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**Assessment of the Safety Case
NP/SC 7154 Addendum 6 - Hartlepool and Heysham 1 –
Boiler Tube Leaks on a Shutdown Reactor, April 2014**

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EXECUTIVE SUMMARY

Assessment of the Safety Case NP/SC 7154 Addendum 6 - Hartlepool and Heysham 1 – Boiler Tube Leaks on a Shutdown Reactor, April 2014

This report presents the conclusions from ONR's assessment of the Safety Case NP/SC 7154 Addendum 6 - Hartlepool and Heysham 1 – Boiler Tube Leaks on a Shutdown Reactor - further referred to as "the Safety Case".

The Safety Case has been produced by the licensee for Hartlepool and Heysham 1 power stations, EdF Energy Nuclear Generation Limited, to support the modifications implemented to address the risk of Boiler Tube Leaks when the reactor is shut down.

Permission Requested

The licensee has requested ONR's Acknowledgement or Agreement of the Safety Case under Licence Condition 22(1), in order to enable finalising the administrative arrangements for the implemented plant modifications.

Background

In an Advanced Gas-Cooled Reactor, the boilers remove heat from inside the reactor pressure vessel and thus prevent the fuel from overheating, which would lead to failure of the fuel cladding, and consequently - to radioactive release into the reactor pressure vessel and from there to the environment. When the reactor is shut down the nuclear fuel continues to produce heat via radioactive decay - hence the heat removal requirement on the boilers remains.

The boilers are arranged in four quadrants, each of which can operate independently to cool the reactor. A boiler tube leak renders the respective quadrant unavailable for this function.

The Gas Circulators provide forced circulation of the primary coolant gas which transfers heat from the fuel to the boilers. Under certain conditions this heat transfer can also proceed through natural circulation (convection), but when the amount of heat is too high or the coolant gas pressure is too low, natural circulation is insufficient. In these circumstances the gas circulators are essential for the base safety function of fuel cooling.

After the reactor is shut down the station is in outage (shutdown mode) and feed water is supplied to the boilers by one of the following systems:

- Emergency Boiler Feed pumps – normally used during the first 2 hours
- 50% Back-up Feed pumps - normally used for the next 2-3 days
- Decay Heat removal Loop at Hartlepool / Outage Cooling System at Heysham 1 – normally used after the first 2-3 days until the end of the outage.

Regardless of the normal use periods outlined above, the station operators may use any of the three systems as necessary at any time during the outage.

In case of a boiler tube leak, the flow-rate provided by the operating feed water system will leak into the reactor pressure vessel. The nuclear safety issues related to this water ingress are:

- Reactivity faults caused by the introduction of water which is a moderator
- Over-pressurisation of the reactor pressure vessel due to steam generation.
- Reduction or loss of fuel cooling:
 - Cooling capability reduction due to loss of water flow through the faulty boiler
 - Failure of forced circulation due to water ingress into the motors of the reactor Gas Circulators

- Flooding of the reactor pressure vessel lower plenum causing failure of the Gas Circulators and hence of forced circulation, as well as blockage of their outlet ports which also inhibits natural circulation

The Safety Case notes that the protections from reactivity faults and reactor pressure vessel over-pressurisation have been justified in other submissions (Ref. 5 – references 3, 4 & 5) and claims that the recently implemented protections against reduction and loss of fuel cooling have brought the overall risk from boiler tube leaks at shutdown to As Low As Reasonably Practicable (ALARP) level.

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

The Safety Case was subject to assessment by a team of ONR specialist inspectors in the following specialist areas:

- Structural Integrity
- Fault Studies
- Human Factors

A meeting was held with NGL during the assessment period to discuss some initial findings. NGL provided presentations and responses which have been found fit for purpose and reflected in the Fault Studies assessment report (Ref. 8).

The Safety Case comprises eight claims supported by arguments and underpinning evidence. Each of the claims has been assessed by one or more ONR specialist inspectors. The conclusions of these assessments are summarised in this Project Assessment Report.

Matters arising from ONR's work

The judgements of the assessment inspectors are unified to support a recommendation that ONR should grant Agreement of the Safety Case as requested by the licensee.

Overall, ONR was satisfied that the Safety Case, the supporting references and the other relevant documents, presented by the licensee, provide an adequate justification for the ALARP level of risk from Boiler Tube Leaks on a Shutdown Reactor at Hartlepool and Heysham 1.

Conclusions

Based on the specialist assessments, and the Project Inspector's review of the Safety Case, ONR was satisfied that the claims, arguments and evidence laid down within the NGL submission are adequate and support the request for Agreement of the Safety Case.

ONR concluded that it is appropriate for ONR to grant an Agreement of the Safety Case under Licence Condition 22(1) by the issuing of Licence Instruments 562 for Hartlepool and 613 for Heysham.

Recommendations

It was recommend that ONR should continue to engage with the licensee in order to ensure that:

- the changes to plant operation documents which are introduced at Heysham 1 in relation to the Safety Case (Ref. 5), are also introduced at Hartlepool.
- the operator training programmes emphasize consideration of the reduced protection when using the Emergency Boiler feed Pumps at shutdown (automatic stop of boiler feed is not available).

It was recommend that Licence Instruments 562 for Hartlepool site and 613 for Heysham site should be issued to grant Agreement under Licence Condition 22(1) of "Safety Case NP/SC 7154 Addendum 6 - Hartlepool and Heysham 1 – Boiler Tube Leaks on a Shutdown Reactor, Revision 000, Proposal Version No: 2, April 2014".

LIST OF ABBREVIATIONS

ALARP	As low as is reasonably practicable
BMS	Business Management System
DHL	Decay Heat removal Loop
EBF	Emergency Boiler Feed
FS	Fault Studies
GC	Gas Circulators
HF	Human Factors
HOW2	(ONR) Business Management System
HAR	Hartlepool power station
HYA	Heysham 1 power station
LC	Licence Condition
LI	Licence Instrument
NGL	EDF Energy Nuclear Generation Limited
OCS	Outage Cooling System
ONR	Office for Nuclear Regulation
PSA	Probabilistic Safety Assessment
PAR	Project assessment report
PVCW	Pressure Vessel Cooling Water
RACW	Reactor Ancillary Cooling Water
RV	Reactor Vessel
RVFDS	Reactor Vessel Flood Detection System
SAP	Safety Assessment Principle(s)
SOI	Station Operating Instructions
SRV	Safety Relief Valve
StI	Structural Integrity
50%BF	50% Back-Up Feed Pump

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1 BACKGROUND

1. In the event of a boiler tube leak (BTL), the flow-rate provided by the operating feed water system will leak into the reactor pressure vessel (RV). The nuclear safety issues related to this water ingress are:
 - Reactivity faults caused by the introduction of water which is a moderator.
 - Over-pressurisation of the RV due to steam generation.
 - Reduction or loss of fuel cooling:
 - Cooling capability reduction due to loss of the fault boiler quadrant.
 - Failure of forced circulation due to water ingress into the motors of the Gas Circulators (GC).
 - Flooding of the RV lower plenum causing failure of the GCs and blockage of their outlet ports which inhibits natural circulation.
2. The protections from reactivity faults and RV over-pressurisation have been justified in other submissions (Ref. 5 – references 3, 4 & 5).
3. The protection from reduction or loss of fuel cooling is currently justified by an interim Safety Case which assumes that the protective modifications planned back in 2010 are implemented. However, in 2012-2014 the protection strategy was revised due to technical challenges, and the following actions were taken:
 - Improvement of the Off-Load Moisture Monitoring System in order to reduce the time for its response to water ingress.
 - Both stations have installed a Reactor Vessel Flood Detection System (RVFDS), which automatically stops the feed flow provided by the 50% Back-up Feed pumps (50%BF) or by the Decay Heat removal Loop (DHL) at HAR / Outage Cooling System (OCS) at HYA upon indication for presence of water in the RV lower plenum.
 - The third shutdown feed system - Emergency Boiler Feed (EBF) can only be stopped by the operators, as it provides important protection in other transients in which a spurious automatic termination of the feed flow is not acceptable. Availability of sufficient time for this action has been confirmed by Human Factors analysis.
4. In order to take account of the implemented protections, EdF Energy Nuclear Generation Limited (NGL) has developed the Category 1 “Safety Case NP/SC 7154 Addendum 6 - Hartlepool and Heysham 1 – Boiler Tube Leaks on a Shutdown Reactor, Revision 000, Proposal Version No: 2, April 2014” (Ref. 5), which is further referred to as “the Safety Case”.
5. The Safety Case (Ref. 5) justifies the sufficiency of these protections by statement of eight claims, each supported by a set of arguments based on different types of evidence (structural integrity analyses, fault studies and human factor analyses, etc.). The Safety Case estimates the efficiency of the introduced plant modifications, as well as the timescales available for operator actions. It supersedes the interim safety case and the long term safety case for BTL on a shutdown reactor at HAR and /HAR.
6. Having noted that the protection from reactivity faults has been discussed in other submissions, the Safety Case supports the conclusion that the currently installed protective systems have reduced the risk from BTL at shutdown to ALARP level.

2 PERMISSION REQUESTED

7. NGL has requested ONR's Acknowledgement or Agreement of the Safety Case under Licence Condition 22(1), to enable finalising the administrative arrangements for the implemented plant modifications (Ref. 3).
8. This PAR presents a summary of the results from the Safety Case assessments undertaken by ONR's specialist inspectors.

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

9. The Safety Case was subject to assessment by a team of ONR inspectors specialised in the following areas:
 - Fault Studies (FS).
 - Structural Integrity (StI).
 - Human Factors (HF).
10. The FS and StI inspectors held a level 4 meeting with NGL during the course of the assessment, in order to gain clarity on some of the questions raised and to receive an update on the current status of the modifications (Ref. 8 - reference 17).
11. The Safety Case presents a set of arguments and underpinning evidence to support the following claims (Ref. 5):

Claim 1: BTF flow rates at shutdown remain bounded by single guillotine tube failures above the bifurcation, and multiple guillotine failures remain only a very remote possibility.

Claim 2: Water ingress faults arising from breaches in the Reactor Ancillary Cooling Water (RACW) or Pressure Vessel Cooling water (PVCW) systems whilst shutdown remain bounded by faults arising from boiler tube leaks at shutdown.

Claim 3: Pressure boundary integrity will be maintained with acceptable reliability following boiler tube failures at shutdown.

Claim 4: GC exposed to moisture laden gas are likely to remain available even for large leak rates estimated for a guillotine tube failure, whether on EBF, 50% BF or OCS/DHL cooling.

Claim 5: Adequate moisture monitoring systems are now installed to enable a claim on forced circulation cooling for the bounding single guillotine tube failure.

Claim 6: Compliance with the Deterministic Shutdown Criteria has been demonstrated, and the risks arising from any shortfalls are identified.

Claim 7: Reactor conditions are stable within the 48 hour mission time and recovery actions for removal of feed water from the vessel are defined in Station Procedures to ensure reactor integrity in the long term.

Claim 8: Risks arising from water ingress faults during shutdown are ALARP and no further plant modifications are required.

12. The credibility of each of these claims has been assessed by one or more specialist assessment inspectors. The conclusions are presented in detail within the respective assessment reports (Refs 8 – 10) and are summarised in Section 4 below.

13. The assessment method has followed the ONR Assessment Process set out within How2 (Ref. 1). The relevant ONR Safety Assessment Principles (SAPs – Ref. 2) have been applied by each of inspectors and are listed in their reports (Refs. 8 – 10). The outcomes of these assessments have been summarised in this PAR to inform ONR’s decision regarding Agreement of the Safety Case.

4 ONR’S ASSESSMENT

14. The StI inspector has reviewed the structural integrity arguments and evidence which support Claim 1. The FS inspector has carried out an assessment of claims 2 – 8.
15. Correspondence has been established and a Level 4 meeting was arranged with NGL to clarify some of the Safety case statements (Ref. 8 – references 12, 14, 17, etc.).

4.1 NOVEL ASPECTS INTRODUCED AS PART OF THE MODIFICATION

16. The Safety Case and the additional clarifications present a set of protections against the risk for reduction or loss of fuel cooling in the event of BTL at shutdown:
- Changes to plant:
 - Improvement of the Off-Load Moisture Monitoring System in order to reduce the time for its response to water ingress.
 - Installation of RVFDS which automatically stops the feed flow provided by the 50%BF or by the DHL/OCS upon indication for presence of water in the RV lower plenum.
 - Rearrangement of the feed line via WF/67Y valve:
 - a) WF/67Y valve provides backup to the WF/58 feed control valve, and is capable of limiting the feed flow to around the 17kg/s limit by itself in the event of a WF/58 failure.
 - b) The additional resistance provided by the WF/67Y valve reduces the pressure drop across the upstream WF/58 feed control valve, reducing the likelihood of failure.
 - Changes to the Station Technical Specifications:
 - The boiler feed flow has been limited to 17kg/s, based on the Safety Case estimate that this allows over 30 minutes for operator’s actions to prevent critical flooding.
 - The availability of the RVFDS and of the supporting Off-Load Moisture Monitoring System and Basement Off-load Moisture Monitoring System has been introduced to the stations Technical Specifications.
 - Changes to the Station Operating Instructions (SOI):
 - 50% BF operation on minimum discharge pressure at shutdown.
 - Instructions to maximise Nitrogen purge flow to GC motor compartments upon detection of a BTL.
 - Avoid operation of GC main motors above 5bar(g) as the Safety Case has indicated that prevention of water ingress into the GC motors by nitrogen purge becomes ineffective at higher pressure values.
17. Upon my request the FS Inspector has contacted the licensee and has provided additional clarification on the status of modifications implementation at each of the HYA/HAR stations (Ref. 11). A summary of this information is presented below:

- All plant modifications relating to the Safety Case have been installed and are the same at both HYA and HRA
- Currently (April 2017) operation documents modifications are introduced, as follows:
 - Instructions to operate 50% BFP on minimum discharge pressure whilst shutdown have been introduced to the SOIs - *Implemented at HYA, changes to SOIs prepared for HRA for implementation following test run in R1 April/May Refuelling outage.*
 - Instructions to maximise Nitrogen purge flow to GC motor compartments upon detection of a boiler tube failure have been introduced to the SOIs - *Implemented at HYA, at HRA reference is made from the SOIs to a procedure which contains the advice.*
 - Advice has been issued to caution against operation of GC main motors above 5bar(g) as purge not demonstrated to be effective - *Instructions included in HYA SOIs, changes drafted at HRA and are undergoing approval prior to implementation in May.*
 - Operation via WF/67Y valve to introduce additional flow resistance into the feed line - *Implemented at HYA where this is now normal practice, awaiting testing at HRA at end of April, although SOI changes for this have been drafted and are awaiting approval in May.*
- All other related improvements are implemented at both stations.

4.2 STRUCTURAL INTEGRITY ASSESSMENT

Claim 1: BTF flow rates at shutdown remain bounded by single guillotine tube failures above the bifurcation, and multiple guillotine failures remain only a very remote possibility.

18. The Stl inspector has carried out an assessment (Ref. 9) of the arguments and evidence supporting Claim 1. Additional clarification was provided in (Ref. 12). The main conclusions of this work are presented below:
- The licensee has appropriate arrangements to monitor and manage the environmental conditions of the boilers during wet or dry lay-up, to minimise the effects of environmental degradation of boiler tubes during shutdown.
 - The likelihood of a BTF at shutdown is low and NGL's assessment of the fault as infrequent can be supported.
 - The presented arguments are adequate to demonstrate that guillotine failure of a boiler tube remains the bounding case at a failure tolerability of $\leq 10^{-3}$ p.a, therefore the likelihood of multiple tube failures is below this value.
 - Adequate margins between the expected system operational stresses and the component allowable stresses have been demonstrated by the seismic assessment performed as part of the at power BTF safety case.
19. The Stl assessor was broadly satisfied that the arguments and evidence presented in support to Claim 1 are adequate.

4.3 FAULT STUDIES ASSESSMENT

Claim 2: Water ingress faults arising from breaches in the RACW or PVCW systems whilst shutdown remain bounded by faults arising from boiler tube leaks at shutdown.

20. The FS inspector has judged Claim 2 to be sufficiently supported by the arguments and evidence that the PVCW or the RACW system could only become sources of relatively small leaks into the RV - allowing extended timescales for the operator to identify the leak and terminate it (Ref. 8).

Claim 3: Pressure boundary integrity will be maintained with acceptable reliability following boiler tube failures at shutdown.

21. Claim 3 was found to be supported adequately by the FS assessment (Ref. 8), considering that the most onerous pressure transient covered by the Safety Case is bounded by the at power case due to the lower power output, temperatures and pressures at shutdown. The argument that the BTL would not impede the resealing of the reactor vessel was found reasonable, considering the availability of clear indications to the control room operators and appropriate instructions to ensure that boilers and gas circulators are configured correctly when the reactor is shut down in air during an outage.

Claim 4: Gas circulators exposed to moisture laden gas are likely to remain available even for large leak rates estimated for a guillotine tube failure, whether on EBF, 50% BF or OCS/DHL cooling.

22. Having reviewed the supporting evidence, the FS inspector has agreed that forced gas circulation will be available in the event of a BTF combined with an infrequent seismic event preventing vessel reseal. This judgement is based on the demonstrated capability of the nitrogen purge system to protect the GC from water ingress when the RV is depressurised and on the long timescales available for the operator to initiate GC purge flow.

Claim 5: Adequate moisture monitoring systems are now installed to enable a claim on forced circulation cooling for the bounding single guillotine tube failure.

23. The adequacy of the protection against lower plenum flooding and the conservatism in the analysis were the main subjects of FS assessment. The detailed HF assessment (Ref. 10) has concluded that the operator has sufficient time and information to prevent loss of forced circulation. Significant margin has also been demonstrated between the loss of forced circulation and the loss of natural circulation, which is the claimed line of protection in most plant states. The FS inspector has judged that this meets adequately the requirements of SAPs FA.4 & FA.7 (Ref. 2).

Claim 6: Compliance with the Deterministic Shutdown Criteria has been demonstrated, and the risks arising from any shortfalls are identified.

24. The classification of a BTF in the region of the upper transition joint at shutdown as an infrequent fault was reviewed and accepted by the StI inspector. The FS inspector has carried out an analysis of the provided evidence against the SAPs Numerical Targets (Ref. 2) to conclude that the risk from this fault is acceptable.

25. At shutdown the boilers are likely to be water solid which reduces significantly the corrosion-related risk and long timescales are available for the operators to terminate the feed to the leaking boiler and ensure provision of primary cooling either through natural or forced gas circulation and supply of feed water to the intact boiler circuits. Considering the demonstration of the above factors in the Safety Case, the FS inspector has concluded that Claim 6 is sufficiently supported.

Claim 7: Reactor conditions are stable within the 48 hour mission time and recovery actions for removal of feed water from the vessel are defined in Station Procedures to ensure reactor integrity in the long term.

26. The FS inspector has observed that the critical safety tasks in case of BTL at shutdown are to ensure the feed to the failed boiler is terminated promptly and to arrange cooling of the reactor by the available intact boilers.
27. The FS inspector has concluded that the Safety Case and the additionally provided evidence have demonstrated availability diverse methods for identification of the leaking boiler and sufficiently long scales for appropriate operator actions. Hence Claim 7 has been judged acceptable.

Claim 8: Risks arising from water ingress faults during shutdown are ALARP and no further plant modifications are required.

28. The FS inspector has reviewed the licensee's report on the evaluation of available options for protecting against BTL on a shutdown reactor, and has found this investigation sufficiently detailed. Following a challenge by the FS inspector, the licensee has submitted a simplified PSA analysis of EBF use while the reactor is shutdown in air. Having considered this evidence and the actual improvements of the operating documentation introduced to HYA and planned for introduction at HAR, the FS inspector has found an improvement over the situation presented in the Safety Case, reflecting the licensee's commitment to reduce the risk to ALARP level.
29. The FS Inspector has recommended that ONR should continue to engage with NGL in order to ensure that:
 - the changes to plant operation documents which are introduced at HYA in relation to the Safety Case (Ref. 5), should be also introduced at HRA.
 - the operator training programmes emphasize consideration of the reduced protection when using EBF at shutdown (no automatic stop of boiler feed).

4.4 HUMAN FACTORS ASSESSMENT

30. The HF Inspector has only carried out a brief review (Ref. 10) of the Safety Case to conclude that the declared task times to respond to the alarm conditions for BTL at shutdown are based on an adequate level of substantiation. This conclusion was used to support the FS assessment of the Safety Case (e.g. Claim 5 above).

4.5 REVIEW OF NGL'S INTERNAL APPROVAL PROCESS

31. Having reviewed the report from the NGL's Independent Nuclear Safety Assessment (Ref. 6) and the minutes of the relevant Nuclear Safety Committee meeting (Ref. 7), the FS inspector has concluded that the Safety Case has completed NGL's own due processes and that no issues have been identified that would prevent implementation of the proposed modifications.
32. My own review of (Refs. 6 & 7) has confirmed the above conclusion and I am satisfied that the Safety Case has been subject to an appropriate internal review process.

5 CONCLUSIONS

33. Based on my review of the assessments undertaken by the specialist assessment inspectors summarised above, I am satisfied that the presented claims, arguments and evidence provide confidence that the risk from BTL at shutdown is reduced to an ALARP level at HYA/HAR.
34. I conclude that it is appropriate for ONR to permission the Safety Case (Ref. 5) granting Agreement under LC22 (1).

35. The relevant LI is one of the standard documents covered by ONR Management System Guidance and, therefore, it has been prepared to satisfy the standard pro-forma and does not require review by Government Legal.

6 RECOMMENDATIONS

36. I recommend that ONR should continue to engage with NGL in order to ensure that:

- the changes to plant operation documents which are introduced at HYA in relation to the Safety Case (Ref. 5), are also introduced at HRA.
- the operator training programmes emphasize consideration of the reduced protection when using EBF at shutdown (no automatic stop of boiler feed).

37. I recommend that Licence Instruments LI 562 for Hartlepool and LI 613 for Heysham should be issued to grant Agreement under LC 22(1) of "Safety Case NP/SC 7154 Addendum 6 - Hartlepool and Heysham 1 – Boiler Tube Leaks on a Shutdown Reactor, Revision 000, Proposal Version No: 2, April 2014".

7 REFERENCES

1. ONR HOW2 Guide - Purpose and Scope of Permissioning - NS-PER-GD-014 Revision 4. July 2014. <http://www.onr.org.uk/operational/assessment/index.htm>
2. Safety Assessment Principles for Nuclear Facilities. 2014 Edition Revision 0. November 2014 <http://www.onr.org.uk/saps/saps2014.pdf>.
3. Request from Heysham 1 (HYA) Power Station for agreement or acknowledgement of the Safety Case NP/SC 7154 Addendum 6 - Hartlepool and Heysham 1 – Boiler Tube Leaks on a Shutdown Reactor Letter of 30-June-2015 (TRIM: 2015/255498)
4. Request from Hartlepool (HAR) Power Station for acknowledgement of the Safety Case NP/SC 7154 Addendum 6 - Hartlepool and Heysham 1 – Boiler Tube Leaks on a Shutdown Reactor Letter of 16-February-2016 (TRIM: 2016/75732)
5. Safety Case NP/SC 7154 Addendum 6 - Hartlepool and Heysham 1 – Boiler Tube Leaks on a Shutdown Reactor, April 2014 (TRIM: 2014/411573)
6. INSA Statement of 18-June 2015 (TRIM: 2016/75724)
7. NSC Minutes of Meeting: April 2014 (TRIM: 2014/159399)
8. Fault Studies: ONR-OPF-AR-16-057, Jan-2017 (TRIM: 2016/443421),
9. Structural Integrity: Structural Integrity Assessment Note, Dec 2016 (TRIM 2016/486686),
10. Human Factor: ONR Email from [REDACTED] 23/11/16, EDF task times, (TRIM, 2016/457065).
11. Clarification of the current status of BTF related modifications at HYA/HAR. Internal ONR correspondence, April 2017, TRIM: 2017/154350
12. Clarification of the structural integrity assessment of Claim 1. Internal ONR correspondence, April 2017, TRIM: 2017/154348