Accommodating the Effect of Sparse Data Input in Engineering Modelling Applications

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Contents

1. Introduction

- In nuclear reactors and nuclear process environments are hostile with a general sparsity of measurement data for thermodynamic variables

- This set of conditions provides a rich source for the development of predictive modelling capability

- Today these models are used predict the behaviour of plant and processes for a range of operational and fault scenarios

- Often only sparse data is available for input to these models

- How do we accommodate this and still perform reliable predictions?

2. NNL Mathematical Modelling Capability

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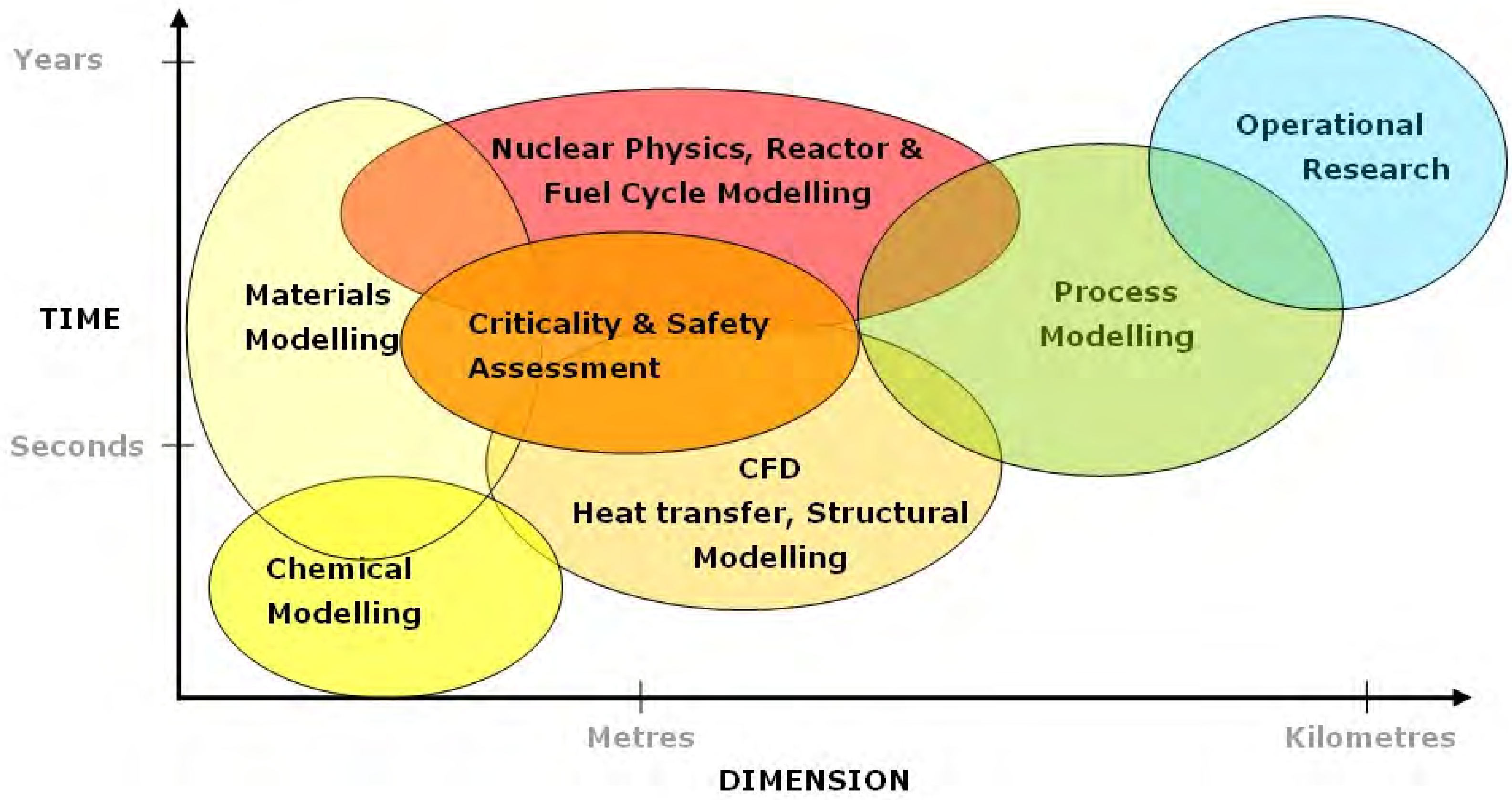

NNL possesses extensive capability in Modelling and Simulation (over 100 specialist scientists and engineers)

3. Uncertainty in the Application of Engineering Modelling Calculations

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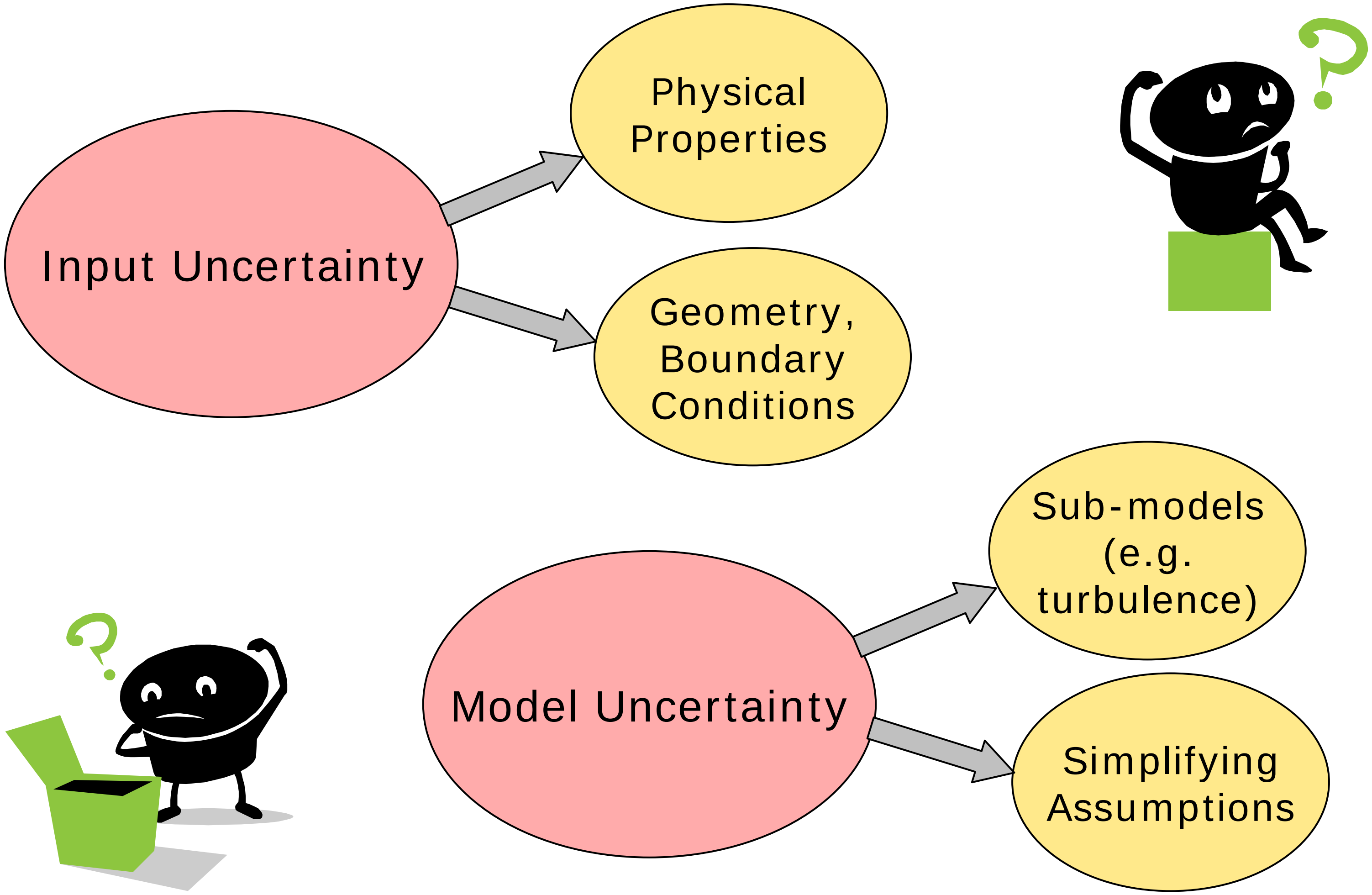

4. Methodologies to Deal With Uncertainty

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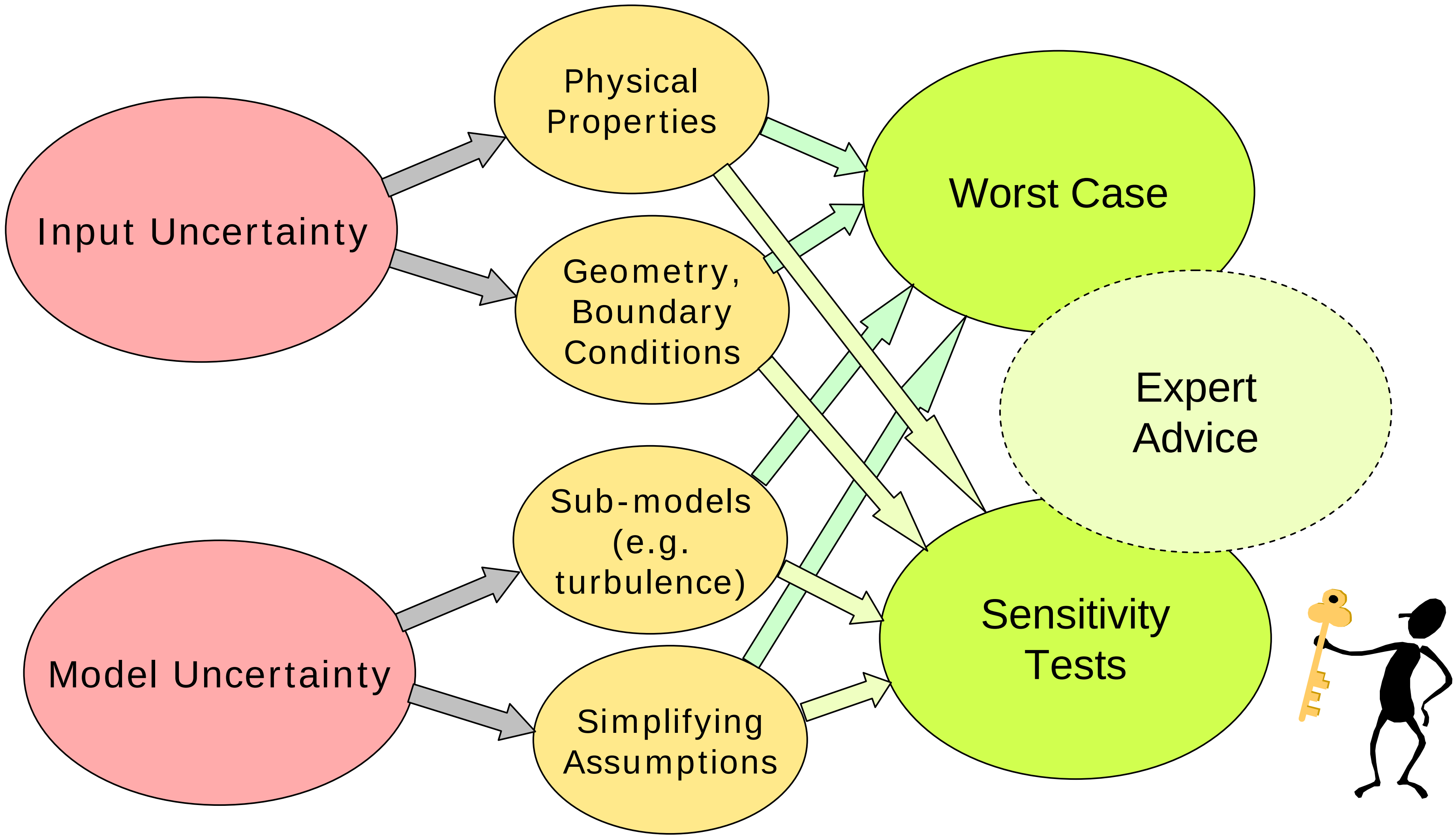

5. Example: Support to the Pile 1 Decommissioning Safety Case (1)

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In October 1957 a fire broke out
in the reactor core of Windscale Pile 1

The fire was extinguished by air starvation
and water deluge

As a result of this and the reactor operating
regime before the event, two potential
hazards could exist in the core inventory:

- Uranium hydride (pyrophoric material)
- Stored energy (Wigner energy) in the graphite

These characteristics have contributed to Pile 1 being classified as a high hazard facility for 50 years since the event.

This contributes to a large maintenance cost and presents major hurdles for decommissioning

5. Example: Support to the Pile 1 Decommissioning Safety Case (2)

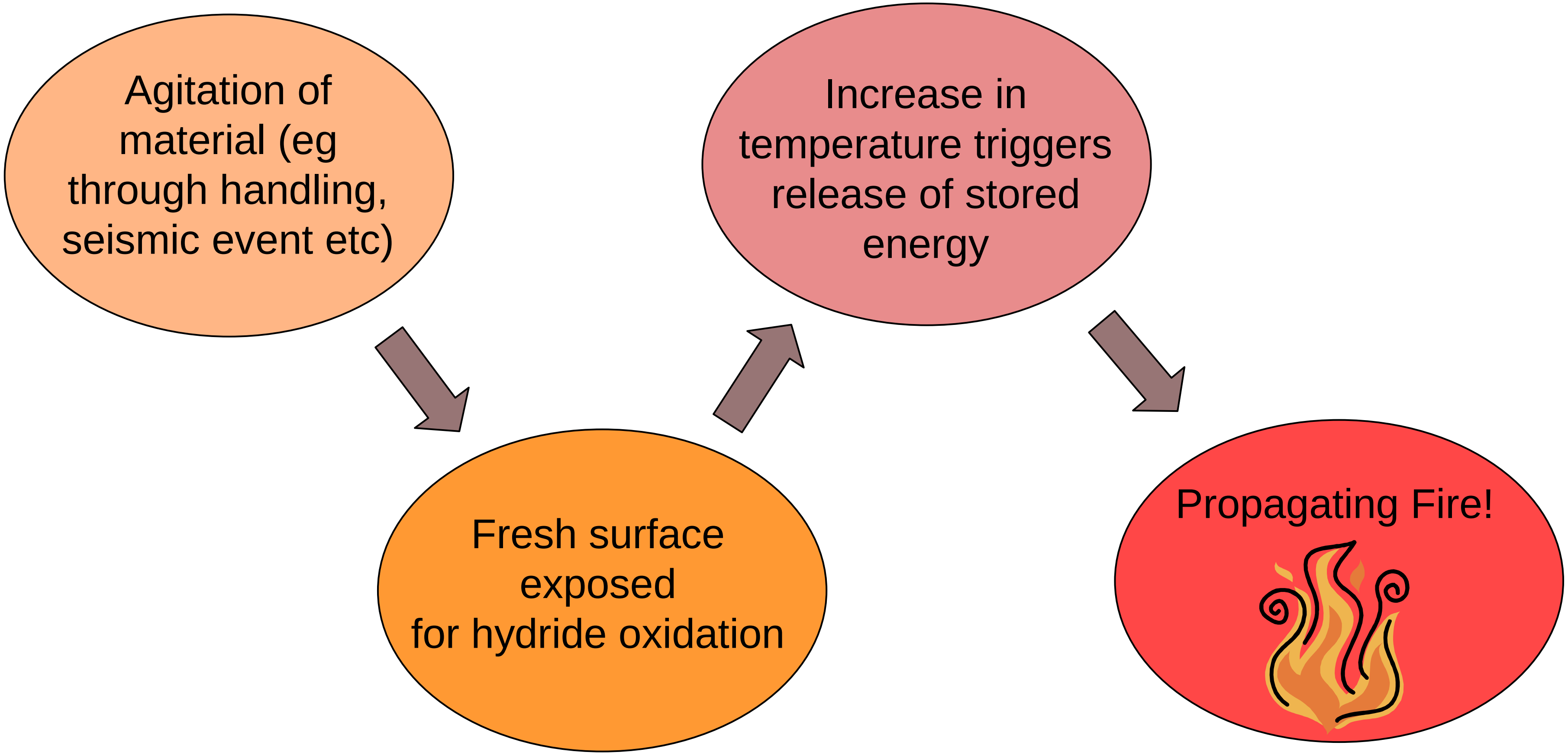
- Adequate control of these hazards must be demonstrated in order to gain access to the damaged core for inspection and decommissioning

- Many uncertainties exist such as the amount of inventory present, its location and the effects of localised geometry and materials in a damaged reactor

- When a large degree of uncertainty is present safety case methodologies tend to magnify the hazard leading to potential solutions that are over-engineered and costly

5. Example: Support to the Pile 1 Decommissioning Safety Case (3)

Following a review of the potential hazards, the worst case hazard scenario considered for the safety case is:



5. Example: Support to the Pile 1 Decommissioning Safety Case (4)

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The issue to be attacked concerns the impact of a thermal excursion in the core of Pile 1

It was decided to develop a predictive approach involving a transient heat transfer calculation:

- Heat sources are defined by incorporating the effect of hydride oxidation and stored energy release
- Heat sinks relate to the prevailing thermal conditions in Pile 1

The model outputs, having passed regulator scrutiny, feed directly into the safety case and engineering associated with the Pile 1 decommissioning project

5. Example: Support to the Pile 1 Decommissioning Safety Case (5)

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The successful resolution of the technical challenges is found to be a function of:

High Level Steer:

Use of a Technical Steering Group with key knowledge and experience in:

- Operational and historical aspects of Pile 1
- Hydride chemistry and graphite behaviour
- Modelling and simulation best practice
- Managing uncertainty in projects

Expert working knowledge:

Use of expert thermal modelling resource with knowledge and experience in:

- Thermal modelling development to implement chemistry and the effects of stored energy
- Context-based application

5. Example: Support to the Pile 1 Decommissioning Safety Case (6)

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The technical challenges are addressed in the following way:

- Effect of thermal convection ignored (worst case)
- CFD used with flow deactivated (can enable if needed later)

- Effect of materials
  - Literature
  - Steering Group advice
  - Vary the thermal properties
  - Calculations to explore effects

- Geometrical uncertainty
  - Steering Group advice
  - Vary materials surrounding heat source
  - Calculations to explore effects

- Amount of inventory
  - Steering Group advice
  - Calculations to explore effects

5. Example: Support to the Pile 1 Decommissioning Safety Case (7)

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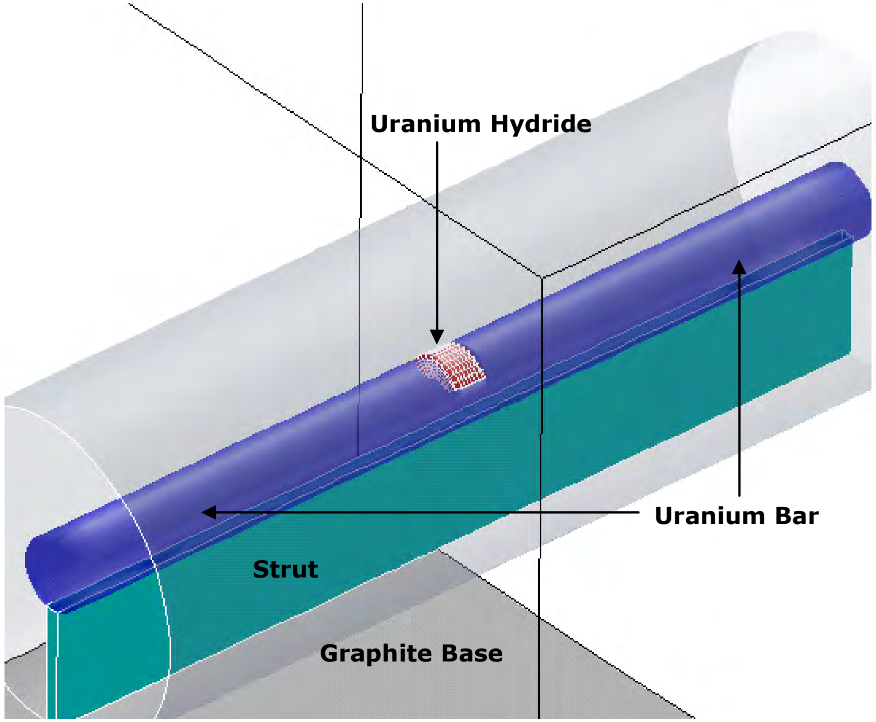


In the core, a single fuel channel is considered for the domain geometry.

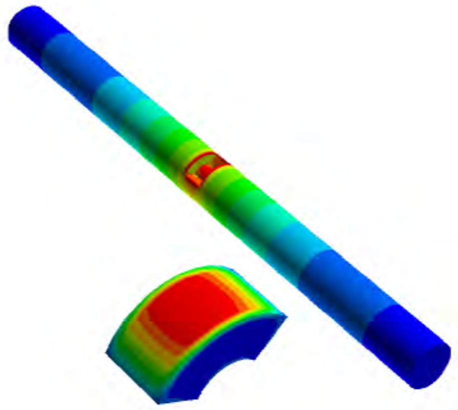
A hydride patch is defined on a uranium bar.

Surrounding graphite contains stored energy to be released as a temperature threshold is exceeded.

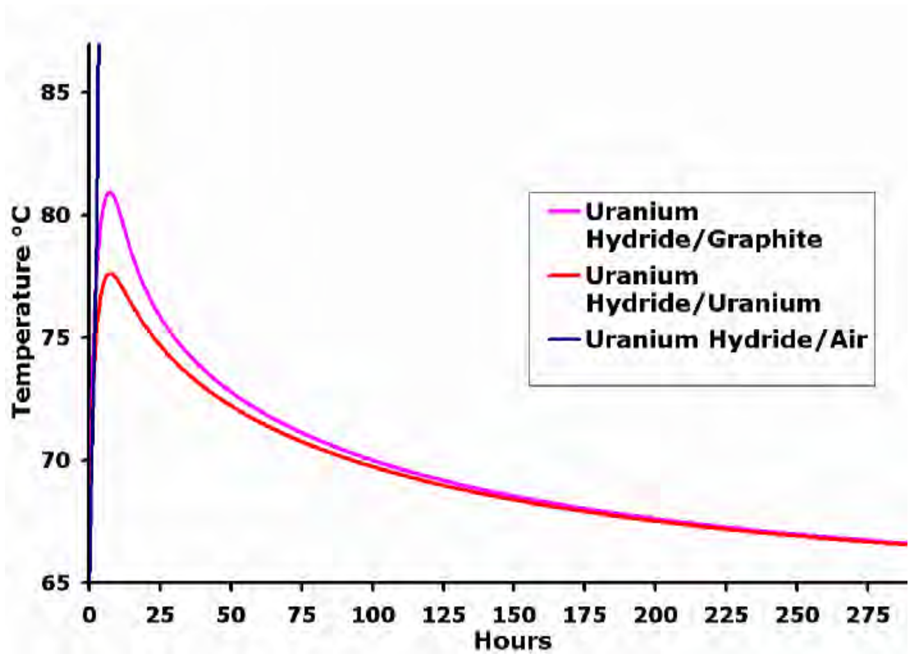
The time dependent energy equation is solved for conduction and radiation only.

The hydride inventory is consumed in the model.

5. Example: Support to the Pile 1 Decommissioning Safety Case (8)



A large number of cases were studied, primarily looking at the sensitivity of the evolution of temperatures with different surrounding materials



All the results indicated that the system is benign.

High, unrealistic initial temperatures were required to deliver a temperature excursion

5. Example: Support to the Pile 1 Decommissioning Safety Case (9)

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- Literature searches provided key information about hydride oxidation for the inclusion of heat sources in the model
- Stored energy input to the model was derived from experimental trials performed on graphite from Pile 2
- The thermal model was verified by comparison of results against benchmark cases. Difficult to validate but large safety margin present.
- The chemistry used in the work was peer reviewed by a key expert in the field
- The thermal modelling was peer reviewed by a CFD expert in the nuclear arena
- The thermal modelling was carried out according to best practice principles originating in the European Fifth Framework Project QNET-CFD

5. Example: Support to the Pile 1 Decommissioning Safety Case (10)

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NNL:

- The methodology has illustrated an effective way of dealing with technical uncertainty in the application of modelling to significant technical challenge
- The combination of an expert Steering Group together with best practice thermal modelling has yielded results that have satisfied the requirements of the safety case and the regulator

SL:

- The project has delivered a resolution to a significant and long standing problem
- The work has resulted in access to the damaged reactor core of Pile 1 and yielded the potential to reduce the cost of the future maintenance regime
- The work has enabled a major step forward in the understanding of the damaged core prior to decommissioning

5. Example: Support to the Pile 1 Decommissioning Safety Case (11)

- The work has shown that the Pile 1 core is safe with respect to any uranium hydride or stored energy hazard being activated during agitation of the inventory

- In the unlikely event of a thermal excursion in a channel, it will not propagate to surrounding channels

6. Closing Points for Consideration (1)

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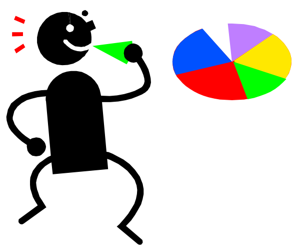
- Two main strands of uncertainty can be identified in the use of mathematical models to support projects in industry:
  - (1) Input uncertainty
  - (2) Model uncertainty

- These are dealt with by using two main approaches:
  - (1) Considering ‘worst case’ scenarios
  - (2) Using ‘sensitivity tests’ within the model

- Key additional inputs to help reduce the uncertainty can be obtained by using expert advice

But there are issues…



6. Closing Points for Consideration (2)

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- Choosing ‘worst case’:
  - (1) Moves the situation away from reality
  - (2) Difficult to assess the margin
- Performing sensitivity tests:
  - (1) Difficult to define and cover the range of parameters to vary
  - (2) Emphasis on overall understanding of the way the system behaves rather than specific variables
- Expert advice:
  - (1) Judgement can vary from expert to expert
  - (2) Experts can get it wrong