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REGULATORY OBSERVATION Resolution Plan	
RO Unique No.:	RO-UKHPR1000-0015
RO Title:	Demonstration that Risks Associated with Fuel Deposits are Reduced so far as is Reasonably Practicable (SFAIRP)
Technical Area(s)	Reactor Chemistry
Revision:	0
Overall RO Closure Date (Planned):	2021-01-30
Linked RQ(s)	
Linked RO(s)	
Related Technical Area(s)	Fuel & Core,Fault Studies,Radiological Protection,Radwaste, Decommissioning & Spent Fuel Management
Other Related Documentation	
Scope of Work	

Background

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. These fuel deposits (also referred to as fuel crud) may have some detrimental effects on the fuel-coolant heat transfer, and lead to phenomena such as Crud Induced Localised Corrosion (CILC) and Crud Induced Power Shift (CIPS) if they increase to a high level. In order to minimise the accumulation of fuel crud and the associated risks, the chemistry regime is required to be carefully controlled [1].

Taking cognisance of ONR's Safety Assessment Principles (SAPs) and Technical Assessment Guides (TAGs) such as NS-TAST-GD-075 Safety of Nuclear Fuel in Power Reactors which states that *"the inspector should consider whether limits on the rate of subcooled boiling are required to limit the concentration of radiolysis products in the coolant and to restrict the rate of deposition of crud."* [3], the formation of, and risks associated with, fuel crud should be minimised so far as is reasonably practicable (SFAIRP).

From the Step 3 submissions assessed to date, ONR has judged that insufficient information relating to the formation and management of fuel crud has been included in the safety case. In order to assist the closure of this gap, ONR raised RO-UKHPR1000-0015, chiefly to:

- Explain ONR's regulatory expectations;
- Ensure the Requesting Party (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 SFAIRP.

This resolution plan provides the intended tasks, deliverables and schedule that will be undertaken to address the concerns raised by ONR regarding the demonstration of fuel deposits.

<u>Scope of work</u>

The scope of work is described as follows:

1) The quantification, characterisation and justification of the fuel deposits will be provided for UK HPR1000, including the following key points:
    - Description of fuel deposits on the physical and chemical nature;
    - Quantification and justification on the information of fuel deposits, including thermal and boiling parameters, total mass, thickness, and radioactivity concentrations;
    - Identification of key parameters and assumptions which have a significant influence to the estimation of fuel deposits.
2) The evaluation of fuel deposits behaviour and the impact on nuclear safety will be analysed for UK HPR1000, including the following key points:
    - Behaviour of fuel deposits under start up, normal operation, shutdown states, covering relevant systems;
    - Behaviour and impact of fuel deposits under relevant fault conditions;
    - Impact of operating UK HPR1000 using Enriched Boric Acid (EBA);
    - ALARP demonstration on the risks of fuel deposits, including the operating practices, material choices, limits and conditions, and clean-up efficiency.

Deliverable Description

For the closure of this RO, the following deliverables will be produced and updated:

<u>New documents (produced)</u>

- Void Fraction for fuel assembly equipped with M5 cladding tube
- Status on Crud Monitoring and Acceptability
- Thermal and Boiling Parameters of UKHPR1000 Core Designs
- Assessment of Fuel Crud for UKHPR1000

<u>Existing documents (updated)</u>

- Design Substantiation Report on Associated Chemistry Control Systems: the Primary Circuit
- ALARP Demonstration Report of PCSR Chapter 21

The contents of each report and how they address each RO action (and sub-actions) are discussed as follows.

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

RO Action 1 states that:

In response to this Regulatory Observation Action, General Nuclear System Limited should:

- ***ROA1-1**: 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*
- ***ROA1-2**: 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.*
- ***ROA1-3**: 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.*
- ***ROA1-4**: 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.*
- ***ROA1-5**: 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 evidence is drawn from should also be appropriately justified.*
- ***ROA1-6**: 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.*
- ***ROA1-7**: Appropriately consider and justify the sensitivity of key supporting assumptions associated with the quantification of UK HPR1000 fuel deposits.*

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

RO Action 2 states that:

In response to this regulatory observation action, General Nuclear System Limited should:

- ***ROA2-1:** Give adequate consideration to how fuel deposits will behave in UK HPR1000, covering all* *operational states, relevant accident and fault conditions and all relevant systems associated with the Nuclear Island (including the Spent Fuel Pool and In-containment Reactor Water Storage Tank (IRWST))*

- ***ROA2-2:*** *Specifically consider the impact of operating UK HPR1000 using EBA and the risk fuel deposits may pose in terms of the onset of CIPS.*
- ***ROA2-3:*** *Identify the underpinning assumptions regarding the clean-up efficiencies of UK HPR1000 systems which are claimed to reduce, minimise, or eliminate fuel deposits, including a proportionate justification for these.*
- ***ROA2-4:*** *Identify operational parameters and/or controls that may significantly impact the generation, transport and accumulation of fuel deposits in UK HPR1000. This should include the clear identification of the UK HPR1000 design features that would be needed to remove excessive levels of fuel deposits, should they arise.*
- ***ROA2-5:*** *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.*
- ***ROA2-6:*** *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.*
- ***ROA2-7:*** *Evidence that the primary circuit operating chemistry for UK HPR1000 has been optimised to reduce the generation and accumulation and fuel deposits, SFAIRP.*
- ***ROA2-8:*** *Evidence that key materials choices and their surface treatments, have been considered from the perspective of reducing the generation and accumulation of fuel deposits, SFAIRP.*
- ***ROA2-9:*** *The identification of suitable and sufficient limits and conditions which are consistent with the design, intended operations and generic safety case claims for UK HPR1000.*

<u>Resolution Plan</u>

■ Report 1 (Void Fraction for fuel assembly equipped with M5 cladding tube) and report 2 (Status on Crud Monitoring and Acceptability) describe the characteristics of the fuel crud linked to **ROA1-2** and outline the impact and role of fuel crud in crud induced localised corrosion (CILC).

Methodology:

- Report 1 states the M5Framatome experience in out-of-pile loop and PWR. It covers the formation of deposits and provides detailed OPEX to show that there has been no impact on M5Framatome cladding corrosion resistance even when a lot of crud has been observed.

- Report 2 describes the origin of crud and its impacts on fuel assemblies in relation to CILC and CIPS. The following aspects will be included in this report:
    - The main driving characteristics: localization in the core and on the fuel assembly, crud composition, thickness, porosity and boron content in the crud are described.

- o Core management and water chemistry, also identified as influencing parameters to take into account in this phenomenon, are discussed.
- o From OPEX, crud phenomena are ranked in four categories and solutions to evaluate and mitigate associated problems are described.
- o Then suitable surveillance scheme is proposed.

■ Report 3 (Thermal and Boiling Parameters of UKHPR1000 Core Designs) will provide information on the allowable, relevant, thermal and boiling parameters (e.g. boiling rate and estimates of boiling area) for the UK HPR1000 core design(s) for GDA linked to **ROA1-3** based on the calculation of sub-channel code with main parameters considering different cycles (i.e. the initial and equilibrium cycles).

Methodology:

The sub-channel LINDEN code will be used for this report.

LINDEN, a thermal-hydraulic sub-channel code used for evaluating PWR reactor cores, will be used. The sub-channel model will be setup considering the ¼ core. Boiling rate and boiling area will be calculated in each channel. The axial and radial power distribution under different fuel arrangements will be considered.

■ Report 4 (Assessment of Fuel Crud for UKHPR1000) will provide the assessment of fuel crud linked to **ROA1-1, ROA1-4, ROA1-5, ROA1-6, ROA1-7** and some sub-actions in Action 2 including **ROA2-1, ROA2-2, ROA2-5** listed below. The quantification, justification and impact of fuel crud will be stated in this report.

Methodology:

The main sections of Report 4 are as follows:

- Quantification of UK HPR1000 fuel crud

There are several aspects that influence the generation of fuel crud. These include thermal-hydraulic conditions, chemical conditions, clean-up efficiency and material selection. Recognising this, the UK HPR1000 fuel crud will be quantified using a combination of computer codes. The 3-D nuclear design code COCO will be used to evaluate power distribution in the core under different cycles. The output of this analysis will then be used as the input in the thermal-hydraulic code LINDEN to evaluate thermal parameters such as boiling rate, local temperature and local flow rate. Based on these thermal parameters and combining the chemical conditions such as pH value and dissolved H_2 concentration, CAMPSIS code, which allows crud deposition under different core positions to be evaluated, will be used to quantify the fuel crud for the UK HPR1000, including mass, thickness and the radioactivity concentration of the crud.

- Sensitivity studies for quantification of fuel crud related to ROA1-5, ROA1-6 and ROA1-7

The following conditions will be considered and based on this analysis, the key parameters influencing the formation of fuel crud will be identified.

- o Sensitivity studies of some key parameters, such as boiling rate, local temperature and local flow rate,

- Sensitivity studies of some chemical parameters, such as pH value, dissolved hydrogen concentration and Lithium-Boron concentration.
- Sensitivity studies of some assumptions, such as corrosion release rates.

- Supporting of plant data (OPEX) and test results related to ROA1-5

  OPEX and test data from domestic and international sources will be used to support the fuel crud assessment. Plant data includes pool-side inspection test data and the concentration of elements such Ni, Fe under different conditions, and some other plant data (if necessary), comparison of CAMPSIS with OPEX and test data, will be provided in this section.
- Behaviour of fuel crud under different conditions and relevant systems related to ROA2-1

  In this section, the following behaviour will be described:
  - Behaviour of fuel crud under start-up, normal operation and shutdown conditions. The process of generation, transport, accumulation, dissolution and re-deposition of fuel crud will be stated. For example, during the shutdown process, Ni metal will be removed after adding H_2O_2 to the primary circuit.
  - Behaviour of fuel crud related to relevant systems. For example, during the loading and reloading process of fuel, the fuel crud may enter into the SFP and IRWST water and the behaviour of the fuel crud on relevant systems will be described.
- Impact of operating UK HPR1000 using EBA related to ROA2-2

  Based on the quantification results of fuel crud, the CIPS analysis will be performed, considering the use of EBA by the method of CIPS mechanism.
- Behaviour and impact of fuel crud under relevant fault conditions related to ROA2-1 and ROA 2-5

  Firstly, accident scenarios/fault conditions related to fuel deposits will be identified. Then the behaviour and impact of fuel crud on accident and fault conditions, such as fuel curd released from fuel cladding, consequence of core cooling including peak cladding temperature and fuel pellet temperature, will be estimated and a sensitivity study will be undertaken if necessary.
- Assessment of consistency with any other claims / arguments related to ROA1-4

  Based on the quantification results, the consistent assessment of the result of fuel crud analysis and related claims/arguments in the safety case, such as fuel / core design criteria, will be performed in this section.
- Summary of assessment of fuel crud.

  In this section, the key parameters or assumptions influencing the formation of fuel crud will be summarised and some impacts of fuel crud will be stated.

- Report 5 (Design Substantiation Report on Associated Chemistry Control Systems: the Primary Circuit) will describe the purification unit of the Chemical and Volume Control System (RCV [CVCS]) which contributes to the removal of impurities, including the fuel deposits from the primary coolant, supporting the justification to ROA2-3.

  Methodology:

  Report 5 is an updated document which describes the design substantiation of the purification unit of the

Chemical and Volume Control System (RCV [CVCS]).

According to the source term and removal requirements of impurities about fuel crud in report 4, this report will justify that the purification unit of RCV [CVCS]) can meet the requirements of impurity removal in terms of filtration accuracy, efficiency and capacity.

- Report 6 (ALARP Demonstration Report of PCSR Chapter 21) will be updated to demonstrate that the risks associated with fuel deposits are reduced SFAIRP linked to **ROA2-4, ROA2-6, ROA2-7, ROA2-8 and ROA2-9** which will consider the following evidence:
  - Evidence on the operating practices;
  - Evidence on the chemistry control parameters of primary circuit;
  - Evidence on the key materials choices and their surface treatments;
  - Evidence on the limits and conditions which are consistent with the design, intended operations and generic safety case claims for UK HPR1000.

Methodology:

Report 6 is an updated document which will provide the ALARP demonstration that crud formation has been minimised ALARP.

In detail, the evidence for fuel crud minimisation will be developed according to the material and chemistry regime optimization. The minimisation of fuel crud induced risks have been considered as an objective for reactor chemistry ALARP demonstration. Further justification will be provided in the ADR report on minimisation of generation and transport of the corrosion product in primary circuit, thus to reduce the crud formation. Links of corrosion minimisation to fuel crud will be also established in the Purpose and Summary sections of ADR report.

Summary of deliverables

The submissions for this RO and related ROAs are summarized as follows,

Document No.	GDA Submission Document	Revision	Related ROAs	Planned Submission Date	Responsible
Report 1	Void Fraction for fuel assembly equipped with M5 cladding tube	A	ROA1-2	14/10/2019 (completed)	Framatome
Report 2	Status on Crud Monitoring and Acceptability	A	ROA1-2	01/11/2019 (completed)	Framatome
Report 3	Thermal and Boiling Parameters of UK HPR1000 Core Designs	A	ROA1-3	30/04/2020	CGN
Report 4	Assessment of Fuel	A	ROA1-1/ROA1-4	30/10/2020	CGN

	Crud for UK HPR1000		ROA1-5/ROA1-6 ROA1-7/ROA2-1 ROA2-2/ROA2-5		
Report 5	Design Substantiation Report on Associated Chemistry Control Systems: the Primary Circuit	E (Updated)	ROA2-3	30/10/2020	CGN
Report 6	ALARP Demonstration Report of PCSR Chapter 21	C (Updated)	ROA2-4/ROA2-6 ROA2-7/ROA2-8 ROA2-9	30/10/2020	CGN

Impact on the GDA Submissions

Relevant information will be incorporated into the final version of Reactor Chemistry submission during Step 4. The submissions that are impacted by this resolution plan include:

- *PCSR chapter 21*
- *Selection of Enriched Boric Acid for the UK HPR1000*
- *Topic Report on Zinc Injection in the Primary Circuit of UK HPR1000*

Timetable and Milestone Programme Leading to the Deliverables

See attached Gantt Chart in APPENDIX A.

Reference

[1] Pre-Construction Safety Report, Chapter 21, Reactor Chemistry, HPR/GDA/PCSR/0021, Rev. 000, GNS, November 2018.

[2] Safety Assessment Principles for Nuclear Facilities, 2014 Edition, Revision 0, Office for Nuclear Regulation,
2014.

[3] Nuclear Safety Technical Assessment Guide, Safety of Nuclear Fuel in Power Reactors, NS-TAST-GD-075 Revision 2, Office for Nuclear Regulation, 2017.

APPENDIX A RO-UKHPR1000-0015 Gantt Chart

Tasks	**Steps**	**2019**				**2020**												**2021**	
		Sep	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
RO Action 1 Action 2																			
Report 1: Void Fraction for fuel assembly equipped with M5 cladding tube, Rev. A	Development																		
	Submission																		
Report 2: Status on Crud Monitoring and Acceptability, Rev. A	Development																		
	Submission																		
Report 3: Thermal and Boiling Parameters of UK HPR1000 Core Designs, Rev. A	Development																		
	Submission																		
Report 4: Assessment of Fuel Crud for UK HPR1000, Rev. A	Development																		
	Submission																		
Report 5: Design Substantiation Report on Associated Chemistry Control Systems: the Primary Circuit, Rev. E	Development																		
	Submission																		
Report 6: ALARP Demonstration Report of PCSR Chapter 21, Rev. C	Development																		
	Submission																		
Assessment																			
Regulators assessment																			
Target RO closure Date																			