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UK Regulatory Experience in Materials Ageing

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History of Nuclear Power in the UK

- Calder Hall was the first commercial power station in the UK:
  - Connection to the grid in 1956.
  - First Generation Magnox design (graphite core,CO_2 coolant)
- 11 Magnox reactor sites were commissioned
  - Final site ceased generation in 2015
- The UK opted to design and build a second generation of high-temperature, graphite-cored, CO_2-cooled reactors.
  - These are named Advanced Gas-Cooled Reactors (AGRs)
  - 7 double-reactor sites built and operating.

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Civil Light Water Reactors in the UK

- In the 1980s, a government strategic decision was made to pursue light-water technologies.
- The Sizewell B PWR reactor was the first of an intended fleet of PWR reactors, but was the only one constructed.
  - Westinghouse 4-loop design
  - Build of the nuclear island led by Framatome
  - Build Started in 1987
  - Connection to the grid 1995

- The Marshall Light-Water Study Group, led by Walter Marshall, was influential in setting UK expectations for Structural Integrity of these plants.

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Operating Plant – Irradiation Embrittlement

- The Marshall Light-Water Reactor Study Group contained advice for the management of irradiation embrittlement:.
  - A surveillance programme was initiated at SZB, including the following items:
    - Charpy Samples
    - Fracture toughness test coupons
    - Samples of pre-strained materials
  - The programme was for the original life of the station (40y)
  - On extension of the plant life, the programme has been extended.

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Civil Light Water Reactors in the UK

- The UK has a process of Generic Design Assessment (GDA) for new nuclear build in the UK
  - Getting a Design Acceptance Certificate (DAC) does not mean that the design is licensed for build.
  - The UK design expectations within Structural Integrity include expectations for monitoring materials properties through-life.
  - The following designs have achieved a DAC:
    - EDF Areva EPR
    - Westinghouse AP1000® nuclear power plant
    - Hitachi-GE UK-ABWR
  - The HPR-1000 by General Nuclear Systems is at Step 3 of GDA
- ONR is performing initial assessments on Small Modular Reactors and Advanced Nuclear Technologies for the UK government.

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Safety Assessment Principles (SAPs)

- The ONR Safety Assessment Principles (SAPs) are:
  - High level expectations for plant built or operating in the UK.
  - Goal-setting regime means that these expectations can be met by any route, at the discretion of the duty-holder.
  - EAD.03 relates directly to materials ageing, including irradiation embrittlement:

Engineering principles: ageing and degradation	Periodic measurement of material properties	EAD.3
Where material properties could change with time and affect safety, provision should be made for periodic measurement of the properties.		

  - The properties should be obtained from fully representative samples of the material especially when the component or structure performs a principal role in ensuring nuclear safety.

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Safety Assessment Principles (SAPs)

- In practice EAD.03 sets the expectation that there will be a suitable and sufficient programmes in place to monitor:
  - Thermal Ageing
  - Irradiation Embrittlement
- The scope and depth of the programmes should be proportionate to the nuclear safety of the system, structure or component.
- There is, for components of the highest reliability, that the surveillance programmes should be fully representative of the plant materials and environment.

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Operating Plant – Irradiation Embrittlement

- The Safety Case for the plant is based around a demonstration of defect tolerance
- Safety Case for SZB is based upon the results of the fracture toughness specimens.
  - Charpy results confirm ASME code compliance, but are not central to the Safety Case for operation for the plant.
- Pre-strained data inform the understanding, but do not contribute directly to the demonstration of defect tolerance.
- The licensee aspire to extend the life of the plant beyond the original 40y lifespan.

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Operating Plant – Irradiation Embrittlement

- Pre-strained samples
  - Included at the suggestion of the Light-Water Reactor Study Group.
  - Pre-strain intended to represent localised strains from pressure testing and manufacture.
  - Pre-strained was present for both Charpy and Fracture Toughness samples

- Pre-Strained samples bring down the fracture toughness and Charpy results, but quantification of the effect is difficult.

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New Build Plant

- The Generic Design Assessment (GDA) process does not licence plant for build in the UK, it provides requesting parties with confidence that the plant has no fundamental issues to prevent UK build.
  - ONR does not licence technologies
  - ONR does permission activities

- The management of materials ageing must be addressed as part of the GDA process.
  - The detail necessary in the submission is directly dependent upon the nuclear safety of the component.
  - The UK interpretation of ALARP is applicable.

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New Build Plant – UK ABWR

- ONR placed the following Action upon Hitachi-GE:
  - Regarding Materials compositions, Hitachi-GE should provide evidence that:
    - Relevant Good Practice regarding Materials compositions has been considered fully, notably from previous GDAs.
    - Irradiation Embrittlement surveillance programmes are adequate to mitigate the risk of irradiation embrittlement through-life.

- The requesting party proposed an irradiation embrittlement surveillance programme that was:
  - In excess of that required by code
  - As large as possible, without requiring redesign of core components.
  - Backed up by modelling to international codes

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New Build Plant – UK EPR™

- The design of the UK EPR™ includes a heavy reflector to prevent excess embrittlement of the RPV steel.
- This has been the subject of a GDA issue:
  - Demonstration that the principles of the surveillance scheme adequately take account of the implications of the differences in neutron energy spectra between the location of the specimens and the RPV wall. This is expected to include the following activities:
    - Provision of evidence showing that the principles of the surveillance scheme adequately take account of the implications of the differences in neutron energy spectra between the location of the specimens and the RPV wall;
    - Justification of the concepts inherent in the analysis and interpretation of the surveillance scheme results including the treatment of uncertainties and consideration of any implications for the withdrawal scheme

- (GDA Issue GI-UKEPR-SI-02 "RPV Surveillance Scheme –Implications of Change in Neutron Energy Spectrum Caused by the Heavy Reflector " http://www.onr.org.uk/new-reactors/reports/step-four/gda-issues/gda-issue-gi-ukepr-si-02.pdf)

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New Build Plant – UK EPR™

- Subsequently, for GDA, EDF and AREVA proposed an approach which comprises:
  - Derivation of a tentative dose-damage correlation based on dpa as the dose parameter to take account of the differences in neutron spectrum between the EPR™ surveillance specimen location and the RPV wall.
  - Analyses of the advantages and disadvantages of fluence and dpa indexations.
  - An example of a flexible withdrawal scheme using dpa as the dose parameter

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Conclusions

- UK Regulation is goal setting and not prescriptive.
- The ONR expectation for irradiation embrittlement of major vessels is that code compliance is not necessarily, in and of itself, sufficient.
- The UK has one Civil light-water reactor, Sizewell B, which has a surveillance programme containing Charpy and Fracture Toughness specimens.
- Operating Civil plant contains pre-strained samples; this was a direct result the UK Light-Water Reactor Study Group findings.

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Conclusions

- New build reactors in the UK will demonstrate that they have suitable and sufficient surveillance programmes, going above code compliance and meeting UK ALARP expectations.
- The expectations vary between technologies and reactor designs, depending upon the nuclear safety significance, and the importance of the degradation mechanism to overall integrity.
- The requesting party must demonstrate an adequate understanding of the mechanism of irradiation embrittlement and how the specifics of the reactor design interact with this mechanism.