Office for Nuclear Regulation

Assessment of NP/SC 7474 Add 2: Hartlepool / Heysham Extension of the Safety Case for the Reactivity Effects of Boiler Tube Failure Faults to End of Station Life

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EXECUTIVE SUMMARY

This report presents the findings of ONR's assessment of NP/SC 7474 Add 2 Hartlepool / Heysham 1: "Extension of the Safety Case for the Reactivity Effects of Boiler Tube Failure Faults to End of Station Life".

Permission Requested

NP/SC 7474 Add 2 has been submitted as a category 1 modification under the Licensee's arrangements for LC 22(4). The safety case covers changes at both Heysham 1 and Hartlepool power stations and EDF Nuclear Generation Ltd has requested agreement or acknowledgment to the changes at each station under their LC 22(1) arrangements. ONR has chosen to assess the safety case for agreement due to the safety significance of the limit which EDF Nuclear Generation Ltd seek to modify.

Background

During normal operation of an Advanced Gas-cooled Reactor, oxidation results in the gradual loss of the graphite moderator. As the moderation provided by the graphite decreases the amount of reactivity which can be inserted through the addition of a moderating material increases. Following a boiler tube leak, water in the form of steam can enter the active core; as water is an effective moderator this results in an increase of reactivity with increasing volumes of water ingress up to a maximum where the optimum fuel to moderator ratio is achieved. Therefore, as Graphite Weight Loss increases and the moderation provided by the graphite declines, the maximum reactivity insertion possible due to steam ingress increases.

The shutdown systems insert negative reactivity into the core to terminate the chain reaction, and their reactivity worth is essentially fixed; as Graphite Weight Loss increases, and thus the moderation provided by the graphite decreases, and the potential reactivity insertion due to steam ingress faults increases, the margin of shutdown supplied by the shutdown systems reduces in steam ingress faults. Shutdown Margin limits are set such that there is sufficient negative reactivity available from the shutdown systems to ensure shutdown and long-term hold-down of the reactors with high reliability. The station compliance routes must demonstrate that shutdown margin limits are met.

NP/SC 7474 Add 2 has been produced to raise the graphite weight loss limits at Heysham 1 and Hartlepool power stations to 17% and 20% from 12% and 17% respectively, but also presents justification for graphite weight loss up to 23% at Hartlepool power station, although the safety case does not seek to implement this as the limit. NP/SC 7474 Add 2 also seeks to implement revised shutdown margin limits based on a reassessment of the risk at the increased graphite weight loss limits. The justification for the increase in the graphite weight loss limits is based on the implementation of revised shutdown margin limits, and taking credit from improvements to the reliability of fault termination due to the previously justified installation of automatic protection and mitigation systems.

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 fault studies and structural integrity.

A fault studies assessment was undertaken which focussed on the fault analysis presented in NP/SC 7474 Add 2 , and whether the risks associated with the increased graphite weight loss limit are ALARP.

A Structural Integrity assessment was undertaken as the frequency of the initiating events (boiler tube failure frequencies) for the fault sequences of concern in the safety case depend on structural integrity arguments.

For this assessment, effort has been concentrated on:

- Confirming the adequacy of the methodology for the calculation of the reactivity effects of steam ingress.
- Confirming that the shutdown margin limits are appropriate for the increased levels of graphite weight loss.
- Comparing the safety case to guidance in the ONR Safety Assessment Principles and confirming the acceptability of the quantification of risk against ONR targets.
- Confirming that the boiler tube failure frequencies employed in the fault analysis are bounding, and that boiler tube integrity is appropriately managed.

Matters arising from ONR's work

The structural integrity assessment concluded that, based on the information sampled, the arguments and evidence supporting the boiler tube failure frequencies presented in NP/SC 7474 Add 2 are adequately conservative and appropriate.

The fault studies assessment concluded that, based on the information sampled, the fault analysis was adequate and that appropriate shutdown margin limits were derived for the increased graphite weight loss limits, and that ONR should agree to the changes proposed in NP/SC 7474 Add 2.

Conclusions

ONR considers that EDF NGL has provided sufficient evidence to adequately demonstrate that the risks associated with steam driven reactivity faults at Heysham 1 and Hartlepool power stations have been reduced SFAIRP.

Recommendation

The project assessment report recommends that ONR agrees to the changes to the shutdown margin limits and graphite weight loss limits proposed in “NP/SC 7474 Add 2, Extension of the Safety Case for the Reactivity Effects of Boiler Tube Failure Faults to End of Station Life”.

LIST OF ABBREVIATIONS

AGR	Advanced Gas-cooled Reactor
EDF NGL	EDF Nuclear Generation Limited
GWL	Graphite Weight Loss
HY1	Heysham 1 Power Station
HRA	Hartlepool Power Station
PCI	Pellet Clad Interaction
PSD	Primary Shutdown System
SAPs	Safety Assessment Principles
SDM	Shutdown Margin
SRV	Safety Relief Valve
SSD	Secondary Shutdown System
TSD	Tertiary Shutdown System
UTJ	Upper Transition Joint
SFAIRP	So Far as is Reasonably Practicable

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1 PERMISSION REQUESTED

1. NP/SC 7474 Add 2 (Ref. 1) has been submitted as a category 1 modification under the Licensee's arrangements for LC 22(4). The safety case covers changes at both Heysham 1 (HY1) and Hartlepool (HRA) power stations and EDF Nuclear Generation Ltd (EDF NGL) has requested agreement or acknowledgment to the changes at each station under their LC 22(1) arrangements (Refs. 2 & 3). ONR has chosen to assess the safety case for agreement (Ref. 4) due to the safety significance of the limit which EDF NGL seek to modify.

2 BACKGROUND

2. During normal operation of an Advanced Gas-cooled Reactor (AGR), oxidation results in the gradual loss of graphite moderator. As the moderation provided by the graphite decreases the amount of reactivity which can be inserted through the addition of a moderating material increases. Following a boiler tube leak, water in the form of steam can enter the active core; as water is an effective moderator this results in an increase of reactivity with increasing volumes of water ingress up to a maximum where the optimum fuel to moderator ratio is achieved. Therefore, as Graphite Weight Loss (GWL) increases and the moderation provided by the graphite declines, the maximum reactivity insertion possible due to steam ingress increases.

3. At HY1/HRA reactor shutdown/hold-down is provided by:

   - the Primary Shutdown (PSD) system which consists of control rods falling into the core under gravity,
   - the Secondary Shutdown (SSD) system which consists of Nitrogen injection,
   - and the Tertiary Shutdown (TSD) system which consists of Boron beads injected into hoppers in the reactor.

4. These systems insert negative reactivity into the core to terminate the chain reaction, and their reactivity worth is essentially fixed; as Graphite Weight Loss increases, and thus the moderation provided by the graphite decreases, and the potential reactivity insertion due to steam ingress faults increases, the margin of shutdown supplied by the shutdown systems reduces. Shutdown Margin limits are set such that there is sufficient negative reactivity available from the shutdown systems to ensure shutdown and long-term hold-down of the reactors with high reliability. The station compliance routes must demonstrate that shutdown margin limits are met.

5. NP/SC 7474 Add 2 has been produced to raise the GWL limits at HY1 and HRA to 17% and 20% respectively, but also presents justification for GWL up to 23% at HRA, although the safety case does not seek to implement this as the limit. NP/SC 7474 Add 2 also seeks to implement revised shutdown margin (SDM) limits based on a reassessment of the risk at the increased GWL limits. The justification for the increase in the GWL limits is based on the implementation of revised SDM limits, and taking credit from improvements to the reliability of fault termination due to the previously justified installation of automatic protection and mitigation systems.

2.1 LICENSEE'S SAFETY CASE

6. **Claim 1**: The risk from clad melt, fuel melt and Pellet Clad Interaction (PCI) -induced failure is low for all tube failure fault sequences for core average weight loss to 23%.

7. Claim 1 seeks to demonstrate that the reactivity insertion rates due to steam driven reactivity faults do not lead to a challenge to the fuel safety limits (clad melt, fuel melt), and that the risk of PCI fuel failures is tolerably low.

8. Claim 1 also presents evidence seeking to justify that the rate of negative reactivity insertion from the shutdown systems is sufficient to override the most onerous reactivity insertion due to steam driven reactivity faults, and thus justify that the shutdown systems are effective in fulfilling their design function.

9. **Claim 2**: The imposition of an SDM penalty ensures that the PSD provides a secure line of long-term hold-down for all faults where the PSD is claimed.

10. Claim 2 seeks to justify the SDM limits which the safety case seeks to implement, and presents evidence to justify the calculation methodology, and derive the bounding fault sequences used in the analysis.

11. **Claim 3**: The SSD/TSD continues to provide a second line of hold-down protection for frequent water ingress faults where Safety Relief Valves (SRVs) do not lift.

12. Claim 3 seeks to justify the SSD/TSD as a diverse line of shutdown and hold-down for faults in which the reactor SRV do not lift, but concedes that in the event of SRV lift the SSD cannot be justified as a reliable shutdown system.

13. **Claim 4**: The protection systems are robust against hazards and faults associated with water ingress faults.

14. Claim 4 restates the hazard qualification of the shutdown systems as presented in the previous safety cases, and does not represent any change in position.

15. **Claim 5**: The imposition of an SDM penalty ensures hold-down in all water ingress faults from a shutdown condition.

16. Claim 5 presents evidence seeking to justify that the SDM limit required to protect against at-power steam driven reactivity faults bounds the SDM limit required to protect against steam driven reactivity faults whilst shutdown.

17. **Claim 6**: The imposition of the SDM penalties in Technical Specification 4.1.1 to take account of the reactivity effects of steam ingress ensures that the risks associated with reactivity effects following boiler tube leaks are ALARP.

18. Claim 6 argues that the proposed SDM limits are sufficient to reduce risks to ALARP.

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

19. ONR has carried out a programme of work to produce assessments under the topics of fault studies and structural integrity.

20. A fault studies assessment was undertaken (Ref. 5) which focussed on the fault analysis presented in NP/SC 7474 Add 2 (Ref. 1), and whether the risks associated with the increased graphite weight loss limit were ALARP.

21. A Structural Integrity Assessment Report (Ref. 6) was produced as the frequency of the initiating events (boiler tube failure frequencies) for the fault sequences of concern in the safety case depend on structural integrity arguments.

22. For this assessment, ONR's assessment effort has been concentrated on:

- Confirming the adequacy of the methodology for the calculation of the reactivity effects of steam ingress.
- Confirming that the SDM limits are appropriate for the increased levels of GWL.

- Comparing the safety case to guidance in the ONR Safety Assessment Principles (SAPs) (Ref. 7) and confirming the acceptability of the quantification of risk against ONR targets.
- Confirming that the boiler tube failure frequencies employed in the fault analysis are bounding, and that boiler tube integrity is appropriately managed.

3.1 STRUCTURAL INTEGRITY ASSESSMENT

23. ONR's structural integrity assessment report (Ref. 6) sampled evidence in the following areas:

- The adequacy of the bounding boiler tube failure frequencies.
- The adequacy of EDF NGL's boiler tube integrity management arrangements.

24. NP/SC 7474 Add 2 (Ref. 1) states that the superheater tailpipe failure is the boiler tube failure mode which leads to the bounding fault sequence. This was confirmed by the fault studies assessment (Ref. 5). The structural integrity assessment considered the evidence in support of the given superheater tailpipe failure frequency and found that there were a number of conservatisms in the analysis. These conservatisms relate to the use of; lower bound material properties, upper bound metal losses, and modelling based on start of life wall thicknesses (which result in higher wall stresses). The structural integrity assessment concluded that the superheater tailpipe failure frequency used as an input to the fault analysis in NP/SC 7474 Add 2 (Ref. 1) was adequately bounding, and therefore appropriate.

25. NP/SC 7474 Add 2 (Ref. 1) states that a failure of the Upper Transition Joint (UTJ) is the boiler tube failure mode which leads to the second most onerous fault sequence. This was confirmed by the fault studies assessment (Ref. 5). The structural integrity assessment concluded that EDF NGL had not demonstrated adequate means of monitoring the damage mechanisms which would lead to a UTJ failure, but that the assumed failure frequencies were conservative in nature and thus the shortfall did not undermine the proposal. In support of this conclusion the fault studies assessment confirmed that there was significant margin between this second most onerous failure mode and the bounding fault sequences (i.e. superheater tailpipe failures).

26. The bounding boiler tube failure frequencies used as an input to the fault analysis in support of NP/SC 7474 Add 2 (Ref. 1) are effectively limits set in the safety case, as failure frequencies in excess of those used in the analysis would invalidate the assumptions of the safety case. The structural integrity assessment assessed the adequacy of EDF NGL's ability to appropriately manage compliance with the failure frequency limits set in Reference 1 and concluded that adequate arrangements are in place for the governance and oversight of boiler tube lifetime management.

3.2 FAULT STUDIES ASSESSMENT

27. ONR's fault studies assessment report (Ref. 5) sampled evidence in the following areas:

- The adequacy of the modelling of steam ingress rates and peak steam inventories in the reactor vessel.
- The adequacy of the modelling of the reactivity insertion rate and magnitude.
- The adequacy of the approach to demonstrating sufficient reactor hold-down, and deriving the required SDM limits.
- The acceptability of the risk quantification against ONR targets, including the potential effects of fuel failures resulting from a steam driven reactivity transient.

28. The steam ingress rates and peak volumes following a boiler tube failure were derived in the fault analysis performed in support of NP/SC 7474 Add 2 (Ref. 1) using the MACE transient analysis code. The fault studies assessment found that the MACE code is essentially a best-estimate code with conservatism introduced by the application of user-bias where appropriate, and judged that the results produced were adequately conservative given the conservatisms elsewhere in the analysis.

29. ONR's fault studies assessment reviewed evidence presented to justify the bounding tolerable reactivity insertion rate for preventing fuel limits being reached, and the most onerous credible reactivity insertion rate from a steam driven reactivity fault. The fault studies assessment concluded that the limiting reactivity insertion rate significantly bounded the most onerous credible reactivity insertion rate due to a boiler tube failure, and that as such the potential for fuel safety limits to be reached was not a concern. The fault studies assessment also concluded that the rate of insertion of negative reactivity by the shutdown systems significantly bounds the reactivity insertion of the most onerous credible steam driven reactivity fault, and that as such there is not a risk of failure to shutdown the reactor.

30. The reactivity effects of the steam ingress were calculated using the reactor physics code PANTHER, and the fault studies assessment concluded that the use of conservative moderator, fuel, and fuel sleeve temperatures and zero Xenon conditions ensured that the analysis was adequately conservative. The fault studies assessment also considered the validation of the reactivity insertion calculation methodology and concluded that there was an adequate supporting validation argument.

31. NP/SC 7474 Add 2 (Ref. 1) derived SDM limits associated with GWL levels such that the risk of failure to hold-down the reactor due steam driven reactivity faults is calculated to be adequately small. The fault studies assessment concluded that the derivation of the SDM limits was based on suitably bounding fault sequences and frequencies, and that the basis of the calculation of the SDM limits contains sufficient safety margin. The fault studies assessment therefore concluded that the SDM limits which NP/SC 7474 Add 2 (Ref. 1) proposes are appropriate for the increased GWL limits proposed (i.e. 17% at HY1, 20% at HRA). In addition, the fault studies assessment concluded that an appropriate SDM limit had been derived for a GWL of 23% at HRA, however NP/SC 7474 Add 2 (Ref. 1) states that there is no intention to implement this limit at this stage.

32. ONR's fault studies assessment concluded that the SSD cannot be claimed as a diverse shutdown system in the event of SRV lift, and that this represents a shortfall against EDF NGL's own guidance (Ref. 8). The fault studies assessment also concludes however that as this is not a change over the current position and the proposed changes to SDM limit and GWL limit do not impact the risk in this situation. Therefore, it does not represent an impediment to permissioning the changes proposed in NP/SC 7474 Add 2 (Ref. 1). ONR has raised regulatory issue 6890 to track the resolution to this shortfall as discussed in section 4 of this report.

33. ONR's fault studies assessment concluded that the increase in the risk of a radiological release due to fuel failures caused by a steam driven reactivity fault is tolerable at the increased levels of GWL specified in the safety case, and noted that Commitment 1 to NP/SC 7474 Add 2 (Ref. 1) seeks to reduce the assessed risk presented by such fuel failures.

4 MATTERS ARISING FROM ONR'S WORK

34. ONR's structural integrity assessment concluded that the UTJ failure frequencies were currently conservative, but that EDF NGL did not demonstrate an adequate means of monitoring the damage mechanisms which would inform their controls to prevent UTJ

failures. The assessment recommended that ONR engage with EDF NGL to judge the adequacy of their arrangements for long-term UTJ integrity management; this will be taken forward through routine structural integrity level 4 meetings. An item has been added to the agenda of the next level 4 structural integrity meeting in quarter 1 of 2019 to this effect.

35. ONR's structural integrity assessment concluded that the superheater tailpipe failure frequency is adequately bounding, and that compliance with the failure frequency limit set out in the safety case is adequately monitored; the assessment noted however that an update to the superheater tailpipe analysis to 2027 was ongoing at the time of the assessment and recommended that "The licensee should provide a copy of the update superheater tailpipe and bifurcation assessment (EC 363192), on its completion". This recommendation is to be tracked and managed through regulatory issue 6840, as a level 4 issue with the structural integrity specialist inspector.

36. ONR's structural integrity assessment stated that its conclusions are contingent on the licensee's fulfilment of the action described in regulatory issue 6840; however the structural integrity assessment also concluded that adequate arrangements were in place to ensure that the limit on the superheater tailpipe failure frequency were not exceeded. I therefore judge that it would be disproportionate to withhold permissioning of the modifications described in NP/SC 7474 Add 2 (Ref. 1) pending closure of regulatory issue 6840. In support of this conclusion I note that if the ongoing boiler compliance monitoring arrangements or the conclusions of the upcoming review of superheater tailpipe failure frequencies were to indicate that the limits set out in NP/SC 7474 Add 2 (Ref. 1) were exceeded, then EDF have appropriate arrangements in place to manage the consequences on the safety case via the Safety Case Anomalies Process.

37. ONR's structural integrity assessment concluded that the effects of a recent accidental sulphuric acid boiler dosing event do not undermine NP/SC 7474 Add 2 (Ref. 1) as the boiler tube failure frequency limit set in the safety case is adequately managed to ensure that the limits will not be breached; the increase in risk due to the event would be small; and there are significant conservatisms in the analysis. However, the assessment recommended that following the upcoming review of the effects of stress corrosion cracking "the licensee should confirm that the update of the boiler tube failure predictions, in light of the sulphuric acid contamination event, does not undermine the claims made in this safety case with respect to stress corrosion cracking contribution to boiler tube failure predictions". This recommendation is to be tracked and managed through regulatory issue 6840, as a level 4 issue with the structural integrity specialist inspector.

38. ONR's fault studies assessment judged that the predictions of steam ingress rates and peak steam volumes using the MACE code were adequately conservative due to the application of user bias in the calculations and the presence of significant conservatisms elsewhere in the analysis. The fault studies assessment concluded however that there was not an adequate validation argument for the steam ingress rate model in MACE, which represents a shortfall against relevant good practice. The fault studies assessment recommended that ONR engage with EDF NGL to further assess the shortfall and determine if evidence in support of the validation exists but was not readily available this topic is scheduled to be discussed at the next routine level 4 meeting between ONR and the relevant specialists from EDF NGL, and if necessary a regulatory issue will be raised following this engagement.

39. ONR's fault studies assessment concluded that the risk associated with PCI fuel failures following a steam driven reactivity fault were tolerable. However the assessment concluded that for the frequent superheater tailpipe failure fault with subsequent lifting of the SRVs there was a shortfall against relevant good practice.

For the Design Basis Analysis of a superheater tailpipe failure serval tens of PCI fuel failures are assessed as occurring due to the subsequent reactivity transient. In addition, the reactor pressure vessel SRVs would be assumed to open due to the pressure rise following the steam ingress. In this analysis there are no remaining barriers to a radiological release which represents a shortfall against relevant good practice, and the radiological release would be in excess of the Targets in the SAPs (Ref. 7). EDF NGL argues that the analysis of PCI failures is overly conservative, and that the real radiological consequences in this fault would not exceed the Targets in the SAPs.

40. ONR's fault studies assessment notes that there is a review of the methodology for the prediction of PCI failures ongoing, and that EDF NGL's expectation is that the radiological consequences of steam driven reactivity faults can be demonstrated not to exceed the Targets in the SAPs. On completion of this review EDF NGL has committed (i.e. Commitment 1 of NP/SC 7474 Add 2 (Ref. 1)) to review the probabilistic analysis of risk due to PCI failures following a steam driven reactivity fault. ONR's fault studies assessment therefore recommended that the Design Basis Analysis of the superheater tailpipe fault should also be reviewed by EDF NGL following the PCI methodology review. In addition, as part of this review, EDF NGL should consider any impact on the ALARP position associated with NP/SC 7474 Add 2 (Ref. 1). This recommendation is to be tracked and managed through regulatory issue 6890, as a level 4 issue with the fault studies specialist inspector. ONR's fault studies assessment noted that the PCI failures due to a steam driven reactivity fault are not sensitive to the changes proposed in NP/SC 7474 Add 2 (Ref. 1) (SDM limit and GWL limit) and thus the assessed shortfall should not impede permissioning of the modifications described in the safety case.

5 CONCLUSIONS

41. This report presents the findings of ONR's assessment of NP/SC 7474 Add 2, Extension of the Safety Case for the Reactivity Effects of Boiler Tube Failure Faults to End of Station Life.

42. To conclude, ONR is satisfied with the claims, arguments and evidence laid down within the safety case. The structural integrity assessment report concluded that the boiler tube failure frequencies employed in the fault analysis were adequately conservative and appropriate. The fault studies assessment report concluded that the fault analysis was adequate and that appropriate SDM limits have been derived for the increased GWL limits.

43. ONR considers that EDF NGL have provided sufficient evidence to adequately demonstrate that the risks associated with steam driven reactivity faults at Heysham 1 and Hartlepool power stations have been reduced SFAIRP.

6 RECOMMENDATIONS

44. The project assessment report recommends that ONR agree to the changes to the shutdown margin limits and graphite weight loss limits proposed in "NP/SC 7474 Add 2, Extension of the Safety Case for the Reactivity Effects of Boiler Tube Failure Faults to End of Station Life".

7 REFERENCES

1. EDF NGL Safety Case: NP/SC 7474 Add 2, Hartlepool/Heysham 1 Power Station Extension to the Safety Case for the Reactivity Effects of Boiler Tube Failure Faults to End of Station Life, October 2017, TRIM 2018/180466

2. EDF NGL Letter: CD/NP/SR, NSL/HRA/51180R, Request for Agreement or Acknowledgment under Arrangements made under Licence Condition 22(1), 09 January 2019, TRIM 2019/15489

3. EDF NGL Letter: 197/HYA//CAI – Revision 2, NSL/HYA/50837(Y) – Revision 2, Request for Agreement or Acknowledgment under Arrangements made under Licence Condition 22(1), 09 January 2019, TRIM 2019/12430

4. ONR Task Sheet: TS039, NP/SC 7474 - REACTIVITY EFFECTS OF BOILER TUBE FAILURE ADDENDUM 2, TRIM 2016/42713

5. ONR Assessment Report: ONR-OFD-AR-18-032 Revision 0, Fault Studies Assessment of NP/SC 7474 Add 2: HY1/HRA Extension of the Safety Case for the Reactivity Effects of Boiler Tube Failure Faults to End of Station Life, TRIM 2018/347006

6. ONR Assessment Report: ONR-OFD-AR-18-052 Revision 0, Hartlepool / Heysham 1. Extension of the safety case of the reactivity effects of boiler tube failure faults to end of station life. Structural Integrity Assessment, TRIM 2018/255266

7. *Safety Assessment Principles for Nuclear Facilities*. 2014 Edition Revision 0. November 2014. http://www.onr.org.uk/saps/saps2014.pdf.

8. EDF NGL Specification: EDF NGL Nuclear Safety Principles for AGRs -2014 BEG-SPEC-DAO-021 Rev 002, TRIM 2017/42123