Torness 400kV Shunt reactors replacement – OFGEM justification paper	
Name of Scheme/Programme	Torness 400kV Shunt reactor replacement
Primary Investment Driver	Asset Health (Lead asset – Shunt reactor)
Scheme reference/ mechanism or category	SPNLT 2047 (Transformer)
Output references/type	NLRT2SP2047 (400kV Transformer)
Cost	£7.80m
Delivery Year	2024
Reporting Table	C0.7 / C2.2a_CI / C2.2a_AP / C2.3 / C2.4b / C2.5 / C2.5a
Outputs included in RIIO T1 Business Plan	No

Issue Date	Issue No	Amendment Details
July 2019	Issue 1	First issue of document
December 2019	Issue 2	Gross cost, NPV, Monetised Risk, Long Term Risk Benefit values, delivery year and future pathways – Net zero text updated.
July 2020	Issue 3	Appendix 1 added.

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1 Introduction

The existing Torness 400kV substation comprises a Reyrolle YG GIS, 8 switch mesh substation with the shunt reactors connected to the 400kV mesh via ABB ELK circuit breakers. The shunt reactors circuits are banked with the Strathaven and Eccles 1 circuits for R1 and R2 respectively.

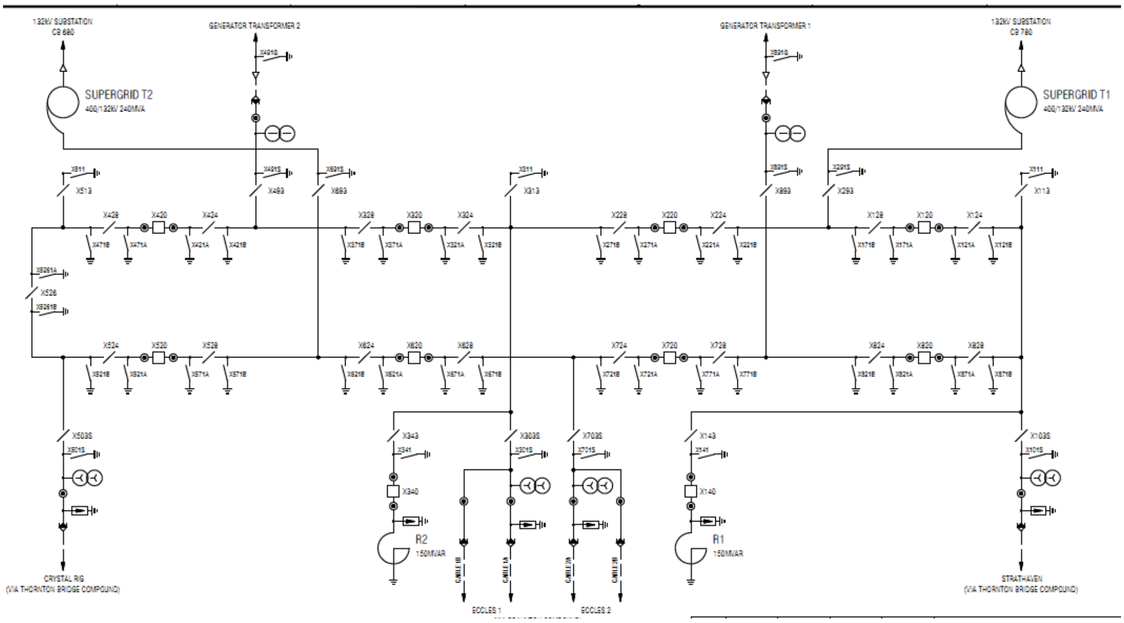

Figure 1: Torness 400kV GSN

Torness shunt reactors R1 & R2 are 400kV 150MVAr Parson Peebles units which were commissioned in 1983. Their intended functions was to provide reactive compensation to counteract the capacitive effect from the long length Strathaven and Eccles 400kV circuits but are currently in service to provide general reactive compensation required by network conditions.

SP Transmission has carried out detailed condition assessment and oil sample tests on the reactors R1 and R2. The assessment has shown that the paper insulation in both the reactors has breached the defined ‘end of life’ limit with no residual life remaining (DP higher than 200). Further the insulating oil in both the reactors is characterised as ‘Poor’ as defined by IEC 60422. Over the samples checked, the breakdown voltage has decreased with periods of time showing a dramatic reduction in the oil’s dielectric strength of both the reactors. Detailed condition assessment reports for both the reactors are available.

As both the reactors have entered an end of life phase, any corrective action taken to improve moisture content, dielectric strength or acidity will not be cost efficient or technically feasible. Considering the inherent issues and in accordance with the scores from NARM methodology, reactors R1 and R2 are now proposed for replacement within RIIO T2 period.

In line with the above, the proposed lead asset outputs for the selected option are:
- 400kV Transformer disposal – 2 unit
- 400kV Transformer addition – 2 unit
-

The replacement works are planned to be completed over 2 outage seasons.

2 Background Information

Based on the values determined in accordance with the NARM methodology, Reactor R1 and R2 at Torness 400kV substation has an EoL modifier score of 12.82 and 14.49 (at end of RIIO-T2 period without any intervention), and based on ongoing issues detected during condition assessment have been identified for replacement.

Accordingly this paper supports a proposal to replace the existing reactors R1 and R2 (400kV 150MVAr) units on a like for like basis within the RIIO T2 period.

This is also in line with the SP Transmission investment strategy for transformers to replace assets at or approaching end of life, particularly those with high Dissolved Gas Analysis (DGA) readings and poor site specific, condition based assessment ranked through our type based operational adequacy methodology TRAN-02-002[1].

Please find details of the lead asset proposed to be replaced:

Asset Description	Manufacturer	Year of Manufacture	EoL score (Transformer) (End of RIIO T2)	Monetised risk
TORN400SHRR1	Parsons Peebles	1983	12.82	£395,557.98
TORN400SHRR2	Parsons Peebles	1983	14.49	£559,659.68

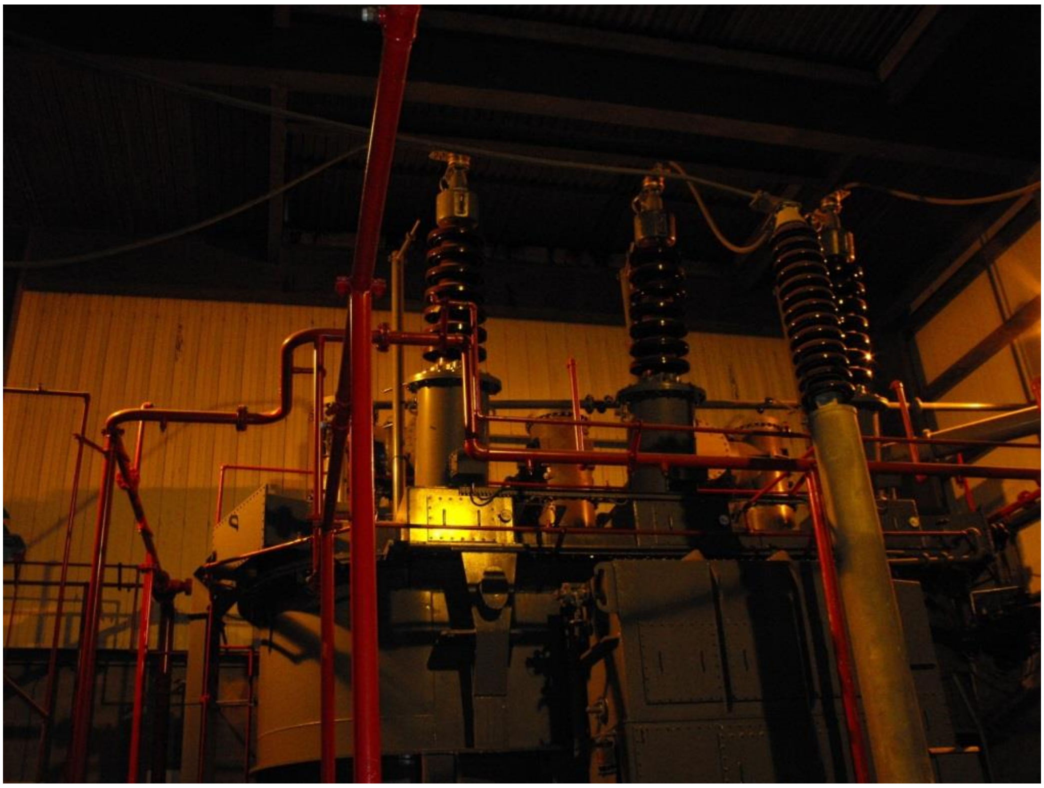

Figure 2: Torness 400kV substation

For this project, no intervention is envisaged on the existing 400kV GIS unit at Torness with the existing ABB ELK circuit breaker being reused for the new reactors as well. As the new reactor would have a

[1] Assessment of Operational Adequacy of Transformers & Reactors (33kV & Above)

different design / connection detail compared to the existing reactors, the GIB connection / coupling arrangement would need to be modified to suit the new reactors.

Note the project will be co-ordinated with ‘SPNLT2091 Torness 400kV (Mech replacement) works.

The existing building requires to be modified to allow the dismantling and removal of existing reactors and installation of new reactors.

No intervention is proposed on the existing auxiliary supply system at Torness 400kV substation.

3 Optioneering

The following is a summary of the options considered for this project. The respective associated drawings for each of these options are available.

	Option	Status	Reason for rejection
	Baseline option: Do nothing in RIIO-T2 period with investment deferred to RIIO-T3 period. Scope of works similar to option 1.	Proposed	-
1	In situ online replacements of existing reactors R1 / R2 on a like for like basis (400kV 150MVAr)	Proposed	-
2	Offline replacements of existing reactors R1 / R2 on a like for like basis (400kV 150MVAr)	Rejected	Torness 400kV substation is an existing 8 switch mesh corner GIS substation located indoors. Reactors R1 and R2 are Teed off Strathaven / Eccles 1 circuits. Any new location considered for Reactors R1 / R2 offline replacement would need to satisfy the existing connection requirement. With the limited space available inside the existing building, an offline build is not possible. Any offline build outside the existing building would not be feasible technically or economically.
3	In situ refurbishment of existing 400kV reactors R1 / R2	Rejected	As explained in section 1 as both the reactors have reached their end of life, any corrective action taken to improve the insulation condition, moisture content, dielectric strength or acidity will not be cost efficient or technically feasible.
4	Remove reactors R1 / R2	Rejected	Both the reactors are required for reactive compensation on the 400kV transmission network. If these are removed, then significant investment would require to be made elsewhere on the network for providing this reactive compensation.

Based on engineering design studies to determine the costs of the options identified as addressing the asset condition issues, the following 2 options have been considered for further review for this project:

- Baseline option: Do nothing in RIIO-T2 period with investment deferred to RIIO-T3 period. Scope of works similar to Option 1.
- Option 1: In situ online replacements of existing reactors R1 / R2 on a like for like basis (400kV 150MVAr)

4 Detailed analysis

Both the options considered achieve the main objective of replacing the reactors while intervening on non-lead assets as required and thereby reducing the overall risks to the network.

As the scope of works is identical for the two options with the only difference being the timing of investment, a common description has been included below which refer to both the options:

4.1 Scope of works

- Replace the 400kV shunt reactors, R1 and R2, at Torness 400kV substation on a like-for-like basis with the location for the reactors remaining the same. Existing building to be modified / adjacent wall to be removed for existing reactor removal / new reactor installation works.
- Modifications to the 400kV GIB connecting to the reactor SF6/oil bushings in line with the new reactor design.
- Each reactor connects to the 400kV system via a dedicated 400kV GIS ABB type circuit breaker. Retain and reuse the GIS circuit-breakers as is with only modifications to the associated GIB connection.
- Replacement of the reactor protection systems shall be included in the project and the Point-on-Wave switching scheme deployed on the circuits shall remain.
- Note final rating of the shunt reactors will be confirmed after detailed design calculation at project delivery stage.

4.2 Specific factors contributing to additional cost

The following factors were identified specifically for this project which is resulting in additional cost:

- Existing reactors are located within the 400kV substation building. Substantial building modification works are required to dismantle, remove and install new 400kV 150MVAr shunt reactors.
- The existing reactors are connected via 400kV GIBs to circuit-breakers X140 / X340. While it is proposed to retain the ABB ELK type 400kV GIS circuit-breaker as is, the associated GIB connections will require substantial modification along with revised coupling arrangement to suit the new reactors. This impacts the overall costing. The GIB costs considered currently are based on a survey carried out by ABB.
- As the works are required within the Torness nuclear power station premises, only authorised contractors can work on this project. Additional design and working requirements are required. This affects the site costs.
- Asbestos contamination in existing infrastructure viz. existing building.
- The existing fire suppression system will need to be modified for the new reactors.

4.3 Selected option

Please find below a cost and construction timescale summary of the short-listed options reviewed:

	Baseline option – Do nothing in RIIO-T2 with investment deferred to RIIO-T3 period. Scope of works similar to Option 1.	Option 1 - In situ online replacements of existing reactors R1 / R2 on a like for like basis (400kV 150MVAr)
Cost (£m)	£ 7.80m	£ 7.80m
Construction timescales	2 outage seasons	

Please also find below a summary of the CBA analysis carried out on the 2 options.

Options	**Deferral**	**NPV (£m)**
Baseline	Do nothing - works deferred to RIIO-T3. Scope of works similar to option 1.	£12.69
1	In situ online replacements of existing 275/33kV 120MVA SGT1 and SGT2 units with new SGT1 and SGT2 275/33kV 90MVA transformers.	£16.21

Based on the technical review carried out, CBA analysis option 1 is the selected option.

Note that the costs have been built up from individual costs for each element and included in a bill of quantities. The bill of quantities has been engineered from the design layouts developed for each option. The basis of individual unit costs has been the SP Transmission MoSC (Manual of Standard Costs) tool which makes reference to costs incurred during previous similar projects.

4.4 Environment & Sustainability

Oil leaks have been recorded in the past from the existing R1 and R2 reactors installed.

As part of this project, we are removing the reactors which were the source of these oil leaks and replacing them with new units thereby reducing the environmental risks associated with these assets.

5 Conclusion

Both the options proposed have been reviewed in terms of scope, costs, timescales, construction risk, and sustainability requirements and have been found to be deliverable.

They also achieve the main objective of reducing the network risks due to existing 400kV 150MVAr reactors R1 / R2 and so are acceptable.

Based on the CBA analysis carried out, Option 1 with a higher NPV has been considered as the preferred option.

- Total project forecast costs for SGT1 / SGT2 replacement:
- Timing of investment: 2024
- Total monetised risk benefit (for R1 and R2): Lr£23.79m
- Declared 400kV lead asset (Transformers) output in RIIO T2 period: Addition – 2 units / Disposal – 2 units

6 Future Pathways – Net Zero

6.1 Primary Economic Driver

The primary driver for this investment is asset condition and risk. The investment does not have a strong reliance on environmental benefits.

6.2 Payback Periods

The CBA indicates that a positive NPV results in all assessment periods (10, 20, 30 & 45 years) which is consistent with the lifetime of the intervention. Consumers benefit from reduced network risk immediately on completion of the project.

6.3 Pathways and End Points

The network capacity and capability that result from the proposed option has been tested against and has been found to be consistent with the network requirements determined from the ETYS and NOA processes. Additionally, the proposed option is consistent with the site-specific capacity requirements from SPT's Energy Scenarios.

6.4 Asset Stranding Risks

Electricity generation, demand and system transfers are forecast to increase under all scenarios. The stranding risk is therefore considered to be very low.

6.5 Sensitivity to Carbon Prices

Carbon price sensitivities have been applied using the higher case CBA template. The CBA outcome is influenced by losses and is sensitive to carbon prices.

6.6 Future Asset Utilisation

It has been assessed that the preferred option is consistent with the future generation and demand scenarios and that the risk of stranding is very low.

6.7 Whole Systems Benefits

Whole system benefits have been considered as part of this proposal. The capacity and capability of the preferred option is consistent with the provision of whole system solutions.

7 Outputs included in RIIO T1 Plans

N/A

8 Appendix 1 SPT Response to Atkins Analysis of EJP_SPT_SPNLT_2047 Issue 2

Torness Shunt Reactor Replacement

CONTENTS

1.0 INTRODUCTION

SPT have identified two 400kV 150MVAr shunt reactors for replacement in RIIO-T2, the main driver for this investment being the reactor insulation being end of life. The planned expenditure for this investment is £7.8m which was supported by engineering justification paper EJP_SPT_SPNLT_2047 Issue 2. Ofgem have rejected this proposal on the basis that ‘Degradation curves pointed towards monitoring in RIIO-ET2 with a review for potential RIIO-ET3 intervention’. This document sets out why the conclusion of the assessment, carried out on behalf of Ofgem, does not suggest an appropriate solution for the Torness reactors and why asset replacement in RIIO-T2 the is appropriate investment for these assets.

2.0 OFGEM ANALYSIS

Ofgem’s consultant (Atkins) has presented their findings when reviewing the need case for investment in document ‘RIIO-T2 TO submission review summary report’ which summarises the review of all three Transmission Owners’ (TO) investment justification papers and also comprises a company specific annex for each company which in the case of SPT this is Annex A. To support the replacement of these reactors SPT submitted EJP_SPT_SPNLT_2047 which was supplemented by Level 1 condition assessment reports carried out by Polaris Diagnostic Ltd, the oil history for both reactors along with document TRAN-02-002 Assessment of Operational Adequacy of Transformer and Reactors (33kV and above) as requested in SPTL_SQ_ENG_7.

Following the assessment of these documents Atkins analysis stated the need case for replacement was not unambiguous. This analysis is based on the end of life criteria in this instance being the degree of polymerisation of the insulation papers, however the units show no other ‘End of Life’ indicators which would be expected. On this basis Atkins believe the replacement of the units was not justified in RIIO-T2 as the assets’ life could be continued to be managed by refurbishment and proper management of oil condition and regular monitoring of the paper insulation degradation and importantly ‘The supporting evidence of oil condition assessment suggest that the oil could be reconditioned.’ On this basis Atkins stated the evidence provided does not sufficiently support early investment.

3.0 SPT ANALYSIS

SPT have considered the analysis provided by Ofgem and also sought the opinion of an independent expert on Atkins analysis. We have also taken the opportunity to update the Level 1 Condition Assessment to calculate the current degree of polymerisation(DP) of the insulating papers based on the most recent oil results. It is the view of SPT that Atkins analysis does not fully consider all aspects which indicate that the Torness Reactors are end of life.

The SPT non-load plan takes due consideration of the End of Life (EoL) score for our assets which have been derived using the approved and calibrated NARM methodology using our CBRM tool. This methodology was developed to ensure the three TOs were calculating end of life criteria for assets consistently and comparably to aid Ofgem’s assessment. The EoL score for the Torness Reactors are R1: 12.82 and R2: 14.49. Using the EoL criteria, an asset with a score of 10 or above is considered end of life. The EoL score does not appear to have been considered by Ofgem or influenced their assessment which is contrary to the development of the NARM process

SP ENERGY NETWORKS

The main reason for the assets being categorised (by the expert independent assessment and the EoL score) as end of life is the degree of polymerisation (DP) of the insulation papers. This is a calculated value based on the concentration of 2-FAL in the reactor oil which is an indicator of the breakdown of the cellulose chain within the reactor paper insulation. Another indicator of the breakdown of the paper insulation is the level of Carbon Monoxide in the oil. The Carbon Monoxide levels in the oil are elevated significantly beyond typical values in both units which is consistent with the 2-FAL level and therefore corroborates the degradation of the insulation papers and the SPT position. Therefore, the suggestion by Atkins that other dissolved gases show no severe trending is incorrect. It is assumed that the comment by Atkins when referring to no other significant indicators pertains to other common gases which indicate different end of life states of a reactor. These gases are Acetylene which is caused by high energy discharges in oil or Ethylene which is caused by localised overheating in a reactor. These gases are not present in the reactor oil in any significant volume because the end of life state is not that which would be indicated by these gases. Therefore, their absence does not correlate to an absence of an end of life state.

The calculated DP levels in the reactors is R1: 185 and R2: 166, this has been recalculated by an independent expert using the latest oil results and the levels have now reduced further to R1: 158 and R2: 145. SPT consider when the DP level of a transformer or reactor is at 300 or below then a transformer or reactor is considered end of life. As part of our assurance process for RIIO-T2 we have sought independent review of document TRAN-02-002 Assessment of Operational Adequacy of Transformer and Reactors (33kV and above) by Doble, an international specialist in this area, (please refer to Annex 1 of the SPT RIIO-T2 business plan). This document discusses how SPT assess and categorise transformer and reactor issues and how they contribute to the categorisation of asset health. Doble comment on the SPT document “As a result of this work, it is the view of Doble that the methodology employed by SPEN is indeed in line with best practice. The methodology is complete in that it addresses all the main components to be considered when assessing the health of transformers and reactors so as to produce an output which is a fair representation of asset condition scoring”. Doble only support some minor improvements to this document. It is a point of note that the author of TRAN-02-002 is currently co-authoring a Cigre position paper on end of life transformers and reactors and as such is considered an industry expert.

It would appear from the SPT analysis that Atkins do not consider the levels of DP evident in these reactors to constitute an end of life condition in line with international best practice as recorded in the SPT methodology. This could be because this value is a calculation rather than a measurement however as previously discussed the corroboration of the 2-FAL and Carbon Monoxide level in the reactors is indicative of significant cellulose degradation of the papers. SPT have also noted inconsistencies in the assessment of DP values by Atkins. Atkins response to EJP_SPT_SPNLT_2047 which discusses the replacement of SGT1 at Giffnock 275kV substation is that refurbishment may have been a valid consideration for this unit as the predicted end of life is 2034 according to the asset condition report. The predicted end of life of Giffnock SGT1 is derived from the calculation of DP level in the unit. It is therefore contradictory for Atkins to consider this measurement to be the determinant of end of life in one unit but not in the case of the Torness reactors.

Atkins have stated the asset could be managed by management of oil condition, regular monitoring of the paper insulation and the units are candidates for the oil to be reconditioned. It is the view of SPT that this statement is contrary to best practice in the long-term asset management of transformers and reactors. SPT only carry out oil reconditioning in very limited circumstances, one of which would be after the repair of a significant internal fault. We would carry this out in these circumstances because the oil has been heavily polluted by gases produced by the fault which would skew any gas trending. Dissolved gas analysis and a transformer’s oil history is critical to the asset management of the unit, reconditioning of oil resets this position and therefore invalidates future analysis for some time afterwards. The issue being experienced by the Torness reactors is due to the breakdown of the cellulose chains in the transformer papers lead to a reduction in the thickness and therefore mechanical strength of the papers. Reconditioning the reactor oil does not alleviate this condition it will merely remove the CO and 2-FAL from the oil and therefore remove these values from analysis. It is likely that it would take some time for these gases to re-establish to their current levels therefore making regular monitoring of the paper condition through oil analysis impossible. It should be noted as insulation paper degrades it loses strength and thickness which could in turn lead to reduced pressure on the reactor clamping arrangement. Reduced pressure associated with clamping arrangement will reduce the reactors' ability to dissipate mechanical forces applied to unit by external electrical faults which could ultimately lead to disruptive failure of the unit.

It is also noted that the analysis by Atkins and decision by Ofgem have disregarded the outcome of the Cost Benefit Analysis. The CBA (published by SPT on its website) indicates that the net present value of the option to replace the reactors during RIIO-T2 is definitively more positive than to defer the intervention until RIIO-T3. In fact, the proposal by Atkins is to refurbish the units which would incur costs in RIIO-T2 prior to replacement in RIIO-T3 which would further strengthen the economic case for replacement in RIIO-T2. It is not clear why Ofgem are proposing a course of action which is substantially less beneficial to consumers than the SPT business plan. In addition, if Ofgem's view is that refurbishment is the correct option, it is not clear why the Draft Determination did not propose any allowance for this intervention.

4.0 POLARIS DIAGNOSTIC LIMITED

SPT have taken the opportunity to engage an independent technical expert to review Atkins analysis of EJP_SPT_SPNLT_2047. The following is an extract from the report for Torness Reactor R1.

The following observations are made in respect to a review of EJP-SPT-SPNLT2047 Issue 2 *"Torness 400kV Shunt Reactors replacement – OFGEM justification paper"*, carried out by W.S.Atkins. This is attached in Appendix A.

"The asset condition reports show dissolved gas analysis (DGA) levels with an upwards trend but no severe DGA trend recordings. The needs case is based upon SPTs asset replacement methodology which designated "end of life" for reactors showing DP (degree of polymerisation) levels of less than 300. It is noted that the DP levels have been estimated from 2FAL and although they show levels of less than 300 this is not coupled with significant "end of life" indicators which would be expected."

The most recent estimated DP derived from the 2FAL was 158 in October 2019. Dissolved gas analysis also includes Carbon Monoxide (CO) which in the case of R1 had varied between 590µl/l and 1300µl/l over the sample range. IEC 60599 "*Mineral oil impregnated electrical equipment in service – Guide to the interpretation of dissolved and free gases analysis"*, states that the "Typical Values" for dissolved CO is between 400µl/l and 600µl/l. The fact that the dissolved CO levels in R1 are consistently higher than the typical values is indicative that there has been long term ageing of the cellulose. IEC 60599 states that "*The polymeric chains of solid cellulosic insulation (paper, pressboard, wood blocks) contain a large number of anhydroglucose rings, and weak C-O molecular bonds and glycosidic bonds which are thermally less stable than the hydrocarbon bonds in oil, and which decompose at lower temperatures. Significant rates of polymer chain scission occur at temperatures higher than 105°C."* With the initiation of decomposition of cellulose components being possible at 105°C, there is a thermal "dead zone" from 105°C up to 150°C where no significant quantities of dissolved diagnostic gases would be generated. So it is possible that degenerative ageing of the cellulose components could take place without producing "significant end of life indicators".

"*Validity of the options considered – Option 3: In situ refurbishment of existing 400kV reactors R1 & R2.* This was rejected (by SPT) as not being cost effective or technically feasible. *This is considered an incorrect assumption. It could be managed with proper oil conditioning and regular monitoring of the issue of paper insulation degradation. The supporting evidence of oil condition assessments suggests that the oil could be reconditioned."*

The 2FAL, and estimated DP should be monitored to keep the ageing rate under surveillance. In this instance it is considered that the suggested oil processing would be the wrong strategy to manage this asset to "end of life" as it is already at "end of life". The main tank oil should not be reconditioned, reclaimed, regenerated or topped up as this will affect the 2FAL concentrations, which is the primary method of surveillance used to monitor the ageing rate of the paper insulation. These interventions will mask any underlying ageing profile. This of course should be reviewed by Transmission Operations in the situation where the dielectric properties of the main tank oil is compromised, deteriorating and presenting a risk of dielectric failure of the liquid insulation.

"*Chosen solution proportionate to the identified needs case – The evidence provided does not sufficiently support early investment."*

R1 Reactor is at "end of life" and should be replaced.

It is also of note that the conclusion was drawn *'Based on the assessment of the historical oil data, there is a high likelihood that the reactor condition will deteriorate during the RIIO-T2 period, resulting in the failure of the asset. The reactor is currently at "end of life" and should be replaced*.

Similar analysis and conclusions have been drawn with respect Torness Reactor R2. The comments on Atkins analysis and proposals are included in the updated Level 1 Condition Assessments which have been included as part of this response

5.0 CONCLUSION

SPT have demonstrated a consistent approach to managing assets and have employed independent external experts to inform and also review their assessment methodologies. This consistent approach can be seen by the high EoL scores of all assets planned for replacement in the non-load plan in line with the approved NARM methodology. In the case of the Torness reactors discussed in the document, the analysis carried out by Atkins is not in line with international best practice and the mitigation measures would not improve the reactors condition but remove the ability to obtain accurate condition information from the oil. It is the view of SPT, and an independent expert, that the Torness Reactors are in an end of life condition and they require to be replaced as planned in RIIO-T2.