De-risking Submarine Programmes Through Risk Analysis

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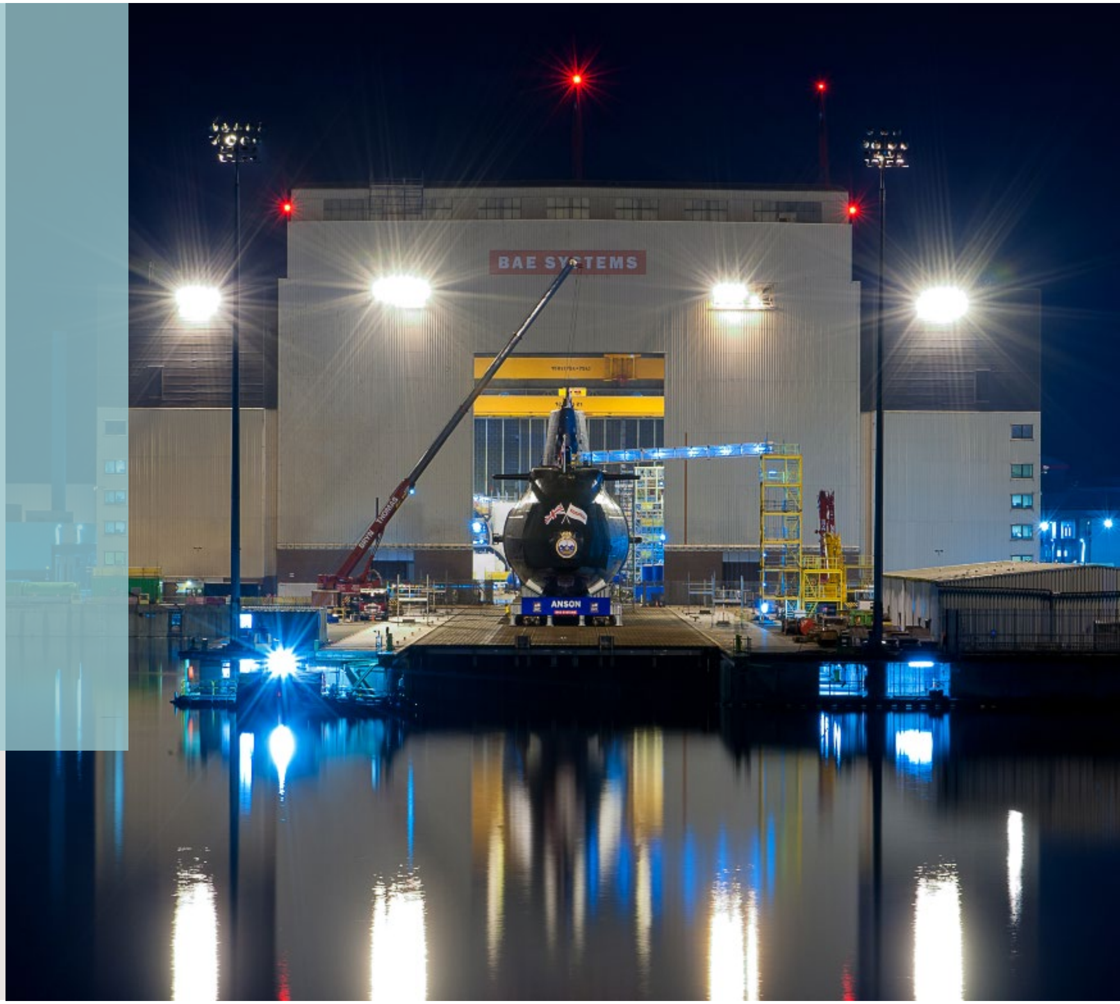
Agenda

- Introducing BAE Systems
- Benefits of de-risking the submarine programme
- Introducing Common Cause Analysis and Design Tools
    - Zonal Hazard Analysis (ZHA)
    - Hazard Identification and Risk Assessment
    - Computational Fluid Dynamics (CFD)



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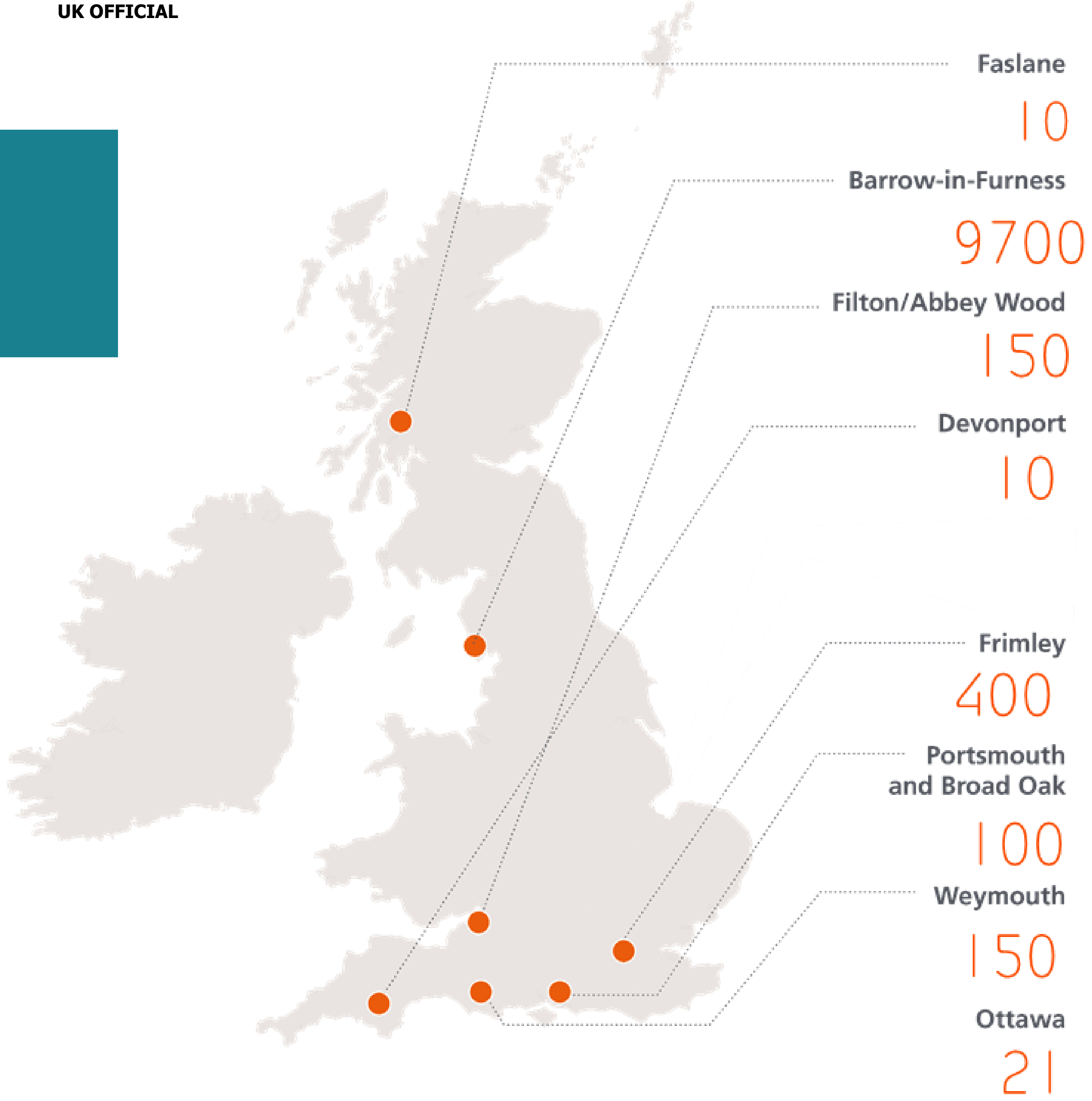
Introducing Submarines

We design, build, test, and commission the most advanced submarines ever operated by the Royal Navy. Employing circa 11,300 people across the UK.



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Submarines

Astute

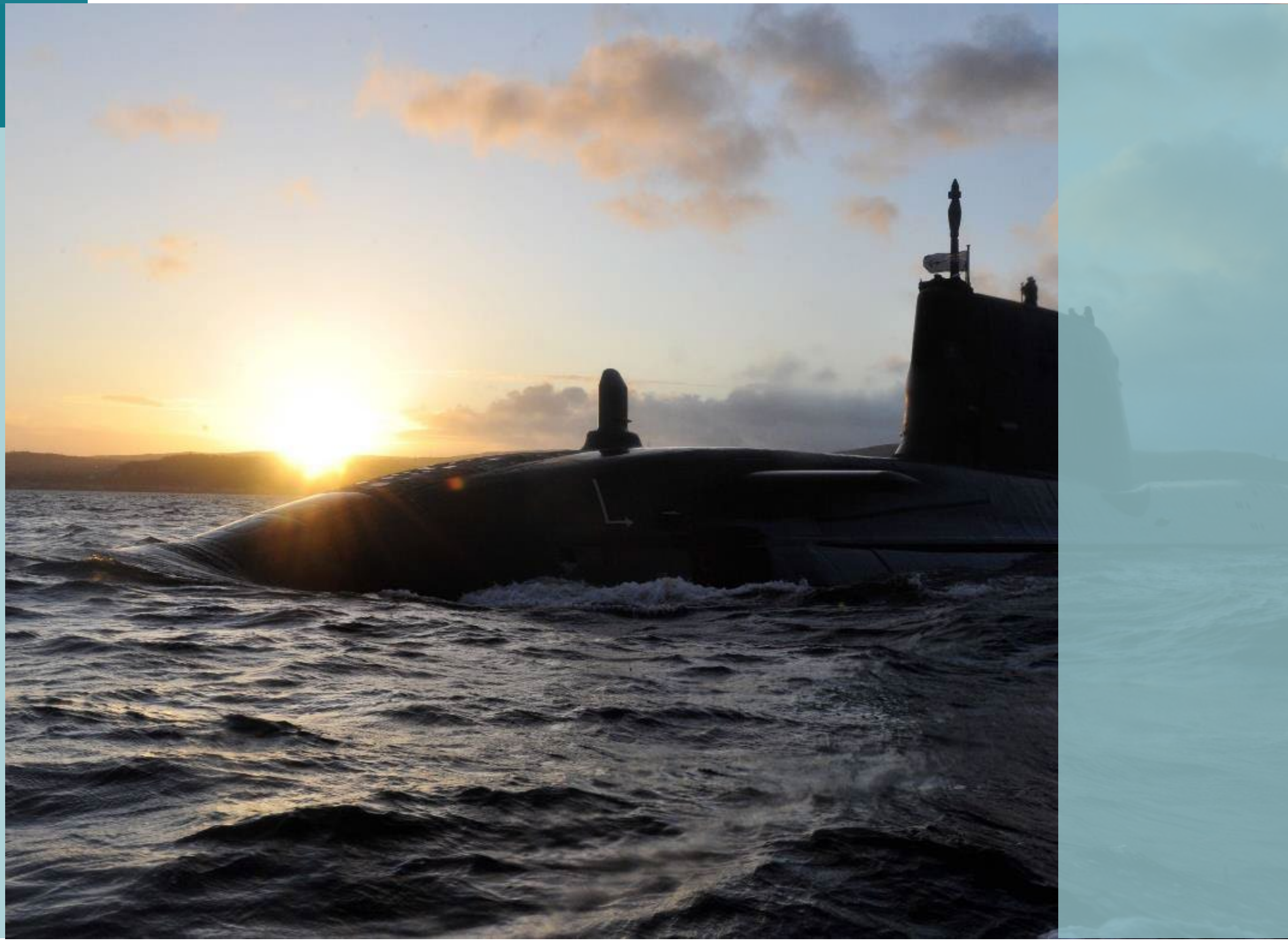
- Replacement to Trafalgar Class
- 4 boats in service
- 1 boat recently exited Barrow (Feb 2023)
- 2 boats in build (launch dates 2025-2027)

Dreadnought

- Replacement to Vanguard Class
- Boat 1 ready for patrol in early 2030s
- 3 further boats planned

SSNR

- Replacement to Astute Class
- Currently at the preliminary design stage
- Launch dates 2037-2060



Benefits of De-risking the Submarine Programme

"You can use an eraser on the drafting table or a sledgehammer on the construction site."

Frank Lloyd Wright

- Reduces expenditure during build and operation.
- Reduces delays in manufacture.
- Reduces the potential for harm during build and operation.
- Improves operational resilience.
- Ensures the submarine is safe to operate.

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Hazard Identification and Risk Assessment

- A hazard is a event with the potential to cause harm.
- Hazard Identification (HAZID) identifies Hazards on the submarine.
- HAZID considers all part of the lifecycle, where greatest benefit is realised through early adoption.
- HAZID is used to eliminate or mitigate hazards such that they cannot develop into accidents.
- Reduces risk to submariners and the mission.


Equipment failure


Solid fuel fire

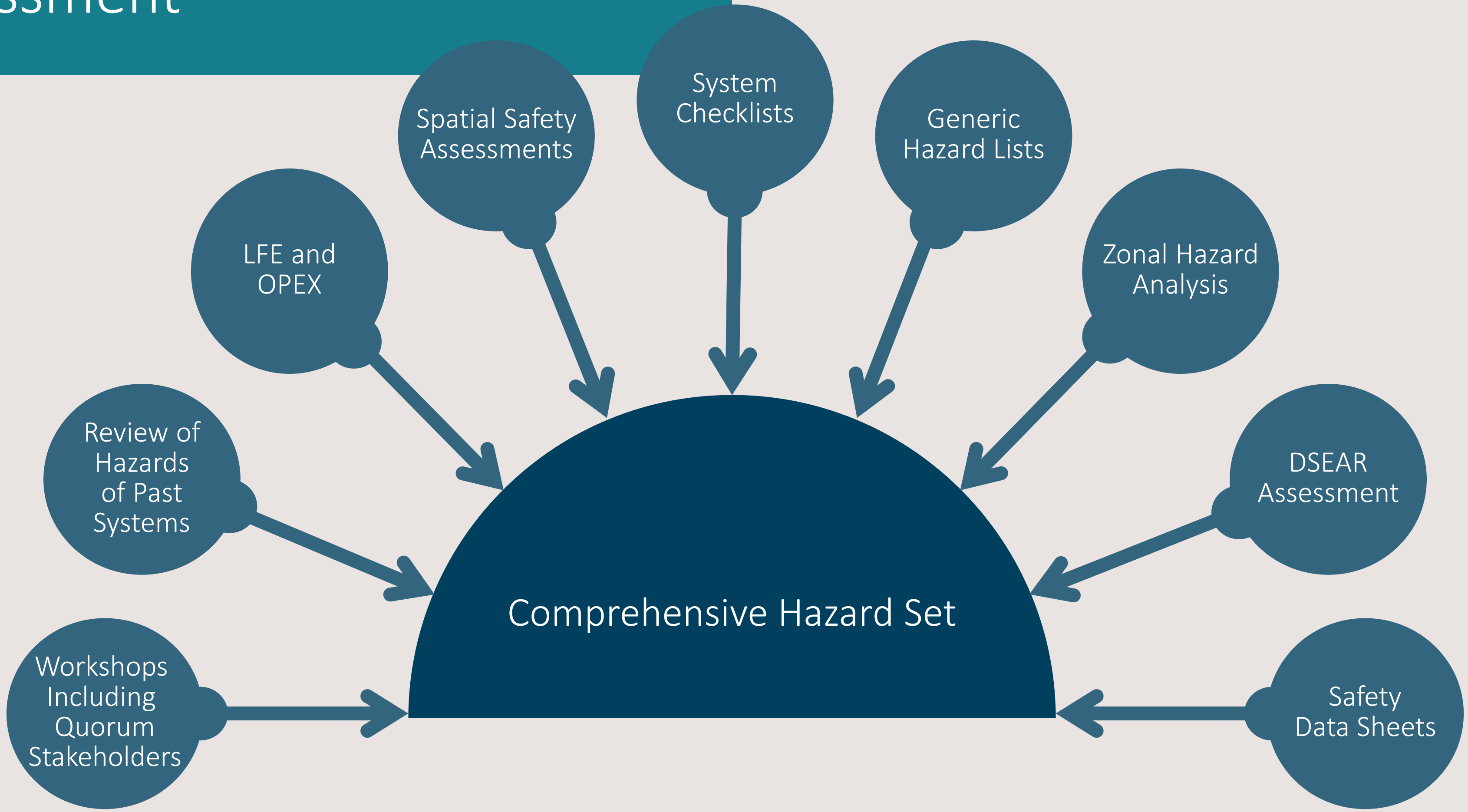

Liquid pool fire


Spray fire


Arc Flash

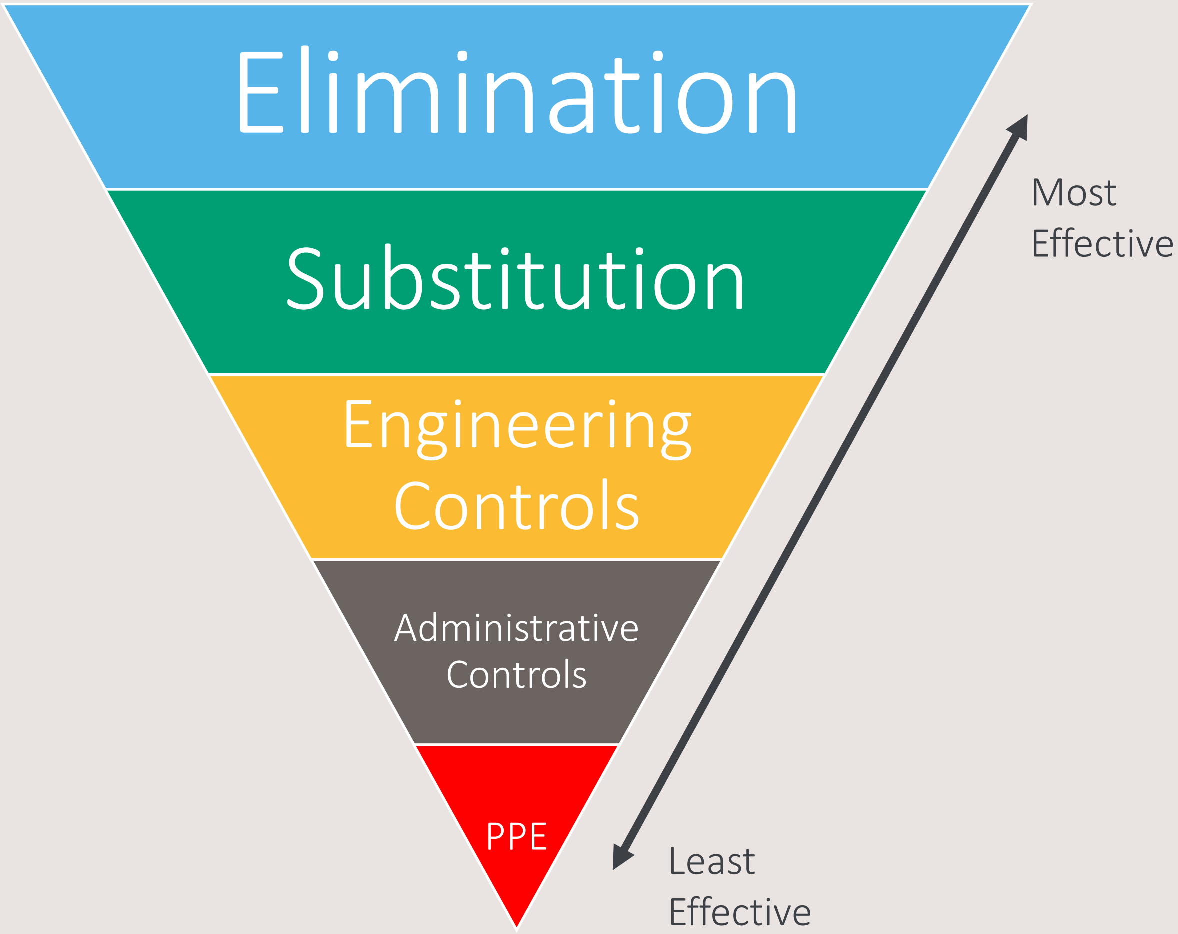

Explosion

Hazard Identification and Risk Assessment



Hazard Identification and Risk Assessment

Accident Frequency	Accident Severity					
	LOS	Catastrophic	Critical	Significant	Marginal	Negligible
Frequent	A	A	A	A	A	B
Probable	A	A	A	A	B	C
Occasional	A	A	A	B	C	C
Remote	A	A	B	C	C	D
Improbable	B	B	C	C	D	D
Highly Improbable	B	C	C	D	D	D
Incredible	C	C	D	D	D	D



Introducing Common Cause Analysis and Design Tools

Common Cause Analysis

- **Zonal Hazard Analysis (ZHA)**

  System to system interaction

- **Particular Risk Analysis (spatial hazards)**

  Consequence analysis - Fire, smoke spread, steam releases, flammable atmospheres, flooding, extreme internal pressures, etc…

  - CFD is a powerful tool for this analysis

- **Common Mode Analysis**

  Hardware/software error, hardware failure, environmental factors, installation error, etc…

See ARP 4761 for more information, see Guidelines and Methods for Conducting the Safety Process on Civil Airborne Systems and Equipment, https://doi.org/10.4271/ARP4761

Zonal Hazard Analysis (ZHA)

- An analysis of the layout of a submarine and its systems and equipment.
- Breaks a platform down into manageable zones.
- Removes / reduces hazardous system to system interactions
- Typical zonal hazards include:
  - Water and Electrics,
  - Combustibles and Ignition sources, and Co-locations

Zonal Hazard Analysis is a major part of the civil aircraft safety assessment process described in Aerospace Recommended Practice 4761

Other Common Cause Analysis Methods

- Fault & Event Trees Analysis

  Identify system dependencies and assess the probability of failure on demand

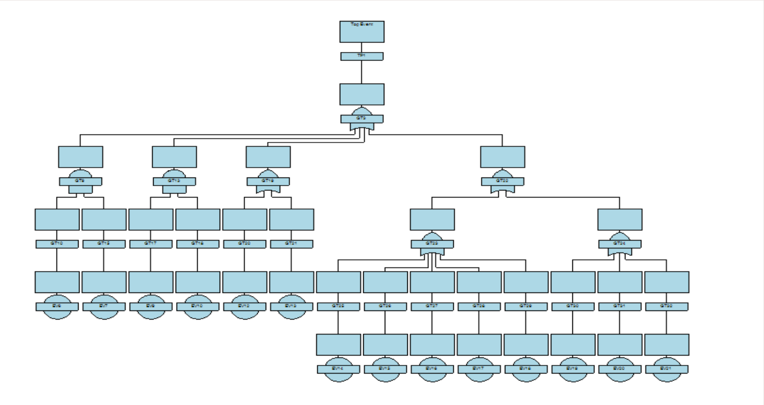
- Accident Sequence Modelling

  Identify worse case accident sequence leading to greatest risk of harm

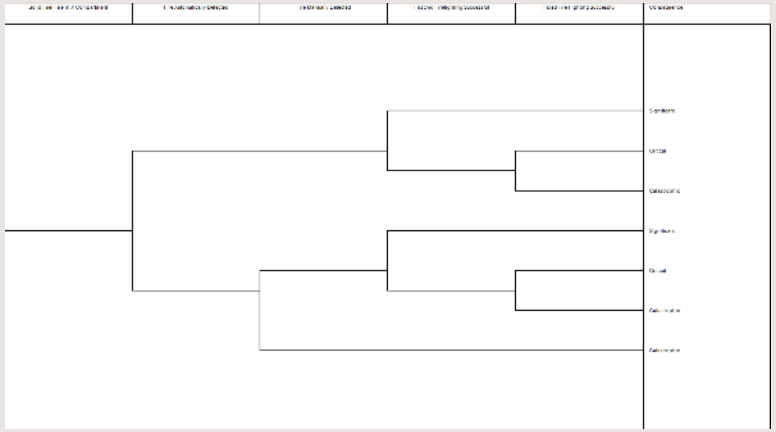
- Critical Systems Threat Analysis

  Safe return to the surface following a damage event: fire, flood, steam or extreme internal pressure

Fault Tree Analysis

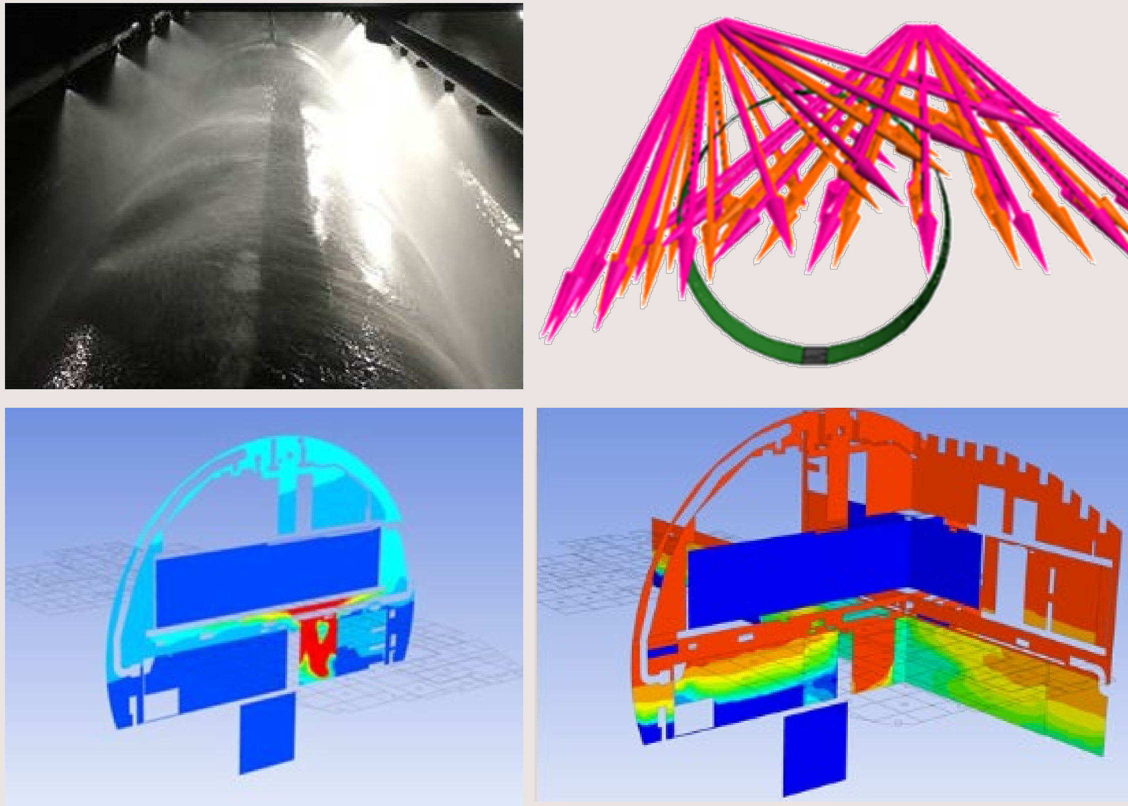


Accident Sequence



Particular Risk Analysis
Computational Fluid Dynamics (CFD)

- Embracing new technology to improve the design.
- CFD allows for a digital representation of real world scenarios.
- Where CFD has been applied to de-risk the programme
  - Steam release modelling
  - Fire modelling
  - Performance of water fire suppression
  - Smoke spread
  - Temperature prediction for component withstand



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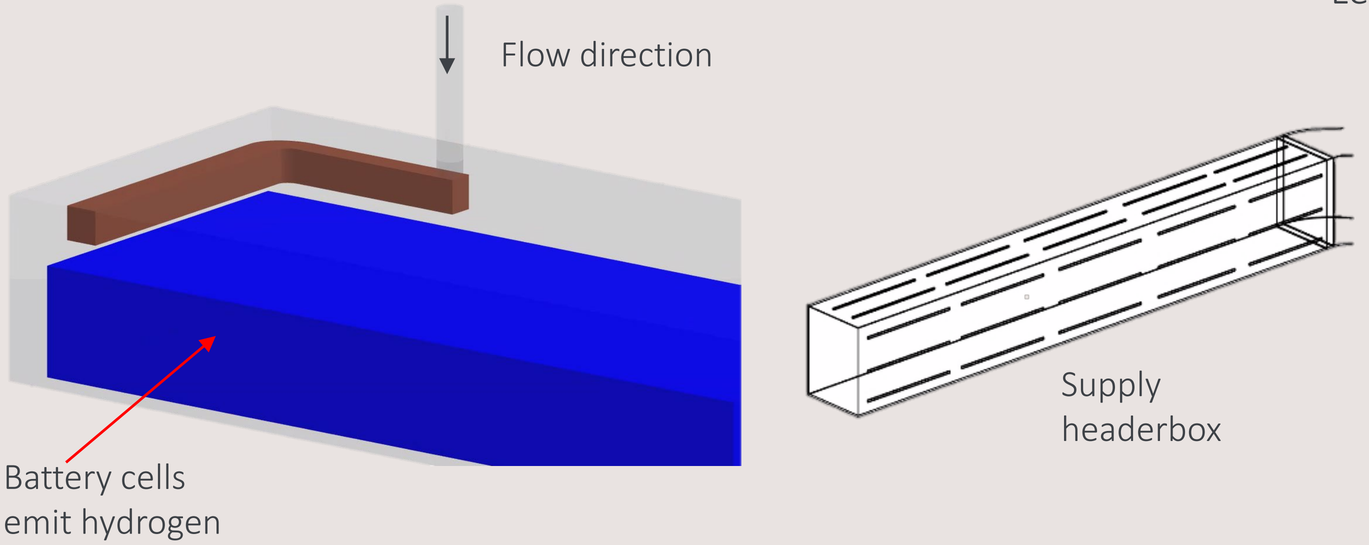
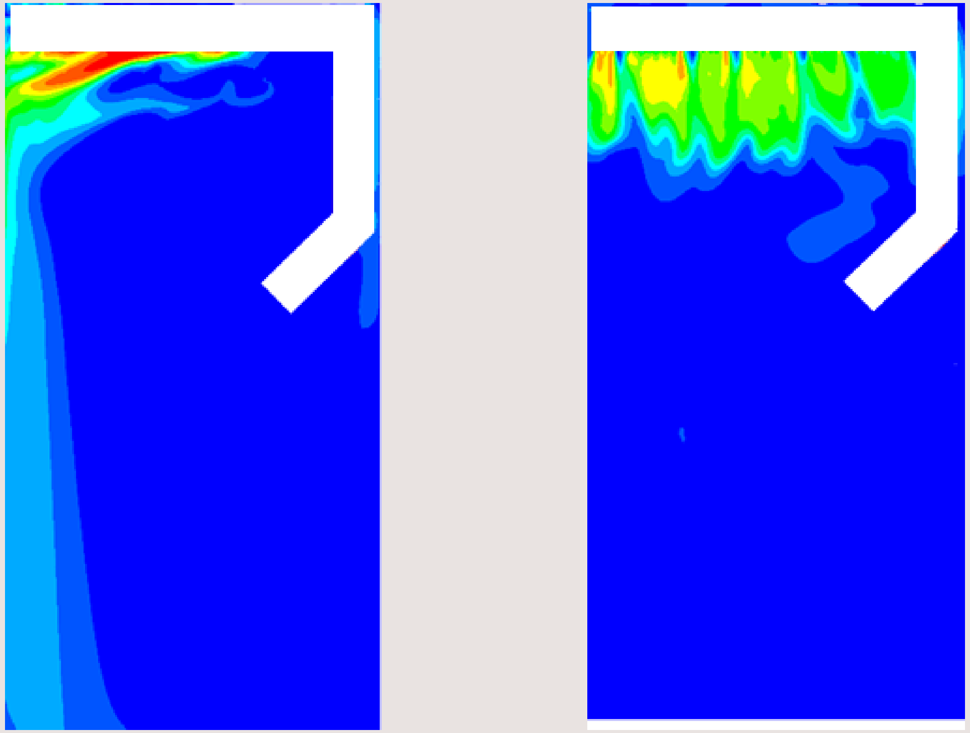
Computational Fluid Dynamics (CFD) – case study

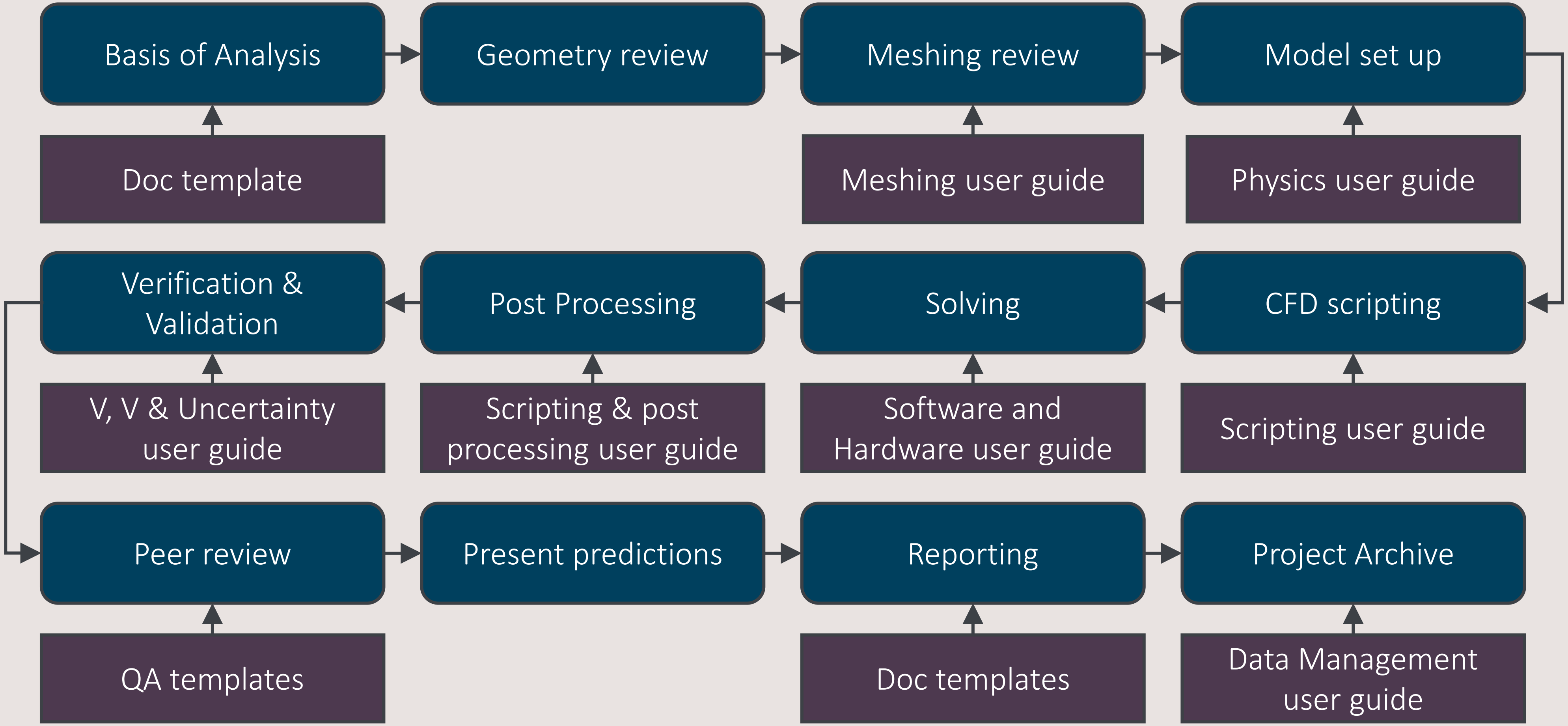


Velocity contour plots
Left: Pre CFD design support | Right: Improved design using CFD

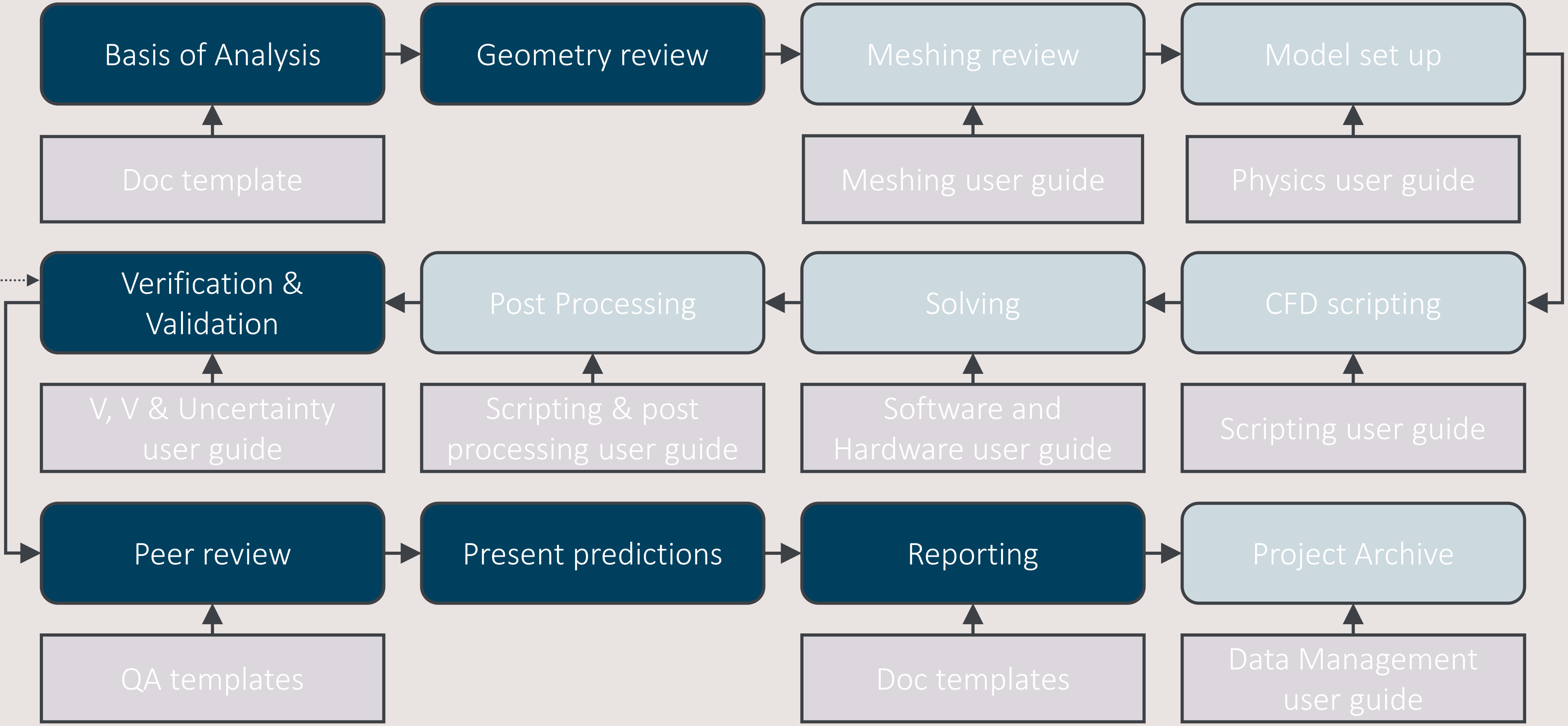


- LFE on fire/explosion caused by ventilation issues and hydrogen
- CFD used to identify potential issue associated to the build up of Hydrogen / poor cooling flow
- CFD used to develop a solution to remove the issue in the design phase

Computational Fluid Dynamics (CFD) – Practitioner workflow



Computational Fluid Dynamics (CFD) – Intelligent Customer Focus



Excellent paper - A comprehensive framework for verification, validation, and uncertainty quantification in scientific computing, Christopher J. Roy a, William L. Oberkampf

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Verification and Validation

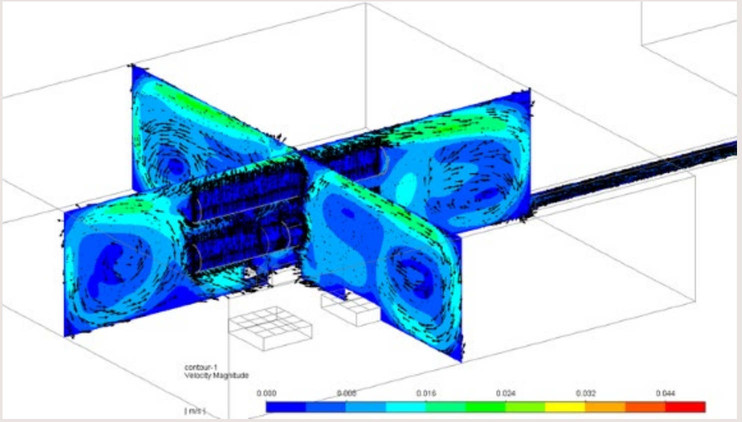
- Verification - checks on the mathematical model
- Validation - comparison to a physical test
- Validation strength varies
  - Direct comparison to physical testing
  - Indirect comparison to physical testing
  - Comparison to a different model (e.g. empirical correlations)
  - SQEP judgement

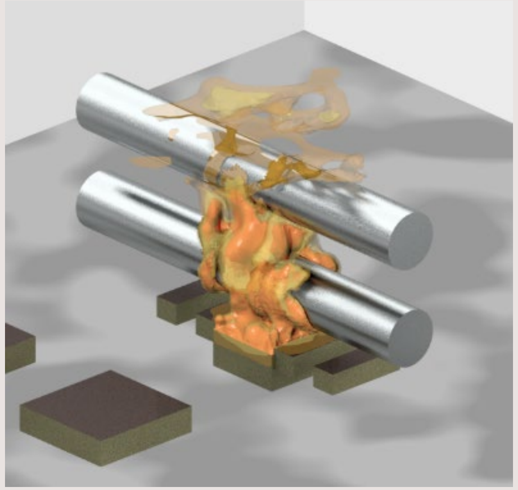
Decreasing strength

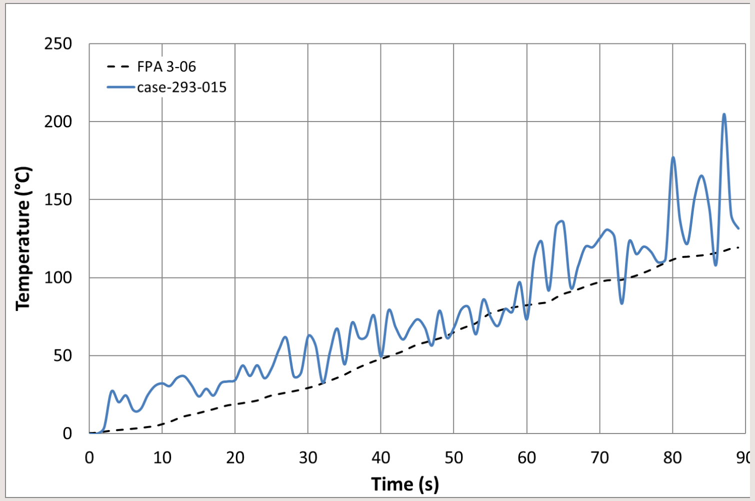
Reality of Interest

abstraction

Conceptual Model







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CFD and Physical Testing Benefits and Issues

CFD	Physical Testing
Benefits • Can be faster. • Can be cheaper. • Performance based approach rather than a prescriptive code base approach. • Appropriately validated models are accepted by the regulator as a means of demonstration. • Can model scenarios which can not be physically tested. • The entire domain can be monitored. • Can model a far greater number of scenarios identifying cliff edge and enabling a risk based performance assessment. • De-risks physical testing.	**Benefits** • More readily accepted by Regulator as a means of demonstration. • Unexpected phenomena can be realised. • Captures highly complex physical interactions • Captures complex material reactions and involvement with fire. • Historical confidence in this approach.
Issues • CFD models need to be validated and an appropriate physical test may not be published. • Requires specialist hardware, software and users need to be SQEP. • Mistakes can be made in the modelling assumptions. • Unexpected phenomena can be missed. • Not perceived to be as strong safety case evidence as physical testing	**Issues** • Can come late in the design where it is difficult to make changes and introduces risk. • Can be expensive and a small number of cases considered. • Instrumentation can influence the test and be unreliable. • Instrumentation can miss phenomena and regions of interest. • Sometimes very difficult or impossible to uncover mistakes made in the testing. • The conceptual model may be a significant extrapolation from the reality of interest due to budget constraints. • There is a high cost with technical oversight and management of the test house.

CFD will never replace all physical testing

The engineer needs to consider the merits of both individually or in conjunction

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