REGULATORY OBSERVATION

REGULATOR TO COMPLETE

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Related RQ / RO No. and CM9 Ref: (if any):	RQ-UKHPR1000-0614 CM9 Ref: 2020/103510 RQ-UKHPR1000-0666 CM9 Ref: 2020/109825 (partial response)
Observation title:	Thermal hydraulic performance at fuel assembly edge
Lead technical topic: 10. Fuel & Core	**Related technical topic(s):** 9. Fault Studies

Regulatory Observation

Background

ONR has commenced Step 4 of the Generic Design Assessment (GDA) for the UK HPR1000 and is assessing safety case submissions for the UK HPR1000 fuel & core designs.

The UK HPR1000 Pre-Construction Safety Report [1] and Thermal Hydraulic Design report [2] require that Departure from Nucleate Boiling (DNB) analysis be undertaken to demonstrate clad integrity in a wide range of fault scenarios. In order to limit the number of fault analysis calculations that must be undertaken, a common approach has been used of defining reference axial and radial power distributions. The core design team verifies that these reference power distributions adequately bound the real power distributions that will exist across the wide range of design basis faults (excluding specific faults that significantly perturb the power distribution during the transient) by undertaking DNB Ratio (DNBR) calculations in a set of sensitivity studies. The fault analyses then use the reference power distributions for all calculations (excluding the specific faults noted above) rather than needing to use the real predicted power distribution in each case.

For UK HPR1000, the reference radial power distribution has been defined in such a way that power is concentrated in a number of assemblies near the centre of the core and in channels away from the edge of each of those assemblies.
The design of fuel assembly for the UK HPR1000 is defined in the Framatome report AFA 3GAA Fuel Assembly Description for HPR1000 [3].

Following assessment of the UK HPR1000 fuel & core thermal hydraulic analyses and methods, ONR have determined that neither of the following phenomena have been explicitly considered:

1) Increase in local power at the edge of a fuel assembly due to an increased fuel assembly gap, which occurs due to fuel assembly bowing under irradiation.
2) Reduction in local flow at the edge of the fuel assembly due to a reduced fuel assembly gap, which occurs due to fuel assembly bowing under irradiation, combined with the effect of the mixing grid geometry in that region defined in [3].

Both of these phenomena will occur in normal operation and are not confined to particular faults.

Further information on the topic of phenomenon 1) was requested in RQ-UKHPR1000-0614, to which the RP have issued a full response [4]. Further information on the topic of phenomenon 2) was also requested in RQ-UKHPR1000-0614 and in RQ-UKHPR1000-0666, to which the RP has issued a partial response [5]. In these responses, the RP claim that use of the reference radial power distribution described above means that the assembly edge channels are never limiting within the analysis and therefore these phenomena will not lead to any reduction in DNBR safety margin. Arguments and evidence have been provided in [4] and [5] to try to justify this claim. However, ONR does not consider what has been presented to date to be sufficient in some respects. In particular:

- ONR does not consider the physics test data referred to in [4] (specifically that used in [6] to derive nuclear uncertainty data) to be adequate to properly quantify the effect of assembly bow on local power peaking at the assembly edge (phenomenon 1)), because the instrument location in the tests is too far removed from the region of interest.
- The calculation provided in [4] to calculate the impact on DNBR of fuel assembly bow due to a reduced gap used the reference power distribution and did not examine the influence of gap closure on hot channel DNBR at the edge of the assembly, nor consider combining the effects of assembly bow with the effect of the local mixing grid geometry. It therefore did not fully address phenomenon 2). In [5] these concerns were addressed by calculations to show the reduction in DNBR margin at the assembly edge due to phenomenon 2), however, a demonstration of the validity of the input data and correlations for these calculations is not yet available.

ONR believes that either of the phenomena 1) or 2) could potentially reduce the DNBR margin at the assembly edge to the extent that the use of the reference power distribution would no longer produce bounding DNBR data for some operating conditions, particularly those where the true power peak is near or at the assembly edge. This would mean that the DNBR analysis completed for fault studies may no longer be conservative for these operating conditions. As such, fuel failures could occur in some fault(s) during which they are not currently predicted.

This RO has therefore been raised to ensure that the safety case, and more specifically the reference power distributions and DNBR limits, for UK HPR1000 consider all relevant phenomena appropriately.

<u>Relevant Legislation, Standards and Guidance</u>

The ONR Safety Assessment Principles (SAPs) [7] include the following expectations that are relevant to this RO:

SAP ERC.1, Fundamental safety functions, states "*The design and operation of the reactor should ensure the fundamental safety functions are delivered with an appropriate degree of confidence for permitted operating modes of the reactor*."

SAP FA.7, Conservative fault analysis, states "*Analysis of design basis fault sequences should use appropriate tools and techniques, and be performed on a conservative basis to demonstrate that consequences are ALARP."*

SAP EAD.2, Lifetime margins, states "*Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components*."

SAP AV.1, Theoretical models, states "*Theoretical models should adequately represent the facility and site*."

SAP AV.2, Calculation methods, states "*Calculation methods used for the analyses should adequately represent the physical and chemical processes taking place*."

ONR's Technical Assessment Guide (TAG) NS-TAST-GD-075 [8] includes the following advice to inspectors that is relevant to this RO:

- On critical heat flux "*In LWR, the cladding surface temperature is generally guaranteed by respecting the critical heat flux limit. The 2005 IAEA guide to Design of the Reactor Core for Nuclear Power Plants (NS-G-1.12) requires that the margin to this limit be demonstrated based on experiments encompassing the anticipated range of normal operating and fault conditions*."
- On structural considerations and fuel assembly bowing "…*As the space between fuel assemblies increases, the thermal neutron flux can be affected. If the coolant is also the moderator, the flux can significantly increase, leading to locally increased fuel pin ratings. Conversely, if gaps between fuel assemblies are reduced or eliminated, a significant reduction in coolant flow may be experienced locally. This may affect heat transfer…The fuel assembly should be able to withstand the mechanical and hydraulic hold-down forces required to maintain core geometry without unacceptable deformation and bowing*…"

Regulatory Expectations

ONR expects the RP to demonstrate that their DNBR design methodology adequately bounds the impact of phenomena at the fuel assembly edge such that the combination of inputs and acceptance criteria passed for use in fault studies analyses (in this case, reference power distributions and DNBR limits) are conservative under all relevant operating conditions. This is required in order to meet the expectations of SAPs ERC. 1 and FA.7.

In completing the above demonstration, ONR expects the RP's analysis to adequately capture differences in grid geometry at the assembly edge where these could affect DNBR performance. This is required in order to meet the expectation of SAP AV.1. ONR also expects the analysis to capture the effect of degradation processes including fuel assembly bow. This is necessary to satisfy SAP EAD.2.

In order to satisfy the expectations of SAPs AV.1 and AV.2, the RP should also provide evidence of the validity of their data, models and methods (for example, pressure drop coefficients and critical heat flux correlations) for the specific purpose of these analyses. This should include use of data derived from experiment to characterise thermal hydraulic performance at the edge of the fuel assembly, including the case where the gap between assemblies is reduced due to assembly bow. When deriving this data, scaling effects should be considered, such as differences in cross-flow that would occur between the test set-up and the reactor geometry.

References

[1] UK HPR1000 Pre Construction Safety Report Chapter 5 - Reactor Core, HPR/GDA/PCSR/0005, Rev 001, January 2020. CM9: 2020/13630.
[2] UKHPR1000 Thermal Hydraulic Design, GHX00100004DRRG03GN, Rev D, November 2019. CM9: 2019/352751.
[3] AFA 3GAA Fuel Assembly Description for HPR1000, GHX42500001SFSL44GN, Rev 3.0, August 2019. CM9: 2019/224212.
[4] Full Response to RQ-UKHPR1000-0614, Follow-up questions on fuel – grid springs, guide thimble material and assembly bow, March 2020. CM9: 2020/103510.
[5] Partial Response to RQ-UKHPR1000-0666, Assembly Edge Flow Blockage, April 2020. CM9: 2020/109825.
[6] COCO, A 3-D Nuclear Design Code – Verification and Validation Report, GHX00600001DRDG02TR, Rev A, January 2020. CM9: 2020/12528.
[7] Safety Assessment Principles for Nuclear Facilities, 2014 Edition, Revision 1, January 2020. ONR. www.onr.org.uk/saps/saps2014.pdf
[8] Technical Assessment Guide - Safety of Nuclear Fuel in Power Reactors, NS-TAST-GD-075, Revision 2, September 2017, ONR.

Regulatory Observation Actions

RO-UKHPR1000-0045.A1 – Impact of an increase in local power at the edge of the fuel assembly

In response to this Regulatory Observation Action, GNSL should demonstrate that the DNBR design methodology adequately bounds the impact of an increase in local power at the edge of the fuel assembly due to an increased fuel assembly gap.

ONR expects that GNSL will need to undertake and document the following activities:

- Conservatively determine the increased water gap(s) to be considered at assembly edge due to assembly bow.
- Determine the magnitude of additional local power peaking caused by the increased water gap, giving consideration to applicable nuclear uncertainties, and determine the impact on DNBR at the assembly edge.
- Compare this impact with the margin provided by use of the reference radial power distribution, for all relevant core states and their associated power distributions.
- Should the response to this Action demonstrate that the reference radial power distribution is not bounding of this phenomena for all relevant core states, provide a strategy and programme to update the relevant aspects of the safety case.

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

RO-UKHPR1000-0045.A2 – Impact of a reduction in local flow at the edge of the fuel assembly

In response to this Regulatory Observation Action, GNSL should demonstrate that the DNBR design methodology adequately bounds the impact of a reduction in local flow at the edge of the fuel assembly due to a reduced fuel assembly gap together with the effects of the mixing grid geometry in that region.

ONR expects that GNSL will need to undertake and document the following activities:

- Obtain data derived from experiment to characterise thermal hydraulic performance at the edge of the fuel assembly (such as pressure drop coefficients or CHF correlations), including the case where the gap between assemblies is reduced.
- Determine any effect of this data on the calculations presented in the partial response to RQ666 [4], giving consideration to scaling effects and consequently determine the impact of the reduced water gap together with the effects of the mixing grid geometry in that region on DNBR at the assembly edge.
- Compare this impact with the margin provided by use of the reference radial power distribution, for all relevant core states and their associated power distributions.
- Should the response to this Action demonstrate that the reference radial power distribution is not bounding of this phenomena for all relevant core states, provide a strategy and programme to update the relevant aspects of the safety case.

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:	