REGULATORY OBSERVATION

REGULATOR TO COMPLETE

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Observation title:	Demonstration that Risks Associated with Fuel Deposits are Reduced so far as is Reasonably Practicable (SFAIRP)
Lead technical topic: 1. Chemistry	**Related technical topic(s):** 9. Fault Studies 10. Fuel & Core 16. Radiological Protection 17. RadWaste, Decommissioning & Spent Fuel Management 21. Environmental

Regulatory Observation

Background

The principal alloys of construction in the primary circuits of the majority of Pressurised Water Reactors (PWRs), including UK HPR1000, are stainless steels and nickel-base alloys. Despite these alloys exhibiting high corrosion resistance and very low overall corrosion rates, some corrosion does still occur during operations. This is the main source of corrosion products present in the primary coolant. It is these corrosion products that can then become activated by the neutron flux in the reactor core, leading to the plant radiation field and ultimately to operator radiation exposure.

If the primary coolant contains dissolved solids (i.e. as a result of corrosion of nickel-base Steam Generator (SG) tubing material), these will deposit on fuel cladding surfaces. This process is exacerbated if there is boiling in the core. However, any amount of fuel deposit[1] increases the radiation fields generated by the plant and will influence the generation and transport of radioactivity.

The nuclear safety risks associated with fuel deposits are determined by the nature and quantity of the deposits formed. PWRs have been shown to be able to safely operate with some amount of fuel deposit. However, as the total mass and thickness of fuel deposits increases, there can be several detrimental effects, including:

- Fuel-coolant heat transfer impairment, leading to: fuel clad temperature increases, fuel degradation and/or fuel failures in extreme cases;
- Crud Induced Localised Corrosion (CILC), leading to: fuel degradation and/or fuel failures in extreme cases; and
- A Crud Induced Power Shift (CIPS)[2], which can occur if the nature of the fuel deposits leads to the absorption of boron from the reactor coolant. This can result in a distorted power profile in the core. UK HPR1000 will use enriched boric acid (EBA) [1]; which could potentially exacerbate the impact of CIPS, if it were to occur. CIPS can also lead to fuel failures and in extreme cases, the loss of an appropriate shutdown margin to criticality.

[1] For the purposes of this RO the terms "fuel deposits" and Chalk River Unidentified Deposit (CRUD) have the same meaning.
[2] The terms CIPS and axial offset anomaly (AOA) are often used interchangeably as they arise from the same phenomena.

For the Generic Design Assessment (GDA) of UK HPR1000, the Requesting Party (RP) has recognised the potential impact of fuel deposits on nuclear safety. Chapter 21, Reactor Chemistry, of the Pre-construction Safety Report (PCSR) [1], contains the following safety argument:

"A-1: Deterioration of heat transfer performance for fuel and spent fuel is impacted by limiting impurities related to CRUD formation and deposition on the surface."

Reference 1 also states that chemistry control is required to minimise risks associated with corrosion and heat transfer degradation by CRUD formation.

Chapter 5 of the PCSR [2] deals with aspects associated with the design of the fuel and core for UK HPR1000. However, it does not present any further information on the impact of fuel deposits.

As well as the PCSR, during Step 3 of GDA, ONR has continued to receive and assess the RP's suite of supporting documentation which defines and justifies the radiological source term(s) for UK HPR1000 [3]. To support the safety arguments presented in Reference 1, and to be able to provide an adequate demonstration of how radioactivity is generated and transported in UK HPR1000, ONR expect this suite of documents to provide information on the nature and quantity of fuel deposits, together with a demonstration of its potential implications for nuclear safety.

Without this information there is currently a gap in the UK HPR1000 generic safety case. When this matter has been discussed during routine technical Level 4 meetings [4] with the RP, it has not been possible for ONR to discern how the RP intends to address this shortfall.

This Regulatory Observation (RO) has therefore been raised to:

- Explain ONR's regulatory expectations;
- Ensure the RP provides a robust quantification (estimation) and justification thereof, of fuel deposits expected for UK HPR1000;
- Obtain confidence that adequate evidence will be provided by the RP to support the claims and arguments made in the UK HPR1000 generic safety case; and
- Assist ONR's judgement of whether a robust demonstration that, the generation and transport of radioactivity within UK HPR1000 will be reduced so far as is reasonably practicable (SFAIRP).

Relevant Legislation, Standards and Guidance

The chemistry section of ONR's Safety Assessment Principles (SAPs) [4] contains SAP ECH.1:

Engineering principles: chemistry	Safety cases	ECH.1
Safety cases should, by applying a systematic process, address all chemistry effects important to safety.		

Paragraph 511 of Reference 5 then goes onto state:

"The safety case should identify and analyse how chemistry can impact safety during normal operations and in fault and accident conditions, and demonstrate how the chemistry will be controlled."

Paragraph 569, supporting SAP EHT.1, is also relevant and states:

"*The design, construction and operation of the facility and the choice of heat transfer fluid should minimise the amount of radioactive material in the fluid. Provision should be made to monitor, control and remove any significant build-up of radioactive material from the heat transport fluid and associated containment.*"

This is further supported in ONR's Technical Assessment Guide (TAG), *Chemistry of Operating Civil Nuclear Reactors* [5]. Paragraph 5.13 of which states:

"The effect of impurities in the coolant on reactivity should be considered (ECH.1). This is particularly relevant for those which can accumulate within the core, especially on the fuel surface (e.g. CIPS in PWRs)."

and paragraph A4.13 of Reference 6 states:

"The transport and deposition of corrosion products must be influenced in such a manner that contamination of

the primary coolant system is kept low and deposition on heat-transfer surfaces, particularly on fuel assemblies, should be prevented as far as possible."

The reactor core section of ONR's Safety Assessment Principles (SAPs) [4] contains SAP ERC.3:

Engineering principles: reactor core	Stability in normal operation	ERC.3
The core should be stable in normal operation and should not undergo sudden changes of condition when operating parameters go outside their permitted range.		

The supporting Paragraph 552 of Reference 5 states:

"The design of the core and its components should take account of any identified safety-related factors, including: (a) irradiation; (b) chemical and physical processes…."

In addition, ONR's TAG, *Safety of Nuclear Fuel in Power Reactors* [6], states:

"The inspector should consider whether limits on the rate of subcooled boiling are required … to restrict the rate of deposition of CRUD".

Regulatory Expectations

ONR expect the claims and arguments presented in the PCSR to be adequately substantiated by suitable and sufficient evidence. ONR would therefore expect the definition and justification of the radiological source term(s) for UK HPR1000 to consider the impact of fuel deposits.

Based on the expectations re-produced from the standards and guidance listed above, ONR expects the generation and accumulation of fuel deposits for a modern PWR design to be minimised, and reduced SFAIRP. To be able to achieve this demonstration, as part of the resolution of this RO, the RP will need to undertake and document the following activities:

- Quantify (estimate) and characterise (i.e. chemical/physical characteristics) of the fuel deposits expected for UK HPR1000 (based on the core design presented during GDA).
- Adequately justify the fuel deposit estimates for UK HPR1000. The information provided should include a suitable amount of robust supporting evidence and be demonstrated to be appropriate for the UK HPR1000 design and consistent with the extant generic safety case.
- Evaluate the behaviour of the fuel deposits expected for UK HPR1000 and the associated nuclear safety implications during both normal operational states* and relevant fault or accident conditions.
- Identify suitable and sufficient measures for managing fuel deposits within the UK HPR1000, including the identification of suitable limits and conditions necessary in the interests of safety.

References

[1] *Pre-Construction Safety Report, Chapter 21, Reactor Chemistry*, HPR/GDA/PCSR/0021, Rev. 000, GNS, November 2018. www.ukhpr1000.co.uk/wp-content/uploads/2018/11/HPR-GDA-PCSR-0021-Pre-Construction-Safety-Report-Chapter-21-Reactor-Chemistry.pdf
[2] *Pre-Construction Safety Report, Chapter 5, Reactor Core*, HPR/GDA/PCSR/0005, Rev. 000, GNS, November 2018. www.ukhpr1000.co.uk/wp-content/uploads/2018/11/HPR-GDA-PCSR-0005-Pre-Construction-Safety-Report-Chapter-5-Reactor-Core.pdf
[3] *Normal Operation Source Term Strategy Report*, GHX90300002DNFP03GN, Rev B, CGN, June 2018. CM9 Ref. 2018/215200.
[4] *Safety Assessment Principles for Nuclear Facilities*, 2014 Edition, Revision 0, Office for Nuclear Regulation, 2014. www.onr.org.uk/saps/saps2014.pdf
[5] *Nuclear Safety Technical Assessment Guide, Chemistry of Operating Civil Nuclear Reactors*, NS-TAST-GD-088 Revision 2, Office for Nuclear Regulation, 2019. www.onr.org.uk/operational/tech_asst_guides/index.htm
[6] *Nuclear Safety Technical Assessment Guide, Safety of Nuclear Fuel in Power Reactors*, NS-TAST-GD-075 Revision 2, Office for Nuclear Regulation, 2017. www.onr.org.uk/operational/tech_asst_guides/index.htm

Glossary*

Normal operational states:

Including “normal operations” and “anticipated operational occurrences”. For a nuclear power plant this includes: start-up, power operation, shutting down, shutdown, maintenance, testing and refuelling.

Regulatory Observation Actions

RO-UKHPR1000-0015.A1 – Quantification, characterisation and justification of the fuel deposits expected for UK HPR1000

In response to this Action the RP should:

- Based on the GDA core design(s) (i.e. for the initial and equilibrium core designs), provide robust estimates of the fuel deposits expected for UK HPR1000. The information should include:
    - Total fuel deposit masses;
    - Radioactivity concentrations in the fuel deposits;
    - Fuel deposit thicknesses;
    - Distribution across the core (fuel); and
    - Sensitivity studies, as necessary, to explore the potential variability in the estimates
- Provide a suitable description of the nature of the fuel deposits, including the physical (i.e. loose, adherent, fixed, mobile etc.) and chemical nature of the deposits expected for UK HPR1000.
- Provide information on the allowable, relevant, thermal and boiling parameters (i.e. boiling rate and estimates of boiling area etc.) for the UK HPR1000 core design(s) for GDA.
- Ensure that the estimates of fuel deposits are consistent with the claims/arguments in the UK HPR1000 generic safety case and, therefore, the specific design and intended operations (i.e. including the impact of the potential adoption of zinc injection) of the UK HPR1000.
- Provide an appropriate degree of robust supporting evidence for the defined (quantified) fuel deposits for UK HPR1000. Where possible, the evidence should be directly applicable to the UK HPR1000 design. However, ONR recognises that sometimes this is not always possible. In these circumstances, it becomes important to justify the processes, judgements and assumptions applied. The evidence should include an appropriate balance of: plant data (OPEX), test results (i.e. scrape data), modelling, estimates or assumptions. The balance of where the evdience is drawn from should also be appropriately justified.
- Clearly identify all relevant assumptions (i.e. materials choices, corrosion rates, operational practices (and many others)), including a judgement on their overall significance to the estimation of fuel deposits expected for UK HPR1000.
- Appropriately consider and justify the sensitivity of key supporting assumptions associated with the quantification of UK HPR1000 fuel deposits.

The response to this ROA may be combined with any other ROA under this RO, if deemed appropriate.

Resolution required by: '*to be determined by General Nuclear System Resolution Plan*'

RO-UKHPR1000-0015.A2 – Evaluation of fuel deposit behaviour in UK HPR1000 and the impact on nuclear safety

The overall intent for this Action is that the RP should identify the relevent nuclear safety risks associated with fuel deposits in UK HPR1000 and provide a suitable and sufficient justification that they have been reduced so far as is reasonably practicable (SFAIRP).

Therefore, in response to this ROA, and based on the outcome of Action 1, the RP should:

- Give adequate consideration to how fuel deposits will behave in UK HPR1000, covering all operational states, relevent accident and fault conditions and all relevant systems asscoiated with the Nuclear Island (including the Spent Fuel Pool and In-containment Reactor Water Storage Tank (IRWST))
- Specifcially consider the impact of operating UK HPR1000 using EBA and the risk fuel deposits may pose in terms of the onset of CIPS.
- Identify the underpinning asumptions regarding the clean-up efficiencies of UK HPR1000 systems which are claimed to reduce, minimise, or eliminate fuel deposits, including a proportionate justifcation for these.
- Identify operational parameters and/or controls that may signifcantly impact the generation, transport and accumulation of fuel deposits in UK HPR1000. This should include the clear identifcation of the UK HPR1000 design features that would be needed to remove excessive levels of fuel deposits, should they arise.

- Identify all relevant accident scenarios/fault conditions where the impact of fuel deposits may need to be considered for UK HPR1000, justify the assumed behaviour and provide a robust demonstration, including an understanding of the sensitivity to any assumptions.

In response to this Action the RP should therefore identify the range of measures in place which either eliminate, reduce and/or control the generation and accumulation of fuel deposits for UK HPR1000. There are several factors, including: materials selecion and their treatments, specific operational practices, and choices associated with the primary circuit operating chemistry, which will influence the generation and accumulation of fuel deposits in a PWR. ONR also recognises that for these particular factors, they also have an impact on other nuclear safety considerations. An appropriate balance therefore needs to be struck and demonstarted. Information provided in response to this ROA should therefore include:

- Evidence that operating practices which are necessary, expected, or can be applied for UK HPR1000 have been optimised in terms of reducing the generation and accumulation of fuel deposits, SFAIRP.
- Evidence that the primary circuit operating chemistry for UK HPR1000 has been optimised to reduce the generation and accumulation and fuel deposits, SFAIRP.
- Evidence that key materials choices and their surface tretaments, have been considered from the perspective of reducing the generation and accumulation of fuel deposits, SFAIRP.
- The identfication of suitable and sufficient limits and conditions which are consistent with the design, intended operations and generic safety case claims for UK HPR1000.

ONR recognise that some of the evidence and justification requested under this Action may exist in other parts of the generic safety case; in those instances the RP should clearly indicate this, including demonstrating its applicability to this Action, in particular the demonstration that it reduces risks SFAIRP.

The response to this ROA may be combined with any other ROA under this RO, if deemed appropriate.

Resolution required by: '*to be determined by General Nuclear System Resolution Plan*'

REQUESTING PARTY TO COMPLETE	
Actual Acknowledgement date:	
RP stated Resolution Plan agreement date:	