Office for Nuclear Regulation

Agreement to NP/SC 7770 - Reactor Primary Circuit Oxygen Injection: Stage Submission 1 – Injection of Oxygen into HYA R2 for Removal of Fuel Carbon Deposit

Heysham 1 Power Station
Project Assessment Report

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EXECUTIVE SUMMARY

Title

Agreement to NP/SC 7770 - Reactor Primary Circuit Oxygen Injection: Stage Submission 1 – Injection of Oxygen into HYA R2 for Removal of Fuel Carbon Deposit

Permission Requested

Under derived powers made under Licence Condition 22(1), the licensee of Heysham 1 (HYA) power station, EDF Energy Nuclear Generation Limited, has requested that the Office for Nuclear Regulation (ONR) issue Agreement to NP/SC 7770, which is the safety case for injection of oxygen into Heysham 1 Reactor 2 for removal of fuel carbon deposit.

Background

Heysham 1 power station, Reactor 2, has been experiencing an increase in fuel pin failures, due to an increase in carbon deposition on the fuel pin surface. Increased carbon deposition on fuel creates high clad temperatures from increased heat transfer impairment, subsequently inducing fuel clad grain boundary restructuring and weakening. EDF Energy Nuclear Generation Limited (NGL) is proposing a modification which will inject a low concentration of oxygen in carbon dioxide into the gas circulator arrangement which in turn will provide oxygen to the fuel channels. Oxygen has been shown to be effective at clearing carbon deposition from fuel surfaces at the Windscale AGR and boiler components at Heysham 2 and Torness.

ONR assessment and inspection in consideration of this request

A high level review and consideration was carried out on the Paper of Principle NP/SC 7770. Based on this, the nature of the proposal and the potential hazards as a result of oxygen injection, I decided that the case should be subject to the following specialist assessment:

- Structural Integrity
- Internal Hazards
- Fault Studies
- Mechanical Engineering
- Chemistry
- Graphite
- Supply Chain
- Fuel
- Control and Instrumentation
- Radiological Consequences

In addition to the above assessments, a readiness inspection was carried out to ensure that the project was progressing suitably and to close out recommendations from specialist assessments. A specialist human factors inspection was also undertaken to ensure that the licensee could demonstrate that suitable arrangements were in place for the oxygen injection project.

A hold point was also placed stipulating that the valve in the oxygen injection storage tank must remain closed until a after the licence instrument is issued.

Matters arising from ONR's work

Following assessment by the specialist inspectors and the evidence observed during the readiness inspections, all specialist inspectors consider Agreement to the proposed modification of NP/SC 7770 to be acceptable. There are some recommendations arising from the specialist assessments which will be followed up by the specialist inspectors via the ONR issues database, but they do not prevent Agreement to this submission and therefore injection of oxygen into Heysham 1 Reactor 2.

Conclusion

Following the specialist assessments, I conclude that the safety case NP/SC 7770 is adequate and that holdpoint ONR-OFD-DR-18-004-0 can be lifted allowing oxygen injection into Heysham, 1 Reactor 2.

Recommendations

I recommend:

- Agreement to the modification proposed in NP/SC 7770, which is to inject oxygen into Heysham 1 Reactor 2 to remove carbon deposition on fuel pins.
- That licence instrument 623 is granted to HYA to implement NP/SC 7770.

LIST OF ABBREVIATIONS

AGR	Advanced Gas Reactor
ALARP	As Low As is Reasonably Practicable
AR	Assessment Report
BMS	Business Management System
CCR	Central Control Room
DSEAR	Dangerous Substances and Explosive Atmosphere Regulations
EC	Engineering Change
GCMC	Gas Circulator Motor Compartment
GCMF	Gas Circulator Maintenance Facility
HOW2	(ONR) Business Management System
HP	High Pressure
HYA	Heysham 1
HTI	Heat Transfer Impairment
IGV	Inlet Guide Vanes
IOF	Incredibility of Failure
LC	Licence Condition
LI	Licence Instrument
LP	Low Pressure
NGL	EDF Nuclear Generation Ltd
NRV	Non Return Valve
ONR	Office for Nuclear Regulation
PAR	Project Assessment Report
PCPV	Pre-stressed Concrete Pressure Vessel
PoP	Paper of Principle
PSA	Probabilistic Safety Assessment
R2	Reactor 2
SAP	Safety Assessment Principle(s)
SS1	Staged Submission 1
SSC	Structure, System and Component
TAG	Technical Assessment Guide(s) (ONR)
TQs	Technical Queries
vpm	volume parts per million
WAGR	Windscale AGR
WENRA	Western European Nuclear Regulators' Association

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1. PERMISSION REQUESTED

1. Under derived powers made under Licence Condition 22(1) (Ref. 1), EDF Energy Nuclear Generation Limited (NGL) has requested (Ref. 2) that the Office for Nuclear Regulation (ONR) issue Agreement to NP/SC 7770 (Ref. 3 and 4), which is the safety case for the injection of oxygen into Heysham Reactor 2 for removal of fuel carbon deposit.

2. BACKGROUND

2. EDF Energy NGL proposes to inject a low concentration of oxygen in carbon dioxide into the reactor primary pressure circuit with the aim of removing carbon deposition on the fuel. EDF Energy NGL has previously presented in EC 358854 (Ref. 5) that increased carbon deposition on fuel creates high clad temperatures from increased heat transfer impairment, subsequently inducing fuel clad grain boundary restructuring and weakening. In this case, EDF Energy NGL justified the presence of up to 6000 weakened fuel pins on the basis of 16 fuel failures at Heysham 1 Reactor 2 in 2016. ONR has previously agreed to the increase in number of weakened fuel pins from this degradation mechanism to 6000, on the basis that currently implemented countermeasures (such as reduced power operation and overblowing of at-risk fuel channels) reduce risks SFAIRP. Importantly, EDF Energy NGLs framework for managing these countermeasures as presented in in EC 358854 is that before any current countermeasures are relaxed:

   - there must be ≤1000 assessed weakened fuel pins (via the Fuel Risk Monitor); and,
   - it is predicted that there will be ≤1000 weakened pins afterwards.

3. The submission presented by EDF Energy NGL which is considered in this project assessment report (PAR), does not alter current reactor load restrictions to 90% power, which were formally implemented as a reasonably practicable measure by EC 358854 at Heysham 1 Reactor 2 in response to the presence of weakened fuel. This submission does however recognise that the oxygen injection is intended to facilitate future easing of the load restriction.

4. Oxygen injection is intended to restore the fuel towards its as-designed condition (i.e. operating temperatures at which the clad does not restructure). Success of oxygen injection is largely substantiated by operating experience (OPEX) from oxygen injection campaigns at Magnox stations, to the boilers at Heysham 2 / Torness and most importantly, the Windscale AGR.

5. It is judged that removal of carbon deposition will reduce the occurrence of weakened fuel and remove the associated burden upon ex-reactor facilities. As such, it can be expected that in time, the radiological risk associated with weakened fuel will diminish as normal refuelling removes weakened fuel from the reactors.

6. EDF Energy NGL's safety case for oxygen injection is presented over a number of submissions. In summary, oxygen injection is presented at the highest level in a Paper of Principle, EC 361222 (Ref. 3), which is not specific to any station. The most recent submission by NGL is the specific stage 1 submission safety case, EC 361696 (Ref. 4). This is the Heysham 1 specific modification providing additional detail and evidence to the Paper of Principle.

7. Stage Submission 1 (SS1) justifies the pilot implementation of oxygen injection at Heysham 1 Reactor 2, including the:

   - Specification of reactor specific injection parameters.
   - Design and substantiation requirements of the injection system.

- Measures for operating, monitoring and controlling the injection, to ensure that reactor structures and systems are not unacceptably challenged.
- Design and specification of the post-injection refuelling batch, and the extent of post injection inspection.
- Returning the reactor to its pre-injection configuration.

8. Following submission of SS1 (version 4), it was identified by EDF Energy NGL that the FOXTROT code which is used to calculate failed fuel oxidation rates was not endorsed for calculating fuel oxidation under at-power conditions. The argument presented in version 4 of the proposal that fuel oxidation would not occur during the oxygen injection campaign could no longer be underwritten. The revised safety justification presented at version 5 included arguments that gross fuel oxidation (i.e. that which would result in release of U_3O_8 particulate into the gas circuit) will not occur unless any clad failure sites are allowed to enlarge and permit unconstrained access of oxygen to the fuel.

9. The nuclear safety issues associated with oxygen being present in the primary coolant are addressed by the Paper of Principle (e.g. potential for detrimental impact on fuel, graphite core and reactor and boiler steel structures). The nuclear safety issues of specific significance to this Stage Submission 1 are :

- Detriment to Gas Circulator operation (e.g. from flow disturbance or from impulse line combustion), resulting in an increased risk of Gas Circulator unavailability. Common cause failure of all Gas Circulators would lead to reliance upon Natural Circulation. Disabling the IGVs whilst in a closed position could jeopardise all available means of post-trip cooling gas flow.
- A fire ignited in the Gas Circulator motor compartment could challenge the integrity of the pressure boundary, which relies on an IoF claim (as set down in the Hot Gas Release safety case).
- The hazard risk to essential plant and systems potentially increases due to additional inventory of on-site oxygen (fire) and pressure systems (cold gas release, pipewhip and missiles).
- An increased risk of a reactor depressurisation due the introduction of additional reactor gas circuit tie-ins and pipework.
- Potential detriment to Fuel Route components and Control Rods associated with increased in-circuit dust burden.
- Oxidation of fuel leading to an increase in the production of U_3O_8.

10. This submission is supported by the following Claims.

- Claim 1: Oxygen injection is designed to achieve the targeted fuel deposit removal.
- Claim 2: Systems and structures of the reactor and fuel route will not be unacceptably challenged.
- Claim 3: The effectiveness of oxygen injection to remove fuel deposit will be evaluated.
- Claim 4: The risks associated with oxygen injection are ALARP.

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

11. A high level review and consideration was carried out on of NP/SC 7770 Paper of Principle (Ref. 6) and based on the nature of the proposal it was decided that the case should be subject to the following specialist assessments:

- Structural Integrity
- Internal Hazards
- Fault Studies

- Mechanical Engineering
- Human Factors
- Chemistry
- Graphite
- Supply Chain
- Fuel
- Control and Instrumentation
- Radiological consequences

12. ONR specialist inspectors have engaged with the licensee in technical discussions to support that work.

13. In addition to the above assessments, the following hold point was placed on the project (Ref. 6):

    Hold point ONR-OFD-DR-18-004-0 – The valve on the oxygen injection storage tank must remain closed under a permit to work until a license instrument has been issued by ONR following assessment of EC361222.

14. Following the issue with the FOXTROT code and subsequent re-issue of the safety case by EDF Energy NGL, updated assessment reports were produced by fault studies, fuel and chemistry. In addition to this, an assessment was carried out by a specialist radiological consequences specialist inspector which is included in the list above for completeness.

3.1 SUPPLY CHAIN ASSESSMENT

15. The specialist inspector focussed their assessment strategy on gaining an understanding of how the licensee and main supplier (BOC) were managing the project delivery of equipment so as to ensure nuclear safety (Ref. 7). To deliver this intent, reports of surveillances conducted by the EDF Energy NGL internal nuclear assurance function (INA) of BOC and other suppliers were reviewed. Additionally, evidence was sought that the oxygen injection equipment complied with the Pressure Systems Safety Regulations 2000 (PSSR). These Regulations require the installed equipment to have a written scheme of examination drawn up and certified by a competent person. The competent person must examine the equipment in accordance with the scheme; and before first use, if that is required by the scheme. Evidence that the system has a written scheme certified by a third party competent person in compliance with PSSR, is an indicator of supplier capability, and the physical safety and integrity of the system

16. Based on assessment of key documentation, the supply chain inspector concluded that EDF Energy NGL's supply chain management arrangements have been applied adequately, and therefore recommend (from a supply chain management perspective) that ONR can issue an agreement for injection of oxygen into Heysham 1 Reactor 2.

3.2 MECHANICAL ENGINEERING ASSESSMENT

17. The mechanical engineering assessor sampled the mechanical structures, systems and components within Heysham 1 Reactor 2 considered most likely to be affected by oxygen injection (Ref. 8).

18. To achieve this, the specialist inspector considered the following hazards relevant to mechanical engineering assessment.

    - Oxygen could be detrimental to gas circulator operation, resulting in an increased risk of the gas circulators (GC) becoming unavailable. In the

extreme, there could be common cause failure of all GCs leading to a reactor trip and reliance upon natural circulation cooling.
- There is an increased risk of a reactor depressurisation due to the introduction of additional reactor gas circuit tie-ins and pipework.
- Carbon deposits might spall off rather than be removed as gaseous reaction products. A significant amount of additional dust in the circuit could challenge safety case claims associated with channel blockage, dust explosion and emergency blowdown.

19. Following their assessment, the specialist inspector concluded that they were satisfied with the claims, arguments and evidence laid down within the licensee's safety case. The specialist inspector was content that the licensee:

- Has established that the Inlet gas vane pressure impulse line route is the most suitable location for injecting oxygen into Heysham 1 Reactor 2.
- Has undertaken a thorough investigation into the risk of combustion and has taken a conservative approach to identify reasonably practicable measures to reduce risk as low as reasonably practicable.
- Has adequately demonstrated that the performance of the gas circulators will not be affected by injection via the Inlet Gas Vane differential pressure impulse lines.
- Has implemented appropriate measures to reduce the risk of a depressurisation event and to prevent backflow of reactor gas.
- Has taken appropriate action to reduce the risk of the additional carbon dust burden, generated by oxygen injection, affecting the by-pass blow down filter system.
- Is taking a suitably conservative approach to identify any potential changes in control rod performance that might result from oxygen injection.

20. The specialist mechanical engineering inspector therefore concluded that they support the issue of a licence instrument to Agree to the injection of oxygen into Heysham 1 Reactor 2 for removal of carbon deposit.

3.3 STRUCTURAL INTEGRITY ASSESSMENT

21. The specialist structural integrity inspector considered the effects of oxygen injection on the steel pressure boundary components including a number of components within the reactor core and the boiler components including (Ref. 9):

- The gas circulator liner weld and penetration as this is deemed a highest reliability component
- Tie bar integrity
- Boiler components and structures
- Reactor components and structures
- Oxygen injection system and associated pipework

22. The specialist inspector concluded that the short duration of oxygen injection in such small quantities will have very little effect on the oxidation of these components. In terms of potential increased carbon deposition on the boiler components, this is a potential risk that EDF Energy NGL has considered and accepted as a commercial risk, as an increase in heat transfer impairment (HTI) would affect both nuclear safety (long term) and consequently commercial operation. Adverse effects of oxygen injection have been evident, such as at Torness with temperature tilts across the boilers. In the event of an adverse side effect such as this, NGL will have to consider counter measures, however, the specialist inspector concludes that consider NGL has balanced the risks appropriately between removal of fuel carbon deposit and potential re-deposit on other systems.

23. In summary, the inspector found no areas of concern from a structural integrity perspective and has no objection to a licensee instrument being granted to allow permissioning of this activity.

3.4 GRAPHITE ASSESSMENT

24. The graphite specialist inspector reviewed the claims, arguments and evidence related to graphite integrity, oxygen injection and suppression of methane from the reactor gas coolant increases the graphite weight loss rate in the core and in the graphite sleeves (Ref. 10).

25. Based on the findings of their assessment, the inspector concluded that they are satisfied that EDF Energy NGL has adequately considered all the relevant aspects of oxygen injection on the integrity of the graphite. The results of EDF Energy NGL's analysis show that the consequences from enhanced oxidation as a result of oxygen injection on the graphite moderator and on the graphite fuel sleeves are acceptable. Furthermore, planned sampling of the graphite core will reveal any adverse effects and mitigate uncertainties in the analysis. The inspector was therefore satisfied that the claims, arguments and evidence presented in the Licensee's safety case are acceptable.

26. The graphite structural integrity inspector concluded that they have no objection to oxygen injection being carried out in Heysham 1 Reactor 2 as described in ECs 361696 and 361222.

3.5 INTERNAL HAZARDS ASSESSMENT

27. The primary focus of the internal hazards specialist was the potential effect of the oxygen injection operations on safety significant equipment (Ref. 11). The internal hazards assessment therefore focussed on the potential for internal hazards to occur in three main plant areas; the inlet guide vanes impulse lines, the gas circulator motor compartment and the oxygen injection skid. The potential for fire and explosion due to increased oxygen levels was a particular focus. The specialist inspector concluded that they are content that the licensee has adequately considered the risks and ensured that sufficient protection and mitigation is in place.

28. Overall the specialist inspector is satisfied that the increase in risks from internal hazards due to oxygen injection operations is low and, if coupled with effective controls over plant configuration and over operations, may be judged as ALARP.

29. A recommendation was therefore made that from an internal hazards perspective, a licence instrument can be issued to EDF NGL giving Agreement under LC 22(1) to the activity of oxygen injection at Heysham 1 Reactor 2.

3.6 CHEMISTRY ASSESSMENT

30. The specialist chemistry inspector selected the following four areas for the focus of their assessment (Ref. 12):

- Success of oxygen injection and demonstration thereof;
- Detriments of oxygen injection and their mitigation;
- Control of oxygen injection; and
- Demonstration that oxygen injection represents the option which will reduce risks So Far As Is Reasonably Practicable (SFAIRP).

31. Overall, the specialist inspector judged that EDF Energy NGL has appropriately justified oxygen injection as a reasonably practicable measure and presented a sufficient case to demonstrate its implementation will reduce risks As Low As Reasonably Practicable (ALARP). While the inspector identified remaining areas of

uncertainty, they were content these have been appropriately considered and mitigated.

32. EDF Energy NGL recognised an opportunity to visually monitor all discharged fuel in the Irradiated Fuel Dismantling Facility (IFDF) ahead of pond endoscopy. Given the variable nature of carbon deposition, the inspector notes that this coarse visual inspection could be used to help inform future endoscopy campaigns at both Heysham 1 and more widely across the fleet to strengthen the monitoring leg of the carbon deposition programme. This is tracked via recommendation 1 from the assessment.

33. The specialist inspector notes that even if oxygen injection is successful in removing carbon deposition, it will not immediately reduce the number of weakened pins in the core. Rather, it will reduce the rate at which the population of weakened pins will be increased. EDF Energy NGL's current framework for managing weakened fuel and current countermeasures in place at Heysham 1 Reactor 2 to reduce the risks of fuel failures So Far As Is Reasonably Practicable (SFAIRP) stipulates that these countermeasures should not be removed unless the weakened fuel pin population will remain <1000. The specialist inspector judges that ONR should review the Engineering Change (EC) relaxing current countermeasures (specifically, returning to full power). This is tracked via chemistry recommendation 2.

34. While the specialist inspector is content that the majority of operating rules have been identified for oxygen from a chemistry perspective, it is noted that there is no absolute limit on the duration for which an uninhibited chemistry (operation without methane injection) may be applied. Notably, the impact of an uninhibited chemistry is significantly greater for graphite weight loss than the presence of oxygen (where there are limits). The inspector judges that this should be captured as an appropriate operating rule. This is tracked via chemistry recommendation 3 and discussed below.

35. EDF Energy NGL accept there remains uncertainty in relation to the potential of increased heat transfer impairment (HTI) on lower fuel pin elements, increased dust burden, carbon deposition regrowth and unintended consequences. While the specialist inspector is broadly content that this uncertainty has been appropriately considered and managed, it is noted that while there are commitments which will help to identify unintended consequences in the short to medium term, this is less apparent for the long term. Notably, there is experience of unintended consequences from chemistry changes (for example from carbonyl sulfide (COS) injection, which is judged to have increased carbon deposition). EDF Energy NGL suggest that oxygen injection may be repeated should significant carbon deposition return within the next fuel dwell. The specialist inspector therefore judges that EDF Energy NGL should continue to consider the potential longer term implications of oxygen injection in justifying any future campaigns. This is tracked via chemistry recommendation 4.

36. The specialist inspector concluded that they are content with EDF Energy NGL's justification that oxygen injection presents the option which reduces risks SFAIRP, balancing the risk of fuel failures by restoring fuel to its design intent against the potential detriments of oxygen injection. Additionally, the inspector is also satisfied that the specific implementation of oxygen injection is ALARP.

37. The following recommendations were therefore raised:

- Chemistry Recommendation 1: EDF Energy NGL should consider the application of visual inspection of fuel to inform the scope of future endoscopy campaigns and in particular if this can be expanded to the wider fleet.
- Chemistry Recommendation 2: ONR should assess any return to full power case relaxing current countermeasures on the basis of successful oxygen injection.

- Chemistry Recommendation 3: EDF Energy NGL should define and include appropriate operating rules relating to the defined period of an uninhibited chemistry for oxygen injection.
- Chemistry Recommendation 4: EDF Energy NGL should consider the longer term impacts of O2I, and use this to inform any subsequent O2I campaigns.
- Chemistry Recommendation 5: Subject to satisfactory addressing of Recommendation #3, ONR should not object to oxygen injection at Heysham 1 Reactor 2.

38. From the recommendations above, Recommendation 3 needed to be resolved prior to oxygen injection. The specialist inspector followed up (Ref. 13) and confirmed that " *A maximum time for operation without methane is captured in the BEOM/211 dispensation […].This therefore closes Recommendation #3 from my Assessment Report."*

39. Recommendations 1, 2 and 4 are being tracked via regulatory issue 7040.

3.7 FUEL ASSESSMENT

40. The specialist fuel assessment included consideration of the balance of risk in undertaking the activity compared to the potential benefits in terms of improving the fuel cladding condition (Ref. 14). The case was assessed on the basis of nuclear safety benefits. Since the safety case is predicated on the nuclear safety benefits rather than the potential commercial benefits to EDF Energy NGL if it is successful, the case was assessed on this basis. The specialist fuel assessor focused their assessment on:

- Fuel integrity as a result of the oxygen injection and associated operational changes (i.e. HTI changes and transients).
- Coolant activity monitoring and a means of online monitoring of the fuel cladding condition and operational risk.
- The oversight of the Fuel Assessment Panel (FAP) in informing decision making with respect to fuel protection countermeasures.
- The adequacy of the population of fuel selected for Post-Irradiation Examination (PIE).
- Compatibility with the current fuel safety case – i.e. the extant Justification for Continued Operation (JCO) as agreed by ONR in ONR-OFD-PAR-18-006 (Ref. 15).
- Potential for unforeseen detrimental effects on the fuel as a result of the exposure to an oxidising environment in the reactor.
- ALARP – the appropriateness of the balance between potential risk increases due to the oxygen injection modification compared to the risk in terms of weakened fuel pins being avoided, including consideration of uncertainties over the effectiveness of the operation.
- The potential for detriments to radiological consequences (with the exception of the risk of U_3O_8 production, which is addressed section 3.10) as a result of oxygen injection as a specific activity or modification, which is covered in the Paper of Principle (PoP) preceding the submission.

41. Overall, based on their sample, the specialist fuel inspector judged that the submission is adequate in justifying the case for implementing oxygen injection as an appropriate countermeasure to improve the fuel cladding condition for Heysham 1 Reactor 2. This is based on the following factors:

- The current operational safety case as assessed by ONR remains valid and is supported by implementation of oxygen injection as a means to remove carbon deposition and thus avoid further cladding degradation. This will improve the

reactor average fuel cladding condition with time as the previously effected stringers are discharged and not subject to additional degradation.

- No evidence has arisen since the implementation of the current safety case for operation that challenges the hypothesis that the root cause of the operational fuel failures is weakening of the cladding through restructuring of the micro-structure brought about through carbon deposition induced HTI.
- Adequate understanding of the process of injection and the effect on carbon deposition, supported by evidence from experiment and prior operations with WAGR has provided confidence that the likelihood of success is reasonably high and that the risk from detriments acceptably low.
- EDF Energy NGL has considered the potential risks to fuel integrity involved with oxygen injection and proposed adequate controls to minimise them.
- Appropriately conservative operating rules for monitoring the fuel condition through the coolant activity during the injection will be implemented.
- The Fuel Assessment Panel (FAP) has considered the ALARP position concerning fuel protection countermeasures and I have seen evidence that the governance arrangements are appropriately robust and open in this regard.
- For Heysham 1 Reactor 2, the long-term potential downsides in terms of oxidation of core graphite have been balanced against the benefits for fuel safety.
- The radiological concerns with regard to the potential for oxygen to increase releases in faults and normal operations (primarily if failed fuel is present) have been addressed and risk shown to be acceptably low.

42. The specialist inspector therefore concluded that it is appropriate for ONR to Agree the submission subject to adequate evidence of readiness for implementation as set out in their recommendations:

- Fuel Recommendation 1: In the event that fuel failures are detected during oxygen Injection, the operational period between injection and shutdown and/or during the blow down of Reactor 2 for refuelling, EDF shall review the selection of stringers for discharge and confirm it remains ALARP such that the opportunity for discharge of failed stringers is appropriately optimised.
- Fuel Recommendation 2: EDF shall provide ONR with the scope of the proposed discharge batch of fuel for the refuelling outage after O_2 injection and demonstrate that it meets the intent of NP/SC 7770 with respect to evaluating the effectiveness of O_2 injection across an appropriate range of the fuel population.
- Fuel Recommendation 3: ONR should request that the EC (or any other mechanism) used to justify returning HYA R2 to full power is provided for appropriate review and consideration, which may include permissioning under derived powers.
- Fuel Recommendation 4: ONR should sample the implementation of revised arrangements for monitoring coolant activity for HYA R2 through the GAM and BCD system as described in NP/SC 7770. This may be achieved through a readiness inspection prior to implementation of oxygen injection to confirm that adequate arrangements have been made.
- Fuel Recommendation 5: EDF to provide ONR with the Fuel Assessment Panel endorsement of revised 2019 oxygen injection dates for HYA R2 in advance of implementation of the modification.
- Fuel Recommendation 6: ONR should sample the INA concurrence process as part of the scope of readiness inspection prior to the EDF oxygen injection readiness hold-point being lifted. This should include supporting quality plans and surveillance interventions executed by INA.
- Fuel Recommendation 7: EDF should provide ONR with copies of temporary SOIs for monitoring differential pressure across blowdown filters in advance of

the go/no-go decision as part of readiness preparations. This may be achieved as part of ONR readiness inspections if appropriate.

43. Fuel Recommendations 4, 5, 6 and 7 require closure prior to issuing a Licence Instrument to allow oxygen injection. The closure of these recommendations is discussed in section 3.12.2. Recommendations 1, 2 and 3 are being tracked via regulatory issue 7572.

3.8 FAULT STUDIES ASSESSMENT

44. The primary focus of the fault studies assessment was for the potential for oxygen injection to introduce new faults, and any impact it may have on the likelihood and predicted radiological consequences of faults already identified in the stations' safety cases (Ref. 16). Since the foremost arguments in EDF Energy NGL's safety case for protection against new faults rely on the high reliability of the oxygen injection equipment, the specialist inspector therefore reviewed the evidence supporting this. In considering the risk posed by oxygen injection, the specialist fault studies inspector has also considered the potential effects on the reactor in future operation.

45. With regards to existing faults, following a review of the potential impacts on a carefully selected sample of faults, the specialist inspector is satisfied that the injection of a small amount of oxygen into the primary circuit will have no effect on the reactor's response. Based on their sample, they are therefore satisfied that the increase in risk to faults in the extant fault schedule is negligible.

46. In consideration of faults introduced by oxygen injection, the specialist inspector has considered delivery of gas to the reactor outside the required specification of oxygen injection. In doing this a high level review of the reliability of the oxygen injection equipment was undertaken. Considering advice from the control and instrumentation inspector the specialist fault studies inspector is content that the reliability of the oxygen injection equipment is suitably derived and results in a low frequency for delivery of out of specification gas to the reactor. Given this low frequency and that the likely consequences of the fault are also low; the specialist inspector was content that the risk associated with delivery of out of specification gas is low and well controlled.

47. The inspector also focussed their attention on the potential for oxygen to ignite in the gas circulator motor compartment. This could conceivably rupture the gas circulator pressure boundary, potentially causing damage to the internal structure of the reactor core and unacceptable radiological consequences. A review was undertaken of the conditions under which this fault could occur and the assessor found the combination of events to be highly unlikely such that they are confident that the incredibility of failure claim on the pressure boundary should not be challenged.

48. With regards to the risk to future operation, the specialist considered potential increases in HTI to lower elements and the generation of dust within the primary circuit. Through review of OPEX they were content that the likelihood of these effects occurring is low and that should they occur, the reactor has significant tolerance to these effects and sufficient mitigation measures are in place to control reactor conditions.

49. Following the issues with the FOXTROT code, revision 1 of the specialist assessment reviewed the additional radiological consequences information and the potential effect on a depressurisation fault. Given advice from the radiological consequences inspector, the specialist inspector is content that it is unlikely that oxygen injection will have a significant adverse effect on the radiological consequences of a depressurisation fault should it occur during oxygen injection.

50. Overall, based on the sample assessed, considered alongside advice from other specialist inspectors, the specialist fault studies inspector was satisfied that the increase in risk to the reactor during and following oxygen injection, as proposed by the submission, is low. and can share EDF Energy NGL's judgement that all reasonably practicable measures have been implemented to reduce the risks sampled to as low as reasonably practicable.

51. The inspector therefore recommended, from a fault studies perspective a licence instrument can be issued to EDF NGL giving Agreement under LC22(1) to the activity of oxygen injection at Heysham 1 Reactor 2 upon closure of the following recommendation:

    Fault studies recommendation 1: Project inspector to consider reviewing the arrangements for monitoring oxygen levels during oxygen injection in the lower plenum during the ONR readiness inspection.

52. Closure of this recommendation is discussed in section 3.12.1.

3.9 CONTROL AND INSTRUMENTATION

53. The control and instrumentation specialist inspector focussed their assessment (Ref. 17) on determining the following:

- If the oxygen injection system has been adequately defined;
- If the system's function categorisation and classification has been adequately defined;
- If adequate optioneering has been undertaken;
- If equipment with an adequate integrity has been selected;
- If the reliability claimed for the system is adequate; If adequate commissioning activities will be undertaken.

54. Although the inspector identified some shortfalls in the safety case they did not invalidate the associated safety claims in the opinion of the inspector. The inspector also considered that the shortfalls are outweighed by the amount of relevant good practice system design development work that has been undertaken.

55. Based on the evidence sampled, the control and instrumentation inspector considered that the control and instrumentation architecture of the Heysham 1 Reactor 2 oxygen injection system is adequate and therefore supports the issue of a licence instrument to allow the injection of oxygen into Heysham 1 Reactor 2 for fuel pin carbon deposition removal purposes. However, it is important to note that these conclusions were subject to checking that adequate commissioning activities have been undertaken. This was done by gathering evidence during and following the Heysham 1 Reactor 2 oxygen injection readiness inspection (see section 3.12.3) and was captured under ONR regulatory issue database (RID) number 7117.

3.10 RADIOLOGICAL CONSEQUENCES

56. The specialist radiological consequences inspector focussed their assessment on the degree of risk, which may be realised through oxidation of graphite or degrading the condition of components and systems important to safety as a result of oxygen injection (Ref. 18).

57. The specialist radiological consequences inspector notes that arguments have been presented which preclude gross fuel oxidation and that if it does occur, it would not be mobile. However, it was noted that a conservative assessment would result in some mobile U_3O_8 powder production.

58. The radiological consequences assessment has therefore primarily focused on:

- Assessing arguments that U_3O_8 mobile powder is not produced as a result of the proposed oxygen injection countermeasure.
- Assessing the licensee's analysis of radiological consequences in the event of U_3O_8 mobile powder production taking place (by use of a conservative analysis tool), for decommissioning activities, simultaneous faults and the fuel route.

59. The specialist inspector was not convinced that U_3O_8 mobile powder production could not occur during the oxygen injection, they noted however that the analysis performed by EDF Energy NGL is conservative and placed their reliance on the conservative analysis of radiological consequences. The specialist inspector has assessed this analysis and concludes that should powder production occur during oxygen injection that:

- This will have no significant effect on decommissioning
- There is no significant increase in radiological risk from simultaneous faults
- The radiological consequences for the fuel route are acceptable.

60. Overall, based on their sample, the specialist inspector concluded that implementing oxygen injection is appropriate on radiological consequences grounds. The specialist inspector therefore concluded that it is appropriate for ONR to Agree to the proposal for oxygen injection. This is conditional on there being no large fuel failures (consistent with the go/no go criteria proposed by the licensee) present at the start of oxygen injection.

3.11 EDF ENERGY NGL SELF-IDENTIFIED QUALITY ISSUE

61. During the project a quality issue was identified by EDF Energy NGL (Ref. 19).

62. As a prerequisite to completing the Factory Acceptance Test (FAT) for the Injection System Skids, the EDF Energy NGL project team were completing an audit (100% check) to confirm all the procedures and drawings referenced within the FAT procedure (approx. 50 docs and drawings) were complete, and approved by both BOC and EDF Energy NGL.

63. The audit carried out by EDF Energy NGL included an inspection of the hardware to confirm the system matched the drawings and that all instruments/software and hardware versions were as expected, and all instrument certification was present and in date.

64. The audit was attended by the central technical organisation, Heysham 1 site project teams, Heysham 1 quality assurance and independent nuclear assurance. During the audit it was evident to EDF Energy NGL that the revision control of documentation was poor and tracking of changes between revisions was not robust.

65. The issue was immediately escalated within BOC to BOCs EDF Energy NGL Interface Manager who raised this with BOCs Engineering Discipline Manager and elevated to the BOC Executive. The BOC management recognised the significance of the findings and took the following actions:

- The BOC Project Manager was replaced.
- BOC conducted an independent internal investigation to establish the scope of any issue; this was not limited to the oxygen injection Project.
- BOC agreed to repeat their verification and approval process for the oxygen injection documentation.

66. With regards to the impact for the oxygen injection project, BOC provided the following to EDF Energy NGL:

- BOC reviewed the approval status of the other project documents and did not identify any additional approved documents where the evidence of approval is missing.
- As a further measure BOC continued to re-check and approve documents using PDF document signatures. The EDF Energy NLG Project Manager was satisfied with this approach.
- In addition to the reapproved documents, EDF Energy NGL requested evidence that the BOC verification had been completed.

67. EDF Energy NGL confirmed that all documentation approvals required to be completed before the start of Factory Acceptance Testing were completed and the FAT started on the 18 March 2019.

68. Subsequent audits of the EDF project arrangements were completed by INA on the 2nd April and 17th June to evaluate the effectiveness of arrangements for managing the oxygen Injection project in support of the safety case requirements and to understand the project. No further issues relating to the control of BOC documentation were identified.

69. Based on the immediate response taken by both EDF Energy NGL and BOC, I am content that the quality issues encountered on the oxygen injection project were addressed and that there are no implications to the oxygen injection project.

3.12 READINESS INSPECTIONS AND FOLLOW UP OF RECOMMENDATIONS

70. A readiness inspection was carried out on the 22 July 2019 (Ref. 20) the purpose if this readiness inspection was to view progress with the project, to close-out recommendations and other outstanding issues from specialist assessments and to carry out an inspection into the human factors aspects of the oxygen injection process.

71. Based on the stage of the project, it was agreed that a dedicated human factors inspection would take place at a suitable time when EDF Energy NGL were in a position to demonstrate site acceptance testing or commissioning activities following the readiness inspection. This inspection is summarised in section 3.13.

72. The inspection provided evidence that EDF Energy NGL were progressing well towards being ready to commence oxygen injection at Heysham 1 Reactor 2. Whilst there was still some work to do, we did not foresee any issues with all activities being completed in time for commencement of the project.

73. There were a number of actions which required closeout following the intervention these and the closeout response are documented in Ref. 21 and are discussed in this section.

74. During the readiness inspection, the following recommendations were discussed:

3.12.1 FAULT STUDIES

- **Fault Studies Recommendation 1: Project inspector to consider reviewing the arrangements for monitoring oxygen levels during oxygen injection in the lower plenum during the ONR readiness inspection**

75. During the inspection, EDF Energy NGL explained that lower plenum monitoring limits depend on base level reading on the instrument which will not be known until oxygen injection starts. The monitoring arrangements are controlled using the chemistry quality plan which specifies a comprehensive structure for determining the efficacy of lower plenum monitoring and gives corresponding limits to control the lower plenum oxygen

levels within. The chemistry quality plan requires that readings be taken every 30 minutes from the installed instrument in the reactor basement annulus.

76. EDF Energy NGL explained that during oxygen injection there will be a chemistry office set up near the reactor basement annulus; this will be manned by three chemists and has capability to remotely monitor lower plenum oxygen levels. There will therefore be a constant monitor on the lower plenum oxygen level in addition to the recording every 30 minutes. These staffing arrangements will ensure constant monitoring in the chemistry office with capability to take readings directly from the equipment nearby and allow comfort breaks for the operators. Overall from the procedures, the walkdown and discussions with the station staff, the fault studies inspector determined that the arrangements for the monitoring of oxygen levels in the lower plenum were adequate with a good understanding by appropriate station staff. As a result the recommendation was closed.

3.12.2 FUEL

- **Fuel Recommendation 4: ONR should sample the implementation of revised arrangements for monitoring coolant activity for HYA R2 through the GAM and BCD system as described in NP/SC 7770. This may be achieved through a readiness inspection prior to implementation of oxygen injection to confirm that adequate arrangements have been made.**

77. The specialist inspector concluded that overall, the arrangements, while subject to final verification appear to be robust and meet the expectations of the specialist inspector against the safety case requirements. The nuclear safety group (NSG) Engineer present was well informed and provided confidence in the team's capability.

78. The specialist inspector therefore concluded that, notwithstanding the outstanding items (See Ref. 20), the expectations against Recommendation 4 of ONR-OFD-AR-18-066 (Ref. 14) have been met and appropriate arrangements for monitoring of coolant activity during oxygen injection have been put in place.

- **Fuel Recommendation 5: EDF to provide ONR with the Fuel Assessment Panel endorsement of revised 2019 oxygen injection dates for HYA R2 in advance of implementation of the modification.**

79. This recommendation was closed after the readiness inspection when EDF Energy NGL provided minutes from the 10th Fuel Assessment Panel which took place in June 2019 during which, they confirmed that there are no objections to the proposed schedule for oxygen injection in October 2019 (Ref. 22). This therefore closed recommendation 5 from the specialist fuel assessment.

- **Fuel Recommendation 6: ONR should sample the INA concurrence process as part of the scope of readiness inspection prior to the EDF oxygen injection readiness hold-point being lifted. This should include supporting quality plans and surveillance interventions executed by INA.**

80. Some issues were identified with the concurrence Part A, both prior to and during the readiness inspection. Following some discussion with EDF Energy NGL, the Concurrence Part A was amended. The specialist inspector reviewed the revised Concurrence Part A and received feedback from the nominated site inspector for HYA, who sampled the evidence pack and working version at Heysham 1. The specialist inspector confirmed that the information was adequate to close actions 1 and 2 of ONR regulatory issue 7402. These actions are those that were linked to the oxygen injection project (Ref. 23) and this recommendation is therefore closed.

- **Fuel Recommendation 7: EDF should provide ONR with copies of temporary SOIs for monitoring differential pressure across blowdown filters in advance of the go/no-go decision as part of readiness preparations. This may be achieved as part of ONR readiness inspections if appropriate.**

81. During the readiness inspection, the EDF Energy NGL Operations Technical Support Chemist explained the Station Operating Instruction (SOI 01/05/16) for "Bypass Blowdown Filter Operations during oxygen injection" (Ref. 24) which has been raised as a temporary SOI for the duration of the activity. The specialist inspector was taken through the procedure step by step and found it to be clear and straight-forward to follow. The pressure drop across the filters will be monitored by the central control room central control room and the Chemist every 15 minutes using the chemistry screen on PI Historian. The monitoring examines the pressure drop and any rate of rise to head-off any significant filter blockage before it might disable the blowdown capability in the event that significant dust burden arises during the activity. The criteria are set with sufficient margin to avoid challenging the plant and in the event that an increase in pressure drop is seen the procedure requires that oxygen injection is suspended and the filters blown in reverse to unblock them before proceeding further.

82. Overall the specialist inspector was satisfied that the SOI implemented the intent of the safety case with respect to blowdown filter monitoring which closes Fuel Recommendation 7.

3.12.3 CONTROL AND INSTRUMENTATION

- **The correct input of protection equipment set-points and the correct initiation of alarms;**

83. During the readiness inspection, the project engineer stated that the oxygen injection system factory acceptance testing (FAT) involved checking that trip signals were initiated when required and that these checks will be repeated during site acceptance testing.

84. Regarding the correct isolation of the oxygen and process gas supply lines in response to protection equipment trip signals and emergency stop button presses, the project engineer stated that this will be checked during site acceptance testing (SAT) which was ongoing at the time of the inspection. The project technical lead stated that correct operation of the emergency stop buttons has been confirmed during SAT. The specialist inspector also asked about the verification of some of the 'failsafe' claims. The project technical lead provided this information following the inspection. This action has since been closed out to the satisfaction of the specialist inspector (Ref. 25).

- **The correct isolation of the oxygen and process gas supply lines in response to protection equipment trip signals and emergency stop button presses;**

85. The project engineer stated that this will be checked during site acceptance testing. The project technical lead stated that correct operation of the emergency stop buttons has been confirmed during SAT. The specialist inspector also asked about the verification of some of the 'failsafe' claims. This has since been closed out to the satisfaction of the specialist inspector (Ref. 25).

- **The security arrangements that have been put in place to prevent unauthorised equipment setting changes;**

86. The project engineer and project technical lead stated that the site acceptance testing will involve checking that password / PIN protection has been initiated for those devices that include such functionality. The project engineer and project technical lead stated that FAT involved checking that each of the Smart devices contained the correct firmware and software and that these checks would be repeated during SAT. EDF Energy NGL was asked whether a system level cyber risk assessment had been undertaken. The project engineer, project technical lead and project control and instrumentation engineer stated that it had not.

87. A cyber risk assessment was carried out following the readiness inspection. The ONR specialist control and instrumentation inspector has confirmed that improvements to cyber security made in line with the outcome of this assessment are acceptable (Ref. 26).

- **The EMC / EMI testing activities that have been undertaken;**

88. The project technical lead stated that the susceptibility of the Heysham 1 oxygen injection system to radio frequency (RF) transmissions from site hand held radios has been tested during FAT and SAT and that no issues had been identified. The project technical lead also stated that the system's equipment and cabling is not located near any significant RF sources and that the reactor building shields the system from Heysham Port radar transmissions. The project engineer and project technical lead both stated that no EMC / EMI related issues have been identified during SAT to date.

- **Operator procedures for cross-monitoring protection equipment outputs;**

89. During the plant walkdown, the project technical lead and project engineer showed how the various operating parameters and trip signals will be displayed to operators and how operators will cross-monitor the outputs of the blending skid oxygen analysers (AT405 and AT420). The specialist inspector judged that the displays appeared to be clear and easy to read and the cross-monitoring process appeared to be straightforward.

- **Operator procedures for overriding the closure of the GCMF valve station process gas supply isolation value at the start-up of the oxygen injection process;**

90. The project technical lead explained the process for overriding the closure of the gas circular maintenance facility (GCMF) valve station process gas supply isolation valve at the start-up of the oxygen injection. The override is initiated by holding a spring loaded 'low flow override' switch in the 'ON' position.

91. During the plant walk down the project technical lead demonstrated that the GCMF valve station process gas supply isolation value will automatically close in the event that process gas oxygen concentration exceeds the 23 per cent v/v trip limit. This was achieved by injecting a sample gas into the oxygen analyser (AT616) that is located in the GCMF valve station and steadily increasing its oxygen concentration.

92. The project technical lead also demonstrated that the GCMF valve station process gas supply isolation value will automatically close in the event that power is removed from the trip amplifiers that are associated with the oxygen analyser (AT616) and process gas flowmeters (FE610 & FE611) that are also located in the GCMF valve station.

- **The tracking of smart device assessment 'restrictions of use' recommendations.**

93. The project technical lead stated that the operating recommendations that are contained in the Emphasis / modest integrity guidance (MIG) assessments that have

been produced for each of the oxygen injection system's Smart device will be addressed during SAT. The project technical lead stated that these recommendations have been captured in a quality plan. The specialist inspector asked if a quality assurance (QA) check of the quality plan had been undertaken to verify that all of the operating recommendations had been captured. The project technical lead provided this information after the inspection (Ref. 25). The specialist inspector also asked if the smart device related recommendations contained in the oxygen Injection Monitoring and Protection Panel DSR were being tracked. The project technical lead provided this information following the inspection (Ref. 25)

94. All actions raised at the readiness inspection were successfully closed out. Closure can be found in Ref. 21.

95. All work that required completion during the SAT testing has now been completed to the satisfaction of the specialist inspector and the regulatory issue can be closed (Ref. 26).

3.12.4 HUMAN FACTORS INSPECTION

96. A separate readiness inspection was carried out by a human factors specialist inspector (Ref 27).

97. The scope of the inspection was:

- Confirmation that training material is appropriately scoped with suitable content.
- Confirmation that activity specific training is now complete or likely to be complete by permission date.
- Confirmation that the task design, conduct of operations, and command and control is fit for purpose.
- Confirmation that the procedures follow relevant good practice and accurately reflect the job design.
- Confirmation that the equipment design supports reliable human interaction.

98. The key findings from the inspection comprise:

- The specialist inspector found that the training material and subsequent competence assessment process to be fit for purpose and follow EDF Energy NGLs processes.
- EDF Energy NGL has developed a comprehensive suite of training material for all stakeholders: EDF and BOC operations personnel; EDF chemists; main control room personnel; and first responders. This comprises both normal and fault responses. It also includes within scope, the hazards associated with the process with appropriate links to the safety case.
- EDF Energy NGL has recognised the issue of currency and taken actions to ensure that personnel remain familiar with the training material; an important consideration given the unplanned delays to the programme. Shifts have allocated sessions to re-visit and discuss key material, and in the run up to the commissioning activities oxygen injection was the topic of morning briefings. Similar currency training is planned in the run up to the activity date.
- Competence assessment has been via a combination of exam and task assessment. Exam questions are suitably testing and cover both task activity knowledge, safety case requirements, hazard awareness, and what to do post fault. At the time of inspection, approximately 95% of personnel had completed the training. EDF Energy NGL is confident that training will be 100% complete by the permission date. The specialist inspector is content for EDF Energy NGL internal assurance to confirm this.
- Crew Resource Management (CRM) practices were in evidence during the observed period of commissioning.

- The setting to work process was comprehensive and covered a suitable range of topics, with active participation by all stakeholders.
- The safety message of 'it takes as long as it takes' was repeatedly reinforced and the Operations Lead took time to confirm that all stakeholders knew what their key risk-important activities were.
- The specialist inspector later fed back at the wash-up session that this brief could be enhanced further by going into more detail on what to do if the risk important activities failed. EDF Energy NGL acknowledged the benefit of this and took an action to expand the scope of the pre-job briefings.
- The command and control process appears to work effectively. Roles are clearly understood as is the supervisory structure. All personnel are vested with the authority to shutdown the injection process via the e-stop system – of which there are multiple locations. There are also multiple semi-independent groups, all able to monitor key safety parameters. These comprise: skid control room, chemistry control room, and the new monitoring station just inside the reactor building. Additionally, an extra operator has been assigned to the main control room to monitor the 02 injection process parameters visible to the reactor C&I. Should any significant faults occur, EDF confirm the fault responses are entirely bounded by those within the extant safety case.
- Communication protocols aligned with CRM techniques and employed positive confirmatory responses used to reduce the risk of communication error. Alternative radio channels have been allocated to accommodate the possible need for direct communications outside of the Operations Lead channel. A telephone is also provided, along with key contact numbers, as a diverse means of assuring communication. There was appropriate discussion and challenge between EDF and BOC when confirming task steps had been completed.
- The procedures did not clearly define responsibilities per task step. Given the activity is performed from multiple locations and each location can be on a different step, the specialist inspector advised that enhancements could be practically made to minimise potential confusion to clearly state who was responsible for each task step. In addition, note taking was observed in the margins of the procedure and EDF Energy NGL were advised that these notes could be used as the basis for further procedural enhancements.
- With regard to the equipment used for oxygen injection has been subject to EDF HF assessment. This also included reviews of procedures and job design. The findings of this assessment were largely positive.

99. The specialist inspector judged that EDF Energy NGL and BOC have done enough to demonstrate that the risk from human error is suitably controlled so far as is reasonably practicable – with the caveat that EDF Energy NGL implement the enhancements to the procedures and pre-job brief.

100. Given the low importance level of these enhancements, the specialist inspector did not consider this requires further ONR inventions to follow up and was content for EDF Energy NGL's internal assurance process to confirm that they have been completed.

101. In the event that any latent human factors deficiencies do lead to unforeseen human errors, the specialist inspector also draw confidence that the impact of human error appears suitably mitigated by the engineering:

- There is a mechanical gas regulator - which limits maximum oxygen flow into the reactor at 28% concentration.
- The C&I system also restricts oxygen concentrations to below 28%.
- The combined system reliability has been assessed by EDF at 10^{-6}/year. ONR's fault study assessment concludes this is suitably conservative.

3.13 ISSUE WITH FLOWMETERS

102. During site commissioning of the oxygen injection distribution system testing was being carried out with carbon dioxide, two unrelated issues with instrumentation were identified by EDF Energy NGL. Both relate to shortcomings in the performance of flowmeters.

103. The flowmeter issues identified were as follows:

- A differential pressure (dP) was measured across the valve station in the Gas Circulator Maintenance Facility that was far greater than that calculated at the design phase. The magnitude of the dP generated an unacceptable backpressure to the BOC delivery system such that there would be insufficient pressure to achieve the design flow of process gas to the impulse line injection routes at the Gas Circulators. Investigations identified the Yokogawa Rotamass 3 flow transmitter as the component causing the issue.
- The second issue identified related to the performance of the Gas Circulator Impulse Line VA 500 flowmeters 6FZ2/FITX4101 to 4801. The flow indications from all eight instruments were indicating a maximum range value whilst at only approximately 75% of the maximum flow conditions.

104. To address the issue with the high differential pressure (bullet 1), EDF Energy NGL have added a bypass flow route such that the flow through the instrument is reduced and the system pressure drop overall is reduced to an acceptable level. For the Impulse Line flowmeters (bullet 2), configuration changes were made by the supplier to increase the velocity range to ensure the indications are in range.

105. The testing and commissioning of the above changes were sampled by the ONR specialist control and instrumentation inspector who confirmed that they are content (Ref. 26).

3.14 FAILED FUEL - SPECIAL PROGRAMME BOARD

106. In the lead up to the planned oxygen injection into Reactor 2 EDF Energy NLG received additional preliminary fuel pond endoscopy data from a planned survey. Fuel pond endoscopy is used to assess the level of carbon deposit on fuel pins by visual inspection. The technique is well established for assessing the deposit thickness and has been compared against detailed measurements from in cave PIE. The visual method is sufficiently accurate to make judgements of the thickness to within tens of microns.

107. The most recent endoscopy survey examined fuel discharged in the last refuelling outage and found that there is a trend of decreasing carbon deposit thickness for fuel that has been subject to a significant period of operation with a reduced rate of COS injection. The reduced rate of COS injection is a countermeasure against carbon deposit introduced in parallel to the development of oxygen injection. These preliminary results are generally positive in that it demonstrates that modifications to the rate of COS injection may be bringing about an improvement in the fuel condition. However, it could be viewed as potentially reducing the benefit brought about by oxygen injection and thus have an impact on the ALARP argument for proceeding. EDF Energy NGL has considered this and have concluded that while there has been an improvement in the deposit levels the fuel cladding condition is degraded as evidenced by the recent our fuel failures identified during the last refuelling outage and remaining high levels of carbon deposit on the longest dwell fuel. This leads EDF Energy NGL to the position that while it is positive that the trend in deposition is improving there remains sufficient risk associated with the current core condition, which will be most efficiently addressed by injection of oxygen. Furthermore, without a step change to reduce the fuel cladding deposition EDF conclude that it will be difficult to demonstrate that the carbon deposit has been reduced sufficiently to increase the reactor power back to 100%. EDF have communicated the revised position to ONR

and provided the logic behind the decision to proceed with oxygen injection in light of the new preliminary data (Ref. 28).

108. In the specialist fuel inspectors judgement (Ref. 29), there remains sufficient evidence that Heysham 1 Reactor 2 will benefit in terms of risk reduction through improvement to the fuel cladding condition by oxygen injection to remove carbon deposits. The primary evidence in support of this judgement is the continued operational fuel failures, which represent the leading edge of a current population of fuel pins with weakened cladding. In the near-term this reduction in risk will only be achieved by removal of carbon deposit and reduction in the associated HTI. While a demonstration of effective cleaning of the cladding post-oxygen injection will assist EDF Energy NGL in making a future safety case for increasing the power of Reactor 2 this will only be realised if the fuel cladding condition is demonstrably improved and thus the risk associated with weakened fuel cladding reduced. Therefore the commercial benefit to EDF Energy NGL will only follow the safety improvement brought about by the activity.

4. MATTERS ARISING FROM ONR'S WORK

109. All ONR specialist inspectors consider agreement to the proposed modification of NP/SC 7753 to be acceptable. On that basis I have prepared a licence instrument for Heysham 1 (Ref. 30). This has been written according to ONR guidance (Ref. 31) and is of routine type, for which the text and format have been agreed with the Government legal department.

110. I have discussed the permissioning of this modification with a representative from the Environment Agency who has confirmed that the Environment Agency does not object to ONR issuing an Agreement to allow Heysham 1 to inject low concentrations of oxygen in carbon dioxide for the purpose of removing carbon deposit on fuel (Ref. 32).

111. I have confirmed that EDF Energy NGL has followed due process. An INSA statement for the case has been submitted (Ref. 33) and Nuclear Safety Committee (NSC) meeting minutes have also been submitted (Ref. 34) in support of this case.

112. A number of recommendations were raised by ONR specialist inspectors; these are discussed throughout this report. All recommendations which needed to be resolved prior to oxygen injection have been resolved. There are some recommendations remaining which do not need to be closed prior to oxygen injection and which are being managed by the individual specialist inspectors.

5. CONCLUSIONS

113. I conclude that based on the specialist assessments and the evidence from the readiness inspections and other interactions; oxygen injection in order to remove carbon deposition on fuel elements in Heysham 1 reactor 2 has been adequately justified by the licensee. I am therefore recommend that ONR issues a license instrument to that effect and that holdpoint ONR-OFD-DR-18-004-0 can be lifted allowing oxygen injection into Heysham 1 Reactor 2.

6. RECOMMENDATIONS

114. I recommend:

- Agreement to the modification proposed in NP/SC 7770, which is the Injection of oxygen into Heysham 1 Reactor 2 for Removal of Fuel Carbon Deposit
- That licence instrument 623 is granted to Heysham 1 to implement NP/SC 7770.

7. REFERENCES

1. BEG/SPEC/DAO/020, Nuclear Generation Limited, Company Specification, Modification process, Revision 008, May 2019.

2. NSL/HYA/50852(Y) – Request for Agreement under arrangements made under licence condition 22(1) NP/SC 7770 SS1 reactor primary circuit oxygen injection: stage submission 1 – injection of oxygen into HYA R2 for removal of fuel carbon deposit (EC361696) – 12 September 2019 (CM9 2019/273264).

3. EDF Energy - EC361222 Paper of Principle NP/SC 7770 “Removal of Carbon Deposition on Fuel Pins by Injection of Oxygen into the Primary Circuit”, December 2017 (CM9 2018/3793).

4. NP/SC 7770, Reactor Primary Circuit Oxygen Injection Stage Submission 1 – Injection of Oxygen into HYA R2 for Removal of Fuel Carbon Deposit. Revision 0, Version 06, September 2019 (CM9 2019/256671).

5. EDF Energy – EC358854 Rev 000 Version 03, NP/SC 7757 “JCO - Continued Operation for Heysham 1 R2 following Detection of Multiple Fuel Failures in 2016” – (CM9 2017/426120).

6. ONR-OFD-DR-18-004 Review and Consider – EC361222 – Removal of Carbon Deposit on Fuel Pins by Injection of Oxygen into the Primary Circuit (NP/SC 7770) (CM9 2018/151574).

7. ONR-OFD-AR-18-068 - Supply Chain Assessment of request for ONR agreement (under derived power arrangements made under Licence condition 22 (1)) for injection of oxygen into HYA Reactor 2 for removal of fuel carbon deposit (EC 361696) (CM9 2019/42381).

8. ONR-OFD-AR-18-44 - Mechanical Engineering Assessment of Removal of Carbon Deposit on Fuel Pins by Injection of Oxygen into the Primary Circuit of Heysham 1 Power Station Reactor 2 (CM9 2018/307895).

9. ONR-OFD-AR-18-035 - Structural Integrity assessment of Primary Circuit Oxygen Injection: Stage Submission 1 – Injection of Oxygen into HYA R2 for Removal of Fuel Carbon Deposit (CM9 2018/272991).

10. ONR-OFD-AR-18-043 - Graphite Integrity Assessment of Injection of Oxygen into Heysham 1 Reactor 2 for Removal of Fuel Carbon deposit (CM9 2018/304657).

11. ONR-OFD-AR-18-054 - Internal Hazards Assessment of the Injection of Oxygen into the Primary Circuit in Heysham 1 R2 for the Purpose of Removal of Fuel Carbon Deposit (CM9 2018/344978).

12. ONR-OFD-AR-18-060 - Reactor Chemistry Assessment of Primary Circuit Oxygen Injection: Stage Submission 1 – Injection of Oxygen into HYA R2 for Removal of Fuel Carbon Deposit (CM9 2018/261996).

13. Email: FW Chemistry Operating Rules – 10/04/2019 (CM9 2019/107047).

14. ONR-OFD-AR-18-066, Rev 1 - Fuel Safety Assessment of NP/SC 7770 Reactor Primary Circuit Oxygen Injection: Stage Submission 1 – Injection of Oxygen into HYA R2 for Removal of Fuel Carbon Deposit (EC 361696) (CM9 2019/195240).

15. ONR-OFD-PAR-18-006 Revision 0 - 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. (CM9 2018/122338).

16. ONR-OFD-AR-18-049, Rev 1 - Fault Studies Assessment of the Injection of Oxygen into the Primary Circuit of Heysham 1 Reactor 2 for the Purpose of Removal of Fuel Carbon Deposit (CM9 2018/295452).

17. ONR-OFD-AR-18 - Control and Instrumentation (C&I) Assessment of EDF NGL's HY1 Power Station R2 Oxygen Injection Modification Submission – NP/SC 7770 (CM9 2019/52122).

18. ONR-OFD-AR-19-037 - Radcons Assessment of NP/SC 7770 Reactor Primary Circuit Oxygen Injection: Stage Submission 1 – Injection of Oxygen into HYA R2 for Removal of Fuel Carbon Deposit (EC 361696) (CM9 2019/200655).

19. Heysham 1 Oxygen Injection Project BOC Quality Issues Brief Rev 001 03 July 2019 (CM9 2019/207524).

20. ONR-OFD-IR-19-055 - Heysham 1 – Oxygen Injection Readiness Inspection (CM9 2019/221215).

21. Email - O2I Readiness Review Actions – 30/08/2019 (CM9 2019/252380).

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23. Email - Regulatory Issue 7402 - INA Concurrence for HYA R2 Oxygen Injection - 02/10/2019 (CM9 2019/285098)

24. Email – OFD EDF NGL SOI 01/05/16 Reactor 2 – Bypass Blowdown Filter Operations During Core Oxygen Injection – NP/SC 7770 EC 361696 – 22/07/2019 (CM9 2019/223125).

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26. Office for Nuclear Regulation (ONR) Heysham 1 (HY1) Power Station Reactor 2 (R2) Oxygen Injection System Control and Instrumentation (C&I) Related Commissioning Activities Review (CM9 2019/304299).

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28. Email – HYA Failed Fuel – Special Programme Board – 16/10/2019 (CM9 2019/299900).

29. Email – Pond Endoscopy Results – 16/10/2019 – (CM9 2019/302683)

30. Agreement Under Arrangements Made Under Licence Condition 22(1) NP/SC 7770 SS1 Reactor Primary Circuit Oxygen Injection: Stage Submission 1 – Injection Of Oxygen Into HYA R2 For Removal Of Fuel Carbon Deposit (EC361696) (CM9 2019/284078).

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