Ministry of Defence

de&s

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[redacted]

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Our Reference: FOI2015/03573

6th November 2017

Dear [redacted],

Request for Information under the Freedom of Information Act (FOIA) 2000

Thank you for your letter of 1 April 2015 to the Ministry of Defence (MOD). I am now in a position to provide you with a substantive response to your Freedom of Information (FOI) request, in which you requested the following information:

A copy of the report of the Royal Navy Nuclear Reactor Prototype Review, which was announced in a Written Statement made by the Secretary of State for Defence on 25th March 2015 (House of Commons Written Statement HCWS482).

A search for the information has now been completed within the Ministry of Defence, and I can confirm that information in scope of your request is held.

When examining the information that falls in scope, by virtue of section 10(3) of the FOI Act, public authorities have to consider the balance of the public interest in relation to a request. Within this document there is some information which has been withheld under the qualified exemptions section 26 (defence) and section 27 (international relations) as well as the absolute exemption section 40 (Personal Information). For the two qualified exemptions, before making these redactions, we considered, in all circumstances of the case, where the balance of the public interest lay in relation to the information that you have requested.

For section 26(1)(b), we looked at whether information within these documents, if disclosed, would prejudice defence or the capability or effectiveness of security or relevant forces. We considered that it would promote openness and transparency to release the documents in full and that additional information may provide reassurance to the public about nuclear reactor test establishments. However, to release this information in full would increase the vulnerability of those engaged in defence activities because it would provide an adversary with a greater understanding of the design, hazards and risks associated with the UK's current and future designs of Naval Reactor Plant. We have determined that this would provide useful information to hostile forces and would prejudice the defence of the UK and the effectiveness of the UK Armed Forces. For this reason, on balance, we have taken the decision to withhold some information under section 26(1)(b) of the FOI Act.

For section 27, we looked at whether information within these documents, if disclosed, would compromise international relations. We considered that it would promote openness and transparency to release the documents in full and that additional information may provide reassurance to the public, particularly with reference to the close inter-co-operation of the UK and our Allies in the maintenance of nuclear safety within the UK's Defence Nuclear Programme. However, conversely, to release this information in full would potentially harm our relationship between the UK and our Allies. For this reason, on balance, we have taken the decision to withhold some information under section 27 of the FOI Act.

Section 40(2) is an absolute exemption so all personal information, such as names, photographs and telephone numbers of staff lower than the level of a military 1*, have been withheld.

A redacted copy of the report is attached.

If you have any queries regarding the content of this letter, please contact this office in the first instance. If you wish to complain about the handling of your request, or the content of this response, you can request an independent internal review by contacting the Information Rights Compliance team, Ground Floor, MOD Main Building, Whitehall, SW1A 2HB (e-mail CIO-FOI-IR@mod.uk). Please note that any request for an internal review should be made within 40 working days of the date of this response.

If you remain dissatisfied following an internal review, you may raise your complaint directly to the Information Commissioner under the provisions of Section 50 of the FOIA. Please note that the Information Commissioner will not normally investigate your case until the MOD internal review process has been completed. The Information Commissioner can be contacted at: Information Commissioner's Office, Wycliffe House, Water Lane, Wilmslow, Cheshire, SK9 5AF. Further details of the role and powers of the Information Commissioner can be found on the Commissioner's website at https://ico.org.uk/.

Yours sincerely,

DE&S Policy Secretariat

Royal Navy Nuclear Reactor Test Facility Review

Prof Dame Sue Ion
Prof Andrew Sherry

Presented to MOD Chief Scientific Adviser
on 28 October 2014

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RN Nuclear Reactor Test Facility Review

Prof Vernon Gibson
Chief Scientific Adviser
Ministry of Defence

28 October 2014

Dear Vernon,

RN Nuclear Reactor Test Facility Review Panel Final Report

In March you invited us to review the evidence and decision making process which concluded that the Ministry of Defence should not 'prototype' the next generation PWR3 naval nuclear propulsion plant. We updated you in July and undertook to report substantively in October. Please find attached our final report.

We have reviewed the evidence and decision-making and are grateful to all those who we have met and welcomed their honesty and candour. We were truly impressed by their dedication to the naval nuclear propulsion programme.

[redacted]

[redacted]

The technical advice clearly pointed, and still does, to there being no overriding technical need for a prototype. **In our opinion it was a valid decision not to prototype PWR3 and we concur with the Technical Authority that even given the recent fuel element breach this advice still stands.** We also agree that the programme constraints, driven by the need to maintain Continuous At Sea Deterrence, meant there was no practical course of action that would have enabled a facility to be built ahead of the Successor SSBN first of class. Our view is based on six factors.

(a) The inability of a prototype to uncover performance deviations in a sufficiently timely manner to inform plant design and manufacture;

(b) [redacted];

(c) A rigorous regulatory regime requiring similar verification, validation and testing, already in place for an operational PWR3, offered no benefit or cost saving;

(d) Each component is derived from one that is to a large extent known and supported by the non-nuclear verification, validation and test programme;

(e) The wealth of performance data available to the programme; and

(f) [redacted]

A shore prototype facility is not a panacea but part of a broad through-life verification, validation and test regime supported by test rigs, modelling and operational experience. There is no possible way that such a facility could be operational before the first of class Successor SSBN submarine was operational, defeating the objective of operating a lead plant ashore.

With no PWR3 shore test facility far greater requirements will need to be placed on other elements of the submarine enterprise to provide data, experience and assurance to underpin safety and availability [redacted]. This represents a significant change to the balance of the overall programme with greater requirements placed on a number of elements of the overall system that will need to be protected and strengthened. We have therefore looked at the activities underpinning the naval nuclear propulsion programme through the PWR3's life and have identified a number of risks that concern us with some of these also applying to the legacy PWR2 programme. These risks are associated with:

(1) [redacted]

(2) [redacted]

(3) Maintaining a funded and viable programme to address previous removal of necessary contingency and deferring of longer-term activities. Also, [redacted] a need to reinvigorate the supply chain. This may call for a single senior MOD Head Office sponsor.

(4) Maintaining a credible and funded underpinning research and technology programme to (i) address long-term nuclear plant husbandry and (ii) develop the next generation of nuclear propulsion experts.

(5) The need to undertake a new internal Nuclear Propulsion Capability Review.

(6) [redacted]

(7) Avoiding introspection through better engagement with the civil nuclear sector and strengthening the input from civil and academic experts.

(8) Sustaining nuclear suitably qualified and experienced engineers and scientists.

(9) Maximising the investment in the Shore Test Facility to extract knowledge and understanding from it and maintain access to its unique capabilities.

(10) [redacted]

Addressing the above, we believe, is essential to place the Royal Navy nuclear propulsion programme [redacted] to maintain the current fleet and also deliver Successor SSBN and future nuclear submarine designs. We have observed a 'culture of optimism' that assumes success. The programme has a choice in how it handles risk. It can have a subsystem that cannot or is extremely limited in its ability to accommodate contingency but underpinned by a design that has been sufficiently and robustly validated. Alternatively, it can have a less established design with sufficient contingency built in. [redacted]

We suggest that you share this report with Departmental advisory boards who, we are sure, will have constructive comments to make to assist the Department in taking forward our recommendations.

NRTE Review Panel

Prof Robin Grimes, FREng
Prof Dame Sue Ion, FREng
Prof Andrew Sherry, FREng

Contents

Annexes

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2 Executive Summary

2.1.1 During his 6th March 2014 parliamentary statement the then Secretary of State for Defence, Rt Hon Philip Hammond MP, announced his decision to refuel the ballistic missile submarine HMS VANGUARD (i.e. replace the nuclear reactor core) during its planned deep maintenance period beginning in 2015. This was a prudent precaution following the January 2012 discovery of a microscopic fuel element breach in the cladding around one of the fuel elements in the prototype reactor plant at the Shore Test Facility at the Vulcan Naval Reactor Test Establishment in Dounreay Scotland, resulting in low levels of radioactivity in the cooling water surrounding the core.

2.1.2 The Ministry of Defence had decided some time previously not to prototype its next generation PWR3 nuclear steam raising plant. However, responding to concerns expressed in Parliament about this decision, Mr Hammond asked the MOD's Chief Scientific Adviser to "*review again the evidence on which the decision not to operate a test reactor was based*". The MOD Chief Scientific Adviser, Prof Gibson, invited us (Prof Robin Grimes, Chief Scientific Adviser at the Foreign and Commonwealth Office, Prof Andrew Sherry Director of the University of Manchester Dalton Nuclear Institute and Dr Dame Sue Ion formerly British Nuclear Fuels Ltd. Group Chief Technology Officer) to advise him requesting that we:

> *Review the evidence and decision making process which concluded that MOD should not operate a Royal Navy Nuclear Reactor Shore Test Facility; assess the risk to be carried by the PWR3 programme as a consequence; and revisit the options for MOD to maintain an effective through-life naval reactor plant validation & verification regime.*

2.1.3 We have reviewed the evidence and decision-making that led to the MOD's decision not to prototype in a shore test facility the new PWR3 reactor plant for the next generation of ballistic missile submarine (Successor SSBN). We provided our initial analysis in July and this final document forms our concluding report. In reaching our conclusions and recommendations we looked at the justification for the decision, whether there was a need to revisit it, and considered the implications for the UK's Naval Nuclear Propulsion Programme (NNPP). We examined the relevant documentation and met with key individuals and organisations involved in the programme. We are grateful to those we have met for their assistance, candour and insightful discussion.

2.1.4 [redacted] Vulcan's PWR2 Shore Test Facility allowed [redacted], testing and active experimentation to be undertaken than would have been possible on an operational submarine. Operating for almost 30 years, the Shore Test Facility has provided a wealth of data associated with [redacted], which are all relevant to the design and operation of the PWR3 core. The capabilities available have also enabled investigations on plant and components [redacted] Importantly, the establishment has demonstrated its worth in investigating the current fuel element breach and continuing to assess its implications.

2.1.5 [redacted] We agree with MOD's decision only to prototype the then new design PWR2 reactor core [redacted] and associated primary circuit ahead of its entry into service. [redacted] Similarly, and with hindsight presciently, we support strongly the decision to test the [redacted]

2.1.6 To be good custodians of what will be a British reactor design, MOD and its industrial partners (primarily Rolls-Royce Submarines) must sustain a competent and enduring nuclear propulsion capability [redacted] regardless of the decision on Successor SSBN as there will be a need for stewardship of the ASTUTE class and if required any future nuclear powered platform.

2.1.7 In this executive summary we address first the justification for the decision and whether there is a need to revisit it. We then consider the risks / technical consequences for the Naval Nuclear Propulsion Programme. We recognise that the Successor SSBN programme is driving forward, however, it is important in the light of this review and even though they may be limited, any opportunities to influence and further de-risk and assure the submarine programme are maximised.

Prototype Decision

2.1.8 The technical advice clearly pointed, and still does, to there being no overriding technical need for a prototype. We have concluded that there was, in 2007 when the initial decision was made, no overwhelming technical need for a PWR3 shore based prototype nor was there any practical course of action that would have enabled such a facility to be built ahead of the Successor SSBN first of class. This is based on technical advice dating back a decade and the programme constraints driven by the need to maintain Continuous At Sea Deterrence (CASD). **In our opinion it was a valid decision not to prototype PWR3 and we concur with the Technical Authority that even given the recent fuel element breach this advice still stands**. Our view is based on the following six main factors.

a) **Prototype not sufficiently ahead of the submarine plant:** The benefit of prototypes has significantly lessened as [redacted] as their ability to lead in-service plant and inform design and manufacture has been all but lost. In particular, [redacted] would become evident long after the submarines were in service. Advances in manufacturing and quality assurance mean the plant and its operation is much better understood so, where the system element is not novel, performance in the submarine can be better predicted over the life reducing the need for a prototype to uncover deviations in performance. Further, key PWR3 design parameters were only agreed in recent years which would have delayed any prototype design decision. Thus the time to construct, commission and operate a prototype would not have put it sufficiently ahead of the Successor SSBN first of class to be of any practical value (as a lead core).

[redacted]

c) **Rigorous regulatory regime to assure a test facility:** The regulatory regime does not discriminate between a prototype and an operational plant. The Reactor Plant Safety Justification would therefore be no less rigorous for the shore facility [redacted] verification, validation and test regime already in place to support the PWR3 plant, offering no benefit or cost saving.

d) **Historical experience of most of the system:** The design of each component is derived from one that has already been operational in PWR2 [redacted] and whose performance is to a large extent known. An appropriately funded and executed non-nuclear verification, validation and test programme was already underway in industry [redacted] to robustly support safety justification conclusions. The non-nuclear verification and validation programme can also push the boundaries of component performance beyond what would be safe operation in a nuclear prototype to test, for example, failure modes that a nuclear prototype's safety case would never allow.

e) **Wealth of existing data:** There is a wealth of data associated with the [redacted] available to the programme and the limited requirement to generate significant additional data of this type in a shore facility.

f) [redacted]

2.1.9 A shore-based prototype facility is not a panacea but part of a broad through-life verification, validation and test regime supported by test rigs, modelling and operational experience which also provides the evidence for the plant's safety justification. The lack of need for a shore-based submarine reactor prototype requirement for PWR3 is attributed to the very different design specification, [redacted], and the current availability of advanced modelling tools underpinned by an extensive validation, verification and test programme.

2.1.10 There is no rowing back from this decision. Even if the MOD were now to overturn the decision and require a prototype, at considerable cost (we have been given estimates just shy of £1Bn with whole life costs considerably more), there is no possible way that the facility could be operational before the first of class Successor SSBN submarine was operational, defeating the objective of operating a lead plant ashore. It would, in fact, hinder the programme by diverting components and staff from the current lead PWR3 plant design and manufacture. The Dounreay host site is already well into its decommissioning and in the coming years critical site services will be progressively withdrawn, requiring Vulcan NRTE to establish and maintain them.

Assessment of Risk

2.1.11 **With no PWR3 shore test facility far greater requirements will need to be placed on other elements of the submarine enterprise to provide data, experience and assurance to underpin safety and availability** [redacted]. This represents a significant change to the balance of the overall programme with greater requirements placed on a number of elements of the overall system that will need to be protected and strengthened. We have therefore looked at the activities underpinning the Naval Nuclear Propulsion Programme through the PWR3's life and have identified a number of risks that concern us with some of these also applying to the legacy PWR2 programme. These risks are associated with:

(1) [redacted];

(2) [redacted];

(3) Maintaining a funded and viable programme;

(4) Maintaining a credible and funded research and technology programme;

(5) Revisiting the Nuclear Propulsion Capability Review;

(6) [redacted];

(7) Avoiding introspection within the Naval Nuclear Propulsion Programme;

(8) Sustaining nuclear qualified and experienced engineers and scientists;

(9) Maintaining the residual Vulcan NRTE capabilities; and

(10) [redacted].

2.1.12 [redacted]

2.1.13 [redacted]

2.1.14 We were grateful to the captain and crew of [redacted] for hosting us on-board and providing us with an opportunity to observe nuclear plant operation and maintenance. [redacted]

2.1.15 [redacted]

2.1.16 **Funded and Viable Programme** – We have observed a 'culture of optimism' within the Naval Nuclear Propulsion Programme that assumes success within the tight confines of the required timescales and is then caught unawares when a problem arises such as a fuel element breach – something routinely experienced in the civil sector. The Naval Nuclear Propulsion Programme cannot have it both ways in handling uncertainty – it has a choice. It can either have a subsystem that cannot or is extremely limited in its ability to accommodate contingency but underpinned by a design that has been sufficiently and robustly validated. Alternatively, it can have a less established design with sufficient contingency built in. [redacted] Where the programme positions itself will be a matter of MOD's risk appetite. We have drawn the impression that the programme has clear confidence in the PWR3 design [redacted]

[redacted] This confidence has translated into minimising the operational contingency [redacted]

2.1.17 ***We are concerned that in driving down costs the programme has and is removing necessary contingency and removing or deferring longer-term activities (such as*** [redacted]

2.1.18 [redacted]

2.1.19 [redacted] ***We recommend that the Submarine Enterprise programme actively consider proactive mechanisms to reinvigorate the UK supply chain to support the procurement of future (e.g. Maritime Underwater Future Capability) submarines.***

2.1.20 There are naturally competing drivers for any programme and more so where there is a single customer who has an operational imperative to maintain a strategic capability (such as the deterrent) from a sole commercial supplier who cannot seek commercial markets to offset costs. Also, as we have already noted, the continued pressure to find savings and the short-term disaggregated approach to funding work is likely to lead, sooner rather than later, to a fractured and unsustainable capability base along with vulnerability in the deep and enduring support within the programme, at a time when capability is sparse. Restricting ourselves to the delivery of the Naval Nuclear Propulsion Programme we have heard consistently from those we have spoken to that this situation is, in part, due to the lack of an empowered senior expert champion for nuclear propulsion within the MOD's Head Office. The complexity of the endeavour, its safety implications, [redacted]

[redacted], and long-term liabilities arguably makes nuclear propulsion a special case.

2.1.21 ***We recommend MOD review nuclear propulsion governance with the view of appointing a single senior (probably at 2* or 3*) MOD Head Office sponsor. With access to independent senior specialist technical advice, this individual should provide robust oversight and governance while balancing the competing operational, industrial and policy drivers to ensure this non-negotiable Naval Nuclear Propulsion Programme is sufficiently supported, funded and resourced for the duration of the current and potential future fleet.***

2.1.22 <u>Capability Review</u> – We began this review by considering Prof Burdekin's 2002 review [redacted] and the subsequent MOD Nuclear Propulsion Capability Study. [redacted] his review did raise concerns that still to a lesser degree resonate today: introspection within the nuclear propulsion community [redacted], a lack of an organisational 'champion' for nuclear propulsion technology, a worrying thinness of expertise across the programme, investigation into [redacted] of cores and plant, difficulty in securing 'spend to save' investment and dealing with actual problems rather than 'predictive work'. While the MOD has sought to deal with many of Burdekin's observations we have found [redacted]. ***The Burdekin review highlighted many issues; we strongly recommend a thorough analysis of the post-Burdekin landscape along the lines of the Nuclear Propulsion Capability Review to address our recommendations and observations alongside those of the previous reviews.*** We fully accept the limited room to manoeuvre provided by the Successor SSBN programme, but would suggest its Main Gate business case as a potential vehicle to implement the analysis' conclusions.

2.1.23 <u>Avoiding introspection</u> – We accept the need to limit the programme's openness and sharing to protect information and technology [redacted]. The programme is demonstrably less inward looking and insular than it was at the time of Prof Burdekin's review , but we believe there is more that could be done to benefit from work outside of the programme. ***We recommend the programme seek imaginative methods to better engage with the emergent civil new build programme on nuclear matters to the benefit of Defence.***

2.1.24 The establishment of the Research Programme Group in 2002 was a welcome improvement in the management and governance of the underpinning research and technology programme. The group places a heavy reliance on the Technical Working Groups in ensuring that research and technology formulation and outputs match the programme's requirements and that the programme takes account of civil experience. Civil and academic experts contribute to these groups and have done so for many years with many now well into their 60s. These groups are to be welcomed, but we have been told that while they are considered to be a good concept they can be overly orchestrated, defensive and closed. This has, in part, allowed the current programme to be viewed as somewhat 'incestuous' in terms of supporting the important verification and validation programme. We believe that they may have lost their creative tension by being introspective and closed rather than a critical friend of the research and technology programme that can effectively challenge it. We believe this requires an immediate injection of new blood. ***We recommend that the role of the Research Programme Group and supporting Technical Working Groups be reviewed with the intention of strengthening the input from civil and academic experts, encouraging challenge and making the groups more influential within the programme. We also recommend that the MOD begins to identify and recruit the 'next generation' of independent national experts on to the Technical Working Groups to revitalise them and bring a new perspective.***

2.1.25 The 25-year hiatus in UK new build nuclear plant in the civil sector now looks to be over. Many other countries are actively considering restarting their civil nuclear power build. We are not clear how much value the Naval Nuclear Propulsion Programme is extracting from this considerable investment in the civil nuclear field which includes national and academic centres of excellence. Our experience in the civil sector suggests that there are more opportunities than are presently being explored. ***We recommend that the Research Programme Group establish a workstrand to look at leveraging to maximum effect civil nuclear investment.***

2.1.26 **Research and Technology Programme** – The Naval Nuclear Propulsion Programme needs to be underpinned by a credible and sustainable research and technology programme that needs to sustain PWR3 out to the [redacted] in concert with future nuclear propulsion capabilities and PWR2. There needs to be a through-life verification and validation programme that sufficiently maintains and utilises the large investment and associated expertise in test rigs, computer modelling and other research and design techniques. [redacted]

2.1.27 We understand that the budget for research and technology has been reducing and is due to reduce further. Longer-term research has already been sacrificed to fund investigation of [redacted]. Such research would underpin understanding the condition of the PWR3 to the end of its operational life and support potential future nuclear propulsion plant design. ***We recommend that a long-term research programme be established with assured funding, similar to that recommended by the Burdekin report, to address long-term nuclear plant husbandry and critically act as a basis for developing the next generation of nuclear propulsion experts.*** [redacted] ***To enhance the mechanistic understanding of*** [redacted]***, the programme should look at gaining access to test reactors such as the*** [redacted]***, the UK National Nuclear Users Facility, other research council funded facilities and international facilities.***

2.1.28 [redacted] The programme must make effective use of its investment in rigs now and in the future. It is an effective way of maintaining capability in both facilities and personnel. Without sufficient long-term support the capital expenditure in costly rigs can be wasted and the capability lost. ***We recommend that the programme produce a comprehensive and funded plan to ensure continued PWR3 through-life verification, validation and test that specifically ensures the sustainment of a suite of current and future test rigs.***

2.1.29 **Suitably Qualified and Experienced Personnel** – People are critical to a successful Naval Nuclear Propulsion Programme. Regardless of adopting the PWR3 design, maintenance of the current fleet and its eventual decommissioning is non-negotiable. The gap in the production of nuclear-powered submarines between the VANGUARD and ASTUTE classes coupled with a long period of depressed activity in the UK's civil nuclear sector has led to significant reductions in the skills base for nuclear plant design, manufacture, support and repair. Across the enterprise the availability of deep specialist expertise in key [redacted] and suitably qualified staff appears to be at the bare minimum necessary to deliver the programme. The programme also has no 'strength in depth' in some fields where it is often overly reliant on individual experts. We believe the Naval Nuclear Propulsion Programme could soon be facing a 'perfect storm' with an ageing expert community facing competition from a resurgent civil nuclear industry and other industries (such as oil and gas) at the same time as the programme is increasing and becoming more diverse [redacted]

2.1.30 Staff within the programme and its cadre of world leading independent experts, have supported the programme for many years (decades in some cases). They are ageing and there is an urgent need to pass on knowledge and develop the next generation. While there have been some successes in industry (for example the AMEC programme to recruit and develop young scientists and engineers), the general age distribution within the defence nuclear business is too strongly skewed towards the upper quartile. We believe there needs to be a reliable pipeline for British citizens to qualify in nuclear professions for both defence and civil sectors and recruit the best and the brightest into the Naval Nuclear Propulsion Programme. ***We recommend that the programme should look at enhancing its presence in universities through diverse mechanisms including sponsorships and summer placements.***

2.1.31 The stop-start nature of contracting a long-term programme together with the tactical approach to procurement and commercial competition risks leading to a fragmented and unsustainable expertise base. Defence will also increasingly be in competition with the revitalised, and better paying, civil programme. ***In order to attract, develop and maintain the necessary pool experts within the Naval Nuclear Propulsion Programme the MOD needs to commit to a long-term technology programme.***

2.1.32 **Residual Vulcan NRTE Capabilities** – The Naval Nuclear Propulsion Programme has made a significant investment in the Shore Test Facility and Vulcan NRTE in general. As it comes to the end of its life there is, within the regulatory limits, an opportunity to undertake [redacted] which could enhance [redacted] knowledge and understanding. ***We recommend that the programme should maximise the investment in the Shore Test Facility to extract as much***

***knowledge and understanding from its operation including considering undertaking* [redacted] *prior to final decommissioning*.**

2.1.33 Vulcan NRTE has substantial expertise, knowledge and national niche engineering resources [redacted] – saving the programme money and delivering [redacted] This forms an important element of the overall UK nuclear propulsion capability. We believe strongly that some of these capabilities will need to be maintained in some form or other once Vulcan NRTE closes. ***The programme must ensure that the Vulcan NRTE unique capabilities are regenerated elsewhere within the programme and its substantial expertise and knowledge is retained.***

[redacted]

2.1.35 [redacted] With this need for data, it surprises us that with the Shore Test Facility due for decommissioning its defuel project is still in the concept phase. We are concerned that for past small budgetary savings the MOD chose not to maintain a core [redacted] programme. It will take several years to be in a position to defuel the Shore Test Facility. ***We, therefore, strongly support the programme's decision to continue the Shore Test Facility's operation to enable further investigation of PWR2 operation with a fuel element breach*** [redacted]

2.1.36 We were surprised that Vulcan NRTE was identified as the only facility where [redacted] could be undertaken particularly as this would (if the originally proposed [redacted] programme were undertaken) entail [redacted] within Vulcan NRTE and between it and the Wet Inlet Facility at Sellafield. [redacted]

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3 Conclusions and Recommendations

3.1.1 We have come to the following four conclusions and make twenty recommendations to the naval nuclear propulsion programme management:

Need for a Prototype

Conclusion 1: In our opinion it was a valid decision not to prototype PWR3 and we concur with the Technical Authority that even given the recent fuel element breach this advice still stands.

[Paragraph: 5.7.2]

Assessment of Risk

Conclusion 2: With no PWR3 shore test facility far greater requirements will need to be placed on other elements of the submarine enterprise to provide data, experience and assurance to underpin safety and availability [redacted]

[Paragraph: 6.1.2]

Funded and Viable Programme

Conclusion 3: We are concerned that in driving down costs the programme has and is removing necessary contingency and removing or deferring longer-term activities (such as [redacted] research and technology activities) which is potentially introducing consequent risks which do not to us appear to have been properly addressed.

[Paragraph: 7.2.3]

[redacted]

Conclusion 4: We strongly support the programme's decision to continue the Shore Test Facility's operation to enable further investigation of PWR2 operation with a fuel element breach [redacted]

[Paragraph: 8.2.2]

[redacted]

Recommendation 1: [redacted]

[Paragraph: 6.1.4]

Recommendation 2: [redacted]

[Paragraph: 6.1.5]

Recommendation 3: [redacted]

[Paragraph: 6.1.7]

[redacted]

Recommendation 4: [redacted]

[Paragraph: 7.3.12]

Funded and Viable Programme

Recommendation 5: Given the risk carried by the [redacted], we recommend this decision is revisited.

[Paragraph: 6.1.10]

Recommendation 6: We recommend that the Submarine Enterprise programme actively consider proactive mechanisms to reinvigorate the UK supply chain to support the procurement of future (Maritime Underwater Future Capability) submarines.

[Paragraph: 7.2.5]

Recommendation 7: We recommend MOD review nuclear propulsion governance with the view of appointing a single senior (probably at 2* or 3*) MOD Head Office sponsor. With access to independent senior specialist technical advice, this individual should provide robust oversight and governance while balancing the competing operational, industrial and policy drivers to ensure this non-negotiable Naval Nuclear Propulsion Programme is sufficiently supported, funded and resourced for the duration of the current and potential future fleet.

[Paragraph: 7.2.8]

Capability Review

Recommendation 8: The Burdekin review highlighted many issues; we strongly recommend a thorough analysis of the post-Burdekin landscape along the lines of the Nuclear Propulsion Capability Review to address our recommendations and observations alongside those of the previous reviews.

[Paragraph: 7.2.9]

Avoiding Introspection

Recommendation 9: We recommend the programme seek imaginative methods to better engage with the emergent civil new build programme on nuclear matters to the benefit of Defence.

[Paragraph: 7.5.9]

Recommendation 10: We recommend that the role of the Research Programme Group and supporting Technical Working Groups be reviewed with the intention of strengthening the input from civil and academic experts, encouraging challenge and making the groups more influential within the programme.

[Paragraph: 7.5.12]

Recommendation 11: We recommend that the MOD begins to identify and recruit the 'next generation' of independent national experts on to the Technical Working Groups to revitalise them and bring a new perspective.

[Paragraph: 7.5.12]

Recommendation 12: We recommend that the Research Programme Group establish a workstrand to look at leveraging to maximum effect civil nuclear investment.

[Paragraph: 7.5.13]

Research and Technology Programme

Recommendation 13: We recommend that a long-term research programme be established with assured funding, similar to that recommended by the Burdekin report, to address long-term nuclear plant husbandry and critically act as a basis for developing the next generation of nuclear propulsion experts.

[Paragraph: 7.5.4]

Recommendation 14: To enhance the mechanistic understanding of [redacted], the programme should look at gaining access to test reactors such as [redacted] the UK National Nuclear Users Facility, other research council funded facilities and international facilities.

[Paragraph: 7.4.6]

Recommendation 15: We recommend that the programme produce a comprehensive and funded plan to ensure continued PWR3 through-life verification, validation and test that specifically ensures the sustainment of a suite of current and future test rigs.

[Paragraph: 7.4.9]

Suitably Qualified and Experienced Personnel

Recommendation 16: We recommend that the programme should look at enhancing its presence in universities through diverse mechanisms including sponsorships and summer placements.

[Paragraph: 7.6.7]

Recommendation 17: In order to attract, develop and maintain the necessary pool experts within the Naval Nuclear Propulsion Programme the MOD needs to commit to a long-term technology programme.

[Paragraph: 7.6.11]

Residual Vulcan NRTE Capabilities

Recommendation 18: We recommend that the programme should maximise the investment in the Shore Test Facility to extract as much knowledge and understanding from its operation including considering undertaking [redacted] prior to final decommissioning.

[Paragraph: 6.1.8]

Recommendation 19: The programme must ensure that the Vulcan NRTE unique capabilities are regenerated elsewhere within the programme and its substantial expertise and knowledge is retained.

[Paragraph: 6.1.9]

Core Manufacture

Recommendation 20: [redacted]

[Paragraph: 8.3.10]

Recommendation 21: [redacted]

[Paragraph: 8.3.11]

Recommendation 22: We recommend that Rolls-Royce Submarines look at developing an enduring knowledge capture activity along with a recruitment, training and development programme.

[Paragraph: 7.6.3]

[redacted]

Recommendation 23: We recommend that MOD revisit the possible option of utilising other nuclear facilities including those in the civil sector to undertake [redacted], not least given the possibility that the Shore Test Facility storage pond could be [redacted] is stored [redacted].

[Paragraph: 8.4.6]

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4 Introduction

4.1.1 This is the final report of our review. We have summarised our findings in Section 2 and in the following sections we address first the justification for the decision and whether there is a need to revisit it and then consider the technical consequences for the Naval Nuclear Propulsion Programme. In particular we consider the PWR3 through-life technical support and core manufacture.

4.1.2 The UK has operated nuclear submarines since the early 1960s. Despite having a strong civil nuclear research programme, the Government sought assistance in the early years for their introduction into the Royal Navy Fleet through the transfer of US Navy nuclear plant and technology facilitated by the 1958 UK/US Agreement for Co-operation on the Uses of Atomic Energy for Mutual Defence Purposes (The Mutual Defence Agreement - MDA). This exchange enabled the UK to quickly establish a sovereign nuclear propulsion capability (design, manufacture and maintenance of plant and fuel). In the six decades since, a series of cores and reactor designs have [redacted]. The Royal Navy has operated around 80 cores, at sea and in shore-based test reactors.

[redacted] The physical and operational demands of a submarine drove the selection of a compact pressurised water nuclear reactor (PWR) propulsion system. These reactors use nuclear fission to generate heat, which turns water into steam to turn main turbines that produce electricity and propel the submarine. The gas cooled Magnox and Advanced Gas Cooled designs adopted by the UK civil nuclear sector were considered inappropriate for submarine propulsion applications that had to be [redacted]

4.1.4 Royal Navy submarines provide the nation's nuclear deterrent through a force of four VANGUARD class nuclear powered ballistic missile submarines (SSBN) with nuclear armed Trident ballistic missiles operated such that at least one is continually on deterrent patrol (Continuous At Sea Deterrence – CASD). These submarines will, if the business case is approved in 2015/16, be replaced from the late 2020s by the Successor SSBN class. The nuclear powered attack submarine (SSN) fleet is capable of [redacted]. They constitute the Royal Navy's principal sea denial threat system having anti-submarine, anti-ship and land attack capabilities. The current fleet of TRAFALGAR class SSNs are progressively being replaced by the ASTUTE class which will themselves eventually be replaced by the Maritime Underwater Future Capability (MUFC).

4.1.5 The programme is managed by the Nuclear Propulsion Project Team (NPPT) within the Defence Equipment and Support (DE&S) organisation who is tasked to '*deliver safe, reliable and militarily effective Naval Reactor Plant through-life*' (from research through design, build, operational support and eventual decommissioning). The Head of Nuclear Propulsion as the Design Authority and plant Authorisee is responsible for the safe operation of the naval reactor plant at sea and controls and manages its design through-life. He is supported by a number of Technical Authorities, primarily Rolls-Royce Submarines and AMEC Safety and Reliability Department who provide independent advice. Rolls-Royce

Submarines is the sole manufacturer of naval nuclear steam raising plants in the UK and BAE Systems Maritime – Submarines the sole designer and builder of nuclear submarines. We cover this in more detail in Annex A.

4.1.6 The [redacted] and parts of the steam raising plant [redacted] are, or will be, either manufactured by Rolls-Royce Submarines at their Raynesway facility in Derby or subcontracted to specialist suppliers. The plant is assembled and commissioned at the BAE Systems submarine manufacturing facility at Barrow. To maintain the capability for production into the future MOD agreed in June 2012 a Core Production Capability contract with Rolls-Royce Submarines worth approximately £1.1bn. The 11-year programme of work includes a major £500M programme of site regeneration at Raynesway to replace much of the core factory that has reached the end of its life. The remaining £600M will sustain reactor core production until 2023 including sustaining its core fabrication workforce. We consider core manufacture in Section 8.

4.1.7 [redacted] We refer back to Burdekin's findings (see paragraph [redacted] for a summary of his findings) in this report.

[redacted]

4.1.9 Nuclear submarines are considered some of the most effective, but complex military platforms to design and build coupled with the safety issues of operating a nuclear propulsion system and, in the case of SSBNs, carrying nuclear armed solid fuelled intercontinental ballistic missiles. For the nuclear propulsion system, the MOD has in the past adopted a prototyping approach where a new reactor plant and new reactor cores were tested onshore ahead of being operated in the Fleet, to provide advance notice of issues or problems that might occur onboard a submarine in-service. This prototyping facility is the Vulcan Naval Reactor Test Establishment (NRTE) located at Dounreay in the north of Scotland and operated by Rolls-Royce Plc under a long term partnering arrangement. By the late 2000s MOD had decided that there was no technical requirement for a shore based prototype of its latest PWR3 submarine nuclear steam raising plant destined to power the Successor SSBN and potentially MUFC. A prototype PWR2 plant (the Shore Test Facility – STF) remains operational and is scheduled to be shutdown in 2015 when it will be defueled and decommissioned.

5 MOD's Decision to Decommission Vulcan NTRE

5.1 *Introduction*

5.1.1 The Vulcan NRTE carries out evaluation of the safety, reliability performance and maintainability of the Royal Navy's nuclear propulsion plant. Unlike the original PWR1 prototype (Dounreay Submarine Prototype 1 - DSMP-1), which was in essence a facsimile of the submarine reactor compartment and power train, the PWR2 Shore Test Facility (STF) is not, and was not intended to be, a full prototype but was established as essentially [redacted]

5.1.2 The PWR1 programme was introducing a nuclear steam raising plant where the UK had not operated a pressurised water reactor before, let alone a naval one. For the Royal Navy and its industrial partners there was great uncertainty in operating a naval nuclear reactor and a shore based prototype made prudent sense. By the time the Royal Navy was planning to introduce PWR2 the community had clocked up some thirty years experience in operating naval reactors and, in the case of reactor cores, designing and manufacturing them. [redacted]

5.1.3 The need for a prototype was considered in the early 2000s coming to the opinion that there was no technical need. The advice was revisited in 2007/8 and confirmed that it still stood [redacted] In reviewing the technical programme following the 2012 fuel element breach the advice from the Technical Authority still stands.

5.1.4 In considering the MOD's decision we have reviewed the technical advice provided by Rolls-Royce Submarines at the time and discussed this with some of those who were involved in the discussion and the current technical management team. We have also reviewed documents that relate to the decision and the wider programme.

5.1.5 We note that the PWR3 final design had not been fully defined when the initial decision was made (the design selection was formally approved in the 2010 Successor SSBN Initial Business Case) which introduced uncertainty into the decision.

5.2 *What is a prototype?*

5.2.1 There is no general agreement on what constitutes a 'prototype' and it is often used interchangeably with a proof-of-principle model or pre-production model under test. As some refinement to the design would be expected, prototypes will, in general, differ from the final production variant in its use of production materials, fabrication processes and/or its fidelity. Prototypes can be used to 'prove' out a potential design approach and identify which design options will not work, or where further development and testing are necessary. The philosophy of prototyping has changed as analytical techniques and modelling have enabled designers to use them to refine a design rather than proving that it worked. Advances in computer modelling makes it now practical to eliminate the creation of a physical prototype, instead modelling all aspects of the final product as a computer model. The Boeing 787 Dreamliner is such an example in which the first full sized physical realisation was built on the series production line[1] (six 'prototype' aircraft were built for flight testing and type certification). However, such an approach requires high fidelity validated models particularly where safety is critical. Similarly, long before the 787, the Concorde project only built two prototype aircraft that acted as design demonstrators, development aircraft and pre-production aircraft.

5.2.2 Nuclear reactors are dynamic entities and engineers need to understand the whole system and its subsystem interactions. It is typical engineering practice for large complex systems to be developed by using a broad range of subsystem test rigs, individual component tests and various models and simulations. Where a component or material is well understood in the proposed application or an analogous situation it will likely be used without much investigation as long as its use is within known and understood parameters. These test rigs and models enable subsystems and components to test particular design features or to be operated outside their in-service limits (pushing the envelope) without threatening a complete prototype plant. This is all the more important with a nuclear system where safety concerns would prevent any such investigation on a live plant, yet the operator (and the Regulator) would want to know the consequences of a failure or particular mode of operation.

5.2.3 There is nothing like the real thing. While a nuclear prototype can mitigate some operational availability risk, it is heavily limited in its operation by its safe operation. A full-size non-nuclear test rig could be used to make excursions outside of normal safe operation (although not truly representatively) eliminating more, but not all, risk. The fidelity of the testing and experimentation will be driven by how much risk the programme wished to bear. This situation is not unique to naval reactors, the civil nuclear sector has a significant number of nuclear reactors that were built as 'first of class' models usually, but not always, based on a generic design. As with naval reactors, the safety justification for the design had to be based on extensive modelling and simulation building on (and validated by) previous prototypes, experiments and operational plant. What is important is to be clear about what is not known about a system or plant and how these knowledge gaps can be filled either through experimentation, demonstration or analysis.

5.2.4 The prototypes operated by MOD at the Vulcan NRTE do not meet the basic 'pre-production' criterion for a prototype. DMSP1 was a replica of the reactor compartment entering service and STF was a representative reactor pressure

[1] Jane's All the World's Aircraft 2013/14: Development & Production, page 781.

vessel[2] with an unrepresentative balance of plant. DMSP1 provided confidence that the UK design worked and then its focus shifted to core performance and training. The primary focus for STF has been on core burn-up in part because the balance of plant was little changed and considered well understood.

5.2.5 Neither have these prototypes acted as validation and verification rigs as they have not validated reactor designs but provided confidence for their safety cases and mitigated operational [redacted] risk. This is due in large part to the need to justify a design to the Regulator, resulting in a nuclear reactor prototype needing the same, [redacted] safety justification as the proposed operational plant before it can be operated. If the requirement of the prototype was to validate the operational plant design it would potentially suggest sufficient risk and uncertainty that a regulator would be wary to approve its operation.

5.2.6 For the purpose of this review we have adopted a far broader understanding of 'prototype' to encompass an integrated nuclear validation and verification rig in support of nuclear steam raising plant safety cases and mitigating operational risk – essentially the first of class plant (and lead core) not installed aboard an operational submarine.

5.2.7 A naval nuclear propulsion prototype should ideally represent as complete a nuclear reactor plant as possible and run ahead of the lead core in the fleet. The prototype provides analysis of whole system effects (or of as much as is represented) with a representative nuclear and water chemistry environment. When coupled with [redacted] it provides insight into through-life effects. Whole plant trials and experiments can be undertaken in a safe and controlled environment including gaining operator experience outside of an operational submarine. The prototype will provide confidence for the safety case and supports system availability by taking the burden off the lead core / first of class submarine, in particular, and minimising the burden on the fleet in general. However, a prototype does not usually represent the complete nuclear reactor plant as it only represents what has been built (such as with STF where the balance of plant is not representative). [redacted]. So while the prototype can provide confidence it cannot validate the design. It is also less relevant for [redacted] as to be of little use in supporting design, manufacture and husbandry.

[2] Albeit modified to facilitate [redacted].

5.3 *Effectiveness of the Shore Test Facility*

5.3.1 We consider the Shore Test Facility to be a reactor core performance facility and not a PWR2 nuclear steam raising plant prototype. It is an instrumented nuclear reactor test rig burning the lead core – to a certain degree its function was to burn up the core sufficiently ahead of the in-service cores to inform subsequent designs. This in no way detracts from the excellent engineering and research undertaken at the STF; but when considering the nuclear steam raising plant on submarines in the fleet, the STF only represents part of the overall system (albeit, an important part). It has nevertheless [redacted] allowed modifications and new procedures to be trialled in a safe, controlled and instrumented environment without recourse to investigation and trialling on operational submarines. Without STF the only source of experience will be operational plant and, for core issues, the lead core powering (in the first instance) the first of class submarine.

5.3.2 We understand and agree with the MOD's decision only to prototype the then new design PWR2 reactor [redacted] and associated primary circuit ahead of its entry into service. [redacted] Similarly, and with hindsight presciently, the decision to test the [redacted] is strongly supported [redacted]

5.3.3 [redacted]. Even before operation, the experience of constructing and commissioning STF led to PWR2 plant design changes being identified and introduced. STF could never provide the level of assurance desired of a prototype as its design and operation was core physics led. It was, however, a useful tool. [redacted] STF allowed [redacted], testing and active experimentation [redacted] to be undertaken than would have been possible on an operational submarine. Vulcan's PWR2 facility allowed [redacted], testing and active experimentation to be undertaken than would have been possible on an operational submarine. Operating for almost 30 years, the Shore Test Facility has provided a wealth of data associated with [redacted], which are all relevant to the design and operation of the PWR3 core. [redacted] The capabilities available have also enabled investigations on plant and components to [redacted] and [redacted]. Importantly, the establishment has demonstrated its worth in investigating the current fuel element breach and continuing to assess its implications.

5.3.4 [redacted]

[redacted]

5.3.5 The capabilities available at STF have enabled investigations on plant and components [redacted]. Improved operational processes and procedures have been developed [redacted] STF also has the facilities to [redacted]. The skills and experience at Vulcan enabled the programme to save money [redacted].

5.3.6 The value of STF was demonstrated by the novel technique developed to locate the fuel element breach without impacting on the operational submarine fleet. While a procedure could have potentially been developed on a submarine reactor experiencing a similar breach, we are of the opinion that given the onboard environment it would have been far more difficult. [redacted]

5.4 *What is involved in building a prototype*

5.4.1 We discussed what was involved in building a shore test facility with the team at Vulcan NRTE, the Head of Nuclear Propulsion and the Regulator and were briefed on the 1980s build and commissioning of STF. It was clear to us that, as with the move from DMSP1 to STF a new facility would be required on the Vulcan NRTE site [redacted] Reuse of the current building and plant would be unlikely as the STF PWR2 pressure vessel would require decommissioning and the current building would not meet the safety standards required for a new build. [redacted]

5.4.2 Construction and commissioning of a nuclear test facility is a complex and challenging engineering project as would be its final decommissioning and remediation. Safety and design best practice has moved on since STF was built. A far more costly facility would be required than STF to meet the clear Departmental policy setting a safety standard at least as rigorous as that for a civil nuclear plant. Before construction and again before operation the facility would require significant safety justifications. The opportunities to undertake experiments would likely be greatly reduced from what had been possible in the past to comply with modern nuclear safety justification standards. Experiments undertaken on non-nuclear rigs, on the other hand, require far less regulation and are far less onerous to execute and can therefore push the envelope further than a nuclear test rig or prototype.

5.4.3 The obvious location for a PWR3 shore test facility would have been the current Vulcan NRTE site at Dounreay. Vulcan infrastructure would have to be capable of economic and safe operation for another 20+ years (including the availability of essential services such as high integrity electrical power and waste removal). If reused, major STF components would have to be capable of extended life and requalification. The neighbouring civil site is now being decommissioned on behalf of the Nuclear Decommissioning Agency and it is expected that the site will be closed by 2022-25. Over this time essential services currently provided by the site to Vulcan NRTE will be gradually withdrawn. The MOD site would have to provide these services itself at some cost to establish and maintain.

5.4.4 The MOD site at Dounreay is a Crown site and Defence is a reserved matter under *The Scotland Acts 1998 and 2012*. There continues to be local support for the continued operation of Vulcan NRTE and, if required, the construction of a PWR3 prototype. Any new build would to some extent need the consent of the Scottish Government not least because environmental and planning powers are devolved to it. While the constitutional and legal position of a new build would be for others to consider we note that the Scottish Government has a 'no new nuclear power strategy'. In its October 2007 response to the UK Consultation on the Future of Nuclear Power the Scottish Government stated that Scottish Ministers had made it clear that: "*it is unlikely that proposals from the industry for new nuclear [power] generation, would find favour with the Scottish Government.*" The clearly stated non-nuclear position of the Scottish Government would, we believe, present challenges to the idea of Vulcan NRTE hosting a future nuclear prototype.

5.4.5 A decision not to invest in a new facility at Dounreay would require investment at a site elsewhere in the UK. Wherever a prototype was to be built its construction and operation would require significant investment and based on civil nuclear experience it would be subject to an extensive planning approvals and licensing process. Given the strength of the case against constructing a PWR3 prototype we decided not to consider options for an alternative site but note that there are already several nuclear licensed sites in England that would have the capacity to host a prototype. Regardless of the location we have been informed that construction of a PWR3 prototype would be in the excess of £1Bn and a not insignificant sum to operate and finally decommission.

5.4.6 Any prototype would, of course, require a PWR3 nuclear propulsion plant to host which could have significant programme implications in an already compressed timescale. This plant would necessarily be drawn from the production line. Ideally the plant would be as representative as possible of the proposed in-service plant.

5.5 *PWR3*

5.5.1 [redacted] The 2010 Future Deterrent Submarines Project Initial Gate business case[3] considered two broad submarine concept families: Adapt ASTUTE (with a PWR2 plant or PWR2 derivative) and a Derived Submarine (with a new PWR3 plant) exploiting technology not available when the ASTUTE design was finalised. The analysis of the Successor SSBN nuclear steam raising plant concluded that, [redacted] the adoption of PWR3 for the Successor SSBN programme was recommended – Ministers agreed with this recommendation. If nuclear powered, a PWR3 based plant will also likely power the Maritime Underwater Future Capability (MUFC) successor to the ASTUTE class.

5.5.2 The PWR3 project marks the first new nuclear steam raising plant design for over twenty years. PWR3 design commenced in 2006 (about the same time the initial prototype decision was being made) with the requirement [redacted] to adopt proven technologies. [redacted]

5.5.3 The nuclear safety bar continues to be raised and ALARP best practice[4] evolves becoming more challenging. [redacted]

5.5.4 [redacted]

[3] Successor SSBN Initial Business Case, November 2010, Annex D.
[4] See para A.2.4.

[redacted]

5.5.5 [redacted]

5.5.6 [redacted]

5.6 *Requirement for PWR3 Prototype*

5.6.1 The need for prototype testing, either in a nuclear or non-nuclear facility was a live issue towards the end of 2006 as a decision was needed to be taken within a couple of years to ensure STF operations could be appropriately managed. Historically, a fully validated through-life safety case had never been completed before the first critical operations of the design in a prototype. This also provided stepwise confirmatory data about the performance of each new design to justify continued operation and to feed into later submarine core safety cases. [redacted]

5.6.2 A number of workshops were held to discuss the requirement for a prototype. The need was heavily dependent on the detail of the design and operational characteristics – which at that time were far from fully substantiated. Therefore, a number of scenarios were considered for Successor SSBN and MUFC ranging from a very conservative evolution of PWR2 to significant redesign [redacted]. The technical advice can be summarised: [redacted] This view was generally accepted by the MOD. The technical basis was scrutinised on a number of subsequent occasions within the programme and by a consultant (brought back by Rolls-Royce Submarines from retirement) each time the recommendation not to pursue a prototype was supported.

5.6.3 The PWR2 nuclear reactor plant was well understood and if there had been little change in the design there would have been no overwhelming requirement for the plant to be tested prior to going into operation in a submarine. The PWR3 plant differs from PWR2 in a number of aspects, as outlined in the previous (Section 5.5). [redacted]

5.6.4 A prototype is a risk reduction exercise to support (but not form the basis of) the nuclear plant safety justification [redacted] New or novel components or mechanisms drive towards building a new evidence base. [redacted]

[redacted]

5.6.5 The nuclear steam raising plant system was broken down into subsystems and the separate testing and examination of each was considered in detail to eventually come together in a whole system computer model. Based on the database of knowledge built up by operating PWR1 and PWR2 [redacted] Rolls-Royce Submarines developed a disaggregated verification and validation plan that in their opinion did not require a nuclear prototype. They concluded, however, that a prototype would more than likely be required where a design was expected to operate outside the current knowledge base[5]. [redacted]

5.6.6 [redacted]

[5] NGNPP Full Scale Nuclear Prototyping Policy, RRMP 32649, Version 1, January 2008 and NUPIP 805A Reactor Technology Systems Requirement 14.5 Future Reactor Design and Nuclear Prototyping, RRMP 22243, Issue 1, January 2003.

5.7 *The Decision not to Prototype PWR3*

5.7.1 When in the mid-2000s MOD was considering the Next Generation Nuclear Propulsion Plant for the Successor SSBN – later to become PWR3 – a significant decision programmatically and cost-wise was whether there would be a need for a prototype facility. A formal decision on the plant design was not made until the Successor SSBN Initial Gate decision in 2011 and PWR3 was adopted over the [redacted] PWR2 derivatives. [redacted]

5.7.2 The technical advice clearly pointed to, and still does, there being no overriding technical need for a prototype. We have concluded that, based on technical advice dating back a decade and the programme constraints driven by MOD's need to maintain Continuous At Sea Deterrence (CASD), there was, in 2007 when the initial decision was made, no overwhelming technical need for a PWR3 shore based prototype nor was there any practical course of action that would have enabled such a facility to be built ahead of the Successor SSBN first of class. **<u>In our opinion it was a valid decision not to prototype PWR3 and we concur with the Technical Authority that even given the recent fuel element breach this advice still stands</u>**. [Conclusion: 1] This decision was predicated on there being in place a comprehensive verification and validation programme. This conclusion was based on a number of factors we now cover.

5.7.3 The benefit of prototypes has significantly lessened [redacted] as their ability to lead in-service plant and inform design and manufacture has been all but lost. In particular, [redacted] will become evident long after the submarines are in service. Advances in manufacturing and quality assurance mean the plant and its operation is much better understood so, where the system element is not novel, performance in the submarine can be better predicted over its life reducing the need for a prototype to uncover deviations in performance. Further, key PWR3 design parameters were only agreed in recent years which would have delayed any prototype design decision. Thus the time to construct, commission and operate a prototype would not have put it sufficiently ahead of the Successor SSBN first of class to be of any practical value as a lead core.

5.7.4 It would have been unlikely that a fully representative prototype (such as DSMP-1) would be constructed as again the technical interest would remain focused on the [redacted] (similar to STF). [redacted]

5.7.5 Fundamental to any decision is the regulatory regime that does not discriminate between a prototype and an operational plant – in fact, it could be argued that it discriminates against a prototype as it would be expected to undertake experiments and tests increasing the safety risk. The Reactor Plant Safety Justification would therefore be no less rigorous for the shore [redacted], validation and test regime already in place to support the PWR3 plant offering no benefit or cost saving.

5.7.6 The design of each component is derived from one that has already been operational in PWR2 [redacted] and whose performance is to a large extent known. An appropriately funded and executed non-nuclear verification, validation and test programme was already underway in industry [redacted] to robustly support safety justification conclusions. The non-nuclear verification and validation programme can also push the boundaries of component performance beyond what would be safe operation in a nuclear prototype to test, for example, failure modes that a nuclear prototype's safety case would never allow.

5.7.7 [redacted] The absence of this performance data adds analytical uncertainty that while mitigated by drawing on other sources will ultimately be required before the programme can have a high degree of confidence in its modelling.

5.7.8 There is now a wealth of data associated with [redacted] available to the propulsion programme [redacted]. There is, we have been told, a limited requirement to generate significant additional data in a shore based facility.

[redacted]

5.7.10 The role of a prototype is to be the lead plant / core and therefore needs to operate sufficiently ahead of the lead submarine to be of benefit. The key PWR3 design parameters were only agreed sometime after a decision was needed. The time to construct, commission and operate a prototype would have put it several years behind the Successor SSBN first of class negating any practical value (as a lead core). [redacted]

5.7.11 [redacted]

6 [redacted]

[redacted] Regardless, STF's defuel and recertification could have been prohibitive in the modern regulatory regime. A new facility even built at Dounreay would come at a high cost (we have been given estimates just shy of £1Bn with whole life costs considerably more). Little or no savings could be realised elsewhere in the supporting programme as it would be still be required to support the prototype's safety case. A prototype would represent a significant part of the overall Successor SSBN project and given its role to essentially mitigate availability risk and not to substantiate the in-service plant, we think it would be highly questionable that any prototype justification would have survived a robust balance of investment analysis.

5.7.12 Establishing a prototype now (or in the past decade) would require diverting critical components ([redacted], etc.) and people away from the Successor SSBN design and build programme to construct the facility.

5.7.13 The decommissioning of the neighbouring Dounreay civil site further complicates development of the Vulcan NRTE site as observed in Section 5.4. The provision of various critical support services (such as waste treatment and high integrity electricity supplies) will progressively be withdrawn. MOD would have to commit to providing these services and take on the full cost of eventual decommissioning (that at present could be shared with the Nuclear Decommissioning Authority for STF's decommissioning). The opposition of the Scottish Government to nuclear development would also have to be overcome; although there are a number of potential sites in the rest of the UK that could potentially host a new facility.

5.7.14 In conclusion, a prototype based at a shore test facility is not a panacea but part of a broad through-life verification, validation and test regime supported by test rigs, modelling and operational experience which also provides the evidence for the plant's safety justification. The lack of need for a shore-based submarine reactor prototype requirement for PWR3 is attributed to [redacted], the current availability of advanced modelling tools underpinned by an extensive validation, verification and test programme – using computational modelling, extrapolations from current reactor designs, and testing of individual components and systems using a number of test rigs (a mix of existing, modified, and all-new rigs. [redacted]

6 Implications of not prototyping PWR3

6.1.1 To be good custodians of what will be a British reactor design, MOD and its industrial partners (primarily Rolls-Royce Submarines) must sustain a competent and enduring nuclear propulsion capability [redacted] regardless of the decision on Successor SSBN as there will be a need for stewardship of the ASTUTE class and if required any future nuclear powered platform.

6.1.2 While we agree there is not an overwhelming technical need for a PWR3 shore based prototype, we have come to a view that there are implications and risks from this decision. **With no PWR3 shore test facility far greater requirements will need to be placed on other elements of the submarine enterprise to provide data, experience and assurance to underpin safety and availability** [redacted]. [Conclusion: 2] This represents a significant change to the balance of the overall programme with greater requirements placed on a number of elements of the overall system that will need to be protected and strengthened. We have therefore looked at the activities underpinning the Naval Nuclear Propulsion Programme through PWR3's life and have identified a number of risks that concern us with some of these also applying to the legacy PWR2 programme. We cover these risks here and in the subsequent sections.

6.1.3 [redacted]

[redacted]

6.1.4 [redacted]

[Recommendation: 1]

6.1.5 [redacted]

[redacted] [Recommendation: 2]

6.1.6 [redacted] We have not, nor do we consider we are expected to, consider what the optimum number of submarines would be to maintain CASD. [redacted] We are not convinced that reducing the number of submarines below the current four would not impose unacceptable availability risk nor would it achieve significant savings. [redacted]

6.1.7 We were grateful to the captain and crew of [redacted] for hosting us on-board and providing us with an opportunity to observe nuclear plant operation and maintenance. [redacted] [Recommendation: 3]

Vulcan NRTE Residual Capabilities

6.1.8 STF has provided opportunities to [redacted] The Naval Nuclear Propulsion Programme has made a significant investment in the Shore Test Facility and Vulcan NRTE in general. As it comes to the end of its life there is, within the regulatory limits, an opportunity to undertake [redacted] which could enhance [redacted] knowledge and understanding. ***We recommend that the programme should maximise the investment in the Shore Test Facility to extract as much knowledge and understanding from it operation including considering undertaking*** [redacted] ***prior to final decommissioning.*** [Recommendation: 18]

6.1.9 There is substantial expertise and knowledge along with national niche or specialist capabilities at Vulcan NRTE. These have been demonstrated through enabling rapid refit and practice of essential maintenance and engineering for the submarine fleet. The [redacted] is an important capability saving the programme money and delivering [redacted]. The capability comprises a cadre of experienced engineers and [redacted]. This capability will need to be maintained either at Dounreay or most likely moved to Raynesway where there is potential to utilise the [redacted]. The Vulcan NRTE team form an important part of the overall UK nuclear propulsion capability. While some of the individuals could be based locally, much of their expertise has derived from operating and maintaining STF and will gradually disappear. We believe strongly that some of the Vulcan NRTE capabilities and expertise will need to be maintained in some form or other once the site closes. These capabilities also include [redacted] which provides performance data to inform core design and safety justifications and which we consider later in Section 8.4. **The programme must ensure that the Vulcan NRTE unique capabilities are regenerated elsewhere within the programme and its substantial expertise and knowledge is retained**. [Recommendation: 19]

6.1.10 With Successor SSBN [redacted] it will be possible to simplify the submarine design reducing cost and construction time [redacted] As noted in the Successor SSBN Initial Business Case[8], [redacted] To reinstate the capability once decommissioned would come at significant cost and time. [redacted] ***Given the risk carried by the*** [redacted]

7 [redacted]

8 Successor SSBN Initial Business Case, November 2010, para D.9.a.

[redacted]***, we recommend this decision is revisited.***
[Recommendation: 5]

7 PWR3 Through-life Technical Support

7.1 *Introduction*

7.1.1 We have looked at the activities underpinning the Naval Nuclear Propulsion Programme through PWR3's life and have identified a number of risks that concern us. In this section we consider aspects of the programme's technical support from a number of perspectives and identify what we believe to be risks and concerns that should be addressed to ensure the programme is effectively and efficiently supported for as long as the UK chooses to operate nuclear propulsion plant. First (Section 7.2) we consider the maintenance of a funded and viable programme. [redacted] In Section 7.4 we look at the verification, validation and test regime that the decision not to operate a shore test facility was predicated on and in Section 7.5 we cover its underpinning research and technology programme. We then address the important issue of people and the need to recruit, develop and sustain suitably qualified and experienced personnel upon whom the nuclear propulsion programme is built.

7.1.2 To be a competent and safe custodian of nuclear propulsion plant the UK needs to 'own' key technologies not accessible in the wider supply chain – such as reactor core and plant performance analysis, validation and verification, major reactor plant component design, and high integrity electrical design – has been apparent for some time. This need required focused investment to regenerate the UK nuclear propulsion design and support capability when the absence of any major nuclear steam raising plant development programme since the late 1980s had put pressure on sustaining capability to develop and design new reactor plants for the UK submarine programme. These challenges were recognised in the December 2005 Defence Industrial Strategy[9]. This enshrined the need to sustain a sovereign critical capability for nuclear steam raising plant design, supply, support and disposal. In the intervening period, the emergence of a stable long-term UK submarine programme has brought the visibility demanded by industry to underpin major investment decisions. Attendant to this have been initiatives to promote far greater coherence and collaboration within the submarine enterprise so as to drive performance improvements and cost efficiencies. We have duties of nuclear ownership [redacted] which can only be fulfilled by close control of an onshore submarine business. Therefore, it is essential that the UK retains the capability to safely deliver, operate and maintain these platforms, without significant reliance on unpredictable off shore expertise. The strategy goes on to note that these skills and capabilities may not be available, or which we would not wish to source, from the international market.

[9] Defence Industrial Strategy, Cm 6697, December 2005, paragraphs B2.26-28.

7.2 *A Funded and Viable Programme*

7.2.1 All those we have spoken to were clearly committed to the success of the Naval Nuclear Propulsion Programme and it was clear they sought what was best for it. We are, however, concerned that a culture that does not accommodate failure pervades. The fuel breach was an example of this where a notable recorded programme risk, and something routinely experienced in the civil sector, came as a surprise and diverted limited resources to understand the problem. On the positive side, this was an example of the skill and expertise within the programme. This 'culture of optimism' within the programme assumes success within the tight confines of the required timescales and budget and is then caught unawares when a problem arises. The Naval Nuclear Propulsion Programme cannot have it both ways in handling uncertainty – it has a choice. It can either have a subsystem that cannot or is extremely limited in its ability to accommodate contingency but underpinned by a design that has been sufficiently and robustly validated. Alternatively, it can have a less established design with sufficient contingency built in. [redacted] Where the programme positions itself will be a matter of MOD's risk appetite. We have drawn the impression that the programme has clear confidence in the PWR3 design [redacted]

7.2.2 This is nothing new as, to a degree, this was also observed in Prof Burdekin's 2002 report. When we consider the civil sector where hardly any civil plant has been delivered on time and budget we see this optimism distorting the programme's risk appetite. Budgetary constraints have led to the removal or deferral of longer-term activities (such as [redacted] and research and technology activities) and contingency has been trimmed – all of which introduce consequential risks which do not to us appear to have been properly addressed.

7.2.3 ***We are concerned that in driving down costs the programme has and is removing necessary contingency and removing or deferring longer-term activities (such as [redacted] and research and technology activities) which is potentially introducing consequent risks which do not to us appear to have been properly addressed.*** [Conclusion: 3] We consider [redacted] as an example of this.

7.2.4 For as long as the UK operates nuclear submarines, maintaining a credible and capable programme is a non-negotiable Defence activity. We are concerned that there is not a clear commitment to funding an enduring programme or a commitment to put one in place to maintain underpinning capability and knowledge for the duration of PWR3's anticipated life and to underwrite the design of the Maritime Underwater Future Capability propulsion system should the MOD select a nuclear powered solution. The Naval Nuclear Propulsion Programme has invested in many world-class facilities on a project basis and then proceeded to mothball or write-off assets which may be needed to solve problems that are at present unknown. As a consequence, the experience base has become increasingly vulnerable and fragmented and there are questions over its long-term viability. This is to large degree because of what we have observed as the MOD's stop-start approach to funding coupled with taking short-term savings. The focus has been on meeting the immediate programmatic and regulatory demands rather than the enduring health of the programme as a whole.

7.2.5 [redacted] ***We recommend that the Submarine Enterprise programme actively consider proactive mechanisms to reinvigorate the UK supply chain to support the procurement of future (e.g. Maritime Underwater Future Capability) submarines***. [Recommendation: 6]

7.2.6 There are naturally competing drivers for any programme and more so where there is a single customer who has an operational imperative to maintain a strategic capability (such as the deterrent) from a sole commercial supplier with limited assured supply chain who cannot seek commercial markets to offset costs. Also, as we have already noted, the continued pressure to find savings and the short-term disaggregated approach to funding work is likely to lead, sooner rather than later, to a fractured and unsustainable capability base along with vulnerability in the deep and enduring support within the programme, at a time when capability is sparse. In contrast, we have observed that the weapons programme is managed in far more holistic manner (enduring programmes of research, design and manufacture rather than decoupled projects) to deliver a single capability.

7.2.7 Without a successful submarine and propulsion programme the deterrent cannot deploy. It concerns us, therefore, that the Department's technical nuclear focus would appear to be disproportionately skewed toward the weapons programme. In our discussions we are left with the strong impression that the weapons programme has, and benefit's from, the attention of the MOD's (and National Security Secretariat's) senior leadership whereas the Naval Nuclear Propulsion Programme would seem to be somewhat disaggregated and without long-term certainty. Given its importance to maintaining a nuclear submarine fleet and therefore the strategic deterrent and the importance of keeping the plants operational and safe we believe there should be a shift in the nuclear custodian balance.

7.2.8 Restricting ourselves to the delivery of the Naval Nuclear Propulsion Programme we have heard consistently from those we have spoken to that this situation is, in part, due to the lack of an empowered senior expert champion for nuclear propulsion within the MOD's Head Office. The complexity of the endeavour, its safety implications, [redacted], and long-term liabilities arguably makes nuclear propulsion a special case. ***We recommend MOD review nuclear propulsion governance with the view of appointing a single senior (probably at 2* or 3*) MOD Head Office sponsor. With access to independent senior specialist technical advice, this individual should provide robust oversight and governance while balancing the competing operational, industrial and policy drivers to ensure this non-negotiable Naval Nuclear***

Propulsion Programme is sufficiently supported, funded and resourced for the duration of the current and potential future fleet. [Recommendation: 7]

7.2.9 We began this review by considering Prof Burdekin's 2002 review [redacted] and the subsequent 2003 MOD Nuclear Propulsion Capability Study. [redacted], his review did raise concerns that still to a lesser degree resonate today: introspection within the nuclear propulsion community, [redacted], a lack of an organisational 'champion' for nuclear propulsion technology, a worrying thinness of expertise across the programme, [redacted], difficulty in securing 'spend to save' investment and dealing with actual problems rather than 'predictive work'. While the MOD has sought to deal with many of Burdekin's observations we have found some that have not been or not sufficiently addressed. ***The Burdekin review highlighted many issues; we strongly recommend a thorough analysis of the post-Burdekin landscape along the lines of the Nuclear Propulsion Capability Review to address our recommendations and observations alongside those of the previous reviews.*** [Recommendation: 8]

7.2.10 We recognise that the Successor SSBN programme is driving forward and fully accept the limited room to manoeuvre within the Successor SSBN programme. However, it is important in the light of this review and even though they may be limited, any opportunities to influence and further de-risk and assure the submarine programme are maximised. We would suggest the Successor SSBN programme Main Gate business case as a potential vehicle to implement the outcome of any follow-on MOD nuclear propulsion capability study.

7.3 [redacted]

7.3.1 [redacted]

7.3.2 [redacted]

7.3.3 [redacted]

7.3.4 [redacted]

[redacted]

7.3.5 [redacted]

7.3.6 [redacted]

7.3.7 [redacted]

7.3.8 [redacted]

7.3.9 [redacted]

[redacted]

7.3.10 [redacted]

7.3.11 [redacted]

7.3.12 [redacted]

7.4 PWR3 Verification, Validation and Test Regime

7.4.1 We have been briefed on the verification and validation approach and in general terms how each element will be tested. We have also been shown many of the test rigs that are being used to support the verification and validation process. The programme has used systems engineering principles to develop a comprehensive verification and validation plan, the detail of which is outside of our review. Verification and validation provides evidence through the most suitable method that the plant functions as specified and in the case of PRW3 comprises some 45 areas covering the overall plant performance and each part of it including failure modes. Evidence is drawn from the most suitable methods: testing; demonstration; simulation; using existing data to infer performance; and inspection and review. We are, to the limited degree we have looked, content that the programme has a comprehensive and credible verification and validation process in place and this will be critically assessed by the Regulator as part of the safety justification.

7.4.2 We are concerned that at present the Naval Nuclear Propulsion Programme is funding the verification and validation programme to the commitment to build decision rather than through-life and are therefore unconvinced that the verification and validation programme sufficiently underpins PWR3 through-life. Whilst STF has operated as a lead core facility, there would appear not to have been much importance placed on maintaining the operation of test rigs. Without a nuclear prototype, test rig capabilities become far more important to underpinning through-life performance issues. The impressive capabilities developed at Rolls-Royce Submarines and elsewhere must not be allowed to wane through short-term budgetary savings. [redacted] Such rigs importantly provide the opportunity to test systems and components beyond what would be possible in a nuclear reactor facility shining a light on more system unknowns. We cannot emphasise enough that we see some rigs to be required to operate for very long periods in some critical areas if [redacted] are to be properly investigated and thus underpin existing modelling assumptions.

7.4.3 Prototyping and simulation using test rigs and models can test and prove design claims, substantiate margins [redacted] and investigate emergent phenomena. The use of test rigs can avoid the cost and operational challenges of a full prototype and can be far more flexible and focussed. However, they may miss 'whole system' effects and do not generally represent the real environment [redacted]. Models are potentially cheaper and can simulate a range of conditions with no physical risks, but require validation and can provide 'false confidence' when the base parameters are incorrect. They are also limited to what is being modelled so cannot reveal physical unknowns. [redacted]

7.4.4 Without a nuclear prototype other verification, validation and experimentation techniques and methods will be required. The full system cannot be tested to the same extent, so systematic issues relating to the full PWR3 system will require a combination of test rigs and modelling. In many cases these test rigs and models would be required even if a shore based prototype were available. [redacted]

[redacted]

7.4.5 Any core will be tested in the Rolls-Royce Submarines' NEPTUNE facility before going into service to verify the core meets the design and validate the nuclear physics assumptions supporting the core design. Designers need and the safety case requires an understanding of the time dependent phenomena [redacted] of the plant components, in particular [redacted] Mechanistic understanding is used to inform and underpin predictions of materials performance and is developed from testing and investigation. Tests in near-to-plant conditions are also carried out to develop empirical rules.

7.4.6 The UK DIDO and other similar materials test reactors shutdown some twenty years ago and others like the international HALDEN facility are difficult to access [redacted] The programme requires access to nuclear and non-nuclear materials facilities at home and overseas and should look at gaining more access to the [redacted] and to other facilities such as the University of Manchester's Dalton Cumbrian Facility and National Nuclear User Facility to test [redacted]. While its data are somewhat dated, it is worth noting that DIDO work has informed the current fuel element breach investigation. Core performance can also be supported by laboratory testing, advanced imaging, modelling and [redacted] which remains an effective method of acquiring materials data and we cover this in more detail in Section 8.4. [redacted] Also materials in storage at Sellafield could be used but again their identification and removal would not be trivial. ***To enhance the mechanistic understanding of*** [redacted]***, the programme should look at gaining access to test reactors such as*** [redacted]***, the UK National Nuclear Users Facility, other research council funded facilities and international facilities.*** [Recommendation: 14]

7.4.7 Advanced numerical methods are used in the areas of [redacted]. These are validated against a range of rig and reactor data. The development of these methods is a specialised discipline and requires experienced staff. It often benefits from academia where researchers develop the understanding and techniques. Any technique needs to be verified by the Technical Authority that equations and data used are correctly incorporated validated that the method or technique adequately represents reality by comparison with test data, operating experience and other methods. [redacted]

7.4.8 The programme must make effective use of its investment in rigs now and in the future. While experimentation can be costly and even care and maintenance costs, it is an effective way of maintaining capability in both facilities and personnel. Without sufficient long-term support the capital expenditure in costly rigs can be wasted and the capability lost. Even a pause in maintenance can rapidly put a facility beyond economic future use. Without a shore facility to focus financial attention, the disaggregated nature of test rigs means there is a great risk that relatively small sums of money for each suite could be redirected or saved resulting in costly future replacement.

7.4.9 In an era where there is not a prototype facility available to undertake precautionary investigations and experiments or to respond to an incident in the fleet, the importance of a suite of test rigs becomes even more important including their availability respond quickly to a problem. The programme must make effective use of its investment in rigs now and in the future. It is an effective way of maintaining capability in both facilities and personnel. Without sufficient long-term support the capital expenditure in costly rigs can be wasted and the capability lost. ***We recommend that the programme produce a comprehensive and funded plan to ensure continued PWR3 through-life verification, validation and test that specifically ensures the sustainment of a suite of current and future test rigs.*** [Recommendation: 15]

7.5 *Underpinning Research and Technology Programme*

7.5.1 In our meetings we have discussed at length the Naval Nuclear Propulsion Programme's underpinning knowledge base and supporting research and technology programme. Research and technology facilitates the acquisition of knowledge – making the unknowns known. [redacted] it is an effective mechanism for maintaining suitably qualified and experienced personnel. The current Naval Nuclear Propulsion Research and Technology programme was born out of the Burdekin report and resulting Nuclear Propulsion Capability study which rebalanced and refocused the then programme. Research is delivered through a joint (MOD, Rolls-Royce Submarines and AMEC) programme office overseen by the Naval Nuclear Propulsion Research Programme Group set up in response to the Burdekin recommendation and until recently chaired by Prof Burdekin. As with the Naval Nuclear Propulsion Programme as a whole, research and technology has suffered from instability and a lack of continuity resulting from its stop-start nature. Although, the current ten-year programme has been invaluable, it is concerning that this funding is on a downward trend, and we would hope this trend would be reversed.

7.5.2 The MOD's Research and Technology Strategic Intent has recently been refreshed and recognises that the programme needs to achieve a balance between current cost, capability and safety and work which has application over longer timescales. It identifies programme outcomes against which research and technology activities will deliver over the short (0 to 5 years), medium (5 to 10 years) and long (10 to 20 years) -term. Activities addressing the 'here and now' tend to trump (and therefore secure funding) areas of interest that may deliver solutions to problems further out. This is especially the case when these are characterised as 'blue skies' research. What this has tended to mean is longer range research work which will be needed for a future plant design or to understand the PWR3 condition in [redacted] is far less likely ever to be undertaken. [redacted]. This has further conditioned the programme to under invest in research not directly aligned to current plant so investment is focused on maturing technologies' readiness levels for PWR3. We also noted that there was no programme headroom to allow for effective horizon scanning and technology watch.

7.5.3 The Naval Nuclear Propulsion Programme needs to be underpinned by a credible and sustainable research and technology programme that needs to sustain PWR3 [redacted] in concert with future nuclear propulsion capabilities and PWR2. There needs to be a through-life verification and validation programme that sufficiently maintains and utilises the large investment and associated expertise in test rigs, computer modelling and other research and design techniques. The lack of programme and capability funding for the duration of the anticipated plant lifetime is a worry. The programme has invested in many world class facilities that need to be maintained to address current knowledge gaps and future unknowns that will inevitably need investigation. The current management and governance could be improved to ensure longer term issues are addressed and apportioned sufficient importance and research propositions are better challenged.

7.5.4 We understand that the budget for research and technology has been reducing and is due to reduce further. Longer-term research has already been sacrificed to fund investigation of current problems. Such research would underpin understanding the condition of the PWR3 to the end of its operational life and support potential future nuclear propulsion plant design. ***We recommend that a long-term research programme be established with assured funding, similar to that recommended by the Burdekin report, to address long-term nuclear plant husbandry and critically act as a basis for developing the next generation of nuclear propulsion experts.*** [Recommendation: 13]

7.5.5 [redacted].

7.5.6 [redacted]

7.5.7 [redacted]

10 [redacted]

[redacted]

7.5.8 We discuss the recruitment and development of experts later in Section 7.6 but flag here the important part the research and technology programme plays in attracting and developing scientists and engineers. A forward looking programme will invest in work that enables researchers to develop into the deep specialists that are sorely few at present. [redacted]

7.5.9 The programme is demonstrably less inward looking and insular than it was, but we believe there is more that still could be done to benefit from work outside of the programme. We have seen the programme learning from the fuel element breach and its need to understand what operating with a [redacted] breach will mean [redacted] It is also to a degree working with the civil sector and academics but a major problem is declassifying work into a form that they can undertake (this relates not only to the 'raw' classification but also the intent of the work). [redacted] To the programme's credit it far less introspective and insular than it was at the time of Prof Burdekin's review. We accept the need to limit the programme's openness and sharing to protect information and technology [redacted], military operational capability and national sovereignty. We believe, however, there is more that could be done to benefit from work outside of the programme. ***We recommend the programme seek imaginative methods to better engage with the emergent civil new build programme on nuclear matters to the benefit of Defence.*** [Recommendation: 9]

7.5.10 The University Technology Centres are a good source of accessing technology but we were told that it was difficult to identify what the programme wanted them to do and that the defence profile of the programme was a problem. A good example was Rolls-Royce Submarines work with the Manufacture Technology Centre [redacted] to look at manufacturing processes that included Rolls-Royce Submarines staff who would import the techniques [redacted].

7.5.11 The establishment of the Naval Nuclear Propulsion Programme Research Programme Group in 2002, as recommended by the Burdekin report, was a welcome improvement in the management and governance of the underpinning research and technology programme. The group meets about twice a year to provide assurance and advice to the Head of Nuclear Propulsion and the Defence Science and Technology Director. The group of independent experts provides oversight of the formulation, governance and delivery of the nuclear reactor plant research and technology programme and considers its outcomes advising on the extent to which they have achieved their objectives. The group places a heavy reliance on its subordinate Technical Working Groups in ensuring that the formulation and outputs of the research and technology programme match the Statement of Strategic Intent and associated key technical requirements and that the programme takes account of civil experience. Each group has representatives from MOD, Rolls-Royce Submarines, AMEC and, importantly, a number of independent expert members. Additionally, reports can be independently reviewed through the science support network (SSNet) also comprising experts from industry and academia.

7.5.12 Civil and academic experts contribute to the Technical Working Groups and have done so for many years with many now well into their 60s. These groups are to be welcomed, but we have been told that while they are considered to be a good concept they can be overly orchestrated, defensive and closed. This has, in part, allowed the current programme to be viewed as somewhat 'incestuous' in terms of supporting the important verification and validation programme. Their Breakout Groups which help to open up issues to more technical scrutiny by independent experts are, on the other hand, considered to be effective. We believe overall the Technical Working Groups may have lost their creative tension by being introspective and closed rather than a critical friend of the research and technology programme that can effectively challenge it. The small number of independents on these panels as opposed to customer and industry representatives could mean the independent voice is lost. There is potential to greatly enhance and improve the effectiveness of the groups, particularly to be fit for the future research and technology programme including broadening the independent experts. We believe this requires an immediate injection of new blood. ***We recommend that the role of the Research Programme Group and supporting Technical Working Groups be reviewed with the intention of strengthening the input from civil and academic experts, encouraging challenge and making the groups more influential within the programme.*** [Recommendation: 10] ***We also recommend that the MOD begins to identify and recruit the 'next generation' of independent national experts on to the Technical Working Groups to revitalise them and bring a new perspective.*** [Recommendation: 11]

7.5.13 The 25-year hiatus in UK new build nuclear plant in the civil sector now looks to be over. Many other countries are actively considering restarting their civil nuclear power build. We are not clear how much value the naval nuclear propulsion programme is extracting from this considerable investment in the civil nuclear field which includes national and academic centres of excellence. Our experience in the civil sector suggests that there are more opportunities than are presently being explored. ***We recommend that the Research Programme Group establish a workstrand to look at leveraging to maximum effect civil nuclear investment.*** [Recommendation: 12]

7.6 *Suitably Qualified & Experienced Personnel*

7.6.1 Regardless of adopting the PWR3 design, stewardship of naval nuclear propulsion, including maintenance of the current plant in service, design and production of future plant and the safe disposal of plant and materials, is non-negotiable. This duty demands technical capabilities and sufficiently trained and competent staff including 'suitably qualified and experienced personnel' (SQEP[11]) to at least the standards set by the Regulator – people are critical to a successful Naval Nuclear Propulsion Programme. Maintaining technical capabilities is inextricably linked to having sufficient SQEP today and into the future. A continued push to reduce civil service numbers and reductions in Royal Navy personnel has reduced the number of nuclear qualified posts in MOD. While MOD has outsourced most of its technical expertise it nonetheless runs the risk of not having the resource to be an 'intelligent customer' and could potentially undermine its role as the Design Authority. The gap in the production of nuclear-powered submarines between the VANGUARD and ASTUTE classes coupled with a long period of depressed activity in the UK's civil nuclear sector has also led to significant reductions in the skills base for nuclear plant design, manufacture, support and repair. While the situation in MOD's partners is better we also have concern that they too find it difficult to maintain sufficient technically competent staff. This situation is nothing new and a number of studies have raised concern about the SQEP across the nuclear and other engineering and technical professions[12].

7.6.2 Across the enterprise the availability of deep specialist expertise in key areas [redacted] and qualified staff appears to us to be at the bare minimum necessary to deliver the Naval Nuclear Propulsion Programme. The programme also has no 'strength in depth' in some fields where it is often overly reliant on individual experts. We believe the programme could soon be facing a 'perfect storm' with an ageing expert community facing competition from a resurgent civil nuclear industry and other industries (such as oil and gas) at the same time as the programme is increasing and becoming more diverse [redacted]. This demand comes at a time when the SQEP supply chain is fragile as university nuclear courses have closed. For Defence the need for security clearance also limits the recruiting pool which, while not unique to nuclear activities, is more acute than that experienced in other defence related science, technology and engineering disciplines.

7.6.3 Nuclear expertise and experience is not readily available on the open market so the sustainability of the programme is a significant risk if MOD and its industrial partners fail to recruit and retain younger experts. A degree of attrition is to be expected and accepted as healthy with churn from Defence to the civil sector. However, as the civil sector heats up to deliver the civil nuclear new build there is a risk in some areas that the Naval Nuclear Propulsion Programme could be plundered. This churn is likely to be one-way as the bulk of the civil sector scientists and engineers have little expertise required by naval propulsion except for broad nuclear or specific expertise (such as materials and safety). The Defence programme generally is also less likely to be attractive to engineers and scientists compared to the better paid civil sector (and far less arduous nationality

[11] MOD Nuclear Competence Framework, Version 1.0 - July 2012.

[12] A major reason for setting DE&S up as a 'Bespoke Government Trading Entity' was its difficulty to recruit and retain technical and project management experts.

requirements). We believe there to be similar potential for difficulty in recruiting and retaining into the plant manufacturing base. We are particularly exercised by the core manufacturing capability which has historically required 'artisan' skills and we believe now carries risks as it has lost expert staff over the years and now faces a critical period of increased work and transition to new facilities. ***We recommend that Rolls-Royce Submarines look at developing an enduring knowledge capture activity along with a recruitment, training and development programme.*** [Recommendation: 22]

7.6.4 The nuclear SQEP community within MOD is made up of serving naval officers and civil servants from the Defence Engineering & Science Group. Naval officers have wide operational experience but their opportunities for deep specialist training in design related disciplines are limited. Civil Servants have suffered from out sourcing skills, a lack of career opportunities, an ageing workforce and atrophying of specialist areas [redacted].

7.6.5 We have some concern that there would appear to be a heavy dependency on Royal Navy personnel within the project office and in industry where a notable number of managers are former Royal Navy officers. We in no way question their expertise or commitment but view this situation as a manifestation of the poor SQEP pipeline. We also note that DE&S has secured personnel freedoms to recruit ex-military personnel direct into posts, which is symptomatic of the lack of a SQEP recruitment base outside of the Royal Navy.

7.6.6 Maintenance of deep specialists with credible experience, such as [redacted], is essential now and in the future. Developing these experts is a long-term investment which requires a financial commitment by MOD as the primary customer. Opportunities for 'hands on' experience and therefore understanding are limited and could lead to a community of scientists and engineers who are too theoretical. MOD with its industry partners should look at how to ensure the SQEP community are fully rounded practitioners.

7.6.7 Staff within the programme and its cadre of world leading independent experts, have supported the programme for many years (decades in some cases). They are ageing and there is an urgent need to pass on knowledge and develop the next generation. While there have been some successes in industry (for example the AMEC programme to recruit and develop young scientists and engineers), the general age distribution within the defence nuclear business is too strongly skewed towards the upper quartile. We believe there needs to be a reliable pipeline for British citizens to qualify in nuclear professions for both defence and civil sectors and recruit the best and the brightest into the Naval Nuclear Propulsion Programme. [redacted]. The UK programme should seriously look at enhancing its presence in universities through diverse mechanisms including sponsorships and summer placements. The Research Councils are also a potential platform to set the conditions for the wider nuclear research community to support the programme. [redacted]. ***We recommend that the programme should look at enhancing its***

presence in universities through diverse mechanisms including sponsorships and summer placements. [Recommendation: 16]

7.6.8 The Naval Nuclear Propulsion Programme is living off previous investment by MOD and the civil nuclear programme. Historically, the MOD's programme had been underwritten by civil nuclear research that has over the years been dismantled and commercialised. While some parts of the programme have been maintained within the private sector some significant facilities including materials reactors have been decommissioned and therefore the expertise these activities generated has atrophied. A significant number of the external experts who advise the programme have their background in this programme. We have observed that when an independent expert is sought for advice the same 'usual suspects' are used because they are the only ones who have the requisite knowledge and understanding required. As mentioned in Section 7.5 the Technical Working Groups need to effectively challenge the research and technology programme, we believe this requires an immediate injection of new blood.

7.6.9 We welcome AMEC's recognition of the need to transfer skills and knowledge so as not to lose someone's lifetime of experience. AMEC's knowledge capture programme is a good example where knowledge is actively captured before an expert retires. We would recommend that such an approach be adopted across the programme. AMEC also told us of their sustain programme which has successfully brought in new people such that they have maintained a healthy age profile. Although, in competing the Independent Nuclear Safety Assessment support contract there is a risk that this investment would be lost to the programme.

7.6.10 Rolls-Royce Submarines are to be commended for recovering their manpower from the VANGUARD-ASTUTE fallow years to deliver PWR3. They have doubled their workforce in five years but still outsource some 400 man years of work. Rolls-Royce Submarines is at full capacity and we note there is nothing spare. This was demonstrated in them having to defer work while effort was rightly deployed to undertake the fuel element breach investigation. Resource will be freed up as PWR3 design work begins to ramp down and this should be targeted at ensuring the underpinning research, technology and validation programmes are fully resourced. The new engineers and scientists, while no doubt competent, lack the experience of designing and building nuclear plant. The programme is also undermined by a lack of middle management experience in design and build having been brought up in a plant operation safety justification environment (post-PWR2 design and initial build). [redacted].

7.6.11 The stop-start nature of contracting a long-term programme together with the tactical approach to procurement and commercial competition risks leading to a fragmented and unsustainable expertise base. We believe, for instance, that there is little benefit in competing the Independent Nuclear Safety Assessment role where effort would be better placed improving service delivery with the current long-term provider. Defence will also increasingly be in competition with the revitalised, and better paying, civil programme. ***In order to attract, develop and***

maintain the necessary pool experts within the Naval Nuclear Propulsion Programme the MOD needs to commit to a long-term technology programme. [Recommendation: 17]

8 Core Issues

8.1 *Introduction*

8.1.1 This review was prompted by the STF's [redacted] fuel element breach and as we will now discuss [redacted]

8.1.2 We did not study in depth the fuel element breach but address the likely cause in Section 8.2. [redacted]. The increased life of cores as submarines are fuelled for life increases the importance of their [redacted] as any failure would be financially and more importantly [redacted] very costly. We consider the core manufacture in Section 8.3. We finally discuss [redacted] in Section 8.4 which is a capability proved at Vulcan NRTE and will be lost to Defence once it is decommissioned.

8.2 [redacted] *Fuel Element Breach*

8.2.1 In January 2012, a minor issue with STF was discovered when slightly elevated levels of radioactivity were detected in the primary circuit coolant water. This indicated a microscopic breach in the cladding around one of the [redacted] fuel elements. The levels of radioactivity were low and at no time posed a risk to the plant operators or wider environment – the incident was classified as an International Atomic Energy Agency Level 0 event[13] (i.e. an event that required no action and presented no risk). We have been briefed on several occasions on the subsequent core chemistry investigation. We do not intend to discuss the detail of the breach or its cause but would commend the Rolls-Royce team's investigation.

8.2.2 [redacted] ***We strongly support the programme's decision to continue the Shore Test Facility's operation to enable further investigation of PWR2 operation with a fuel element breach*** [redacted] [Conclusion: 4] and gain additional core burn hours towards its end of life.

8.2.3 The value of STF was demonstrated by the [redacted] technique developed to locate the breach without impacting on operational submarines. The investigation and ongoing work also demonstrates the technical ability within the Naval Nuclear Propulsion Programme [redacted]

8.2.4 We have been briefed on the workshops and discussions that have taken place as a result of the breach and while an undesirable event it has resulted in positive outcomes for the programme. We believe that the programme had developed a corporate attitude that did not accommodate a failure such as the STF fuel element breach. Even though such an event was identified as a risk in the Safety Justification we have not seen evidence that such an event was sufficiently

[13] The Use of the International Nuclear and Radiological Event Scale (INES) for Event Communication, October 2014 – http://www-pub.iaea.org/MTCD/Publications/PDF/INES_web.pdf

[14] [redacted]

addressed in the supporting technical programme and, while handled well, it has had, to a degree, to be addressed from a standing start.

8.2.5 Regardless of the breach's nature, it has moved the conversation and thinking to revisit long held assumptions and shone a light on the manufacture of reactor which we address next. The intellectual climate has changed to a far more questioning outlook which is to be welcomed and many decisions, including the closure of Vulcan NRTE and the validation and verification programme have been re-examined. We have also noted improved engagement between and across the different parts of the naval nuclear propulsion enterprise.

8.3 *Core Manufacture*

8.3.1 We have toured the core production facility at Rolls-Royce Submarines at Raynesway and been briefed on its operation and future (a new facility is under construction on the site). We welcome the Rolls-Royce team's openness and honesty in discussing the manufacturing process and are reassured that they recognise our concerns. [redacted]

8.3.2 [redacted]

8.3.3 [redacted]

8.3.4 [redacted]

8.3.5 [redacted]

[redacted]

8.3.6 [redacted]

8.3.7 [redacted]

8.3.8 [redacted]

8.3.9 [redacted]

8.3.10 [redacted]

[redacted]

[Recommendation: 20]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

8.4 *Core* [redacted]

8.4.1 [redacted]

8.4.2 The benefits of some [redacted] have been questioned and while we agree that it will essentially only find what is being looked for [redacted]

8.4.3 [redacted]

8.4.4 [redacted]

8.4.5 [redacted]

[redacted]. As noted previously (at paragraph 8.2.2) we support STF's continued operation to enable further investigation of PWR2 operation with a fuel element breach.

8.4.6 There is a need to develop an efficient and sustainable [redacted] capability. We were surprised that Vulcan NRTE was identified as the only facility where [redacted] could be undertaken particularly as this would (if the originally proposed [redacted] programme were undertaken) entail [redacted] within Vulcan NRTE and between it and the Wet Inlet Facility storage pond at Sellafield (and ultimately to Sellafield for long-term storage and disposal). There is also potential for [redacted] impacting on subsequent [redacted] and subsequent work. ***We recommend that MOD revisit the possible option of utilising other nuclear facilities including those in the civil sector to undertake*** [redacted]***, not least given the possibility that the Shore Test Facility storage pond*** [redacted] ***is stored*** [redacted]. [Recommendation: 23]

Annex A – Overview of the Nuclear Propulsion Programme

A.1 Introduction

A.1.1 We provided a brief introduction and context in Section 4 and in this Annex we provide further detail on the points covered previously.

A.1.2 The UK has operated nuclear submarines since the early 1960s. Despite having a strong civil nuclear research programme, the Government sought assistance in the early years for their introduction into the Royal Navy service through the transfer of US Navy nuclear plant and technology facilitated by the 1958 UK/US Agreement for Co-operation on the Uses of Atomic Energy for Mutual Defence Purposes (The Mutual Defence Agreement - MDA). This exchange enabled the UK to quickly establish a sovereign nuclear propulsion capability (design, manufacture and maintenance of plant and fuel). In the six decades since, a series of cores and reactor designs have [redacted] The Royal Navy has operated around 80 cores, at sea and in shore-based test reactors.

A.1.3 The physical and operational demands of a submarine drove the selection of a compact pressurised water nuclear reactor (PWR) propulsion system. These reactors use nuclear fission to generate heat, which is used to turn water into steam to turn main turbines that produce electricity and propel the submarine. These reactors differed from the gas cooled Magnox and Advanced Gas Cooled designs adopted by the UK civil nuclear sector as these civil plants were considered inappropriate for submarine propulsion applications. The UK nuclear industry did not adopted PWR technology until the late 1980s with construction of Sizewell B. [redacted] then civil reactors. Safety is paramount in the nuclear industry driven by a culture of driving risks and hazards to as low as reasonably practical (known as ALARP). All nuclear reactors are designed to maximise availability and ensure they fail safe. While civil reactors achieve this in a relatively benign environment, the nuclear reactors onboard submarines have to be designed to also allow for [redacted] – all of which places demands on the nuclear plant not found in the civil nuclear industry.

A.1.4 The Royal Navy submarines provide the nation's nuclear deterrent (Operation RELENTLESS) through a force of four VANGUARD class nuclear powered ballistic missile submarines (SSBN) with nuclear armed Trident ballistic missiles operated such that at least one is continually on deterrent patrol (Continuous At Sea Deterrence – CASD). These submarines will, if the business case is approved in 2015/16, be replaced from the late 2020s by the Successor SSBN class. The nuclear powered attack submarine (SSN) fleet is capable of [redacted]. They constitute the Royal Navy's principal sea denial threat system having anti-submarine and anti-ship capabilities. When combined with land attack missiles, SSNs have a power projection capability of considerable range and penetrability, with important uses for deterrence and coercion. [redacted] They can operate independently or in conjunction with surface forces and contribute to the protection of the strategic nuclear deterrent[15]. The current fleet of TRAFALGAR class SSNs are progressively being replaced by the ASTUTE class which will themselves eventually be replaced by the Maritime Underwater Future Capability (MUFC).

A.1.5 When MOD was establishing its nuclear propulsion capability in the 1960s and developing it in the 1970s, the UK nuclear industry looked very different to what it is today. The UK was a leading nuclear energy nation with a thriving (mostly public sector) nuclear industry. UK research facilities such as Harwell, Dounreay, UKAEA at Risley, Culcheth, and Winfrith, CEGB Leatherhead and Berkeley, Wythenshawe, BNFL Springfields, etc, hosted world class facilities and research reactors generating supporting data for fuel materials' performance – data that are still being used today and underpinning the current naval propulsion design and engineering effort.

[15] Joint Doctrine Publication 0-10 : British Maritime Doctrine paras 327-328.

A.2 Naval Nuclear Propulsion Programme

A.2.1 The Defence Naval Nuclear Propulsion Programme (NNPP) comprises the Ministry of Defence (MOD), Rolls-Royce Submarines, BAE Systems Maritime – Submarines and the Royal Dockyards supported by a number of other specialist partners.

A.2.2 The Nuclear Propulsion Project Team (NPPT) is part of the Defence Equipment and Support (DE&S) organisation's Submarines Operating Centre. Headed by a Royal Navy Commodore (Head of Nuclear Propulsion), the team is tasked to deliver safe, reliable and militarily effective Naval Reactor Plant through-life (research through design, build, operational support and eventual decommissioning). The Head of Nuclear Propulsion is appointed the Naval Reactor Plant Authorisee (NRPA) and as such is responsible for the safe operation of the naval reactor plant at sea and controls and manages its design through-life. He also fulfils the Design Authority function using specialist knowledge from a number of Technical Authorities primarily Rolls-Royce Submarines and AMEC Safety and Reliability Department who provide independent advice. The Design Authority function is a formal process to maintain the 'design integrity' of Royal Navy submarine nuclear steam raising plants and as such the incumbent has overall responsibility for the design process, approving design change and ensuring the requisite knowledge is maintained.

A.2.3 The Nuclear Propulsion Project Team work collaboratively with its industry partner Rolls-Royce Submarines as manufacturer of the nuclear steam raising plant and a Technical Authority. Rolls-Royce Submarines is the sole manufacturer of naval nuclear steam raising plants in the UK[16]. The Nuclear Propulsion Project Team and Rolls-Royce Submarines also work with BAE Systems Maritime – Submarines who is the UK's sole designer and builder of nuclear submarines. AMEC supports the project team through its Independent Nuclear Assurance contract providing the Design Authority with regulatory Independent Nuclear Safety Assessment (INSA), Independent Technical Advice (ITA) and undertakes research and technology for MOD. It also provides support to the Defence Nuclear Safety regulator. AMEC provides similar service to Rolls-Royce Submarines and safety case support to BAE Systems.

A.2.4 Nuclear activities are strictly regulated. The Health and Safety at Work Act 1974 (HSW Act) applies to MOD, its agencies and the Armed Forces. The Act places a fundamental duty on employers to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all its employees and that persons not in their employment are not exposed to risks to their health or safety as a result of their activities. The requirement for risks to be reduced as low as reasonably practicable (ALARP) is fundamental and applies to all activities within scope of the Act. Additionally, the Energy Act 2013 establishing the Office of the Nuclear Regulator (ONR), the earlier Nuclear Installations Act 1965 and the Radioactive Substances Act 1993 establishes the nuclear licensing regime building on but not superseding the Health and Safety at Work Act.

[16] Rolls-Royce and Associates (RRA) was formed to act as the Delegated Design Authority for the manufacture and support of the UK national NSRP [redacted]. The associate companies were Foster Wheeler, Vickers Shipbuilding and Engineering Limited (VSEL), and Babcock and Wilcox over time the involvement of the associates varied and eventually Rolls-Royce became the sole proprietor forming its submarine business.

A.2.5 These licensing requirements do not generally apply to the Crown[17] hence Vulcan NRTE and submarine operations, including at HM Naval Bases (but not the privatised Royal Dockyards), are not licensed by the Office of the Nuclear Regulator. Environmental protection matters including management and regulation of radioactive material discharges is the responsibility of the appropriate environment agency: Environment Agency in England and Scottish Environment Protection Agency (SEPA). Where MOD is exempt from regulation, it is MOD policy and practice to implement parallel administrative arrangements which would have been required by the Acts had it not been exempt or derogated from them.

A.2.6 MOD's internal nuclear regulator is the Defence Nuclear Safety Regulator (DNSR). He (and its predecessors) is an independent regulator in Defence responsible for regulating, were regulatory exemptions apply, the nuclear hazards of the Defence nuclear programme comprising both the Naval Nuclear Propulsion Programme and the Nuclear Weapons Programme. These exemptions primarily relate to the through-life safety on authorised sites which would in the civil sector be covered by the Office of the Nuclear Regulator's remit. While Defence regulation operates on the fundamental principle that its nuclear activities are regulated to the same standard as the civil sector, the nature of the military operational environment means the Defence regulator imposes additional regulation that would not be necessary in the civil sector. There is also a difference between the Defence and civil regulators as the Defence regulator maintains a keen interested in the whole enterprise rather than limiting itself to solely that to be the licensed. The Defence Nuclear Safety Regulator also ensures Defence nuclear activities follow good custom and practice as well as undertaking a purely regulatory function.

A.2.7 ALARP is widely accepted as meaning (in cases where the safety risk is not negligible) that all measures that may be taken to reduce the risk have been taken unless those measures (weighing a risk against the trouble, time and money needed to control it[18]) are grossly disproportionate to the benefit of the reduced risk. [redacted]

[17] The Nuclear Installations Act 1965 also specifically excludes any nuclear reactor in a 'means of transport' such as a submarine.
[18] ALARP 'at a glance' : http://www.hse.gov.uk/risk/theory/alarpglance.htm
[redacted]

A.3 UK Naval Nuclear Propulsion Plants

A.3.1 The early UK nuclear submarine programme was significantly assisted by the US Navy through its provision in 1958 of an entire S5W reactor plant design then powering the latest US Navy SKIPJACK class submarine for the UK's first nuclear submarine HMS DREADNOUGHT. [redacted] The Royal Navy's second nuclear submarine, HMS VALIANT, was commissioned in 1966 and powered by the Rolls-Royce and Associates designed and built PWR1 plant burning its [redacted]. Prior to operation in HMS VALIANT a prototype plant was put under test at the then Admiralty Reactor Test Establishment as the Dounreay Submarine Prototype No.1 – DSMP1. The Admiralty Reactor Test Establishment was commissioned as HMS VULCAN in May 1970. The PWR1 reactor plant powered the VALIANT, SWIFTSURE and TRAFALGAR class SSNs and the RESOLUTION class SSBN.

A.3.2 Pressurised Water Reactors use nuclear fission to generate heat, which is used to turn water into steam to turn main turbines that produce electricity and propel the submarine. Naval reactor plants differ from land-based civil plants in several respects. Civil plants produce thousands of megawatts of steady power over its operational life – although with considerable power cycles – [redacted].

[redacted]

[redacted]

[redacted]

A.3.4 [redacted]

A.3.5 As with PWR1 it was decided to build a prototype known as the Shore Test Facility (STF) at the Vulcan NRTE to validate plant performance and to lead core burn-up ahead of the operational submarines. Unlike DSMP1, STF had a representative pressure vessel (and core) but did not represent the balance of the operational steam raising or propulsion plant. [redacted] was later superseded by [redacted] which was the UK's [redacted]. It replaced [redacted] in the STF and on the VANGUARD class SSBNs during their Long Overhaul Period (Refuel) refits and is fuelling the ASTUTE class SSN from build. The facility has over its operation not only burned [redacted] but successfully tested other system components, [redacted].

A.3.6 Analysis supporting the 2011 Successor SSBN Initial Gate decision[21] concluded that, [redacted] should be adopted.

A.3.7 The [redacted] and parts of the steam raising plant [redacted] are, or will be, either manufactured by Rolls-Royce Submarines at their Raynesway facility in Derby or subcontracted to specialist suppliers. [redacted] The plant is assembled and commissioned at the BAE Systems submarine manufacturing facility at Barrow. [redacted] into nuclear reactor cores in the Raynesway 'core factory' and then tested in their Neptune facility before being shipped for insertion into a reactor pressure vessel. The first reactor core [redacted] was delivered in February 1963 and several of the manufacturing processes and facilities date from that period. To maintain the capability for production into the future MOD agreed in June 2012 a Core Production Capability contract with Rolls-Royce Submarines worth approximately £1.1bn. The 11-year programme of work includes a major £500M programme of site regeneration at Raynesway to replace much of the core factory that has reached the end of its life. The remaining £600M will sustain reactor core production until 2023 including sustaining its core fabrication workforce.

[21] The United Kingdom's Future Nuclear Deterrent: The Submarine Initial Gate Parliamentary Report, May 2011.

A.4 Submarine Availability

A.4.1 While all nuclear plants seek to maintain continuous availability, civil plant operators' overriding duty is to operate safely whereas for naval systems availability is essential while at sea to provide power to ensure the safety of the submarine and crew. The design has to balance nuclear safety against the requirement to be available to make the platform safe. [redacted] the Royal Navy expects a submarine to have the capability and expertise to handle any damage [redacted]

A.4.2 [redacted] The Royal Navy is, for instance, committed to providing Continuous At Sea Deterrence (CASD) to meet the Government's stated commitment to maintain a minimum effective nuclear deterrent[23]. This means that at least one of the four VANGUARD class submarines is on patrol at any given time. The Strategic Defence Review stated that the purpose of CASD was "to avoid misunderstanding or escalation if a Trident submarine were to sail during a period of crisis"[24]. By keeping one submarine on patrol at all times, the UK avoids the risk of sending incorrect or misleading signals to a potential adversary at times of heightened alert.

A.4.3 [redacted]

A.4.4 [redacted]

A.4.5 [redacted]

22 [redacted]

23 Securing Britain in an Age of Uncertainty: The Strategic Defence and Security Review, October 2010, Part 3.

24 Ministry of Defence, The Strategic Defence Review, Cm 3999, July 1998, p 19.

25 [redacted]

[redacted] The nuclear steam raising plant community, while technically professional and competent, had become isolated and introspective with little external peer review coupled with a shortage of staff in some critical areas and inadequate management of knowledge. The supporting research and technology programme was also skewed to dealing with [redacted] at the expense of forward-looking work. [redacted]

A.4.6 Prof Burdekin recommended the implementation of Periodic Safety and Availability Reviews for the nuclear steam raising plant and an Availability Coordinating Board to make balance of investment decisions aimed at optimising available funding streams. He called for a Technology Board to provide advice on supporting research and technology and that the community should be opened up, to the maximum extent, to the civil nuclear and other relevant industries. He was also concerned that the research and technology programme was too skewed to dealing with current problems at the expense of forward-looking work.

A.4.7 MOD responded to the issues raised by undertaking a Nuclear Propulsion Capability Study which identified and led to improvements in the sustainability of the industrial base, governance, [redacted] and research strategy. Work also focused on maintaining essential experienced and qualified staff and developing links into wider nuclear expertise. Improvements in submarine operation and management enhanced operational availability.

A.4.8 We note that since Burdekin assessing the programme [redacted] but rightly not at the cost of safety. Although, the Department would appear not to have gone down the Safety and [redacted] Review route he proposed.

A.4.9 [redacted].

A.5 Vulcan Naval Reactor Test Establishment

A.5.1 Nuclear submarines are considered some of the most effective, but complex military platforms to design and build coupled with the safety issues of operating a nuclear propulsion system and, in the case of SSBNs, carrying nuclear armed solid fuelled intercontinental ballistic missiles. For the nuclear propulsion system, the MOD has in the past adopted a prototyping approach where a new reactor plant and new reactor cores were tested onshore ahead of being operated in the Fleet to provide advance notice of issues or problems that might occur onboard a submarine in-service. This prototyping facility is the Vulcan Naval Reactor Test Establishment (NRTE) located at Dounreay in the north of Scotland and operated by Rolls-Royce Plc under a long term partnering arrangement. Both PWR1 and PWR2 and their associated cores have been tested there. The site is adjacent to the Dounreay civil nuclear site which is currently being decommissioned. Where exempted from the civil licensing regime the establishment is authorised and regulated by MOD's independent Defence Nuclear Safety Regulator. The facility costs some £30M per year to operate.

[redacted] A prototype PWR1 reactor compartment (DSMP1) was operated from 1965 as a test and operator training facility until it was shut down in 1987 and defueled. Training had progressively transferred from live plant training to computer simulators providing the opportunity to test operators under a wider range of conditions, including accident conditions. There was therefore no longer a need for Vulcan NRTE to provide this capability. The facility was then commissioned as a non-nuclear test rig for experiments into [redacted] which operated until 1992. Since 1993, Rolls-Royce Submarines has been contracted by MOD to [redacted]

A.5.3 MOD decided to also prototype the PWR2 plant. The primary focus for the Shore Test Facility (STF) was core burn-up in part because [redacted] and considered well understood STF was, therefore, a representative reactor pressure vessel with [redacted] balance of plant. [redacted] STF remains operational and is scheduled to be shutdown in 2015 when it will be defueled and decommissioned.

A.5.4 In addition to STF and the refurbishment of [redacted] and other sub-assemblies, Vulcan NRTE maintains [redacted], provides test rigs and maintains [redacted] In due course a transfer facility will [redacted] enable radioactive material to be transported within and off site.

A.5.5 The MOD Vulcan Defuel and Decommissioning (VDAD) programme is considering the future options for the site taking account of the risks and opportunities afforded by the decommissioning of the adjacent civil site (the Dounreay decommissioning programme has an interim end-state of around 2025). The civil site provides

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26 [redacted]

Vulcan NRTE with vital support services such as radioactive waste disposal, high integrity electrical supplies and emergency services which are likely to start being withdrawn from 2020. It is planned that once all PWR2 trials, [redacted], is complete all nuclear fuel will be removed from the site to a long-term storage facility, the strategic activities transferred to other sites and the site decommissioned.

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Annex B – Review Panel

The Secretary of State asked Professor Vernon Gibson, MOD's Chief Scientific Adviser, to review, in light of the January 2012 detection of low levels of radioactivity in the cooling water surrounding the prototype core under test, the Department's decision not to operate a test reactor for the new PWR3 reactor and therefore decommission the Vulcan NTRE. He invited a panel of three eminent nuclear scientists to advise him.

Professor Robin Grimes FREng (panel chair) is Chief Scientific Adviser to the Foreign and Commonwealth Office, Professor of Materials Physics at Imperial College, Director of the Centre for Nuclear Engineering at Imperial College, and Director of the Rolls-Royce University Technology Centre for Nuclear Engineering. He is a Fellow of several learned societies including the Institution of Nuclear Engineers and the Institute of Physics.

As a nuclear energy specialist, Professor Grimes has advised the House of Lords Science and Technology Committee's inquiry into nuclear research requirements, and was part of the Scientific Advisory Group for Emergencies (SAGE) which provided official advice on the 2011 Fukushima disaster.

Professor Dame Sue Ion FREng represents the UK on a number of international review and oversight committees for the nuclear sector including the Euratom Science and Technology Committee which she Chairs. She is the only non US member of the US Department of Energy's Nuclear Energy Advisory Committee on which she has served since 2005. She was appointed Chairman of the UK's Nuclear Innovation Research Advisory Board set up in January 2014 and has served as a member of AWE's SETAC since 2006. Dr Ion was BNFL's Group Director of Technology 1992-2006 responsible for all the company's UK R+D facilities and over 1000 staff. She was the UK's representative on the IAEA Standing Advisory Group on Nuclear Energy 2000-2007. She was appointed Visiting Professor at Imperial College in 2006 and has been a member of the Board of Governors at the University of Manchester since 2004.

Dr Ion was a member of the UK Council for Science and Technology from 2004-2011. She was a member of the Particle Physics and Astronomy Research Council from 1994-2001, a member of Council for EPSRC between 2005 and 2010 and Chaired the Fusion Advisory Board for the Research Councils from 2006-2012. Dr Ion served on the DECC Scientific Advisory Group 20010-2014. She was Vice President of the Royal Academy of Engineering 2002-2008 and continues to Chair one of its standing committees.

Professor Andrew Sherry FREng is Director of the Dalton Nuclear Institute at The University of Manchester, which was awarded a Queen's Anniversary Prize in 2011. He studied Metallurgy at Manchester before joining the United Kingdom Atomic Energy Authority in 1987 where he led research into materials ageing and structural integrity of nuclear plant. He was a Royal Society Industry Fellow from 2000 to 2005 and joined The University of Manchester in 2004 as Director of the Materials Performance Centre. He was appointed Director of the University's Dalton Nuclear Institute in 2009, where he established the flagship Dalton Cumbrian Facility, a partnership with the NDA in radiation science and decommissioning with access into the active facilities at the NNL, and led

Manchester's partnership with Sheffield University to create the Nuclear Advanced Manufacturing Research Centre.

He is a member of the UK's Nuclear Industrial Council, leading the workstream on the Public Understanding of Nuclear Energy, and a member of the Nuclear Innovation Research Advisory Board providing advice on national nuclear R&D priorities. His research interests are in materials and structural integrity. He is a Fellow of the Royal Academy of Engineering, a Fellow of the Institute of Materials Minerals and Mining, and a Chartered Engineer.

The Secretariat was provided by [redacted] from the Ministry of Defence.

Annex C – Papers Considered

We considered the following papers:

Review of the aspects of availability of RN Nuclear Steam Raising Plant (The Burdekin report)
Dated: January 2002

Nuclear Propulsion Capability Study
Dated: November 2003

NGNPP Full Scale Nuclear Prototyping Policy
Reference: RRMP 32649, Version 1
Dated: January 2008

Successor SSBN Initial Business Case
Reference: IAC 2607)
Dated: November 2010

NUPIP 805A Reactor Technology Systems Requirement 14.5 Future Reactor Design and Nuclear Prototyping
Reference: RRMP 22243, Issue 1
Dated: January 2003

NuPIP 805a Reactor Technology Systems Requirement 14.5 Variation to PWR2 and Nuclear Prototyping
Reference: RRMP 22550, Issue 1
Dated: January 2003

SESB Action 14.1 – Brief to DNP [why prototype is not required for PWR3]
Reference: RDN46586, Version 1
Dated: September 2013

Summary of discussion and conclusions from Prototyping Workshop (23 March 2007)
Reference: DPA/NP 682/1/1
Dated: 30 March 2007

NGNPP Technical Novelty – De-risking strategy and programme
Reference: Minute to DSM
Dated: 05 November-2013

Critical use of STF beyond 2013
Reference: DE&S/NP/671/30 15/12/08
Dated: 31 March 2009

High level statement on current capability provided by VULVAN NRTE
Reference: PJG/Vulcan Capability/01/JS6
Dated: 28 November 2008

Note from the MOD Decision Making Forum held in March 2014
Review Panel Secretary's note

NSRP Prototyping and Future Programme Options
Reference: DPA/NP/682/01/01
Dated: 07 February 2007

ONR GUIDE - Regulation of the Nuclear Weapon and Naval Nuclear Propulsion Programmes
Reference: NS-INSP-GD-056 Revision 2
Dated: March 2013

The United Kingdom's Future Nuclear Deterrent: Parliamentary Reports
Dated: 2011 onwards

House of Commons Defence Committee - The Future of the UK's Strategic Nuclear Deterrent: the Manufacturing and Skills Base
Reference: HC 59
Dated: 12 December 2006

Vulcan NRTE Decommissioning and Disposal Initial Gate Business Case
Reference: IAC 3057
Dated: July 2012

JSP 518 - Regulation of the Naval Nuclear Propulsion Programme
Reference: V4.1
Dated: July 14

ONR Assessment of Rolls-Royce Marine Power Operations Limited Periodic Review of Safety for the Nuclear Fuel Production Plant Site, Raynesway, 2012
Reference: ONR-RRMPOL-PAR-13-003
Dated: July 2013

NGNPP Test Solution Selection Process
Reference: RRMP33844, version: 1.0
Dated: April 2009

Next Generation Nuclear Propulsion Plant (PWR3) Verification & Validation Plan - Issue 3
Reference: RRMP33603 - Issue 3, version: 1.0
Dated: January 2010

NGNPP Test Rig Design Handbook
Reference: RRMP33505, version: 1.0
Dated: December 2008

NNPP Research and Technology Statement of Strategic Intent 2014-2014
Dated: January 2014

Research and Technology Key Technical Requirements
Dated: February 2014

Defence Nuclear Safety Committee Annual Report 2013
Reference: DNSC 57/13
Dated: 21 March 2014

Annex D – Panel Meetings and Discussions

In addition to considering the relevant papers, we met with a number of key individuals involved in the Naval Nuclear Propulsion Programme and appreciate their openness, candidness and assistance provided. We visited:

Vulcan NRTE facilities – and discussed with the Royal Navy and Rolls-Royce management Vulcan's role, capabilities, skills and expertise and issues covering: core [redacted], constructing a new prototype and final decommissioning.

Rolls-Royce facilities at Raynesway, Derby – and discussed with management and technical experts Rolls-Royce's role and technical experience of designing manufacturing and maintaining naval propulsion plant. We also probed the advice not to prototype PWR3 and the underpinning technical programme that supported that advice.

HMNB Clyde and [redacted] – discussing with the base commander, Cdre Keith Beckett, his staff and [redacted] commanding officer [redacted] and his crew [what?]. We inspected the machine space and reactor compartment where we were briefed on operational aspects of naval propulsion and observed the manoeuvring room simulator.

AMEC facilities at Birchwood, Warrington – and discussed with management and technical experts their role in supporting the Naval Nuclear Propulsion Programme and their views on the need for a prototype and sufficiency of the underlying research and technology.

We met also with:

Cdre John Corderoy, Head of Nuclear Propulsion and Naval Reactor Plant Authorisee – and discussed a range of topics of current and past interest, [redacted], decisions on the plant and core design, funding and support for the propulsion programme and the how the programme will move forward.

Cdre Mike Robertson, Defence Nuclear Safety Regulator – and discussed the naval nuclear propulsion regulatory landscape, his expectations for PWR3 safety justification and the supporting verification, validation and experimentation.

Peter Neumann, chairman of the Nuclear Propulsion Research Programme Group – discussing his views of the programme, its underpinning research and technology and how the relevance and quality of it is ensured.

[redacted]

Dr Colin Dimbylow, formerly Nuclear Propulsion Programme Research Director – We discussed in detail the prototype decision process [redacted] and possible knowledge gaps and how the underpinning research and technology work could address them.

Prof Colin English, Professor Colin English, Technical Working Group member, National Nuclear Laboratory Senior Fellow and Visiting Professor at Oxford University and the University of Manchester – with the discussion focusing on the broader nuclear technical community and the nuclear plant and core design.

We also met on several occasions to discuss the emerging issues and met with Prof Gibson, MOD Chief Scientific Adviser.

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