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REGULATORY OBSERVATION Resolution Plan	
RO Unique No.:	RO-UKHPR1000-0045
RO Title:	Thermal hydraulic performance at fuel assembly edge
Technical Area(s)	Fuel & Core
Revision:	0
Overall RO Closure Date (Planned):	2021-06-30
Linked RQ(s)	RQ-UKHPR1000-0614, RQ-UKHPR1000-0666
Linked RO(s)	
Related Technical Area(s)	Fault Studies
Other Related Documentation	2020/103510, 2020/109825
Scope of Work	

Background

Departure from Nucleate Boiling (DNB) analysis is undertaken to contribute to the demonstration of clad integrity in Fault Studies. In order to limit the number of fault analysis calculations that must be undertaken, a conservative radial power distribution is used in DNB Ratio (DNBR) calculations rather than using the real predicted power distribution in each case. The reference radial power distribution adequately bounds the real radial power distributions that will exist across the wide range of design basis faults.

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 conservatism of the reference radial power distribution has been verified in a set of sensitivity studies.

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 [1].

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 radial power distribution would no longer produce bounding DNBR data for some operating conditions, particularly those where the true power peak is 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 radial power distributions and DNBR limits, for UK HPR1000 consider all relevant phenomena appropriately.

Scope of work

The scope of work is described as follows:

1) Impact analysis of an increase in local power at the edge of the fuel assembly.

- Determine the water gaps due to fuel assembly bow;
- Evaluate the impact on local power peaking;
- Analyse the impact on DNBR design due to assembly bow and demonstrate that the DNBR design methodology adequately bounds the impact of the increased water gap.

2) Impact analysis of a reduction in local flow at the edge of the fuel assembly.

- Determine the local pressure drop coefficients at the fuel assembly edge;
- Evaluate the impact on the DNBR by considering a reduced fuel assembly gap;

Analyse the impact on DNBR design due to assembly bow and demonstrate that the DNBR design methodology adequately bounds the impact of the decreased water gap.

Deliverable Description

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:

- **ROA1-1:** Conservatively determine the increased water gap(s) to be considered at assembly edge due to assembly bow.
- **ROA1-2:** 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.
- **ROA1-3:** 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.

- **ROA1-4:** Should the response to this Action demonstrate that the reference radial power distribution is not bounding of this phenomenon for all relevant core states, provide a strategy and programme to update the relevant aspects of the safety case.

Resolution Plan for ROA1

1) The report *UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – Assessment of water gap core distribution* will be written to determine the increased water gaps due to fuel assembly bow, linked to ROA1-1:

- The report will include a brief description of the methodology, the assumptions and input data used for the calculation of water gaps;
- Based on Operating Experience (OPEX) data, typical water gaps will be determined due to fuel assembly bow to be used for the demonstration.

2) The impact of Fuel Assembly Bow on the local power peaking and on the DNBR will be addressed in the report *The Effect of Fuel Assembly Bow on DNBR* in the ROA2 of the 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:

- **ROA2-1:** 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.
- **ROA2-2:** Determine any effect of this data on the calculations presented in the partial response to RQ666 [2], 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.
- **ROA2-3:** 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.
- **ROA2-4:** Should the response to this Action demonstrate that the reference radial power distribution is not bounding of this phenomenon for all relevant core states, provide a strategy and programme to update the relevant aspects of the safety case.

Resolution Plan for ROA2

1) *UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – Local Pressure Loss Coefficient* report will be provided. This action is linked to ROA2-1.

- The information of local pressure drop coefficients at the fuel assembly edge is contained in this report. The local pressure drop coefficients (PDC) calculation will be performed by Computational Fluid Dynamics (CFD) tools. To ensure consistency with thermal hydraulic analysis with the sub-channel code, the CFD results will be post-processed and calibrated.

The main approach will be as follows:

- Perform a Phenomenon Identification Ranking Table (PIRT) analysis for local PDC CFD calculations on the AFA 3GAA fuel assembly;
- Implement a process to adapt the results to sub-channel codes.

For information, in addition to the validation process performed by the CFD code editor on various applications for industrial needs, multiple validations of calculations over experimental data on pressure loss and flow field have been performed on the specific topic of bundle flow evaluation, with industrial grid designs. These validation calculations are consistent with the methodology, which will be employed for this study. The methodology and the validation information will be outlined in the report. An early technical exchange between Fuel Designer and ONR will be organised prior to the formal submission of the report in order to enable the ONR to have early insights on the relevant information of methodologies and the validation.

2) The report *UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – CHF in peripheral region* will be written to provide the impact of the assembly edge effects on the CHF correlation. This action is linked to ROA2-1.

- The analysis of CHF tests representative of nominal and reduced gap conditions will be performed. Comparing the results of these analyses will allow the applicability of the CHF correlation to be confirmed.

3) The report *The Effect of Fuel Assembly Bow on DNBR* will be further developed to incorporate the assessment of the impact on DNBR at the assembly edge, linked to ROA1-2, ROA1-3, ROA1-4, ROA2-2, ROA2-3 and ROA2-4. This will include:

- Assessing the impact on local power peaking due to fuel assembly bow. Three items are considered to model the impacted core:
  - The water gap distributions calculated in the *UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – Assessment of water gap core distribution* report;
  - The limit applied on core power tilt (the difference of the core power in different reactor core quarters);
  - The limit applied on fuel assembly power discrepancy between the calculated value and measured value according to periodic physics tests.
- Assessing the impact on DNBR due to fuel assembly bow. Two phenomena are considered:
  - The increased water gaps and additional local power peaking;
  - The decreased water gaps and reduction in local flow.
- Consider some conservative assumptions (such as the peak power fuel rod being located at the fuel assembly

edge) in the DNBR assessment.

- Compare the impact on DNBR with the margin provided by use of the reference radial power distribution.

If the DNBR design methodology adequately bounds the impact on the decreased water gap between fuel assemblies, no additional document is needed to be changed.

If the reference radial power distribution is not bounding of this phenomenon, additional penalty will be considered in DNBR design limit. However, some design provision has been considered in the DNBR design limit. If this design provision can cover the additional penalty caused by fuel assembly bow, the DNBR design limit is not challenged. In that case, the DNBR Design Limit Report will be revised to reflect the impact of Fuel Assembly Bow on the safety margin of the UK HPR1000 reactor core.

If the design provision cannot cover the additional penalty, the DNBR limit will be exceeded. In this case, the safety case will be impacted and a strategy and programme to update the relevant aspects of the safety case will be provided, if necessary.

Impact on the GDA Submissions

Relevant information will be incorporated into the final version of Fuel and Core submission during Step 4. For the closure of this RO, the following deliverables will be submitted:

- UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – Assessment of water gap core distribution
- UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – local Pressure Loss Coefficient
- UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – CHF in peripheral region
- The Effect of Fuel Assembly Bow on DNBR

Timetable and Milestone Programme Leading to the Deliverables

Attach a Gantt chart to present the timetable and milestone of the RO resolution in APPENDIX A.

Reference

[1] AFA 3GAA Fuel Assembly Description for HPR1000, GHX42500001SFSL44GN, Rev 3.0, August 2019. CM9: 2019/224212.

[2] ONR, Assembly Edge Flow Blockage, RQ-UKHPR1000-0666, 10/03/2020.

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APPENDIX A RO-UKHPR1000-0045 Gantt Chart

Task and Schedule		2020						2021					
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
RO Action 1 Impact of an increase in local power at the edge of the fuel assembly													
1	Development of deliverable - UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – Assessment of Water Gap Core Distribution												
2	Submission of deliverable - UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – Assessment of Water Gap Core Distribution												
RO Action 2 Impact of a reduction in local flow at the edge of the fuel assembly													
3	Development of deliverable - UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – Local Pressure Loss Coefficient												
4	Submission of deliverable - UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – Local Pressure Loss Coefficient												
5	Development of deliverable - UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – CHF in peripheral region												
6	Submission of deliverable - UK HPR1000 - AFA 3GAA fuel assembly for HPR1000 reactor – CHF in peripheral region												
7	Development of deliverable - The Effect of Fuel Assembly Bow on DNBR												
8	Submission of deliverable - The Effect of Fuel Assembly Bow on DNBR												
Assessment													
9	Regulatory Assessment												
10	Target RO Closure Date												