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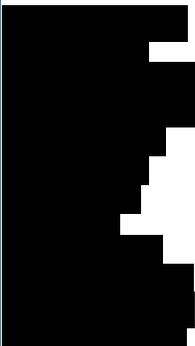
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**Assessment of the extension to the graphite weight loss limit to 10% at Dungeness B  
Power Station**

**Extension to the safety case for the reactivity effects of boiler tube failure including an  
increase in the graphite weight loss limit to 10%**

Project Assessment Report ONR-OFD-PAR-18-015  
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### EXECUTIVE SUMMARY

This Report presents the findings of ONR's assessment of EC 358816 "Extension to the safety case for the reactivity effects of boiler tube failure including an increase in the graphite weight loss limit to 10%."

#### Permission Requested

EC 358816 has been submitted at category 2 and was requested by ONR for 'review and consideration' under derived powers arrangements. ONR has chosen to assess this safety case because the justification for increasing the graphite weight loss limit to 8% has been previously agreed by ONR, and the new submission seeks to justify the increase in the Graphite Weight Loss limit further to 10%; this is a change to a significant safety limit.

#### Background

During normal operation of an Advanced Gas-cooled Reactor, oxidation results in the gradual loss of graphite moderator; as the moderation provided by the graphite decreases the amount of additional moderation required to reach the optimum fuel to moderator ratio 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.

NP/SC 7467 Addendum 2 extended the safety case up to a core average graphite weight loss of 8% based on a new assessment methodology which demonstrated increased margin for steam driven reactivity faults. EC 358816 now seeks to justify a further extension to the graphite weight loss limit up to 10%.

Although the graphite weight loss limit set in NP/SC 7467 Add 2 was 8%, the case presented justification for most types of steam driven reactivity faults up to a weight loss of 10%. The group of faults which limited the graphite weight loss justification in NP/SC 7467 Add 2 was steam driven reactivity faults whilst off-load due to the reduced protection available whilst shutdown. NP/SC 7467 Add 2 identified a strategy for increasing the graphite weight loss limit to 10% through further consideration and justification of off-load boiler tube failure faults; the proposed strategy included improvements to administrative procedures to reduce the probability of boiler tube failures whilst off-load and improve the reliability of operator actions to terminate off-load boiler tube failures. Justification of off-load boiler tube failure faults up to a graphite weight loss of 10% through implementation of the strategy identified in NP/SC 7467 Add 2 is the focus of this new submission.

In order to offset the increased risk associated with increased graphite weight loss EC 358816 introduces administrative controls on the Auxiliary Feed System - spurious operation of which accounts for a significant portion of the risk of a boiler tube failures whilst off-load – such that it is isolated in the most at risk shutdown state (off-load pressurised); this aims to reduce the probability of a boiler tube failure whilst off-load.

EC 358816 presents a review of the functional capability of the moisture in CO<sub>2</sub> monitoring system and seeks to justify that it is capable of detecting boiler tube failures down to low pressures (>2 barg) and temperatures, this – along with human factors analysis – supports an improved claim on the reliability of the operator to terminate the steam ingress following a boiler tube failure fault.

The reduction in the probability of off-load boiler tube failure faults, and the improvements to the reliability of operator actions following an off-load boiler tube failure fault are used to off-

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set the increased risk due to increased graphite weight loss. The assessed risk at 10% graphite weight loss from boiler tube failure faults whilst off-load is calculated to be significantly reduced from that calculated in NP/SC 7467 Add 2.

### **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.

An assessment report was produced for fault studies on the basis that the claims in EDF NGL's safety case are based on the demonstration that adequate protection is in place to protect against steam driven reactivity faults, and the adequacy of the fault analysis in terms of quantification of risk.

A Structural Integrity Assessment Report 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.

### **Matters arising from ONR's work**

The Structural Integrity Assessment Report examined the basis for the boiler tube failure frequencies applied to calculate risk due to 9% Cr oxidation. The assessment considered the methods, their validation, verification and outcome, and found each of these aspects to be satisfactory and that there was sufficient evidence that the assessment is both valid and conservative. The Structural Integrity Assessment Report concluded that application of the results of the structural integrity analysis to the derivation of boiler tube failure frequencies in the 10% graphite weight loss safety case is acceptable.

The Fault Studies Assessment Report concluded that the submission presents an adequate deterministic assessment of frequent boiler tube failure faults, and that the assessment of infrequent boiler tube failures demonstrates probabilistically that there is a sufficiently low likelihood of a large release and thus the submission gave an adequate demonstration that the risk position was ALARP.

### **Conclusions**

ONR is satisfied with the claims, arguments and evidence laid down within the safety case. The Structural Integrity Assessment Report concluded that application of the results of the structural integrity analysis to the derivation of boiler tube failure frequencies is acceptable and the Fault Studies Assessment Report concluded that the submission gave an adequate demonstration that the risk position was ALARP.

ONR considers that EDF NGL have provided sufficient evidence to adequately demonstrate that the risks associated with steam driven reactivity faults at Dungeness B Power Station have been reduced SFAIRP.

### **Recommendation**

Based on the findings presented in this PAR, ONR recommend that EDF NGL is allowed to proceed with the work to implement the modification described in "EC358816 Rev 00 Version 06, Extension to the Safety Case for the Reactivity Control of Boiler Tube Failure Including an Increase in the Graphite Weight Loss Limit to 10% for Off-Load Faults".

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### LIST OF ABBREVIATIONS

AFS	Auxiliary Feed System
AGR	Advanced Gas-cooled Reactor
ALARP	As Low As Reasonably Practicable
EDF NGL	EDF Nuclear Generation Limited
ESD	Enhanced Shut Down system
GWL	Graphite Weight Loss
ONR	Office for Nuclear Regulation
PAR	Project Assessment Report
PSD	Primary Shut Down system
SAP	Safety Assessment Principle(s)
SDM	Shut Down Margin
SFAIRP	So far as is reasonably practicable

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### 1 PERMISSION REQUESTED

1. The safety case (Ref. 1) has been submitted (Ref. 3) at category 2 and was requested by ONR for 'review and consideration' under derived powers arrangements (Ref 2). ONR has chosen to assess this safety case because the justification for increasing the Graphite Weight Loss limit to 8% has been previously agreed by ONR, and the new submission seeks to justify the increase in the Graphite Weight Loss limit further to 10%; this is a change to a significant safety limit.

### 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 additional moderation required to reach the optimum fuel to moderator ratio 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.
3. At DNB reactor shutdown is provided by the Primary Shutdown (PSD) system which consists of control rods falling into the core under gravity, and the Enhanced Shutdown (ESD) system which consists of a subset of control rods which are driven into the core. The ESD system is supported by nitrogen injection for long term hold-down. 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 maximum potential reactivity insertion due to steam ingress faults increases, the margin of shutdown supplied by the shutdown systems reduces in steam ingress faults.
4. Previous safety cases have been produced for Dungeness B justifying operation up to set weight loss limits. NP/SC 7467 (Ref. 6) initially addressed the issue, and justified operation up to a core average graphite weight loss (GWL) of 4.5%. NP/SC 7467 Addendum 1 (Ref. 7) extended the justification to a GWL of 6.2% based on the principle of an additional shutdown margin (SDM) penalty to mitigate the reactivity effects of steam ingress. NP/SC 7467 Addendum 2 (Ref. 8) then extended the safety case up to a core average GWL of 8% based on a new assessment methodology which demonstrated increased margin for steam driven reactivity faults. The new submission (Ref. 1) now seeks to justify a further extension to the GWL limit up to 10%.

### 2.1 LICENSEE'S SAFETY CASE

5. Although the GWL limit set in NP/SC 7467 Add 2 (Ref. 8) was 8%, the case presented justification for most types of steam driven reactivity faults up to a GWL of 10%. The group of faults which limited the GWL justification in NP/SC 7467 Add 2 (Ref. 8) was steam driven reactivity faults whilst off-load due to the reduced protection available whilst shutdown. NP/SC 7467 Add 2 (Ref. 8) identified a strategy for increasing the GWL limit to 10% through further consideration and justification of off-load boiler tube failure faults; the proposed strategy included improvements to administrative procedures to reduce the probability of boiler tube failures whilst off-load and improve the reliability of operator actions to terminate off-load boiler tube failures. Justification of off-load boiler tube failure faults up to a GWL of 10% through implementation of the strategy identified in NP/SC 7467 Add 2 (Ref. 8) is the focus of this new submission (Ref. 1).

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6. In order to offset the increased risk associated with increased Graphite Weight Loss Reference 1 introduces administrative controls on the Auxiliary Feed System (AFS), - spurious operation of which accounts for a significant portion of the risk of a boiler tube failures whilst off-load – such that it is isolated in the most at risk shutdown state (off-load pressurised); this aims to reduce the probability of a boiler tube failure whilst off-load.
7. Reference 1 presents a review of the functional capability of the moisture in CO<sub>2</sub> monitoring system and seeks to justify that it is capable of detecting boiler tube failures down to low pressures (>2 barg) and temperatures, this – along with human factors analysis – supports an improved claim on the reliability of the operator to terminate the steam ingress following a boiler tube failure fault.
8. The reduction in the probability of off-load boiler tube failure faults, and the improvements to the reliability of operator actions following an off-load boiler tube failure fault are used to off-set the increased risk due to increased Graphite Weight Loss. The assessed risk at 10% GWL from BTF faults whilst off-load is calculated to be significantly reduced from that calculated in NP/SC 7467 Add 2 (Ref. 8).
9. Reference 1 also seeks to use the most recent assessment of the risk of boiler tube failures to justify that the risk assessed in NP/SC 7467 Add 2 (Ref. 8) for at-power faults remains bounding for at-power faults until the 2020 outage for R21 and the 2021 outage for R22. The deterministic safety analysis makes use of the probability of a boiler tube failure fault to determine the level of protection required to protect against that fault.

### 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 fault studies and structural integrity.
11. An assessment report was produced for fault studies (Ref. 4) on the basis that the claims in EDF NGL's safety case are based on the demonstration that adequate protection is in place to protect against steam driven reactivity faults, and the adequacy of the fault analysis in terms of quantification of risk.
12. A Structural Integrity Assessment Report (Ref. 5) 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.
13. For this assessment, effort has been concentrated on:
  - Confirming the adequacy of the steam ingress calculation route given the reduced margin in the new submission.
  - The adequacy and functional capability of the protection systems.
  - The acceptability of the quantification of risk against ONR targets (Ref. 10).
  - The safety case compared to the guidance in the ONR Safety Assessment Principles (SAPs) (Ref. 10).
  - Confirming that the boiler tube failure frequencies were derived using appropriate methodologies.

### 4 MATTERS ARISING FROM ONR'S WORK

14. The Fault Studies Assessment Report (Ref. 4) sampled evidence in the following areas with adequate clarifications and further details provided by EDF NGL:

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- The validation of the steam ingress calculation methodology and the treatment of uncertainty within the calculation.
  - That sufficient lines of protection are available to protect against the various faults.
  - The substantiation of the moisture in CO<sub>2</sub> monitoring equipment down to low temperatures and pressures such that it can form part of a functional line of protection for boiler tube leaks when the reactor is shutdown.
  - That sufficient time is available for operator actions.
  - Acceptability of the changes to the way in which some fault sequence frequencies were calculated.
  - That the overall risk is ALARP.
15. The Fault Studies Assessment Report concluded that the submission presents an adequate deterministic assessment of frequent boiler tube failure faults, and that the assessment of infrequent boiler tube failures demonstrates probabilistically that there is a sufficiently low likelihood of a large release and thus the submission gave an adequate demonstration that the risk position was ALARP.
16. The Fault Studies Assessment Report noted that the submission did not consider the effect of uncertainties associated with graphite weight loss, as EDF NGL's strategy was to set the limit with this submission and then consider the uncertainties associated with graphite weight loss as part of the relevant graphite weight loss safety case (A separate safety case which determines the current state of the graphite cores with respect to GWL). The Fault Studies Assessment Report accepted this strategy but noted that ONR's graphite specialist assessors should ensure that the uncertainties associated with graphite weight loss are adequately considered in the relevant graphite weight loss safety case.
17. The Structural Integrity Assessment Report (Ref. 5) examined the basis for the boiler tube failure frequencies applied to calculate risk due to 9% Cr oxidation. The assessment considered the methods, their validation, verification and outcome, and found each of these aspects to be satisfactory and that there was sufficient evidence that the assessment is both valid and conservative. The Structural Integrity Assessment Report concluded that application of the results of the structural integrity analysis to the derivation of boiler tube failure frequencies in the 10% GWL safety case is acceptable.
18. Following the production of the Fault Studies and Structural Integrity Assessment Reports supporting this assessment an error was discovered in EDF NGL's boiler tube failure assessment methodology; this is being managed via a regulatory issue (6432) to determine the impact of the error. ONR's structural integrity specialist assessors (Ref. 11) have confirmed that the error does not impact the boiler tube failure frequencies relevant to Reference 1 as the error occurred in later analysis of boiler tube failure frequencies.

## 5 CONCLUSIONS

19. This report presents the findings of ONR's assessment of EC358816 Rev 00 Version 06, extension to the safety case for the reactivity control of boiler tube failure Including an Increase in the graphite weight loss limit to 10% for off-load faults.
20. To conclude, ONR is satisfied with the claims, arguments and evidence laid down within the safety case. The Structural Integrity Assessment Report concluded that application of the results of the structural integrity analysis to the derivation of boiler tube failure frequencies is acceptable and the Fault Studies Assessment Report

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concluded that the submission gave an adequate demonstration that the risk position was ALARP.

21. ONR considers that EDF NGL have provided sufficient evidence to adequately demonstrate that the risks associated with steam driven reactivity faults at Dungeness B Power Station have been reduced SFAIRP.

### **6 RECOMMENDATIONS**

22. Based on the findings presented in this PAR, ONR recommend that EDF NGL is allowed to proceed with the work to implement the modification described in “EC358816 Rev 00 Version 06, Extension to the Safety Case for the Reactivity Control of Boiler Tube Failure Including an Increase in the Graphite Weight Loss Limit to 10% for Off-Load Faults”.

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