

- Fire frequency model based on up to date statistical data developed to
  - enable relaxation of fire load with respect to fire frequency if default load is cost-driving
  - ensure that the Temperature ball model will generate fire loads that is in line with the requirements to residual risk



Frequency for fires in region where escalation is critical for ultimate consequenes is around $1.0{\cdot}10^{-4}$ to $5{\cdot}10^{-5}$ per year for a typical installation





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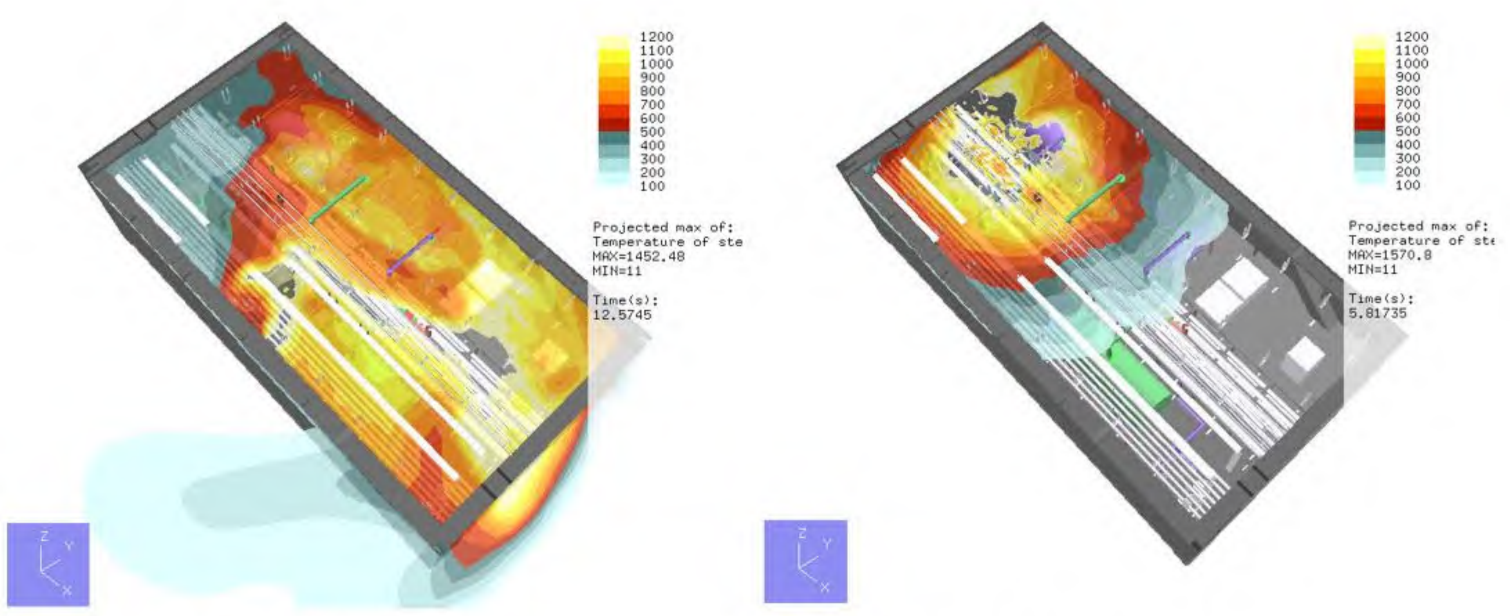
The most severe exposure throught the fire is used as basis

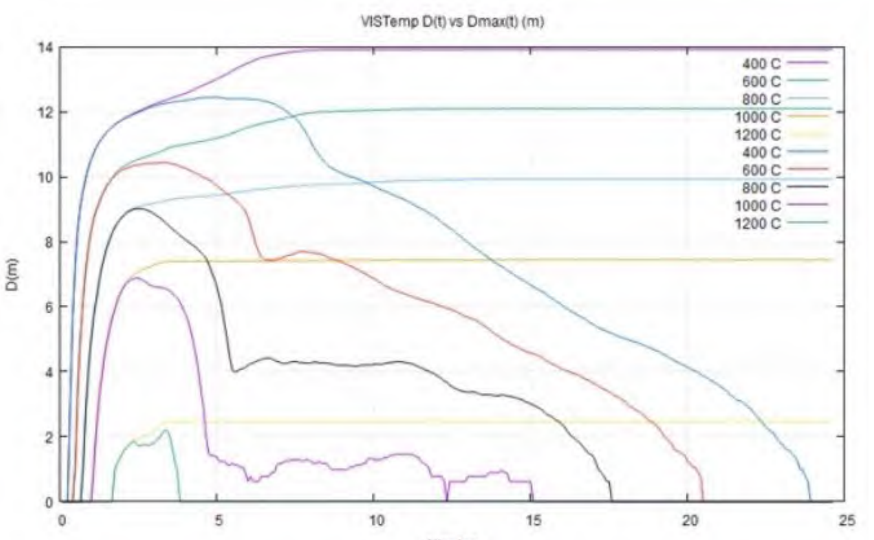
The actual heat distribution in space follows the time-dependendant dynamics of the fire, but, VISTemp extract the all time high temperature at all points in space – which adds conservatism to the method

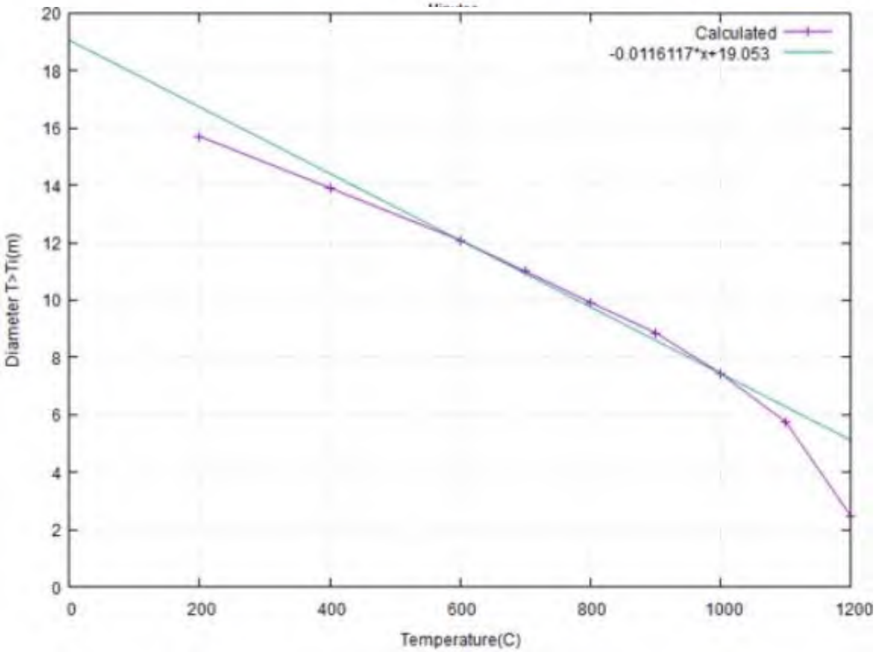


20 seconds into the fire

3 minutes into the fire

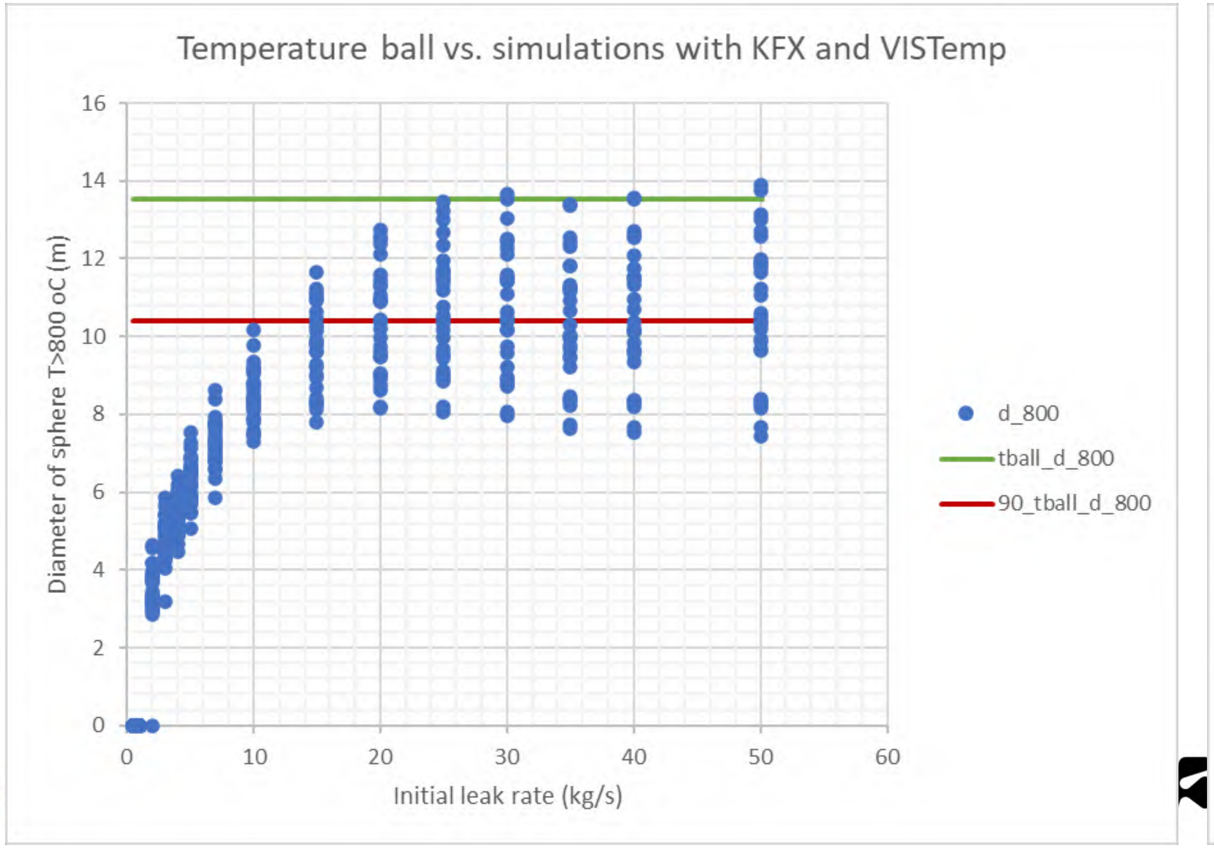
Figure 5.21: Visualization gas temperature in the fire at various points in time (note that the time in the plot is incorrect)

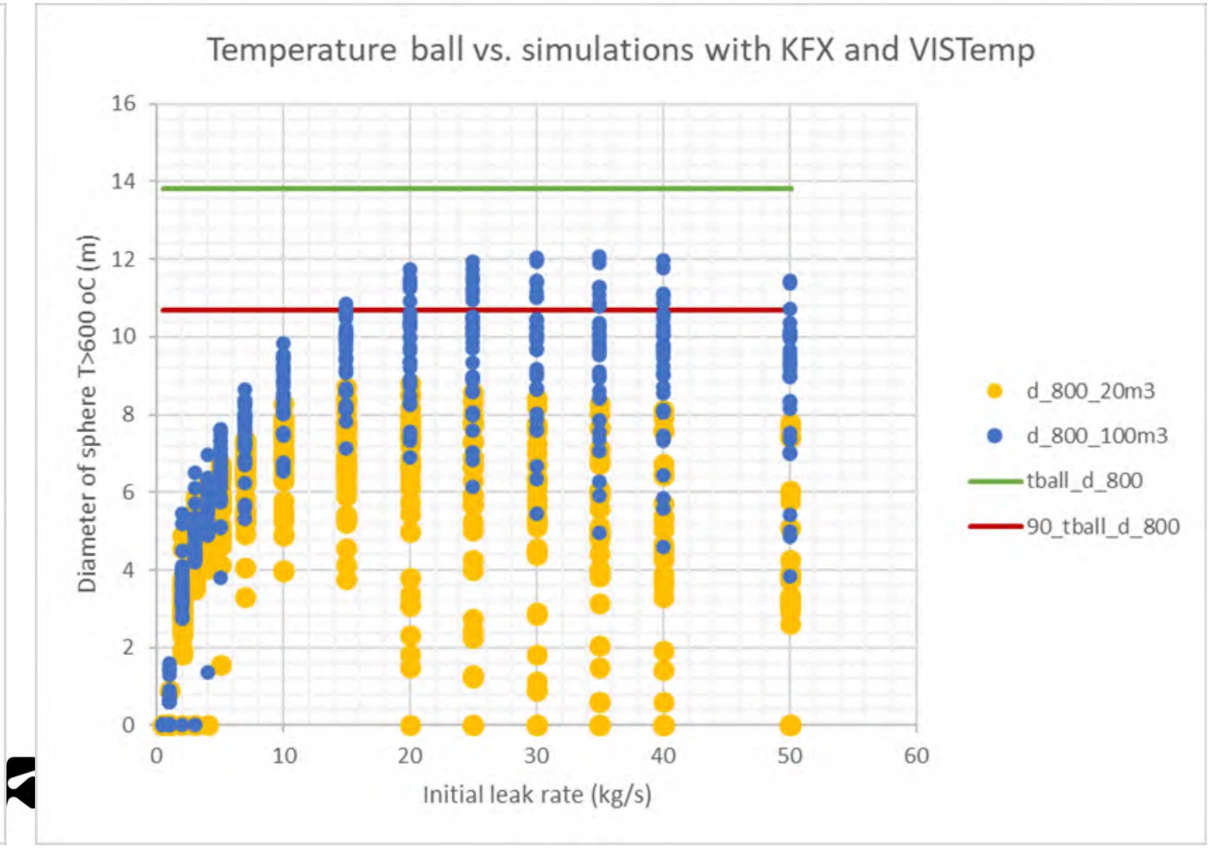




Parameterisation of Temperature ball model

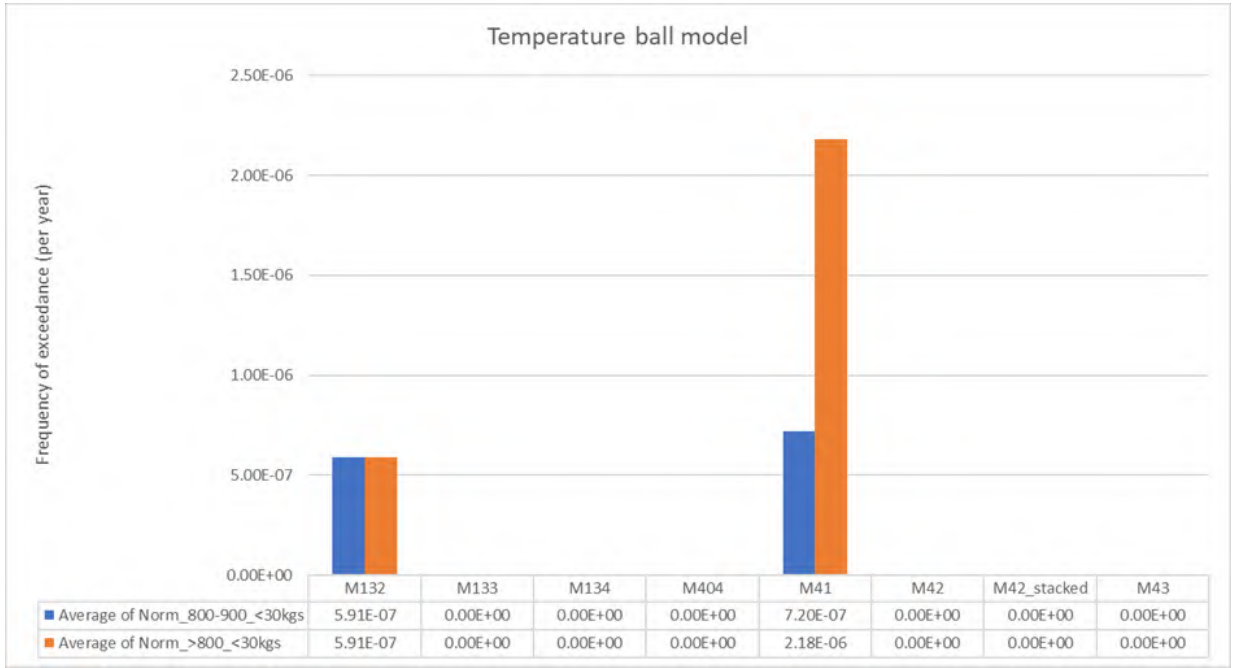
- The overarching principle has been that the diameter corresponding to the aggregated volume reaching a temperature of 800 ºC at any time throughout the fire should envelope the temperature response resulting from all of the simulated fire scenarios in the empirical dataset





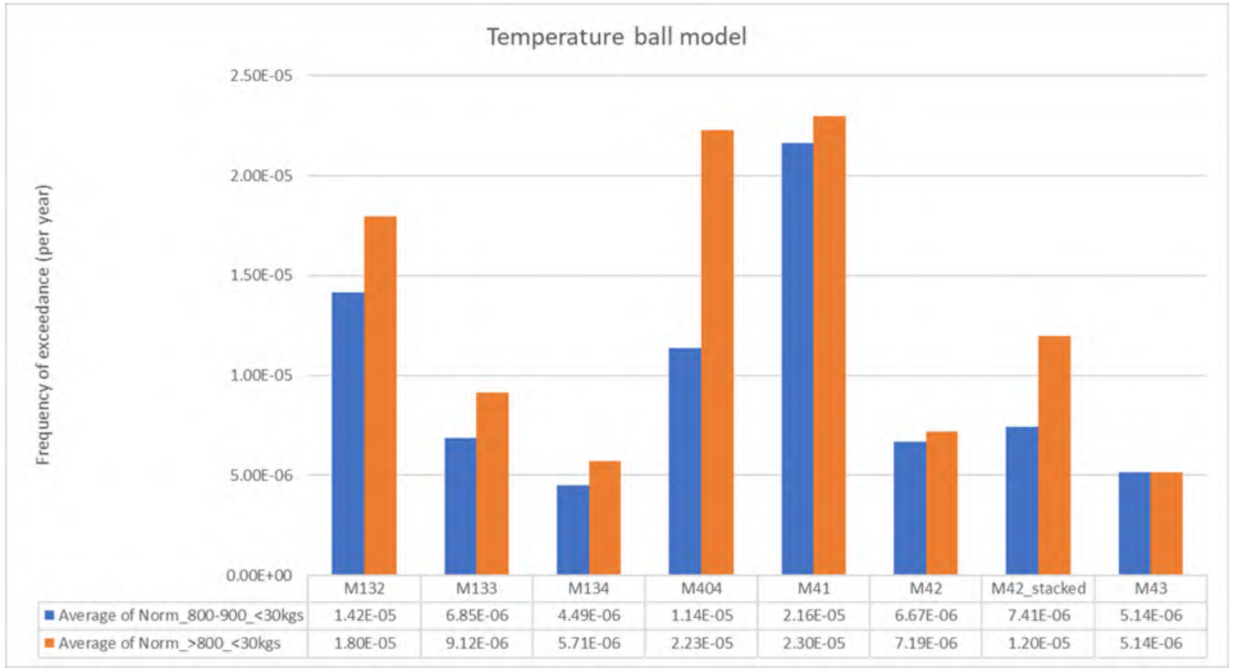
Parameterisation of Temperature ball model

Residual frequency – Worst Credible



	M132	M133	M134	M404	M41	M42	M42_stacked	M43
■ Average of Norm_800-900_<30kgs	5.91E-07	0.00E+00	0.00E+00	0.00E+00	7.20E-07	0.00E+00	0.00E+00	0.00E+00
■ Average of Norm_>800_<30kgs	5.91E-07	0.00E+00	0.00E+00	0.00E+00	2.18E-06	0.00E+00	0.00E+00	0.00E+00

Residual frequency – 90% percentile



	M132	M133	M134	M404	M41	M42	M42_stacked	M43
■ Average of Norm_800-900_<30kgs	1.42E-05	6.85E-06	4.49E-06	1.14E-05	2.16E-05	6.67E-06	7.41E-06	5.14E-06
■ Average of Norm_>800_<30kgs	1.80E-05	9.12E-06	5.71E-06	2.23E-05	2.30E-05	7.19E-06	1.20E-05	5.14E-06

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Spray fire vs gas fire

- In general, a gas jet fire and a spray/pool fire with the same transient behavior in balance with the air supply, the gas jet and spray fire will generate equivalent heat load distributions. Some factors
  - Spray fires radiate more
  - The liquid is released at less speed (less convective heat load)
  - Much more effective combustion in gas fires
- Fire scenarios where liquid leaks may result in more severe fire loads
  - Well stream leaks with gas content and low **watercut**
  - Liquid leaks from large vessels generally possess a slower transient decrease and the overall duration is much longer
- Conclusion:
  - the frequency for liquid leaks resulting in a more severe fire exposure than the **most severe gas leak fire scenario** is low
  - gas leaks can be used to represent spray/pool fires
  - a separate liquid model is however required in cases where the largest gas segment in the module is limited

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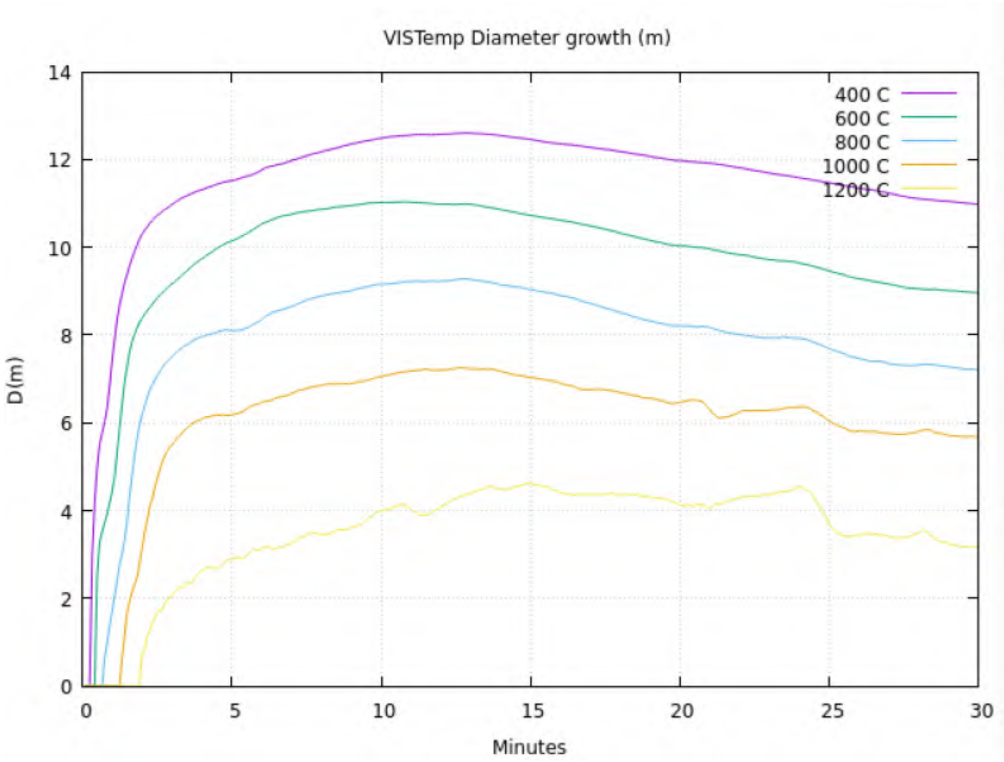
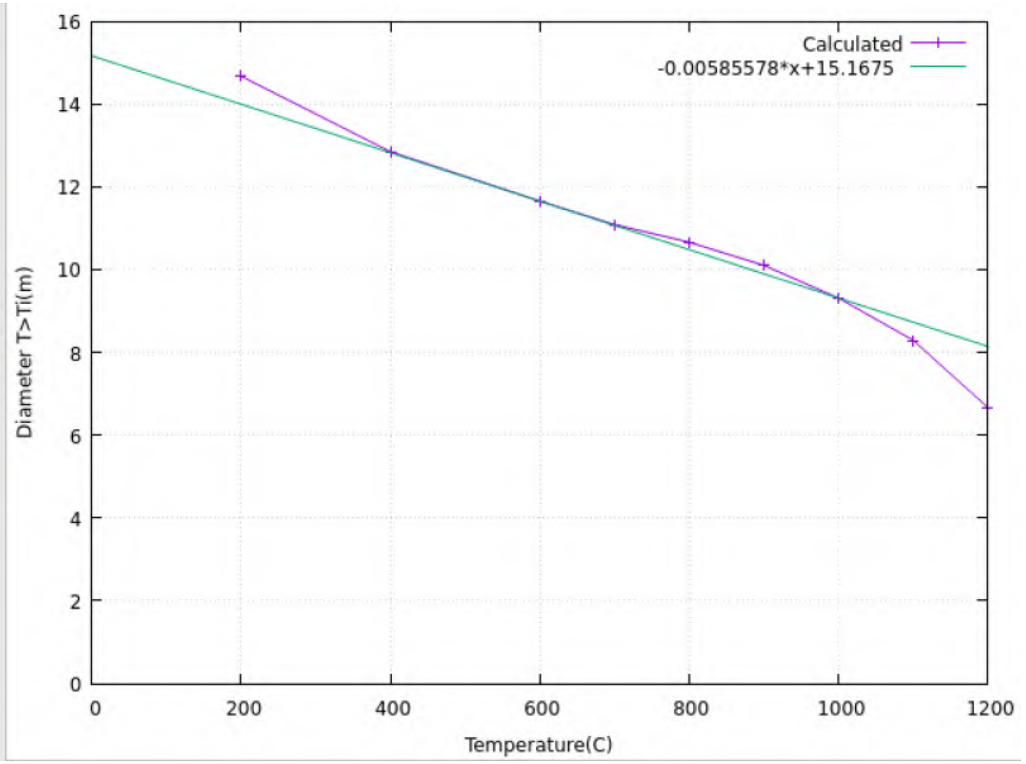
Spray fire vs gas fire





30 kg/s leak from separator liquid phase – note that maximum extent of temperature response is reached after 10 minutes.

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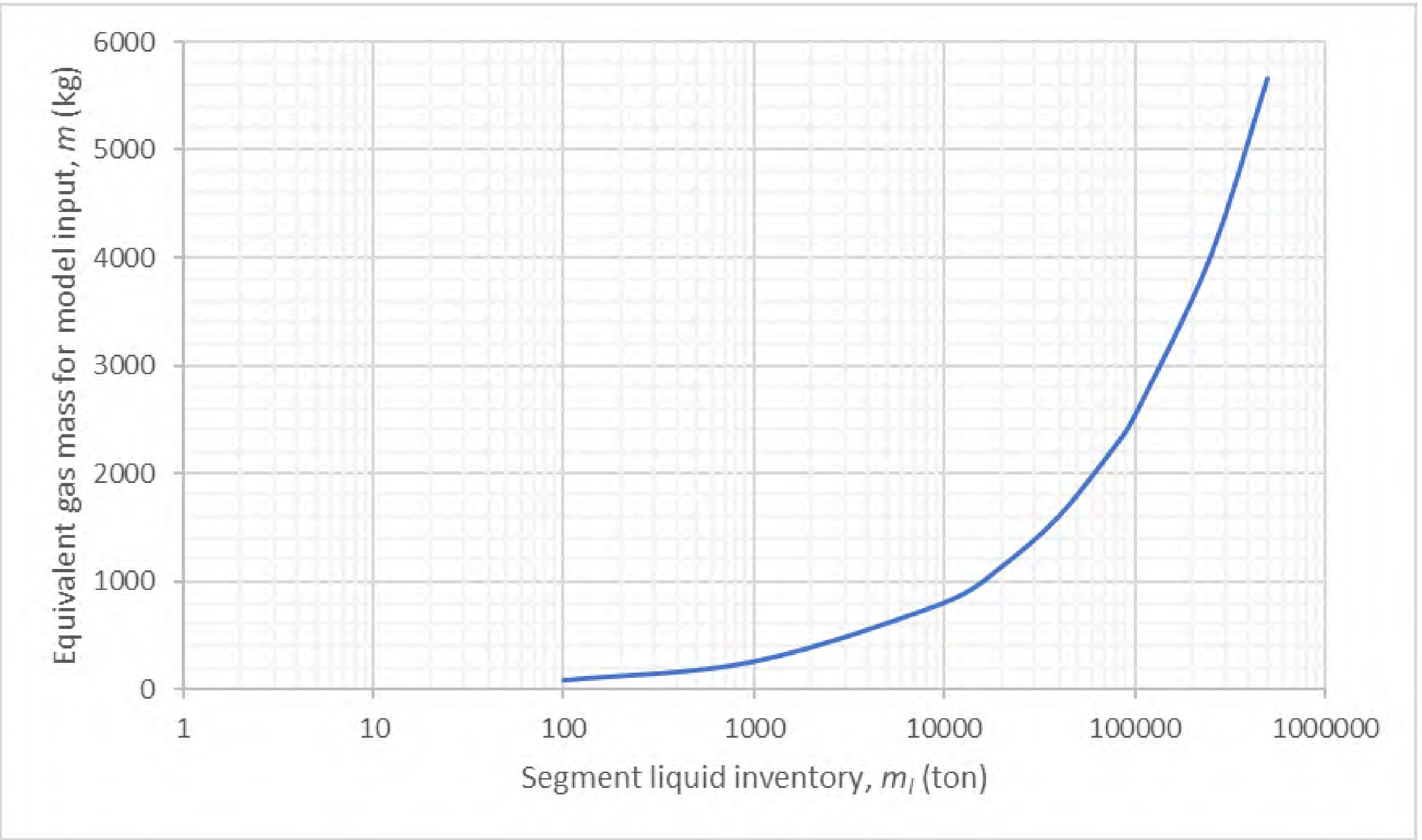
Representation of liquid segments

A relationship between segment liquid inventory and gas mass to be put into model have been developed

Intention is that gaseous segments are governing for the Temperature ball in most modules.

Main objective of this model is to ensure reasonable loads for modules where there is no gaseous segments



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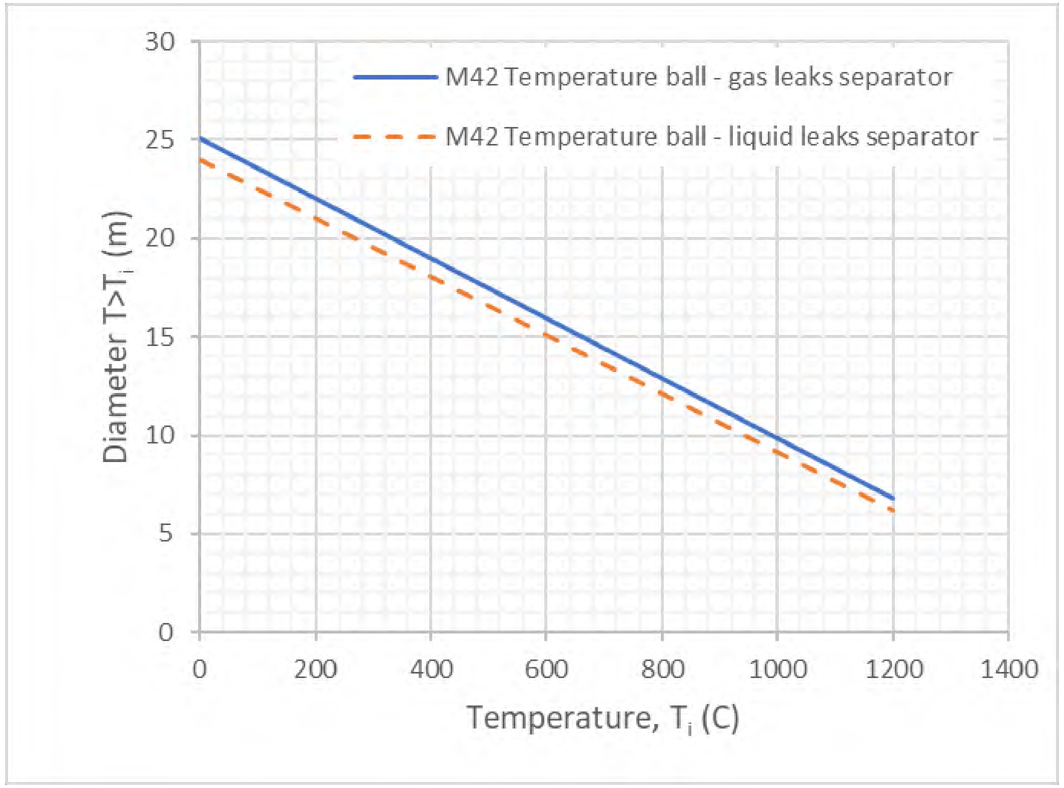
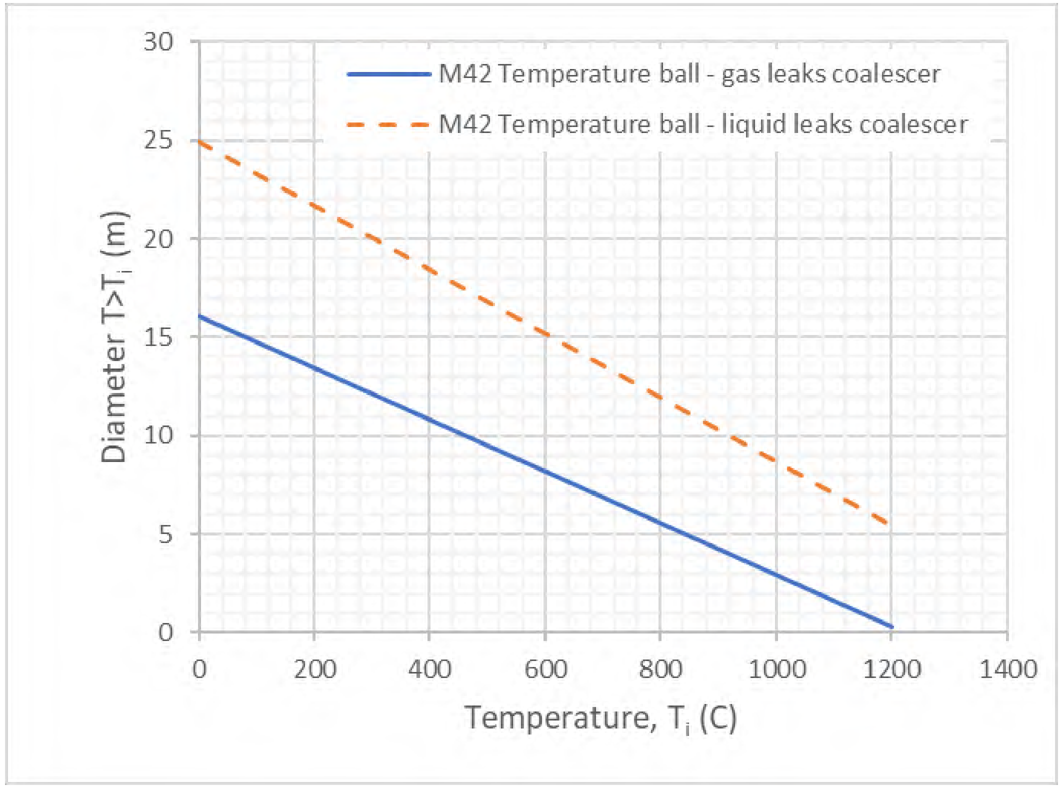
Spray fire vs gas fire



Temperature ball for M42 for separator segment (5 ton gas and 100 ton liquid operating at 20 barg with a depressurisation capacity of 10 min to 6.9 barg.)



Temperature ball for M42 for coalescer segment (100 gas and 250 ton liquid operating at 2 barg with a depressurisation capacity of 10 min to 6.9 barg.

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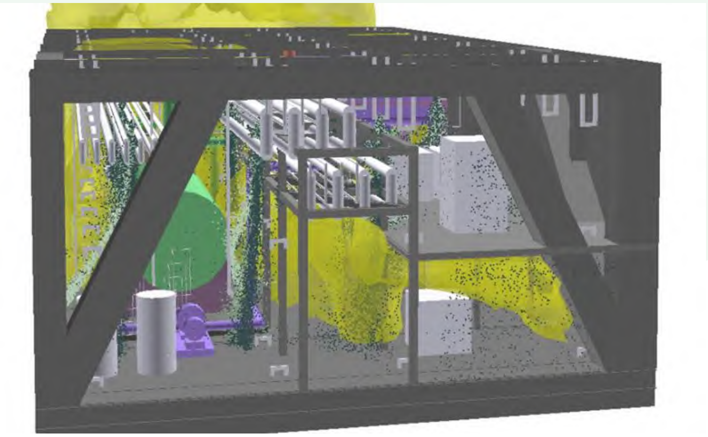
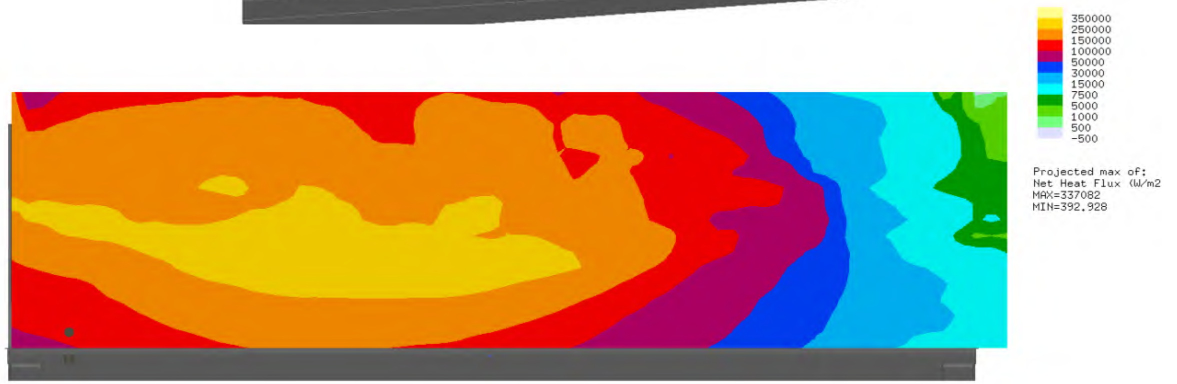
Effect of fire water

- The effect on the Temperature Ball has been investigated with the effect of fire water
- Fire system design in accordance with NORSOK S-001
- Typical result:
  - local maximum heat flux similar (250 – 350 kW/m2)
  - extent of the intermediate fluxes (50 – 250 kW/m2) is reduced for the case with fire water
  - extent of lower heat fluxes similar or more profound (flame size increase)
- An indicative model has been implemented
  - should only be used for evaluation of the potential benefits of accounting for the effect of fire water
  - Specific simulations should be executed with VISTemp to justify the effect in a particular case
- Incorporation of the effect of fire water must be in accordance with the governing authority requirements





Dry

With deluge

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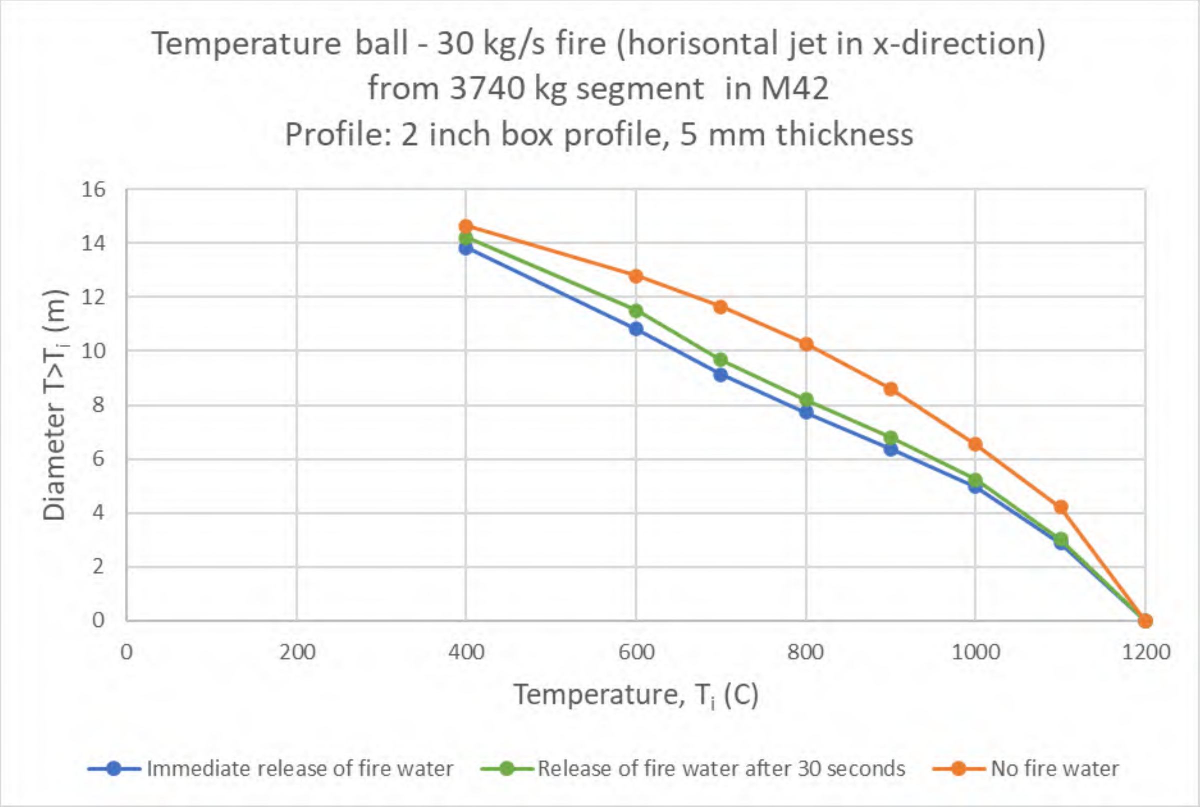
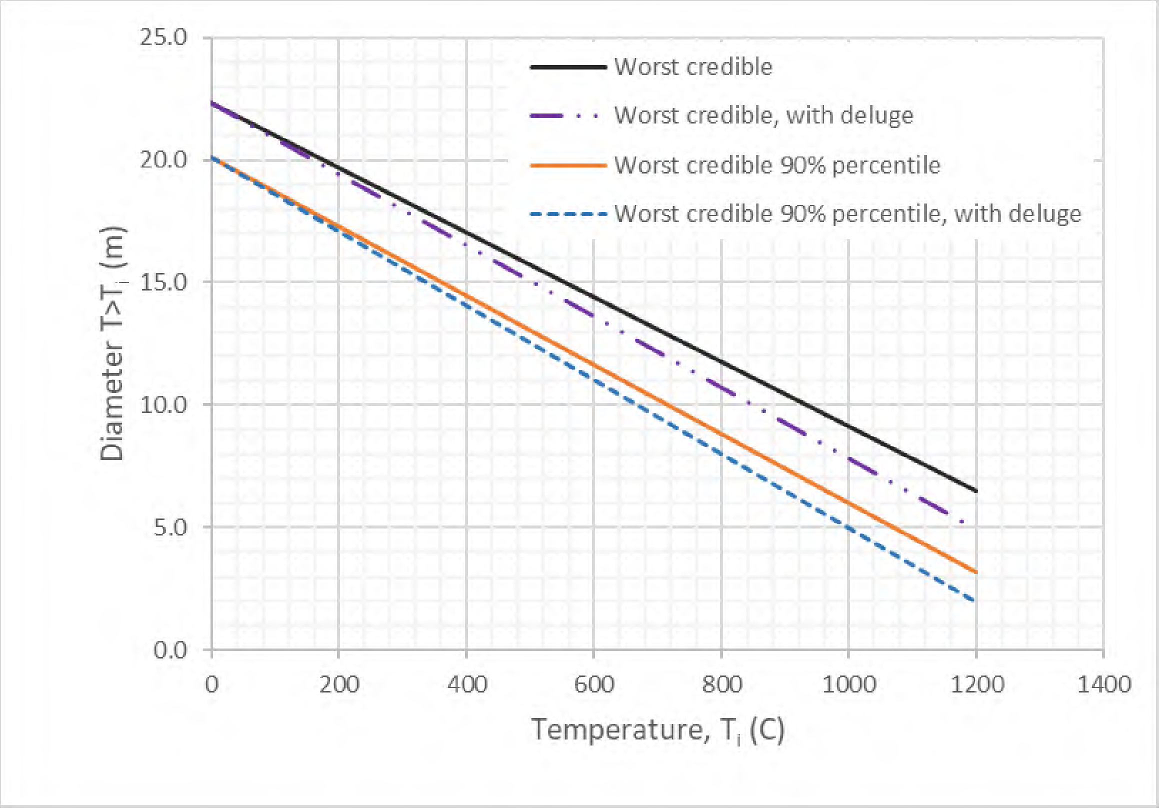
Effect of fire water

Simulation with VISTemp



Estimation with Temperature ball



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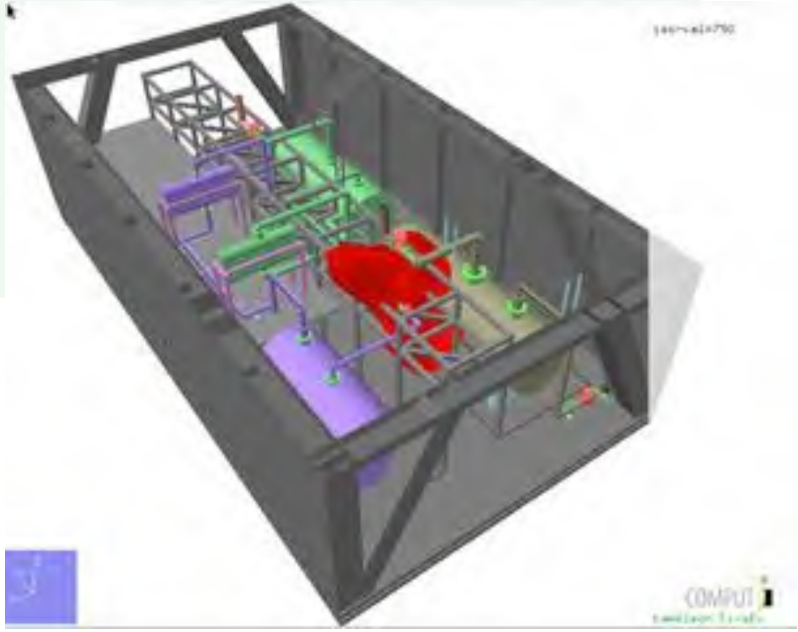
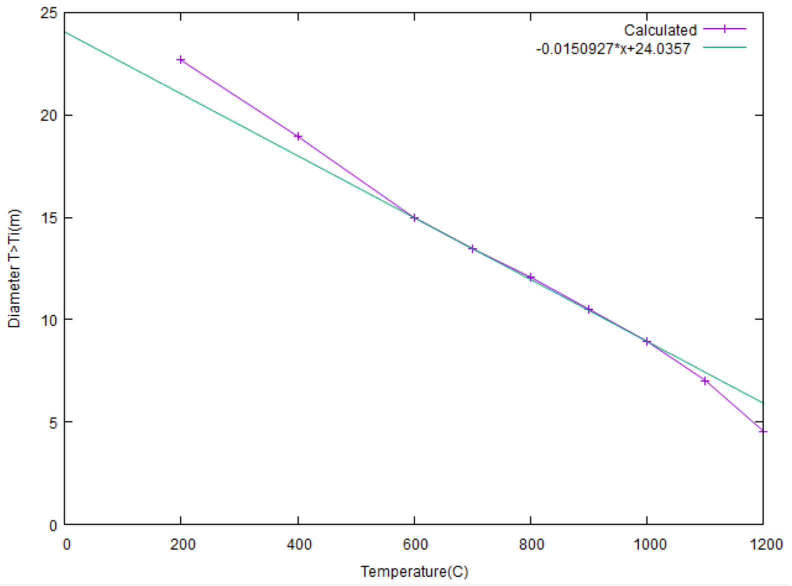
Shape of the Temperature ball

- The resulting volumetric temperature response can generally be approximated by a sphere, which forms an effective basis for making a simple model that can replicate the response in a real fire
- An oblong shape like and ellipsoid will in many cases give a more realistic representation of the fires in the module, but it is considered rather impractical in an engineering context.
- The number of potential shapes to check in the response analysis will be large, and consistent general guidelines will be hard to define
- **And bear in mind that the most severe gas leak scenario in the module is used as basis for the model parameters**
- Therefore, as the method for calculation of the diameter-temperature diameter is on average conservative, it is judged that using a sphere is an adequate approach altogether.
- But it is recommended to evaluate the sensitivity with respect to the shape in certain cases – screening





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Additional parameters affecting heat load

- Blowout fire scenarios
  - it is found reasonable that the secondary structures should resist moderate blowout leak rates for the first part of the incident to avoid escalation hampering evacuation from neighboring areas to mustering areas and/or the mustering areas themselves
  - Fixed input for well head modules representing the damage potential in the initial phase of blowout scenarios has been established as part of guidelines (the blowout rate is constant)
- Water cut
  - Live crude/well stream includes typically a significant fraction of water
  - Experiments and simulations documents that well stream remain flammable for high water cuts, but that the heat load starts to decrease significantly with a water cut higher than 30%
  - The Temperature ball model does not include parameters that reflect water cut, but the effect of water cut can be reflected by use of VISTemp. KFXTM is validated for simulation of water cut.

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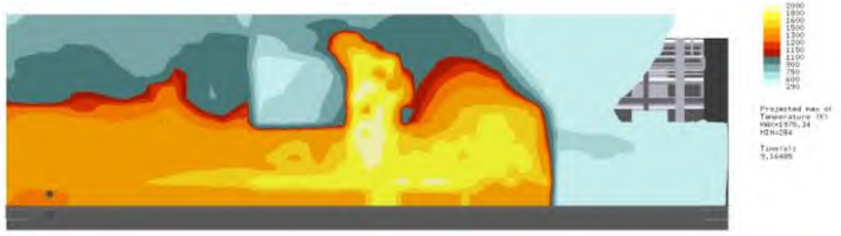
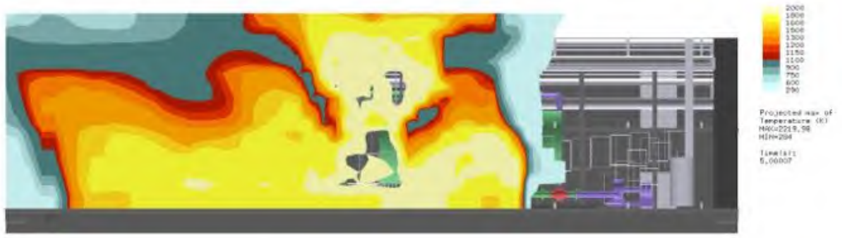
Applicability for hydrogen and other fluids
Methane versus Hydrogen

Gas temperature field



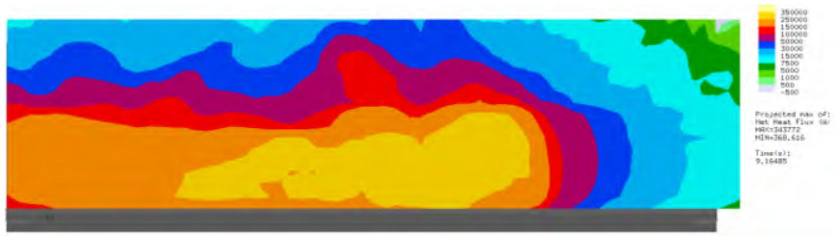
5 kg/s methane



2.1 kg/s hydrogen (same LHV as 5 kg/s methane)

5 kg/s hydrogen (2.4 times higher LHV than 5 kg/s methane)

Radiation field



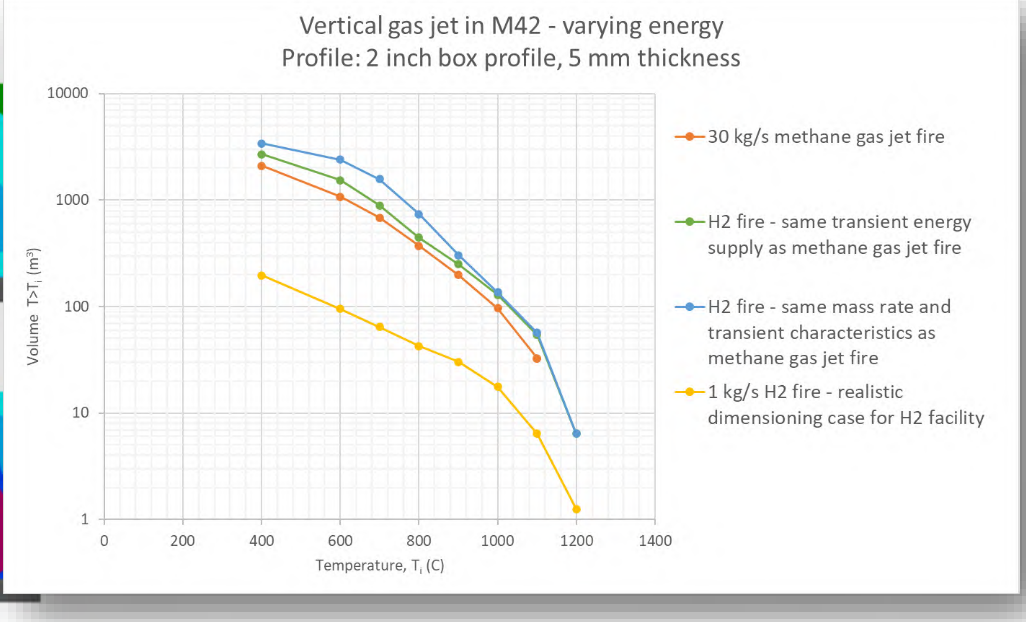
5 kg/s methane fire

2.1 kg/s hydrogen (same power of combustion as 5 kg/s methane fire)

5 kg/s hydrogen (2.4 times higher power of combustion than 5 kg/s methane fire)

VISTemp applicable ✓

Temperature ball only O&G ✗



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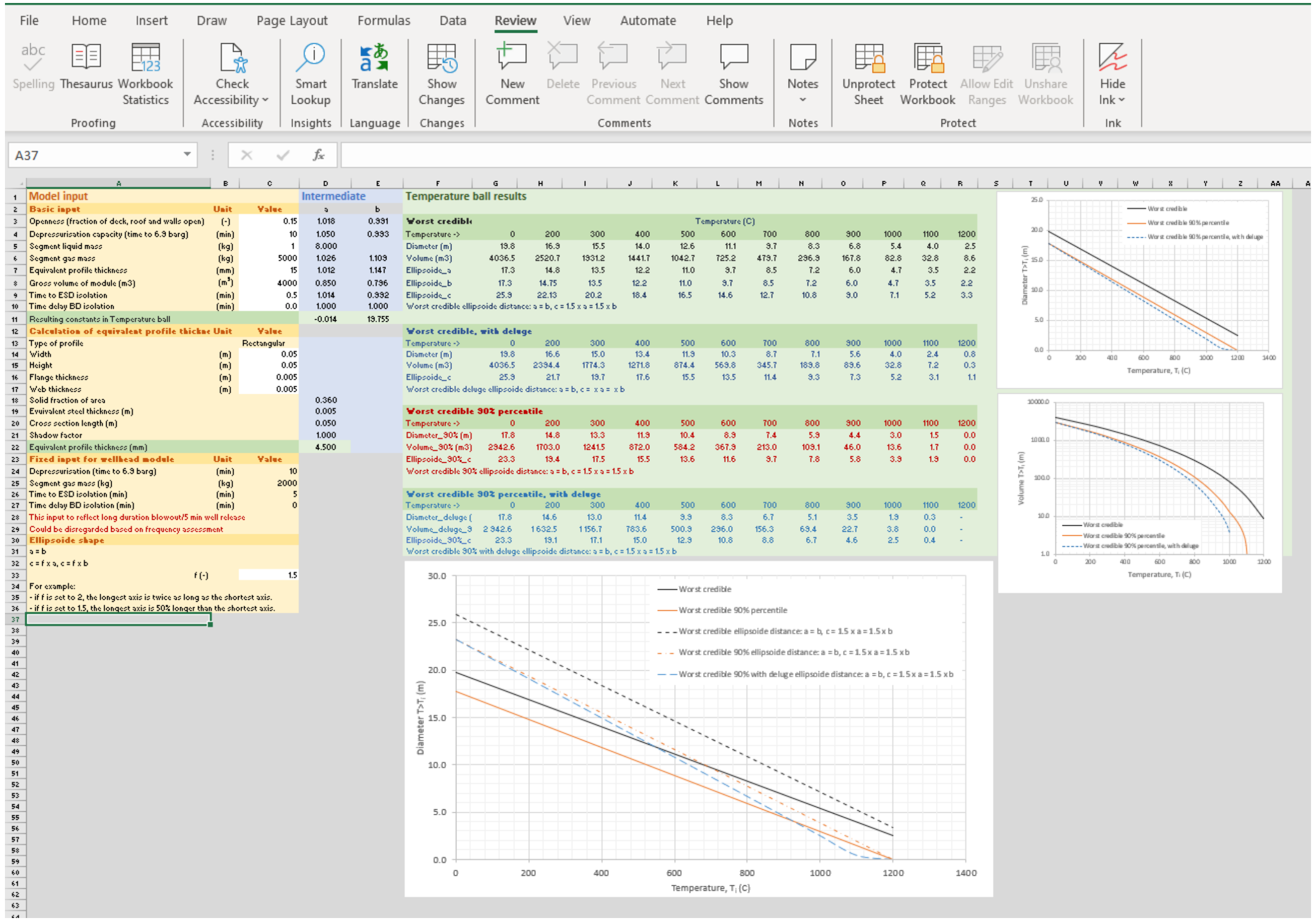
Demo Temperature ball Spread sheet



Model input | **Intermediate**

Basic input	Unit	Value	a	b
Openness (fraction of deck, roof and walls open)	(-)	0.15	1.018	0.991
Depressurisation capacity (time to 6.9 barg)	(min)	10	1.050	0.993
Segment liquid mass	(kg)	1	8.000	
Segment gas mass	(kg)	5000	1.026	1.109
Equivalent profile thickness	(mm)	15	1.012	1.147
Gross volume of module (m3)	(m^3)	4000	0.850	0.796
Time to ESD isolation	(min)	0.5	1.014	0.992
Time delay BD isolation	(min)	0.0	1.000	1.000
Resulting constants in Temperature ball			-0.014	19.755

Calculation of equivalent profile thickne	Unit	Value	
Type of profile		Rectangular	
Width	(m)	0.05	
Height	(m)	0.05	
Flange thickness	(m)	0.005	
Web thickness	(m)	0.005	
Solid fraction of area			0.360
Evuivalent steel thickness (m)			0.005
Cross section length (m)			0.050
Shadow factor			1.000
Equivalent profile thickness (mm)			4.500

Fixed input for wellhead module	Unit	Value
Depressurisation (time to 6.9 barg)	(min)	10
Segment gas mass (kg)	(kg)	2000
Time to ESD isolation (min)	(min)	5
Time delay BD isolation (min)	(min)	0

This input to reflect long duration blowout/5 min well release

Could be disregarded based on frequency assessment

Ellipsoide shape

a = b

c = f x a, c = f x b

f (-) 1.5

For example:

- if f is set to 2, the longest axis is twice as long as the shortest axis.
- if f is set to 1.5, the longest axis is 50% longer than the shortest axis.

Temperature ball results

Worst credibl	Temperature (C)											
Temperature ->	0	200	300	400	500	600	700	800	900	1000	1100	1200
Diameter (m)	19.8	16.9	15.5	14.0	12.6	11.1	9.7	8.3	6.8	5.4	4.0	2.5
Volume (m3)	4036.5	2520.7	1931.2	1441.7	1042.7	725.2	479.7	296.9	167.8	82.8	32.8	8.6
Ellipsoide_a	17.3	14.8	13.5	12.2	11.0	9.7	8.5	7.2	6.0	4.7	3.5	2.2
Ellipsoide_b	17.3	14.75	13.5	12.2	11.0	9.7	8.5	7.2	6.0	4.7	3.5	2.2
Ellipsoide_c	25.9	22.13	20.2	18.4	16.5	14.6	12.7	10.8	9.0	7.1	5.2	3.3

Worst credible ellipsoide distance: a = b, c = 1.5 x a = 1.5 x b

Worst credible, with deluge												
Temperature ->	0	200	300	400	500	600	700	800	900	1000	1100	1200
Diameter (m)	19.8	16.6	15.0	13.4	11.9	10.3	8.7	7.1	5.6	4.0	2.4	0.8
Volume (m3)	4036.5	2394.4	1774.3	1271.8	874.4	569.8	345.7	189.8	89.6	32.8	7.2	0.3
Ellipsoide_c	25.9	21.7	19.7	17.6	15.5	13.5	11.4	9.3	7.3	5.2	3.1	1.1

Worst credible deluge ellipsoide distance: a = b, c = x a = x b

Worst credible 90% percentile												
Temperature ->	0	200	300	400	500	600	700	800	900	1000	1100	1200
Diameter_90% (m)	17.8	14.8	13.3	11.9	10.4	8.9	7.4	5.9	4.4	3.0	1.5	0.0
Volume_90% (m3)	2942.6	1703.0	1241.5	872.0	584.2	367.9	213.0	109.1	46.0	13.6	1.7	0.0
Ellipsoide_90%_c	23.3	19.4	17.5	15.5	13.6	11.6	9.7	7.8	5.8	3.9	1.9	0.0

Worst credible 90% ellipsoide distance: a = b, c = 1.5 x a = 1.5 x b

Worst credible 90% percentile, with deluge												
Temperature ->	0	200	300	400	500	600	700	800	900	1000	1100	1200
Diameter_deluge (	17.8	14.6	13.0	11.4	9.9	8.3	6.7	5.1	3.5	1.9	0.3	-
Volume_deluge_9	2 942.6	1 632.5	1 156.7	783.6	500.9	296.0	156.3	69.4	22.7	3.8	0.0	-
Ellipsoide_90%_c	23.3	19.1	17.1	15.0	12.9	10.8	8.8	6.7	4.6	2.5	0.4	-

Worst credible 90% with deluge ellipsoide distance: a = b, c = 1.5 x a = 1.5 x b

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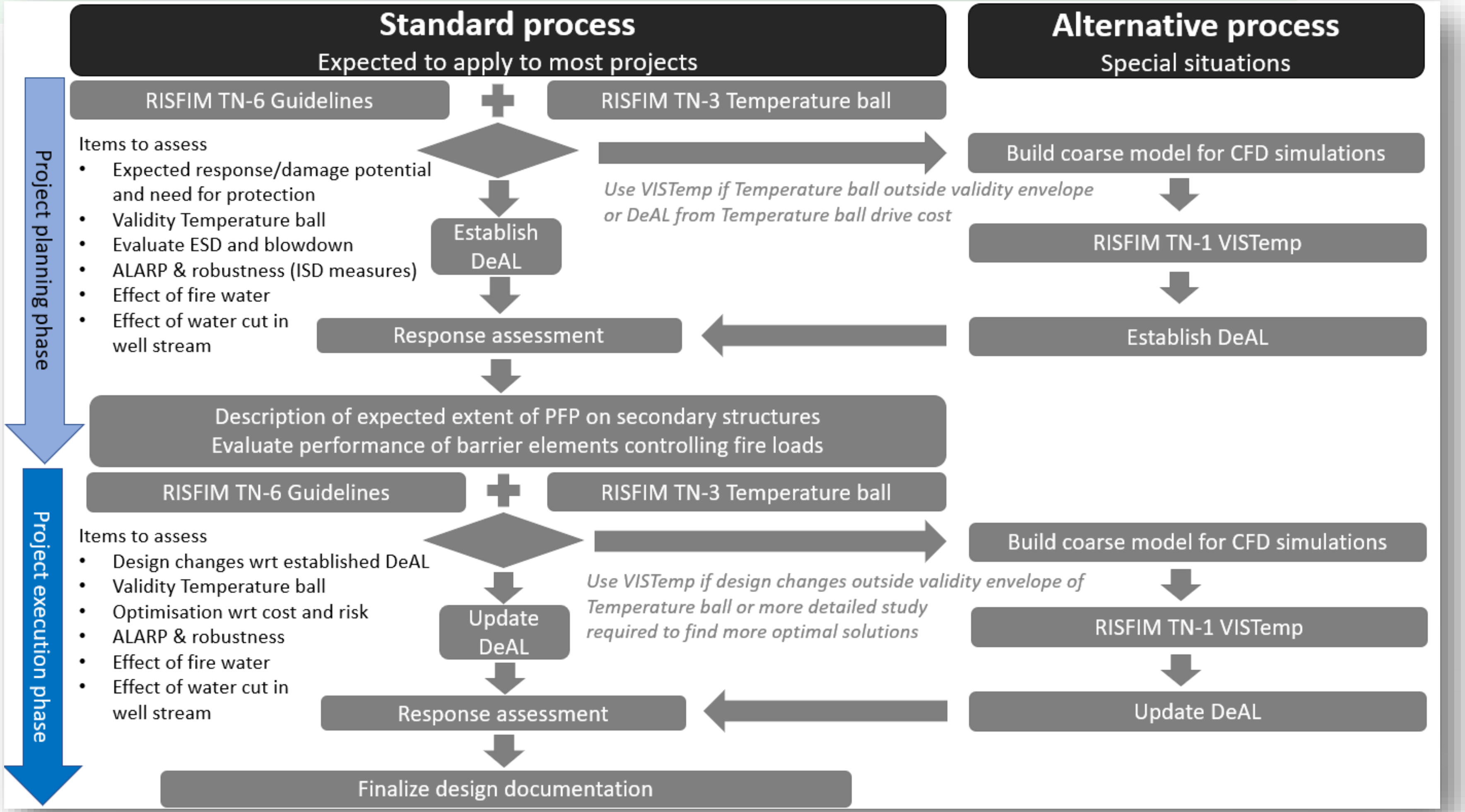
RISFIM methodology for secondary structures

Typical secondary structures

- Pipe systems including pipe supports
- Pipe racks including pipes
- Access platforms

- Objective that
  - standard process is applicable in most cases
  - Temperature ball set in planning phase is applicable throughout project



Standard process
Expected to apply to most projects

Alternative process
Special situations

Project planning phase

RISFIM TN-6 Guidelines + RISFIM TN-3 Temperature ball

Items to assess
- Expected response/damage potential and need for protection
- Validity Temperature ball
- Evaluate ESD and blowdown
- ALARP & robustness (ISD measures)
- Effect of fire water
- Effect of water cut in well stream

Establish DeAL

Response assessment

Use VISTemp if Temperature ball outside validity envelope or DeAL from Temperature ball drive cost

Build coarse model for CFD simulations

RISFIM TN-1 VISTemp

Establish DeAL

Description of expected extent of PFP on secondary structures
Evaluate performance of barrier elements controlling fire loads

Project execution phase

RISFIM TN-6 Guidelines + RISFIM TN-3 Temperature ball

Items to assess
- Design changes wrt established DeAL
- Validity Temperature ball
- Optimisation wrt cost and risk
- ALARP & robustness
- Effect of fire water
- Effect of water cut in well stream

Update DeAL

Response assessment

Use VISTemp if design changes outside validity envelope of Temperature ball or more detailed study required to find more optimal solutions

Build coarse model for CFD simulations

RISFIM TN-1 VISTemp

Update DeAL

Finalize design documentation

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