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**Assessment of the Justification for Continued Operation of Heysham 1 R2 Following
Detection of Multiple Fuel Failures in 2016.**

**Agreement to the modification described in JCO – Continued Operation for Heysham 1
R2 following Detection of Multiple Fuel Failures in 2016 NP/SC 7757 EC358854.**

Project Assessment Report ONR-OFD-PAR-18-006
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EXECUTIVE SUMMARY

This report presents the findings of ONR's assessment of NP/SC 7757 (EC358854), JCO - Continued Operation for Heysham 1 R2 following Detection of Multiple Fuel Failures in 2016.

Permission Requested

The licensee, EDF Energy Nuclear Generation Limited (EDF NGL), requested the Office for Nuclear Regulation's (ONR) 'Agreement' under Licence Condition 22 (1) for the modification described in safety case NP/SC 7757 (EC358854) to justify continued operation of Heysham 1 Reactor 2 following the detection of multiple fuel failures in 2016.

Licence Condition 22 (1) requires the licensee to make and implement adequate arrangements to control any modification (or experiment) carried out on any part of the existing plant or processes which may affect safety. This permission is being performed under a derived powers Agreement.

Background

Failure of an AGR fuel pin is a breach of the primary fission product barrier. A key input into AGR fault studies is the assumptions made on the fuel pin condition, as this affects the likelihood of fuel pin failures occurring during faults.

There has been a recent spate of fuel failures in Heysham 1 (HYA) Reactor 2 (R2); 16 failed fuel stringers (containing one or more fuel pins with a small breach in the fuel cladding) were identified in 2016. This meant that the previously defined safety case criteria of 10 failed fuel stringers per year was exceeded and suggested that the population of weakened fuel pins assumed was being challenged in this reactor.

The fuel stringer failure rate at the other three potentially effected units (i.e. HYA R1 and Hartlepool R1 and R2) remains low and is judged by EDF NGL to remain well within the assumptions of the previous safety case from 2014. The EDF NGL submission supersedes the 2014 safety case for HYA R2 only and justifies continued operation with 6000 weakened fuel pins (pins subject to degraded cladding condition, which though intact during normal operation may be more likely to fail in a fault). This is claimed by EDF NGL to be consistent with an operational fuel failure rate of up to 30 fuel stringers per year, based on the latest post irradiation examination. However, this is a short term upper bound to the safety case and more restrictive long term limits are dictated by the licensee's ALARP assessment.

In practice, the safety case limit of 30 failures per year is not a manageable working level due to limited fuel route capacity for disposal of the affected fuel stringers. This would result in curtailment of reactor operations before the safety case limit is reached.

NGL has categorised the modification at Category 1, which is its highest nuclear safety category. The proposal has completed EDF NGL's due process, including consideration by its Nuclear Safety Committee and Independent Nuclear Assurance function.

Assessment and inspection work carried out by ONR in consideration of this request.

ONR has carried out a programme of work to produce assessments under the topics of Fuel Safety, Fault Studies and Chemistry. Full assessment reports have been produced for Fuel Safety and Fault Studies on the basis that the claims in EDF NGL's safety case are based on the understanding of the mechanism of fuel degradation and its implementation in fault analysis in terms of quantification of risk.

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Matters arising from ONR's work

The main areas of focus and discussion during this assessment were as follows:

- The adequacy of the understanding and extent of the fuel cladding degradation and failure mechanism.
- Implementation of the degraded fuel cladding condition in fault analysis used to determine the radiological risk associated with reactor faults.
- Confirmation that there is a suitable demonstration that risks have been reduced in so far as is reasonably practicable through countermeasures deployed by EDF NGL in response to the increased rate of operational fuel failures.
- Examination of EDF NGL's ongoing and increased governance arrangements for monitoring of the fuel cladding condition and control of the deployment and removal of risk reduction countermeasures.

Conclusions

I am satisfied with the claims, arguments and evidence laid down within the EDF NGL submission. In my judgement, in relation to this submission, EDF NGL have demonstrated that they have implemented risk reduction countermeasures such that the ongoing risk of operation of Heysham 1 Reactor 2 is demonstrably reduced in so far as is reasonable practicable.

Recommendation

Based on the findings presented in this PAR, I recommend that ONR gives Agreement to EDF NGL to implement the safety case, described in "NP/SC 7757 EC358854 Rev 000 Version 03, JCO - Continued Operation for Heysham 1 R2 following Detection of Multiple Fuel Failures in 2016".

Further recommendations to monitor the ongoing work in reducing risk associated with fuel degradation at Heysham 1 are included within the body of this project assessment report. These are captured in Regulatory Issue 5643 and will be monitored as part of ONR's normal regulatory activity.

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LIST OF ABBREVIATIONS

ALARP	As low as reasonably practicable
AGR	Advanced Gas cooled Reactor
AR	Assessment Report
EA	Environment Agency
EDF NGL	EDF Energy Nuclear Generation Limited
FAP	Fuel Assessment Panel
HoF	Health of Fuel
HTI	Heat Transfer Impairment
HYA	Heysham A nuclear power plant
JCO	Justification for Continued Operation
ONR	Office for Nuclear Regulation
PCI	Pellet Clad Interaction
PIE	Post Irradiation Examination
RGP	Relevant Good Practice
R2	Reactor 2
SAP	Safety Assessment Principle(s)
SFAIRP	So far as is reasonably practicable

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1 PERMISSION REQUESTED

1. The licensee requested (Ref. 1) the Office for Nuclear Regulation's (ONR) 'Agreement' under Licence Condition 22 (1) for the modification described in safety case NP/SC 7757 (EC358854) to justify continued operation of Heysham 1 Reactor 2 following the detection of multiple fuel failures in 2016.

2 BACKGROUND

2. Failure of an AGR fuel pin is a breach of the primary fission product barrier. A key input into AGR fault studies is the assumptions made on the fuel pin condition, as this affects the likelihood of fuel pin failures occurring during faults.
3. There has been a recent spate of operational fuel failures in Heysham 1 (HYA) Reactor 2 (R2); 16 failed fuel stringers (containing one or more fuel pins with a small breach in the fuel cladding) were identified in 2016. This meant that the previously defined safety case criteria of 10 failed fuel stringers per year was exceeded and suggested that the population of weakened fuel pins assumed was being challenged in this reactor.
4. The term "weakened" in the context of fuel cladding refers to fuel pins which have an increased probability of failure due to loss of ductility as a result of having been degraded. Operational fuel failures occurring in small numbers (single figures to tens) is, in the case of the systematic mechanism in this safety case, indicative of a larger population of weakened pins at risk in faults.
5. The fuel stringer failure rate at the other three potentially effected units (i.e. HYA R1 and Hartlepool R1 and R2) remains low and is judged by EDF NGL to remain well within the assumptions of the previous safety case from 2014. The EDF NGL submission supersedes the 2014 safety case for HYA R2 only and justifies continued operation with 6000 weakened fuel pins. This is claimed by EDF NGL to be consistent with a fuel failure rate of up to 30 fuel stringers per year, based on the latest post irradiation examination (PIE). However, this is a short term upper bound to the safety case and more restrictive long term limits are dictated by the licensee's ALARP assessment. In practice, the safety case limit of 30 failures per year is not a manageable working level due to limited fuel route capacity for disposal of the affected fuel stringers. This would result in curtailment of reactor operations before the safety case limit is reached.
6. EDF NGL's assessment of the degradation mechanism is that the stainless steel fuel cladding is failing in operation as a result of pellet cladding interaction (PCI) damage, which is a known damage mechanism. However, the propensity for damage by PCI has increased through loss of ductility. Reduction in ductility is brought about through operational transients which ultimately will exceed the creep life. This is accelerated by clad restructuring (increased grain size) brought about by increased temperatures caused by heat transfer impairment (HTI) as a result of carbon deposition which has been an ongoing issue for the advanced gas reactors (AGR) reactors. Carbon deposition levels observed in PIE have been following an increasing trend for HYA R2.
7. A number of countermeasures have been deployed in advance of the submission to reduce risks from weakened fuel and to reduce the rate of weakening, most significantly a reduction in reactor power of 10%. It is acknowledged that these countermeasures may take some time to provide a significant benefit. In time it is claimed by EDF NGL that the countermeasures will significantly reduce both the number of fuel failures and weakened pins.

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8. This EDF NGL submission (Ref. 1) sets out to demonstrate that risks are currently reduced to be ALARP in light of the elevated nuclear safety risk. It also implements a framework aimed at ensuring the condition of the fuel shall be brought back to within the assumptions of the 2014 safety case (aligned with the three sister reactors) and that risks remain ALARP in the future. EDF NGL also claim that this framework may also allow specific countermeasures to be relaxed in the future, provided criteria associated with the condition of the fuel are met.
9. NGL has categorised the modification at Category 1, which is its highest nuclear safety category. The proposal has completed EDF NGL's due process, including consideration by its Nuclear Safety Committee (Ref. 2) and Independent Nuclear Assurance function (Ref. 3).

3 ASSESSMENT AND INSPECTION WORK CARRIED OUT BY ONR IN CONSIDERATION OF THIS REQUEST.

10. ONR has carried out a programme of work to produce assessments under the topics of Fuel Safety, Fault Studies and Chemistry. Full assessment reports have been produced for Fuel Safety (Ref. 4) and Fault Studies (Ref. 5) on the basis that the claims in EDF NGL's safety case are based on the understanding of the mechanism of fuel degradation and its implementation in fault analysis in terms of quantification of risk.
11. The Chemistry topic assessor has produced an assessment note (Ref. 6). This is in recognition that the JCO is linked to the ongoing chemistry work in EDF NGL aimed at addressing carbon deposition. However, since the formal claims of the safety case are not chemistry based a lower level of assessment is proportionate.
12. EDF NGL and ONR engaged via level 4 meetings throughout the safety case production and assessment.
13. For this assessment effort has been concentrated on:
 - Confirming the adequacy of the EDF NGL assessment of the mechanism of fuel degradation and in turn the quantification of fuel pins that are assessed to be weakened.
 - Implementation of the effect of weakening of fuel pins in the fault analysis, focusing on the change in risk for the most significant reactor faults.
 - The safety case compared to the guidance in the ONR Safety Assessment Principles (SAPs).
 - The ALARP balance between deployed countermeasures and the assessed risk against the requirement that EDF NGL reduce risk in so far as is reasonably practicable (SFAIRP).
 - Implementation of countermeasures against the requirements of LC23 – Operating Rules.
 - Adequacy of EDF NGL's arrangements for assessing risk related to weakened fuel pins on an ongoing basis and for controlling changes to the risk reduction countermeasures such that it can be demonstrated that operation will remain ALARP.

4 MATTERS ARISING FROM ONR'S WORK

14. Within the fuel safety assessment (Ref. 4) the following aspects of the safety case were queried and adequate clarifications and further details were provided by EDF NGL:

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- The adequacy of analytical and empirical data for evaluating the fuel degradation mechanism and associated uncertainty. The evaluation relies on historical experimental data and limited current plant PIE. It was confirmed that this is adequately representative and appropriate conservatism has been applied where uncertainty exists.
 - Given that significant uncertainty remains in the number of fuel pins affected (estimated to be around 3000), that an appropriate level of conservatism has been applied to the number of fuel pins assessed to be at risk for the purposes of fault analysis (6000 pins).
 - The adequacy of countermeasures in terms of the risk being managed to ALARP. This included assessment of the arrangements to ensure the level of power reduction and the targeting of fuel stringers are adequately assessed. The potential for further power reduction was discussed and confirmed to be ineffective in terms of an additional consequential reduction in production of weakened fuel compared to the further costs incurred.
 - The adequacy of the implementation of countermeasures in EDF NGL's operating rules compared to the ONR guidance on LC23. This has included examination of the implementation of compliance arrangements controlled by the HYA nuclear safety group. This has confirmed that, where no formal operating rule has been included, control measures commensurate to the level of risk are in place.
 - Revised governance arrangements for control of deployment of countermeasures which has included examination of the output from the EDF NGL panel with responsibility for oversight and the success criteria defined in policy and procedure.
 - Assessed the output of safety case commitments. Most notable the production and implementation of the fuel risk monitor to confirm it is fit for purpose.
15. The fuel safety assessment has raised a number of recommendations with respect to the ongoing work in monitoring risk and managing the deployment or removal of countermeasures.
16. The fault studies assessment (Ref. 5) has sampled and sought adequate clarification of the EDF NGL safety case in the following areas:
- Appropriateness of the level of conservatism that have been applied where there is uncertainty. Particularly in the implementation of the increased number of weakened pins and reduction in creep ductility within fault analysis.
 - The increase in the assessed radiological risk compared to the ONR SAP target 4 for depressurisation, reactivity and shutdown cooling faults.
 - The increase in the assessed radiological risk compared to the ONR SAP target 8 for reactor and fuel route faults.
 - Adequacy of countermeasures designed to reduce the impact of faults such as changes to reactor trip settings to confirm that the changes go far enough when considering the overall ALARP position.
17. Whilst the fault studies inspector has been able to confirm that the level of assessed risk in his opinion remains ALARP, it is recommended that ONR should be informed of any intent to return the reactor to full power so that this position can be re-evaluated given the state of the fuel at that time.
18. The Chemistry assessment noted that relaxation of currently implemented countermeasures on the basis of changes to reactor coolant chemistry aimed at delivering reduction in carbon deposition will require confirmation of success. Since this will necessitate examination of fuel discharged from reactor it may require a long period of time to ascertain the impact on carbon deposition.

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19. Regardless of this, the Chemistry Inspector considered that the arrangements in place and the criteria against which the removal of countermeasures is assessed by EDF NGL are suitably robust.
20. The recommendations raised in these specialist assessments will be followed up and tracked through regulatory issue 5643.
21. I have consulted with the other relevant regulator, the Environment Agency (EA), to establish if they had any specific objections that would prevent ONR from issuing LI 617. The EA confirmed they do not object to ONR agreeing to implementation of this modification (Ref. 7).

5 CONCLUSIONS

22. This report presents the findings of ONR's assessment of NP/SC 7757 (EC358854), JCO - Continued Operation for Heysham 1 R2 following Detection of Multiple Fuel Failures in 2016 (Ref. 1).
23. To conclude, as the fuel's inspector, I am satisfied with the claims, arguments and evidence laid down within the EDF NGL submission (Ref. 1). My assessment has confirmed that the approach adopted by EDF NGL in addressing the increased rate of fuel failures and understanding the associated mechanism for weakening of fuel cladding is appropriate. The fault studies assessment has confirmed that although the risk position has changed, due to the population of weakened fuel pins increasing, the level of risk is ALARP and has been appropriately implemented in fault analysis.
24. In my judgement EDF NGL have demonstrated that they have implemented risk reduction countermeasures such that the ongoing risk of operation of HYA R2 is demonstrably reduced in so far as is reasonable practicable. Furthermore, whilst fuel failures are accepted by the safety case for AGRs, EDF NGL has stated that they intend to work towards a target of zero fuel failures, which is aligned with relevant good practice for power reactor operations. I have also considered the control and governance arrangements for the risk reduction countermeasures and consider them to be fit for purpose.
25. Notwithstanding my conclusion, there remains the need to continue to monitor the operation of HYA R2 and bring the fuel back into the design intent. EDF NGL is addressing this through ongoing programmes of work to monitor the fuel condition and bring about a reduction in carbon deposition on fuel. Whilst such programmes have existed in the past, the recent fuel failures (and reduction of electricity generation as a consequential response) have resulted in an increased level of investment. I have therefore raised recommendations through a revision to regulatory issue 5643 to ensure that these issues are appropriately addressed by EDF NGL and monitored by ONR.

6 RECOMMENDATIONS

26. Based on the assessment reports and conclusions discussed above I have made the following recommendations, which are captured in Regulatory Issue 5643:
 - Recommendation 1: EDF NGL should undertake the following activities and provide regular updates to ONR through routine level 4 interactions with a frequency no less than biannually:
 - a) EDF NGL should undertake an adequate programme of PIE and analysis to continue to improve understanding of the fuel degradation and failure mechanism in JCO EC358854.

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- b) EDF NGL should continue to develop and validate the fuel risk monitor against the plant operational parameters, operational fuel failures and PIE findings so that the process, empirical rules and model for assessment and prediction of fuel cladding weakening can be refined and improved.
 - c) EDF NGL's arrangements include the implementation of a Fuel Assessment Panel (FAP) which issues compelling advice regarding the deployment and lifting of countermeasures. EDF NGL should report the output of the FAP after a meeting is held and the trend in the number of weakened pins on a regular basis. EDF NGL shall provide forewarning to ONR of anticipated reduction in high significance fuel cladding protection countermeasures.
- Recommendation 2: EDF NGL should utilise the Health of Fuel (HoF) information in routine progress meetings with ONR under the topic of Fuel Safety so that the fleet-wide fuel risks are openly shared on a regular basis. EDF NGL shall review the implementation of the HoF against the requirements of the governing company policy after a period of two years and report this to ONR for consideration.
 - Recommendation 3: The effectiveness of the implemented countermeasures and the associated safety case (EC 358854) for reducing risk in so far as is reasonably practicable at HYA R2 shall be reviewed after a period of 2 years or at such time that the fuel is returned to its design intent (whichever is earliest).
 - Recommendation 4: Based on the progress delivered in EC358854 it is recommended that ONR revise regulator Issue 5643 to close action 1 and include additional actions to encapsulate the recommendations contained in the fuel safety assessment report (Ref. 4).
27. Based on the findings presented in this PAR, I recommend that ONR gives Agreement to EDF NGL to implement the safety case, described in "NP/SC 7757 EC358854 Rev 000 Version 03, JCO - Continued Operation for Heysham 1 R2 following Detection of Multiple Fuel Failures in 2016".

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7 REFERENCES

1. EDF NGL Letter NSL/HYA/50825(Y) - Request for Agreement or Acknowledgement under Arrangements made under Licence Condition 22(1) - NP/SC 7757 EC358854 Rev 000 Version 03, JCO - Continued Operation for Heysham 1 R2 following Detection of Multiple Fuel Failures in 2016 – TRIM 2017/420730.
2. EDF NGL Nuclear Safety Committees Minutes of the Meeting. 18 October 2017. TRIM 2017/420744.
3. EDF NGL EC358854 - INSA Comments and Approval Certificate. November 2017. TRIM 2017/443578.
4. ONR-OFD-AR-17-078 Revision 0 - Fuel Safety Assessment of the Justification for Continued Operation of Heysham 1 R2 Following Detection of Multiple Fuel Failures in 2016. TRIM 2018/10948.
5. ONR-OFD-AR-17-073 Revision 0 - Fault Studies Assessment of the Justification for Continued Operation of Heysham 1 R2 Following Detection of Multiple Fuel Failures in 2016. TRIM 2018/90886.
6. ONR Chemistry Assessment Note – Continued Operation for Heysham 1 R2 following Detection of Multiple Fuel Failures in 2016 (EC 358854). March 2018. TRIM 2018/94469.
7. Email confirming no objection from Environment Agency to agreement of NP/SC 7757 by ONR. 18 April 2018. TRIM 2018/131960.