THE BRITISH EXPERIENCE WITH NUCLEAR-POWERED SUBMARINES: LESSONS FOR AUSTRALIA

August 2025

A report by Tim Deere-Jones prepared for Friends of the Earth Australia.[1]

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This report is online at https://nuclear.foe.org.au/nuclear-subs/

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[1] Friends of the Earth Australia gratefully acknowledges the support of the Australian Conservation Foundation for this project.

FOREWORD

Tim Deere-Jones' detailed report on the British nuclear submarine experience should ring alarm bells across Australia. It reveals a litany of problems in the UK and it can confidently be predicted that serious problems will beset the AUKUS submarine programme – the joint development of nuclear-powered submarines by the UK, the US and Australia.

The British experience with nuclear submarines reveals a history of underperformance characterised by lengthy delays, cost blowouts, and safety risks. The risks have been amplified by the abolition of the Naval Reactor Test Establishment, which used to carry out empirical research and testing on naval reactors, thus enabling potential flaws in reactor, core and fuel performance to be identified. Instead of practical testing of new reactors and cores, computer modelling is now being used. This has major relevance for the proposed AUKUS-class submarines, which will be the first UK-designed nuclear-powered submarines to be developed without the benefit of the real-world testing of reactors and cores.

The abolition of the Naval Reactor Test Establishment is just one of many alarming issues raised in Tim's report, which also details the operational risks of nuclear submarine deployment including radiological pollution of marine and coastal environments and wildlife; risks of radioactivity doses to coastal populations; and dangerous collisions between civilian vessels and nuclear submarines, especially in the approaches to busy naval and civilian sea ways and fishing grounds.

The problems appear to be worsening:

* In May 2025, it was revealed that the number of 'incidents' at the Faslane naval base has been on the rise in recent years. The UK Ministry of Defence acknowledged that 12 incidents since 2023 had "actual or high potential for radioactive release to the environment" – but refused to say what actually happened in any of the incidents, or exactly when they occurred.

* *Navy Lookout* reported in January 2025 on a fire in October 2024 at BAE system's Devonshire Dock Hall at Barrow in Furness. After initial claims of no damage or delay to construction of ASTUTE class attack subs, damage was later confirmed and delays in the construction program are certain. The Office of Nuclear Regulation said that BAE's safety practices were "inadequate" and that BAE needs to demonstrate that suitable emergency arrangements in the event of a fire are in place by 12 September 2025.

* Radioactive air emissions have been increasing year-on-year at Coulport, one of Britain's nuclear submarine bases in Scotland. Emissions of radioactive tritiated water vapour doubled between 2018 and 2023.

Australia – be warned. There is no reason to believe that a nuclear submarine program here will be any safer or any more transparent.

None of the issues raised in Tim Deere-Jones' report have been adequately addressed in the Australian context. Indeed a federal EPBC Act assessment absurdly precluded nuclear accident impact assessments as 'out of scope'. If those vital issues are addressed at all, it will be by a new, non-independent military regulator within the Australian Department of Defence, reporting to the Defence Minister – a blatant, deliberate breach of the fundamental principle of regulatory independence.

Meanwhile, successive Australian governments have enacted authoritarian legislation stripping Australians of civil rights in order to progress the AUKUS submarine project. This includes trampling on the rights of Australia's First Nations.

Many of the ingredients are in place to ensure problematic outcomes with the AUKUS submarine project: a questionable rationale; undue hast; a non-independent regulator; secrecy; stripping Australian citizens of our rights; superficial and meaningless public consultation processes, etc.

There are growing doubts about the viability of the AUKUS submarine project: it is becoming increasingly unlikely that second-hand Virginia-class submarines will be supplied by the US to Australia on time – or at all. Multi-year delays with the design and construction of AUKUS-class submarines can be confidently predicted.

There is a growing debate about alternatives to nuclear submarines in Australia. Alternatives include non-nuclear submarines; using a range of technologies and policies to achieve military/security objectives; and proposals which fundamentally rethink defence policy and question the loss of sovereignty entailed in the AUKUS project (and Australian defence policy more generally).

The US and the UK are currently reviewing AUKUS. Former Prime Minister Paul Keating said the US review "might very well be the moment Washington saves Australia from itself … from the most poorly conceived defence procurement program ever adopted by an Australian government".

The US and UK reviews are designed "to see how much more they can squeeze out of" Australia according to Peter Lewis from Essential strategic communications and research company. Convening a review in Australia, Lewis continues, "seems to be the least we should do."

The Australian government must immediately initiate a review of the AUKUS submarine project: a thorough, independent review.

Sincere thanks to Tim Deere-Jones for this excellent report – a report which could and should be an important input into a long-overdue review of Australian policy.

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EXECUTIVE SUMMARY

This report reviews aspects of the UKs SSN (nuclear-powered submarine) fleet design, construction, maintenance and eventual defueling and demolition.

The British experience with SSNs reveals a litany of problems and it can confidently be predicted that problems will beset the AUKUS submarine programme.

The report demonstrates that the development of a nuclear-powered, conventionally-armed SSN fleet is accompanied by multiple risks deriving from ever-expanding cost over-runs regarding SSN construction, maintenance, decommissioning and waste management.

The report also concludes that the operational risks of SSN deployment include radiological pollution of marine and coastal environments and wildlife, risks of radioactivity doses to coastal populations by way of a number of poorly understood and largely underestimated dose pathways and that there is clearly a serious risk of dangerous collisions between civilian vessels and SSNs, especially in the approaches to busy naval and civilian sea ways and fishing grounds.

Detailed information and conclusions supported by relevant scientific and technical references are provided in the main text of the report.

The history of UK submarines (see sections 1–3 for more detail)

Section 1 provides a brief summary of events leading up to the development of the UK nuclear powered fleets of SSNs (conventionally armed/nuclear powered hunter/killer attack submarines) and SSBNs (nuclear armed/nuclear powered ballistic missile submarines).

Sections 2 and 3 provide more detailed summary case studies of PWR-1 and PWR-2 reactors (with various core types) fitted to successive SSNs. Between the 1960s and the present day, UK SSN attack submarines have been fitted with two types of reactors and five types of cores as follows; PWR-1 with three evolving/modified core types (A, B and Z cores) and PWR-2 with two evolving/modified core types (G and H cores).

Case studies of PWR-1 reactors reveal an inconsistent performance history of reactor cores. All SSNs with PWR-1 reactors had to undergo extensive planned maintenance periods consisting of updating military equipment (sonar etc.) and repair, refuelling and back refit of new cores. A surprising number of boats required “unplanned maintenance”.

PWR-1 reactor lifespan was expected to be at least 20 years but the evidence is that, for a number of boats, this projected lifespan was not achieved, or only achieved after major maintenance and life-extension work. PWR-1 reactors were characterised by a marked tendency to develop “serious cracking in the primary cooling circuits” of the reactors leading to leaks of cooling water. In some cases, these problems were recurrent despite repair and were the cause of premature retirement of some boats.

It is equally clear that, due to the complexity of maintenance and refit work, the financial impacts are characterised by high costs, often exceeding the cost of the original build. It is also evident that some boats also suffered from basic, but major, hull integrity issues.

The frequency of “unplanned” dockyard time generated by these problems has generated ever-increasing time and finance costs due to the necessity for unplanned repairs which have delayed planned work due to both docks and facilities being required for the unplanned work.

Because of the lack of transparency, due to "official secrets act" restrictions, important relevant details of these problems have been withheld from the public. Despite the lack of transparency, it is evident that these problems have caused repeated interruptions of SSN service/patrol time and reduced the expected effectiveness of the over-arching proposed SSN deployment strategy.

Astute Class submarines (see section 4 for more detail)

The most recent class of SSN attack submarines (Astute Class) have been fitted with the PWR-2 reactors with two evolving/modified core types (G and H cores). H cores were publicised as having a working lifespan of 30 years and needing no refuel/replacement core. The first PWR-2 reactors were fitted to Vanguard Class SSBN boats, designed and built in advance of the Astute SSNs. Therefore this section has focussed on the experience with the Vanguard class because there is more historical data/reporting of their reactors.

The case study of the Vanguard class PWR-2 reactors reveals that the Vanguards had to undergo extensive planned maintenance periods consisting of updating of military equipment (sonar etc.) and repair, refuelling and back refit of new cores (originally fitted with Type G Cores and refitted with Type H Cores). The cost of this refit was in excess of £400 million. "Unplanned" maintenance outages disrupted the programme of "planned" maintenance and clearly increased the wear-and-tear pressure on boats waiting for their planned maintenance.

The HMS Vanguard seven-year long maintenance outage occurred in the wake of a series of reports of observed H Core reactor misfunctions from the Naval Reactor Test Establishment (NRTE). In 2009 the NRTE reported that such misfunctions posed a risk of "potential failure of the reactor primary coolant circuit", leak of "highly radioactive fission products" and "significant risk to life in close proximity and a public safety hazard out to 1.5 km from the submarine." In 2011 the NRTE discovered unexpected increases in radioactivity concentrations in the reactor cooling water attributed to microscopic cracking defects in the cladding of the fuel elements used in the reactor.

Review of the reporting of the HMS Vanguard second (unplanned) H Core refit revealed that the no-refuel H Cores were designed and constructed as sealed units, and that this generated serious problems for the reactor engineers tasked with dismantling the reactor and replacing the suspect H Core. It was also revealed that, during the dismantling process, a number of bolts on the cooling system had been "sheared", but that, instead of being properly replaced, the sheared bolt heads had been re-attached with superglue. The cost of this refit was in excess of £400 million. "Unplanned" maintenance outages disrupted the programme of "planned" maintenance and clearly increased the wear-and-tear pressure on boats waiting for their planned maintenance.

No further detail about the cause and remedy of the H Core reactor and fuel problems detected at the NRTE has been made public. In the aftermath of the NRTE reports of H Core reactor and fuel malfunction, the UK Government and the Ministry of Defence took a surprise decision to close down the NRTE and to abandon empirical "lead" research on naval reactors in favour of computer modelling analysis of the performance of all new reactors and cores, including those intended for the UK's future SSBN fleet and the AUKUS SSNs.

Delays and cost blowouts (see section 5 for more detail)

Section 5 reviews issues arising from the AUKUS Agreement proposal for the operational placement of a UK owned Astute class SSN at Australian bases. It is clear that the presence of the UK Astute, along with the presence of a number of US Virginia Class SSNs, is believed integral to Australia's ability to gain operational and management experience towards future manage its own SSN fleet. The presence of US and UK SSNs at Australian bases is reported to include (as yet undefined) maintenance activity, involving Australian personnel in a training scenario.

It is not yet clear if the proposed maintenance activity will involve the handling, management, transfer, movement, transport or storage of radioactive materials either at sea/afloat or on land/Australian territory. It is not yet clear if this maintenance activity on Virginia and Astute Class SSNs will involve the planned and managed release of radioactivity to aquatic or atmospheric environments, or incur the risk of unplanned, unmanaged releases of radioactivity to the aquatic or atmospheric environments.

In November 2009, the UK House of Commons Defence Select Committee found that delays due to technical and programme issues meant that the Astute class programme was 57 months late and 53 per cent (or £1.35 billion) over-budget, with a forecast cost of £3.9 billion for the first three boats.

The hand-over of boat 4 of class HMS Audacious was delayed from 2019 to 2021 due to undefined "emergent technical issues", though it was reported that Audacious had significant internal changes and improvements building on lessons learned from the first three boats. The requirement for such back-fits on new boats and the necessity to install so many modifications to what are supposed to be state-of-the-art vessels raises considerable concern. No detail of the reason for such action has been made public.

However, it is relevant to place such action into the context of the international submarine arms race, in which boats, weaponry and ancillary equipment must be continually uprated to maintain "advantage" over the perceived enemy. This is an issue that Australia will have to address, along with the financial implications of such an arms race.

The underlying causes of the delay to Audacious have never been properly explained to the public but it had a knock-on effect for the delivery of the last three boats. The first four boats were supposed to cost £5.86 billion but are now expected to total £6.7 billion. The final vessel, HMS Agincourt will cost an eye-watering £1.64 billion, although this compares reasonably well with the US$2.8 billion cost of a Virginia class SSN. In February 2020, the Under-Secretary of State for Defence confirmed that the proposed in-service date for the final Astute Class SSN, HMS Agincourt, had slipped to 2026.

By March 2021 the Astute project had cost £9.6 billion with boats delivered between 3-5 years behind the original schedule. This necessitated the extension in service of HMS Trenchant, Talent and Triumph with the attendant costs of keeping ageing boats running. The first three Astutes cost a total of £3.53 billion, 21% more than the original £2.8 billion contract.

It is relevant to note that only six years after HMS Astute's achievement of operational status in 2014, the confidence in the life-time "no-refuelling" capability of the PWR-2 reactor with H Core was shown to be already outdated in the context of concern about emerging delays in the implementation of the programme for the follow-on classes of both SSBNs (Dreadnought Class) and SSNs (AUKUS Class).

There are now growing indications from sources close to the UK Government and Ministry of Defence that the AUKUS successor to the Astute class may be delayed (due to financial and technical issues) and not available until beyond the design life of the H Core. "It's early days for SSN(R) [replacement] but the first boat is unlikely to arrive before the mid-2040s," the independent *Navy Lookout* publication reported last year. The implications for the Australian Navy, re the proposed Astute operations out of Australian bases, require further investigation.

The UK abandons testing of naval reactors in favour of computational modelling (see section 6 for more detail)

Despite the evident benefit of empirical evidence of H Core, and other Core, malfunction, and the supposed improvements provided by HMS Vulcan's testing regime, the Admiralty Naval Test Reactor at Dounreay, Rolls Royce, the Admiralty and the Ministry of Defence agreed that the proposed new PWR-3 does not require reactor core prototype testing and that the Naval Reactor Test Establishment (NRTE) should be closed and its empirical work replaced with (hypothetical) "computational modelling". It is proposed that Computational Modelling and "high confidence" in new reactor design means that physical testing is no longer necessary. Consequently, the NRTE was closed down and decommissioned in 2015.

As a result of the closure of the NRTE there is no longer any empirical research study of UK nuclear submarine propulsion systems and future attempts to ensure design and operational integrity and safety will be highly reliant on hypothetical modelling without the benefit of any actual "lead" empirical experiential observation of the operational behaviour and function of future reactors as their deployment unfolds. In order to achieve best case accuracy and precision, computer modelling requires the input of the most accurate and detailed data inputs followed by verification against real life scenarios. Whether this can be achieved in the case of the entirely novel naval PWR-3/core combination to be fitted into the proposed AUKUS SSNs remains a matter of some doubt.

This clearly has major relevance for the proposed AUKUS Class SSN boats which will be the first UK designed and built nuclear powered submarines to be run without the benefit of the NRTE input. All previous UK nuclear submarine reactors and core types have been built and put into operation at the NRTE at least two years before their deployment in nuclear submarines under operational conditions, thus enabling potential flaws in reactor, core and fuel performance to be identified in advance of at-sea operation and also informing core and fuel designers working towards the development of improved reactors, cores and fuels.

Since the decision to close down the NRTE, Rolls Royce and the Navy have continued with the development of a new reactor design which will be fitted to the proposed Dreadnaught class of successor ballistic missile boats. Known as the PWR-3 reactor, it is reported to cost about £50 million more per boat to purchase and operate compared to PWR-2 designs, but this is offset by its claimed longer life relative to the PWR-2 design.

On the basis of proposed Computer Modelling and "high confidence" in new reactor design, Rolls Royce PR has claimed that PWR-3 design is superior to the PWR-2 design for a number of reasons, principally because it too would have an operating life span of at least 30 years and no need for refuelling during it is expected service. Additionally, it is claimed that it has significantly lower maintenance requirements and costs due to the fact that it has 30% less component parts than the PWR-2 series. These optimistic claims have been made without the benefit of significant empirical/evidential support and are therefore largely hypothetical in nature.

Decommissioning and dismantling nuclear-powered submarines (see section 7 for more detail)

The UK experience is that the decommissioning, defueling, deradiation and scrapping of time-served nuclear submarines is fraught with technical problems and delays arising from those problems. It is also clear that these issues give rise to ever increasing costs.

In this context it is noted that, under the AUKUS agreement, it is proposed that Australia will take delivery of US Virginia Class SSNs and AUKUS class submarines. As of yet, there has been no discussion of the dock-related ramifications of the proposed Australian multiple class nuclear powered submarine fleet, nor of the long-term storage of decommissioned submarines. Given that some of the first generation of Australian owned SSNs will be "second hand" (i.e. Virginia Class) boats, the likely date of decommissioning is even less secure than it would be for "new" boats.

National Audit Office report on the failure of submarine disposal (see sections 8, 12 and 13 for more detail)

In 2019 the National Audit Office (NAO) published its report of an investigation, by the Public Accounts Committee of the UK House of Commons, into submarine defueling and dismantling. The investigation took place between 2017 and 2019.

The NAO report noted that since 1980, the Ministry of Defence (MoD) had decommissioned 20 submarines from service and replaced them with updated boats and that the MoD had committed to handling the arising nuclear liabilities responsibly and disposing of submarines "as soon as reasonably practicable". (Disposal includes removing the irradiated nuclear fuel (defueling), safely storing defueled submarines (afloat), taking out the radioactive parts (dismantling), and then recycling the boat.)

However, by 2019 none of the 20 decommissioned boats had been disposed of and nine of them still contained irradiated (spent) nuclear fuel. The NAO noted that it was proposed to take a further three submarines out of service over the next decade (i.e. by 2029). The Department stores out-of-service submarines at dockyards in Devonport (Devon) and Rosyth (Fife).

The NAO report noted that the Public Accounts Committee had critiqued the lack of berthing space within the Devonport dockyard and recommended that the MoD take steps to end the delays to submarine disposals. The MoD confirmed that although it had deferred dismantling submarines on affordability grounds in the past, this was no longer acceptable on safety and reputational grounds.

The MoD confirmed its intention to fully dismantle its first submarine, HMS SSN Swiftsure, by 2023. However, in August 2023 it was announced that *"the British Submarine Delivery Agency (SDA) has achieved a significant milestone as the retired Royal Navy submarine HMS Swiftsure has docked at Rosyth for a pioneering dismantling process. This move marks the first step in what is set to become a historic accomplishment, as HMS Swiftsure is poised to be the inaugural UK nuclear-powered submarine to undergo a complete dismantling by the end of 2026."*

These announcements have, yet again, illustrated the speed with which the MoD's ambitions and claims fall behind the proposed timeline for full dismantling of the first nuclear submarine and explain why many in the UK have low confidence in MoD pronouncements on many nuclear submarine related issues, particularly those related to costings and timeline delays.

The NAO estimated that it would cost around £96 million to fully dispose of a single submarine. However, there is considerable uncertainty about these costs given the high rate of inflation and overall rising costs since 2019 and the fact that, as of 2019, the MoD still needed to confirm and approve how it will remove and transport intermediate-level waste. The figure reported by the NAO did not include the costs associated with the MoD establishing the dockyard facilities and infrastructure for storage and final disposal of nuclear waste at the end of its storage period.

The NAO reported that despite the 20-year-old MoD commitment to dispose of the 20 submarines it had decommissioned since 1980, none had been completely dismantled by 2019 and that, as a result the MoD now stored twice as many nuclear submarines as it operated, with seven of them having been in storage for longer than they had been in service. The MoD had spent an estimated £0.5 billion on maintaining and storing its retired, but still floating, submarines since 1980.

The NAO reported that the MoD had to set aside a £7.5 billion liability in its 2017–18 accounts for maintaining and disposing of its out-of-service submarines. This sum did not provide for the liabilities associated with storing and disposing of submarines not yet in operation. In the case of its newly launched Astute Class SSNs, the MoD increased its liability by an average £100 million for each of the Astute-class boats brought into service.

The NAO report catalogues the many delays and time overruns of the submarine dismantling project initiatives including its dismal failure to complete the dismantling of even one submarine by 2023 and to remove all radioactive fuel from all decommissioned boats in a similar timescale.

The 2019 NAO report offers the following "Key Facts" regarding the 20 out-of-service submarines then stored by the MoD:

- 19: average number of years submarines out-of-service, against 26 years in-service
- £0.5 billion: estimated total cost to the MoD of maintaining retired submarines from 1980 to 2017
- £96 million: estimated cost to the MoD of fully disposing of one submarine
- £7.5 billion: MoD's future liability for maintaining and disposing of its 20 stored and 10 in-service submarines, as of March 2018
- 11: number of years' delay in re-establishing an ability to defuel submarines, moving from 2012 to a current planning estimate of 2023 (decommissioned submarines still not defueled as of June 2024)
- 57% (£100 million): budget increase for re-establishing a defueling capability from £175 million (2007) to £275 million (2018)
- 9: average number of years fuelled submarines have been stored as at 2019
- 15: number of years delay rolling out a tested submarine dismantling approach, moving from 2011 to a current planning estimate of 2026
- 50% (£0.8 billion): increase in the cost of the project from £1.6 billion (2002) to £2.4 billion (2016)

- £0.9 billion: estimated increase in the MoD's longer-term financial liabilities related to submarine dismantling should it take six months longer to remove intermediate-level waste from boats dismantled in two stages than the expected 18 months; and a similar delay dismantling the remaining submarines.

Looking to the future the NAO report concluded that the MoD had not fully considered its approach to disposing of all its operational and future submarines. As of 2019, the MoD did not have a fully developed plan to dispose of the later SSN and SSBN (Vanguard, Astute and Dreadnought) class submarines, which have different types of nuclear reactors, but it had identified suitable dock space which, if used, would need to be maintained. The NAO noted that within the civil nuclear sector, organisations are under an obligation to consider nuclear waste disposal during the design stage of power stations and nuclear infrastructure. The MoD does not have a similar obligation.

It is vital that the Australian Defence Ministry does not make the same mistakes.

Unsolved nuclear waste problems (see sections 9–11 for more detail)

Both the International Atomic Energy Agency and the International Maritime Organization recognise spent nuclear fuel as irradiated nuclear fuel, a category of radioactive material similar to high-level waste (HLW). Some nuclear source definitions of HLW clearly include used reactor fuel either *in situ* in reactors or awaiting storage or reprocessing.

Despite the UK Defence Nuclear Organisation assertion that they "have NO High Level Waste", used reactor fuel held in decommissioned nuclear submarines fulfils the definition of HLW. It may be useful to submit FoI/EiR requests to the Australian authorities requesting further information on this issue in order to transparently characterise the nature of any irradiated/spent nuclear fuel arisings from the Australian deployment of nuclear submarines and any arisings from any "maintenance" of Virginia Class, Astute Class or AUKUS SSNs.

It appears inevitable that Australia must face the fact that, if it accepts ownership of US SSNs and later undertakes construction of its own AUKUS class boats, it will have to find ways to deal with the irradiated/spent nuclear fuel (HLW), intermediate and low-level wastes arisings from those boats.

The government of Australia will have to have management plans in place for all grades of nuclear submarine radioactive waste including:

- the identification, design and construction of HLW treatment and management facility/facilities and a long-term repository site.
- design and construction of relevant/appropriate holding, transport and storage containers for HLW.
- intermediate and low-level waste will require the design and construction of appropriate facilities and long-term repositories.
- design and implementation of transport modes and routes for the carriage of all grades of radioactive arisings between dockyards and interim and long-term storage/repository sites.
- nuclear emergency reaction plans re nuclear dockyards and operational bases.
- nuclear emergency response plans re transport route incidents.

- decisions on the distribution (or non-distribution) of radio-iodine tablets as part of emergency response planning.

The long-term management, storage and disposal of radioactive waste streams from nuclear submarines remains unsolved in the UK after many decades. These are issues which Australian will have to resolve speedily if a massive backlog of naval radioactive wastes is to be avoided.

A summary review of UK Defence Nuclear Organisation description of proposals for the removal of nuclear submarine low-level waste notes various stages of removal and disposal, including the technically complex strategy for removing the steam generator, and notes that around 52 tonnes of low-level waste had been successfully removed from the SSN Swiftsure by 2022.

Similarly, the Defence Nuclear Organisation report describes proposals for the removal of intermediate-level waste including the bulky and heavy submarine Reactor Pressure Vessels (RPVs). The long-term intended disposal destination for the submarine RPVs is the proposed national Geological Disposal Facility (site not yet identified). In 2019, after decades of procrastination, an interim storage site was identified at an existing licensed nuclear facility. However, as of April 2024 no RPVs have been removed from any decommissioned nuclear submarines and, in order to confirm access/use of the identified interim storage site the MoD is paying an estimated £1.5 million a year to reserve storage at the site which it currently expects to use from the mid-2020s.

The UK's spent nuclear submarine fuel, when removed from decommissioned submarines, is dispatched to a special facility at Sellafield, where it is held and managed under the same conditions as the used fuel from UK civilian reactors while, along with other HLW, it awaits final deposition in a proposed (i.e. non-existent) national Geological Disposal Facility.

Cannibalisation of used parts (see section 13 for more detail)

A 2017 National Audit Office (NAO) investigation reported that cannibalisation (re-use of used parts scavenged from other boats) is endemic throughout the UK Navy and that the nuclear submarine force is not exempt from this issue. The NAO investigation confirms that the most recent SSN (Astute) Class boats are heavily impacted by this practice, with a 43% increase in cannibalisation incidents between 2012/2013 and 2016/2017.

The NAO confirmed that cannibalisation caused a 42-day delay and led to the Ministry of Defence having to pay an additional £4.9 million in relation to HMS Artful (Boat 3), and has also affected other boats. The NAO noted that cannibalisation generated engineering risks, the need for extra testing of used parts and demoralising effects on personnel. The revelation that such cannibalisation occurs is a clear indication of the problems that can impact the safe and effective management of an SSN fleet.

In the context that Australia is expecting to host and engage in the maintenance of at least one UK built and deployed Astute Class SSN, it is strongly advised that the repair/spare part history of any Astute Class boat offered to Australia should be closely investigated and that any decision to accept or reject that offer should be based on the outcome of that investigation.

Will Australia be reliant on the US and UK for any necessary spare parts for Virginia Class and AUKUS Class SSNs?

Can Australia implement an SSN "spare parts" industry in sufficient time to be able to support its proposed "home built" fleet of AUKUS SSNs?

Will Australia, at any stage, be reliant on UK or other sources for spare parts for its AUKUS fleet?

Will Australia be willing to make use of "cannibalised" spare parts?

Sinking of civilian vessels, collisions, near misses, groundings (see section 14 for more detail)

Between 1982 and 2015, UK civilian sources collated a dossier of information on 170 "interactions" between civilian vessels and nuclear submarines including net "snaggings", collisions, near misses and at least 30 suspicious unexplained sinkings in UK waters. These incidents have led to loss of life, total loss of vessels and loss of fishing gear. In the UK it is evident that, despite not firing a shot in anger, UK nuclear submarines have been responsible for the death of a number of UK citizens as a result of such interactions. Wider research has uncovered a number of other incidents involving nuclear submarines across the world's oceans.

A summary review of interactions between nuclear submarines and civilian vessels illustrates that nuclear submarine patrol routes, exercise and training areas, followed by maritime choke points and port approaches, present the greatest risks to the safety and operation of civilian vessels and their crew, ranging from small inshore commercial fishing boats up to super tankers.

It is clear that, despite the best attempts of both civilian and Defence authorities, the secrecy surrounding nuclear submarine operations makes risk avoidance that much more complex, with notification of nuclear submarine movements not publicised and the details of patrol and training strategies not divulged to judicial or government agency inquiries.

On a number of occasions civilian stakeholder groups (fishers etc.), local authorities and citizens campaigns have attempted to initiate improved protocols for submarine activity by interacting with the International Maritime Authority. However the International Maritime Authority does not have the power to mandate a set of standard procedures to prevent damaging interactions between civilian vessels and nuclear submarines.

It will be the responsibility of the Australian Defence Department and Australian Navy to draw up a set of protocols for the protection of motor fishing vessels, other civilian surface vessels and their crews, passengers and cargo from the risks generated by the deployment of nuclear submarines.

Radioactivity discharged from nuclear submarine bases (see Appendix 1 for more detail)

Appendix 1 provides a detailed review of the behaviour and fate of radioactivity discharged from UK nuclear submarine bases during repair, maintenance and refit operations on SSNs and SSBNs. This reveals discrepancies between the traditional official monitoring, analytical and dosimetry programmes deployed by UK nuclear regulatory agencies and the conclusions of recent scientific reviews and studies which identify flaws in the official programmes leading to inadequate understanding of the dose pathways by which coastal populations may be exposed to doses of radioactivity from nuclear submarine bases.

A number of case studies are reviewed including a study which demonstrated that a coastal population living approx. 20 miles (32 km) downstream of a UK nuclear submarine base received a higher dietary dose of man-made radioactivity from locally grown terrestrial food stuffs, than did a population living next to a four-reactor civilian nuclear power station. An unchallenged independent interpretation of this study showed that the radionuclide implicated in the higher dose was Cobalt-60, a radionuclide characteristic of naval PWR discharges and indicated the likelihood that the Cobalt-60 and other nuclear submarine derived radioactivity had transferred from the sea to the land by way of a number of mechanisms

Appendix 1 also notes that recent science, reported in peer-reviewed journals, has cast major doubts on the long-term orthodoxy that tritium, the major constituent of discharges to atmospheric and aquatic discharges from nuclear submarine bases, is of very low radiological significance.

Probable impact of nuclear submarine base radioactive discharges on Australian marine and coastal environments and populations

Appendix 1 references multiple studies showing that the Gulf of St Vincent (the water body adjacent to the Osborne Naval Dockyard) is recognised for its diversity with many species of crustaceans and polychaete worms, sea quirts and sea urchins. The seabed is largely composed of a soft sediment shelf, with species of seagrass around the mouth of the Port River. A Cardinal fish, genus Vincentia, gets its name from Gulf of St Vincent where the type specimen of its species was first identified and collected. The Gulf of St Vincent coastline incorporates the Adelaide International Bird Sanctuary National Park and also a large network of coastal protected areas off the northern shoreline, including the Adelaide Dolphin Sanctuary, the Upper Gulf St Vincent Marine Park and Light River Delta Sanctuary, as well as two Aquatic reserves: Barker Inlet-St Kilda and St Kilda-Chapman Creek.

The Gulf is recognised as a “low energy”, semi-enclosed waterway, where wave action is limited and flushing exchange with the open ocean is seasonally (summer) severely restricted. Modelling studies indicate that the Upper Spencer Gulf has flushing times of between 1 and 2 years. Near-field studies imply that dilution of anthropogenic effluent discharge water may be substantially reduced in the absence of tidal mixing during weak neap “dodge” tides.

There is no evidence that the implications of the proposed nuclear submarine maintenance and construction facility at the Osborne Naval Dockyard have been investigated regarding the radiological implications for the Gulf environment, wildlife or coastal communities.

Such investigation, particularly in the context of the likely discharges of nuclear effluents to sea from such a facility, are strongly indicated by the brief summary of relevant environmental parameters. Such parameters are strongly associated with the long-term presence and environmental re-concentration of radioactivity in biota and estuarine and near coastal fine sediments and the water body, likely to give rise to doses of nuclear submarine marine radioactivity via the pathways described in Appendix 1.

The Stirling Naval base on the eastern/inland facing coast of Garden Island, inside the Cockburn Sound, and already the major submarine base of the Australian Navy, is proposed as the operational base for both the AUKUS fleet and their proposed predecessor boats. Garden Island and the man-made causeway from Cape Peron have made the enclosed Cockburn Sound into a semi enclosed marine area with a restricted flushing exchange with the open ocean. In that context some of the environmental parameters summarised above re Gulf of St Vincent may be relevant to the potential for radiological pollution in the context of routine nuclear submarine operations at the Stirling Naval base.

Both the Gulf of St Vincent and the Cockburn Sound and their approaches represent potential areas of peak nuclear submarine activity under the AUKUS proposals. Given the regionally high concentration of other maritime activity: commercial fishing, pleasure/sport boating, heavy commercial traffic there is clearly an elevated potential for serious incidents between nuclear submarines and civilian traffic.

The addition of nuclear-powered submarine traffic, with its inherent requirement to submerge as soon as is practicable, coupled with the necessity for a designated training area and training patrols will clearly exacerbate an already complex regional scenario. Many of the parameters contributing to negative interaction scenarios are present in the vicinity of the Stirling Naval base proposed nuclear submarine operational HQ. This issue has not been addressed in any detail to date, if at all.

It is absolutely vital that the development of both the Osborne and the Stirling nuclear submarine bases should not proceed until such issues have been thoroughly investigated, researched and consulted on and contingency plans have been designed, analysed and tested under many different scenarios.

UK emergency planning regulations (see Appendix 2 for more detail)

Appendix 2 presents extracts from UK emergency planning regulations covering radiation emergency actions, exclusion zones and the distribution of iodine tablets at UK nuclear submarine bases and reports the very wide discrepancies between various nations regarding such actions.

For instance: information from a number of countries indicates that Belgium, Canada, the Czech Republic, Finland, France, Germany, Luxembourg, Sweden and Switzerland have pre-distributed iodine in the vicinity of nuclear reactors – the area covered has ranged from 4 km to 20 km radius of the nuclear reactors. In the UK, the decision to pre-distribute rests with the local authority and it has only occurred in a limited number of cases and a 3 km radius has tended to be used.

As of yet, no decisions on these issues appear to have been mandated within Australia. This may be a matter which will be mandated by the current federal government which has vigorously supported the AUKUS proposals, or it may be devolved to those regional authorities in the areas where proposed AUKUS submarines bases are to be sited.

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1. EVOLUTION OF THE UK NUCLEAR SUBMARINE FORCE

The UK has three active nuclear submarine (N.Sub) bases: Faslane/Coulport, Rosyth and Devonport:

Faslane/Coulport base is a patrol operational base for the fleet. Coulport is the adjacent storage base for the UK ballistic weapons which arm the UK N.Subs.

Rosyth base carried out the refitting of N.Subs until 2006. Seven UK decommissioned N.Subs are currently in storage at Rosyth awaiting decontamination and dismantling.

Devonport base is a patrol operational base for the UK sub fleet and also the current and sole refit, defuel/refuel, maintenance and repair UK N.Sub base. 14 decommissioned UK N.Subs are in storage at Devonport awaiting decontamination and dismantling.

1:1 Evolution of the UK nuclear submarine fleet: During the 1950s, the UK nuclear deterrent was airborne by V. Bombers of the Royal Airforce, but technological advances in both radar and surface -to-air missiles made V Bomber forces increasingly vulnerable. In that context, the UK Ministry of Defence concluded that the V. Bomber forces would fail to penetrate Soviet airspace by the mid-1970s.

1:2 As a result, the UK initially sought to develop a medium range ballistic missile capability named Blue Streak, which in its turn also became vulnerable to Soviet air defence. Subsequently the UK Government acquired the US Skybolt air-launched ballistic missile in an agreement which gave the US permission to construct a US N.Sub base at Holy Loch, on the west coast of Scotland near the city of Glasgow. When the American government cancelled Skybolt in 1962, President Kennedy of the United States and UK Prime Minister Harold Macmillan negotiated a deal under which the US would sell Polaris missile systems to be deployed on UK-built submarines.

1:3 The first nuclear submarines built for the UK Navy were Attack/Hunter-killer submarines designated SSNs (Submersable Ships Nuclear powered) designed to attack other submarines, surface warships and civilian merchant ships. They are also used to protect “friendly” naval units and SSNBs (Submersible Ships Nuclear powered Ballistic missiles). Attack submarines are armed with conventional cruise missile weapons, increasing the scope of their potential missions to include land targets. Nuclear powered attack submarines are often referred to as “fleet submarines” (i.e. with the speed, range, and endurance to operate as part of a navy's long-range battle fleet.)

1:4 The UK commissioned its first SSN in 1963 after a 4-year build process. The boat, named HMS Dreadnought, was built at Barrow-in-Furness, Cumbria, North West England by the Vickers-Armstrong company. The submarine was powered by a US navy fifth generation S5W design naval PWR reactor made available as a direct result of the 1958 US/UK Mutual Defence Agreement. The hull and combat systems of HMS Dreadnought were of British design and construction. The hull was constructed of QT35 steel (Quenched and Tempered) designed to withstand greater depths than previous submarines.

1:5 During the period of HMS Dreadnought’s construction, Rolls-Royce collaborated with the UK Atomic Energy Authority at HMS Vulcan (the Admiralty’s shore-based naval nuclear Research Station at Dounreay, Scotland) to develop a UK built, nuclear naval propulsion reactor, the Rolls-Royce PWR-1.

1:6 The first boats fitted with this UK built reactor were 2 attack submarines of the Valiant class. In subsequent years 4 additional classes of entirely UK built attack submarines have been launched as follows: 3 Conqueror Class, 6 Swiftsure Class, 7 Trafalgar Class and most recently 7 Astute Class.

2: UK/ROLLS ROYCE NAVAL REACTORS: INTRODUCTION

2:1 A publicly available Rolls Royce power point presentation provides a clear, basic, summary of the reactors and reactor cores fitted to the various classes of the UK N.Sub fleet.

The reactor core is the sector of the reactor containing the fuel assemblies and other components (moderator/control rods etc) where the nuclear reaction take place and heat/energy is generated.

To date, 2 naval PWR reactors have been built and deployed in the UK N/Sub fleet. These reactors have been fitted with a succession of Core types. It is clear that there was a rolling process of reactor and core design and refit as follows:

2:2 PWR-1: Core type A was originally fitted to 2 Valiant and 3 Churchill class SSNs and 4 Resolution class SSNBs. At refit of all boats, Core type B was back fitted. Core type B was originally fitted to 6 Swiftsure class SSNs. At refit of all boats of class, Core type Z was back fitted. Core type Z was originally fitted to 7 Trafalgar class SSNs. These boats are more recently commissioned, incomplete back fit reported to date.

2:3 PWR-2: Core type G originally fitted to 4 Vanguard class SSNBs. At refit of all boats Core type H was back fitted (RR claim that Core type H "represents a ten fold improvement" in core life span and "avoids the need to refuel" over the working life of the reactor and boat). Core type H originally fitted to 5 Astute class SSNs. (2 boats still in build phase expected to be fitted with Core type H)

REF: https://fissilematerials.org/library/uk11.pdf recovered March 2024

2:4 Further detail on core types might be obtained in response to the submission of an FoI request but response time to such submissions may be protracted and disclosure may be limited or denied because of security considerations.

2:5 In August 1960 the UK's construction of the first entirely UK built, nuclear powered attack submarine was initiated. Also built by Vickers-Armstrong at Barrow-in-Furness, HMS Valiant finally entered service 18 July 1966. HMS Valiant was the first of a "class" of 2; the second boat was HMS Warspite, in service by 1967.

2:6 Both boats were fitted with a Rolls Royce built naval PWR (designated PWR-1: Core A) which was built at the Roll Royce reactor fabrication centre at Derby, England. This reactor, in common with all the subsequent Rolls Royce naval reactors fitted to UK N.Subs, was fuelled with High Enriched Uranium (HEU), enriched to between 93-97%. The original design statement proposed a working life span of around 20 years for the Valiant class boats, with refuelling expected to occur every ten years.

2:7 In 2011 the UK Government issued the following statement:

"Producing a small, highly robust reactor plant contained within a submarine hull, withstanding a hostile ocean and wartime environment, and yet safe enough for the crew to live within feet of the reactor core, is a remarkable achievement.

"The United Kingdom is at the forefront of this advanced technology. To protect these advantages the Royal Navy takes operational security very seriously and, understandably, does not publish any details of submarine reactor plant design or operation.

"Information security, however, is never allowed to take precedence over the safety of our reactors, and detailed scrutiny of submarine nuclear safety is carried out by expert personnel from within the Ministry of Defence, the Health and Safety Executive's Office for Nuclear Regulation, and by independent nuclear safety assessors."

REF: https://www.gov.uk/government/news/csa-safety-paramount-for-rn-nuclear-submarine-reactors recovered March 2024

2:8 Information reported in the following pages has been gathered and collated in the context of that UK Government statement.

3: PWR-1: SUMMARY CASE STUDIES

(Reporting/analysis of naval reactor issues is limited by UK National Security restrictions and influenced by PR spin from Ministry of Defence (MoD) and Navy "spin)

3:1 Valiant Class SSN attack submarines: Initially 2 boats: HMS Valiant and HMS Warspite. They were later augmented by the construction of a further 3 boats. Based on the Valiant Class and referred to as "Churchill class" or "repeat Valiants", the Churchill, Conqueror and Courageous were in service until the early 1990s. All five boats were designed and built as the first entirely UK fabricated nuclear powered submarines. All five were powered by the UK naval PWR-1 initially fitted with Type A core.

3:2 HMS Valiant: build commenced 1962, entered service 1966/67, fitted with a UK built PWR-1 reactor with a Type A Core. HMS Valiant was the first UK designed and built nuclear powered attack submarine to undergo "refit" in 1970. This took place at Chatham Dockyard on the Thames estuary, close to London where a nuclear submarine refit dockyard had been established in 1968 but after a 16-year life span was closed in 1984.

3:3 The refit began in May 1970 and took two years to complete. The work involved maintenance, refit and nuclear refuel. HMS Valiant was re-commissioned at Chatham in May 1972, later returning for a second refit in 1976. The work was centred on the Nuclear Refitting and Refuelling Complex, based between No. 6-7 Docks, which had opened in June 1968 after major upgrading costing millions of pounds.

3:4 In 1976 HMS Valiant was in dock for "essential defect repairs" due to "feed water purification problems". These repairs lasted until June 1977 when the boat returned to duty. At least some of the refits may have been occasioned by on-board machinery and/or infrastructure failings. In 1977 HMS Valiant was on active patrol, tasked with tracking a Soviet submarine in the Mediterranean, when a salt water pipe leak flooded the reactor compartment with salt water.

3:5 The reactor was shut down and the compartment pumped dry and, after a "clean-up" of the compartment, the reactor was re-powered. Following this incident HMS Valiant returned to Chatham Dockyard for a further "refit" later in 1977. While it might be assumed that the 1977 refit may have been, at least in part, occasioned by the ingress of salt water into the reactor compartment, official sources are vague about the real reason for the refit.

3:6 Chatham Dockyard sources briefly reported that "After her second commission, the HMS Valiant was due for essential repairs and was refitted once again at Chatham Dockyard. She arrived in November 1977 for her refit and was given a new "high powered nuclear core**"** (Core type B). The submarine re-joined the 3rd Submarine Squadron in Faslane after her second re-commission".

REF: https://thedockyard.co.uk/news/warship-wednesday-hms-valiant-the-first-nuclear-submarine-to-be-refitted-and-refuelled-at-chatham/ (recovered March 2024)

3:7 A third "refit" commenced in 1986 and was completed in 1988.

3:8 It was widely reported that, following the discovery of reactor problems in June 1994, the boat was paid off on 12 August 1994. At least one source states that both boats of the

Valiant class boats were prematurely withdrawn from service as a result of serious cracking in the primary cooling circuits of their refitted Core Type B nuclear reactors.

Ref: http://www.globalsecurity.org/military/world/europe/htms-valiant.htm

3:9 HMS Warspite, the second boat of the Valiant class, entered planned refit and refuel in 1971, completed in November 1974. Warspite entered dock for refit and back fitting of a Type B Core to the reactor in 1979. HMS Warspite was retired mid-refit in 1991, after the discovery of yet more mechanical failure associated with the reactor.

3:10 As referenced above, at least one source states that both boats of the Valiant class boats were prematurely withdrawn from service as a result of serious cracking in the primary cooling circuits of their Core Type B nuclear reactors. To date I have not been able to access details of the reason for replacing the Type A Cores. It is clear the Type B Cores had suffered unexpected, life shortening degradation.

3.11 Despite the Roll Royce PR expectation that the reactors with Type A Core fitted to both Valiant and Warspite would have a life span of 20 years, at refit after 10 years (Valiant) and 12 years (Warspite) they were both fitted with new reactor cores (PWR-1: Core Type B). Valiant's Type B Core lasted for 17 years; Warspite's Type B Core lasted for 12 years. Both boats were reported prematurely retired due to serious cracking to primary cooling circuits of their Type B Core reactors. These were problems that were replicated through each successive class of SSNs.

3:12 HMS Valiant is now decommissioned from the Royal Navy and stored afloat at Devonport. The defuel of HMS Valiant took place in 14 Dock for Dock Down and Lay-up Preparations and was successfully completed and the submarine left 14 Dock on 6 March 2003. The spent nuclear fuel (high-level waste) was dispatched to Sellafield. The boat has now been moored in 3 Basin along with other defuelled submarines awaiting further decontamination of radioactivity. Her hull and reactor are currently laid up, under a regime of regular inspection and maintenance, until facilities are available for the removal and long-term storage of her remaining intermediate- and low-level radioactive components.

3:13 Swiftsure Class SSNs: 6 boats of Class entered service between 1973 and 1981, each originally fitted with PWR-1 reactor with Type B Core: all "back-fitted" with Type Z Core at first refit.

3:13 During a Parliamentary debate on 18th November 1981 on issues surrounding the refit of Swiftsure class boats, the Secretary of Defence was asked "How many SSNs have already been fitted with long life cores for their reactors?" Sec of State (MoD) responded that "All SSNs, apart from Dreadnought, have been, or will be fitted with improved reactor cores"

REF: https://hansard.parliament.uk/Commons/1981-11-18/debates/ee95f180-e841-4054-a3bb-b83ff8ee1ac0/SsnSubmarines

N.B. It is assumed that this Parliamentary Q &A about "long life cores" refers to the Core Type Z

3:14 First of class HMS Swiftsure entered service in 1973 : build cost £37.1 million. First refit occurred in 1979, Type B Core removed (after 6 year life span): Core Z back-fitted at a cost of £85 million. Second planned refit commenced in 1992: during which the PWR-1 reactor, with Type Z Core, was found to have suffered severe cracking (assumed cooling system) to such an extent that the boat was decommissioned, the Z Core removed (after 13-year life span) and the boat laid up for decontamination and eventual scrapping.

Other boats of the Swiftsure Class experienced similar reactor problems as below:

3:15 **HMS Sovereign**: build commenced 1970, entered service 1974. Build costs £31 million From 1992 to 1997 Sovereign entered a refit period at Rosyth Dockyard. During post refit sea trials (1997/98) major deterioration/metal fatigue cracking of tail shaft was discovered and Sovereign was returned to Rosyth for 14 weeks of emergency repairs in June 1998 before returning to Faslane.

3:16 By 2000 the Sovereign was still in dock. The *Herald of Scotland* newspaper reported that a naval source said that "Sovereign's problems have reached the state where the law of diminishing returns has started to kick in. A decision is expected soon on the economic wisdom of keeping her in service. The probability is that she will be decommissioned to cut the navy's overstretched budget".

REF: "Nuclear submarine set to be scrapped after £192 million refit." Herald of Scotland. 27 Dec. 2000

Build cost of HMS Sovereign was £31 million (equivalent to £82.32 million as of 2021). Cost of this refit was at 2005 £192 million.

3:17 A press release issued by the Ministry of Defence on 1 November 2000, about reactor problems in the Swiftsure Class and its Trafalgar class successors, stated that HMS Sovereign was at Faslane base for maintenance – "clear of flaw."

REF: https://www.nuclearinfo.org/wp-content/uploads/2023/05/House_of_Commons_HMS_Triumph_1_November_2000.pdf

3:18 However, following that announcement Sovereign was reported out-of-service for some time due to the same reactor problems experienced by others of her class. Although she was back in full service by July 2005, the submarine was decommissioned in September 2006.

3:19 HMS Sceptre: in service from 1978 to 2010. Build cost £58.9 million (equivalent to £155.9 million at 2021 rates).

1987: entered major refit and maintenance process including removal of Type B Core and back fit of new Type Z Core.

1990: reactor coolant leak discovered: re-dock for repairs etc at Devonport.

1995: abandoned patrol duty and returned to Faslane due to what the Ministry of Defence referred to as "an unspecified fault in the propulsion system."

1998: defects in Sceptre's reactor discovered: significance not reported at the time.

2000, 6 March: serious incident while inside a drydock at Rosyth while undergoing trials towards the end of a major refit. The test involved flooding the drydock, and running the main engines slowly with steam supplied from the shore. However, too much steam was used and the engines went to full speed, Sceptre broke her moorings and shot forward off the cradle she rested on. The steam line ruptured, scaffolding buckled, a crane was pushed forward some 15 feet, and the submarine moved forward some 20 yards (18 m) inside the dock.

3:20 A Ministry of Defence spokesman in London confirmed the above incident. He said it happened during basin testing of the main engines and shaft. He added: ''On ordering minimum revs ahead, on remote throttles, the main engines oversped, causing the submarine to break its moorings.'' An investigation was underway, he said, but routine work on HMS Sceptre would continue.

Globalsecurity.org, a well-respected US based, independent and nonpartisan research and consultancy group, focused on national and international security issues and military analysis, systems, and strategies reported on the Rosyth incident as follows:

"In March 2000 HMS Sceptre's engines, powered by shore-side steam, sped up without warning during repair work and the 3500-ton sub lurched forward towards the dock wall. Workers and anti-nuclear campaigners claim the incident could have sparked a Chernobyl-style meltdown. One member of staff at Rosyth naval dockyard said: "If it had hit the dock and cracked the reactor, that would have been goodnight Scotland." The nuclear-powered vessel pulled a huge dockyard crane off its tracks, broke free of its moorings and caused thousands of pounds worth of damage."

REF: https://www.globalsecurity.org/military/world/europe/hms-swiftsure.htm (Recovered March 2024)

3:21 The official investigation into the March 2000 Rosyth incident also reviewed the Sceptre's 1998 reactor problems and in January 2002, the Defence Minister stated that the problem was "small original fabrication imperfections" in the reactor pressure vessel and declined to provide further detail or say how long it would take to inspect and repair the problem.

3:19 However, the boat was held at Rosyth for unplanned work and did not return to service until March 2003, when Sceptre left Rosyth, after being in refit for six years, to undertake sea trials; she was the last submarine refitted in Rosyth. In late October 2003, the boat completed her post-refit sea trials and returned to active service. The cost of the refit has been reported as £154 million.

3:20 The extended timescale and high cost of the refit is presumed related to both the engine runaway incident at Rosyth dock and also to the reactor inspection and repairs. Sceptre was decommissioned in 2010. As with a number of other incidents, Navy and Ministry of Defence sources are clearly reluctant to speak frankly about reactor flaws and failures.

3:21 Trafalgar Class SSNs: The first submarine in this class, HMS Trafalgar, was commissioned in May 1983. HMS Turbulent commissioned in April 1984, HMS Tireless commissioned in October 1985, HMS Torbay commissioned in February 1987, HMS Trenchant commissioned in January 1989, HMS Talent commissioned in May 1990, and HMS Triumph commissioned in October 1991.

3:22 The design life span of Trafalgar class boats was around 30 years and in the event the boats had a service life of between 28 and 32 years: last of build HMS Triumph is expected to be decommissioned in 2024. The hull design of the Trafalgar Class is identical to that of the Swiftsure Class submarine.

3:23 Trafalgar Class design also incorporated a new nuclear reactor fitted with Core type Z. As is the case with all of the naval reactors, details of those aboard the Trafalgars are classified but it is claimed to be sufficient to power the submarine at substantial speed and retain a high load within the submarine. Like all of the earlier SSNs, the Trafalgar PWR-1 reactors used highly enriched uranium as fuel and as such the Trafalgar class reactor core life span was between eight to ten years resulting in at least two refuels during each boats life time.

3:24 Service issues: In 1998, Trenchant experienced a steam leak, forcing the crew to shut down the nuclear reactor. In 2000, a leak in the reactor primary cooling circuit was discovered on Tireless, forcing her to proceed to Gibraltar on diesel power. The fault was found to be due to thermal fatigue cracks, requiring other Trafalgar-class boats, and some of the remaining Swiftsure-class boats, to be urgently inspected and if necessary modified.

3:25 In August 2000 it was revealed that, with Tireless still at Gibraltar, Torbay, Turbulent, Trenchant and Talent were at Devonport for refit or repair and with Trafalgar undergoing sea trials, only one boat, Triumph, was fully operational. Following publicity of this event Geoff Hoon, Secretary of State for Defence, told the House of Commons “inspections have shown that there is no evidence of the problem in five submarines”

REF: “Defence and Armed Forces Debate” Hansard. 1 November 2000: col. 724-725

3:26 Later, on the same day, a press release issued by the Ministry of Defence, and referring to the Secretary of State’s statement was appended to the Hansard record. The press release briefly noted the following: “The status of UK SSNs is as follows: Trafalgar: Devonport…… signs of flaw; Turbulent: Devonport…… signs of flaw; Torbay: refit Devonport………. Signs of flaw; Talent: Devonport for maintenance……signs of flaw; Tireless: Gibralter…..defect under repair .

Ref: “Defence and Armed Forces Debate” Hansard. 1 November 2000: col 724-725. MoD Appendix.

3:27 By 2005, refits had reportedly corrected these problems. In 2013 the Defence Nuclear Safety Regulator reported that the reactor systems were suffering increasing technical problems due to ageing, requiring effective management. An example was that Tireless had had a small radioactive coolant leak for eight days in February 2013.

REF: https://www.seaforces.org/marint/Royal-Navy/Submarine/Trafalgar-class.htm

3:28 HMS Talent was commissioned in May 1990. In 2007 Talent rejoined active service following extended refit, refuel and back fit of new reactor core at Devonport, costing £386 million. In 2009, Talent suffered loss/failure of primary and alternative power supplies to its nuclear reactors while in dock.

3:29 In February 2013: HMS Tireless at Devonport undergoing emergency/unplanned maintenance following discovery of a poorly defined coolant circuit leak detected while at sea. A Royal Navy spokesperson said: “HMS Tireless returned to Devonport Naval Base last week for repair following a small coolant leak that was contained within the sealed reactor compartment. There is no risk to the public, the environment, or the crew.”

REF: https://www.nuclearinfo.org/article/astute-safety-faslane-coulport/radiation-leak-forces-royal-navy-nuclear-submarine-return

3.30 *Nuclearinfo.org* issued a briefing on this incident as follows: “After the submarine arrived at Devonport on 6 February the reactor was shut down to allow a reactor compartment entry and during a reactor compartment inspection on 7 February a leak was visually identified. According to a Parliamentary written answer, the duration from the initial report of the problem to the cessation of the leak was approximately 192 hours, suggesting that the leak was finally stopped on 12 February, several days after the submarine berthed at Devonport.

According to local sources, repair work on the submarine was undertaken by workers from Rosyth naval dockyard, rather than from Devonport itself."

REF: https://www.nuclearinfo.org/wp-content/uploads/2020/09/HMS-Tireless-briefing.pdf

3.31 The *Nuclearinfo.org* briefing went on to report that "Permission was given by the Defence Nuclear Safety Regulator for a radioactive discharge to be made from the submarine, and it appears that this discharge may have occurred to the atmosphere when the reactor compartment was ventilated. The Ministry of Defence has refused to say which radioisotopes were released as a result of the leak, but the reactor cooling circuit is likely to have been dominated by a few radiologically significant nuclides, including H-3, N-13, N-16, F- 18, Na-24 and Cl-38. The most significant radionuclide vented would probably have been tritium (H-3) with its 12.3-year half-life. It is not clear where exactly the discharge took place, but the timing of regulatory permissions suggests that it occurred when the submarine was berthed at Devonport. No information is available as to whether the discharge took place at a time or under weather conditions that would have minimised risks to residents living near the dockyard."

3.32 "According to Ministers, no liquids associated with the leak were offloaded at Devonport or discharged at sea. On return to Devonport the reactor compartment was surveyed and a small amount of dry surface radioactive contamination was detected in the vicinity of the leak. The area was cleaned following standard nuclear procedures and solid wastes arising from the cleaning and subsequent repair work were removed in accordance with normal waste disposal procedures. No members of the crew were exposed to additional or unexpected doses of radiation during the incident".

3:33 The Defence Nuclear Safety Regulator stated that it was "involved in all stages following the initial discovery of the leak in line with its role as regulator of nuclear and radiological safety of the UK's Naval Nuclear Propulsion Programme". Ministers have said that an investigation into the incident by the Defence Nuclear Safety Regulator is considered unnecessary as the Naval Reactor Plant Authorisee (NRPA) is required to thoroughly investigate such matters, but have stopped short of undertaking to release the NRPA report when it has been completed"

REF: https://www.nuclearinfo.org/wp-content/uploads/2020/09/HMS-Tireless-briefing.pdf

3.34 The *Nuclearinfo.org* briefing also reported that "on the basis of the very limited information available about the incident, it appears that pipework in the submarine's reactor cooling system – most likely a subsidiary section of pipework, such as the residual heat transfer line, rather than the main cooling circuit – experienced a leak. If the leak was in the main circuit the incident would potentially have been more serious, possibly representing a 'leak before breakage'. A leak before breakage is a small creeping leak in pipework which, if left unchecked, will gradually expand and eventually break, resulting in a catastrophic failure of the cooling system. Operating the submarine under such circumstances obviously poses a risk that such a failure will occur, leading to a reactor accident. In response to questions about the cost of repair work to the submarine, the Ministry of Defence has to date stated that it is too early to confirm the cost of repairs. The work has now been completed and the costs are likely to amount to work with the value of several million pounds."

REF: https://www.nuclearinfo.org/wp-content/uploads/2020/09/HMS-Tireless-briefing.pdf

3.35 **Conclusions (Sections 2&3):** Despite security restrictions and PR spin from both the Ministry of Defence and Navy sources it is evident between the 1960s and the present day UK SSN attack submarines have been fitted with 2 types of reactor and 5 types of core as follows.. PWR-1 with 3 evolving/modified core types (A, B and Z cores) and PWR-2 with 2 evolving/modified core types (G and H cores).

Case studies of PWR-1 reveal an inconsistent performance history of reactor+cores. All SSNs with PWR-1 had to undergo extensive planned maintenance periods consisting of updating of military equipment (sonar etc.) and repair, refuelling and back refit of new cores. A surprising number of boats required "unplanned maintenance". Maintenance "outages" usually required 2 years out of service, sometimes longer (up to 5 years). "Unplanned" maintenance outages disrupted the programme of "planned" maintenance and clearly increased the wear-and-tear pressure on boats waiting for their planned maintenance. PWR-1 reactor lifespan was expected to be at least 20 years but the evidence is that, for a number of boats, this projected life span was not achieved, or only achieved after major maintenance and life-extension work. PWR-1 reactors, with various cores fitted, were characterised by a marked tendency to develop "serious cracking in the primary cooling circuits" of the reactors leading to leaks of cooling water. In some cases these problems were recurrent, despite repair.

It is equally clear that, due to the complexity of maintenance and refit work, the financial impacts are characterised by high costs, often exceeding the cost of the original build. It is also evident that some boats also suffered from basic, but major, hull integrity issues (e.g. HMS Sovereign: which had to undergo "unplanned" emergency repair/reconstruction of its tail shaft).

It is also clear that the frequency of "unplanned" dockyard time generated by these reactor/core problems has also generated ever-increasing time and finance costs due to the necessity for repairs, which have in themselves delayed planned work due to both docks and facilities being required for the unplanned work.

Because of the lack of transparency, due to "official secrets act" restrictions, important relevant details of these problems have been withheld from the public. Despite the lack of transparency it is evident that these problems have caused repeated interruptions of SSN service/patrol time and reduced the expected effectiveness of the overarching proposed SSN deployment strategy.

4: SUMMARY CASE STUDY OF PWR-2 REACTORS

4:1 PWR-2 reactors are fitted to both SSN and SSNB submarines. However, the build and launch of the most recent SSNBs has preceded the build and launch of the latest SSN (Astute) Class, so this section will focus on the performance of the SSNB PWR-2 reactors, which have a longer service history than the Astutes.

The PWR-2 reactor was designed for the UK's Vanguard Class SSBNs which entered service in the 1990s to carry the US Trident strategic weapon system. Design work began in 1977 and the first PWR-2 reactor was designed with Type G Core and completed in 1985, when testing of the reactor began prior to its actual deployment at sea in 1993.

4:2 HMS Vanguard is the "lead" boat of the Vanguard Class SSNB nuclear submarine flotilla, which carries the current nuclear weapon deterrent deployed by the UK Government.

Vanguard carries nuclear-armed ballistic missiles and was powered by a Rolls Royce PWR type 2 reactor with a Core Type G. It took six years to construct the Vanguard and she was finally launched in 1993. The last of the four boats in her class was commissioned in 1999.

4:3 According to contemporary publicity the 4 Vanguard boats were fitted with Rolls Royce built PWR-2 (Core Type G) reactors which would require 2 refits and refuels during their planned 25 year operational lifespan, a 5 year extension of the 20 year life span proposed for the PWR-1 boats.

4:4 Between 1999 and 2002 a major refurbishment of No 9 Dock at the Devonport base was initiated in order to provide refit and refuel facilities for the Vanguard boats and their PWR-2 Core type G reactors.

4:5 Between 2002 and 2005, HMS Vanguard underwent her first maintenance and refuel period during which she was back-fitted with the Type H Core which had been designed and built to last for 25 to 30 years without the need for refuelling or replacement.

4:6 By 2015 HMS Vanguard was back in dock for an emergency unplanned replacement of the Type H Core reactor following reports from test reactor trials that the H Core reactor was flawed. The initiation of the Core H replacement gave HMS Vanguard not only the distinction of being the first submarine to have the lifetime (no refuel) Core H fitted but also the distinction of being the first boat to have the lifetime (no refuel) Core H removed and replaced, a task that was not envisaged when it was designed. The actual working life time of the Vanguards Type H Core reactor was 14 years.

4:7 HMS Vanguard eventually left Devonport dock in May 2023 and returned to active service later that year. Full details of issues remedied during Vanguard's refit have only been publicised slowly. In 2024 it was reported that during the 2015 to 2023 refit it was discovered that the entire tail section of the boat, containing the rudder and the aft hydroplane bearings, was so badly corroded that it had to be virtually reconstructed, "a complex project never before attempted".

4:8 **Type H reactor core issues:** At refit of the Vanguard Class SSNBs between 2002 and 2012, the Type G Core was replaced by the Type H Core designed to last the lifetime of the reactor (25 to 30 years) and to eliminate the need for costly mid-life reactor refuelling.

4:9 In November 2009 the Defence Nuclear Safety Regulator carried out a safety review of the Type H Core reactors fitted to the Vanguard Class boats, based on observations of the H Core "lead/test" reactor which had been constructed at the UKs Naval Test Reactor base at Dounreay and activated prior to the activation of any of the H Cores fitted to N. Subs.

4;10 The 2009 safety assessment by the Defence Nuclear Safety Regulator concluded that PWR-2 reactor safety was significantly short of good practice in two important areas: a loss of coolant accident and control of submarine depth following emergency reactor shutdown.

REFS: "Annex B: Successor SSBN - Safety Regulator's advice on the selection of the propulsion plant in support of the future deterrent (4 November 2009)" (PDF), and "Successor Submarine Project - Update, Ministry of Defence, 24 November 2009, p. 21, EC-14-02-02-01-14 / Annex B: DNSR/22/11/2,*(PDF) both de-classified but heavily redacted.*

4:11 The Defence Nuclear Safety Regulator further concluded that PWR-2 was "potentially vulnerable to a structural failure of the primary circuit", a failure mode with significant safety hazards to crew and the public. The failure could cause a leak of "highly radioactive fission products" and "a significant risk to life to those in close proximity and a public safety hazard out to 1.5km from the submarine". The same source reported the following contradictory statement: “Rear Admiral Simon Lister, the MoD's Director Submarines, said: "While the Pressurised Water Reactor used in our existing submarines is a robust, highly controlled system that meets our stringent safety standards, the new Pressurised Water Reactor 3 will deliver further improvements such as ease of operation and lower costs over its extended life."

REF: http://www.defencemanagement.com/news_story.asp?id=16337 Recovered March 2024

4:12 The outcome of the review was initially kept confidential, but in response to Freedom of Information requests the details of the report were eventually made public in 2011. Publication disclosed that the Defence Nuclear Safety Regulator Safety Assessment had reported loss of coolant accidents in the H Core test reactor and an inability to manage depth control of the submarine during emergency reactor shutdown exercises.

4:13 In the context of those findings the Safety Assessment concluded that the Vanguard H Core reactors were “potentially vulnerable to a structural failure of the primary (coolant) circuit” and went on to categorise this as a “failure mode” presenting significant safety hazards to both crews and the public.

4:14 Subsequently, in 2011 further trials at the Admiralty Naval Test Reactor at Dounreay discovered microscopic cracking in the fuel canisters used in H Core reactors. As a result of the cracking the Vanguard test reactor coolant water had shown an unexpected increase in radioactivity concentrations and this was attributed to defect breeches in the fuel cladding. This new information also remained supressed and was not publicised until 2014.

4:15 It remains unclear if the fuel and canisters used in conjunction with Type H Cores were of a different design from those used in conjunction with previous core types, or if the fuel cladding cracking was a specific function of the H Core.

4:16 As a result of these problems and the eventual publicity that surrounded them in 2014, the Ministry of Defence ordered all Vanguard class boats (Vanguard, Victorious, Vigilant and Vengeance) to undergo retrofitting of replacement H Core reactors at the Devonport N.Sub base at an estimated cost of £120 million per boat. HMS Vanguard arrived in December 2015 for her second Long Overhaul Period and the previously unplanned refuelling and back-fit of its second Type H Core.

4:17 The *Navy Lookout* publication, an independent Royal Navy News and information outlet, reported that “Unable to take risks with the availability of deterrent submarines, refuelling HMS Vanguard was an expensive insurance policy at around £270 million. The core replacement has added around £120 million to the refit cost. A further £150 million had to be spent on reactor infrastructure at Devonport and the Rolls Royce facility in Derby so as to retain the ability to manufacture Core H potentially, for HMS Victorious and the other two boats. These additional expenses were met from contingency funds held in the submarine programme, not the MoD’s annual budget.”

REF: https://www.navylookout.com/a-relief-for-the-submarine-service-hms-victorious-does-not-need-nuclear-refuelling/

4:18 Because the H Cores fitted to the PWR-2 reactors had been designed to need no mid-term refuel or refit, they had been designed with “sealed unit” features. It is reported that reactor engineers at the Babcock-run Devonport N.Sub base experienced major ongoing problems in establishing exactly how to safely re-open, refuel and close the Vanguard's H Core. In 2018 naval sources reported that the project was then in its 44th month.

4:19 Reliable sources told the *Financial Times* at the end of 2018 that the Vanguard was still "in pieces" and that the Ministry of Defence had "low confidence" that Vanguard would meet her originally planned return to the fleet in 2020. Naval sources also confirmed that experts from the Submarine Delivery Agency were drafted in to support Babcock in 2018, effectively putting the project into 'special measures'. The low confidence expressed by the Ministry of Defence in 2018 has been borne out and during the last quarter of 2021 there was still no indication of the Vanguard's swift return to operational status.

4:20 It later emerged that, during February 2023, inspection had revealed that the heads of a number of bolts, attaching insulation to the reactor coolant pipework, had been glued in place, having been sheared off after being over tightened during the Core H replacement. The glued bolts, which should have been replaced, were discovered shortly prior to re-activation of the reactor.

4:21 Quoted by *Navy Lookout*, an anonymous senior uniformed stakeholder admitted that "Vanguard is a textbook example of how not to set up a major project. Among other things, we changed the scope of the project, did not invest in the workforce and did not invest in the infrastructure." As a non-fixed-price contract, cost to the Ministry of Defence is thought to have ballooned to over £500 million.

REF: https://www.navylookout.com/hms-vanguard-finally-sails-from-devonport-after-refit-lasting-more-than-7-years/

4:22 Vanguard's Long Overhaul Period was intended be the final major refit until she is replaced by HMS Dreadnought in the early 2030s. The Long Overhaul Period and H CORE replacement project is effectively a "life extension" that will have to see Vanguard through another 10-12 years of service. Launched in 1992, the boat will be 38 years old by 2030. Her construction began in 1986, so by that date most of the Vanguard's structure will be 44 years old.

4:23 HMS Victorious (2nd boat in Class): In November 2023 the *Navy Lookout* publication reported that HMS Victorious would NOT need nuclear refuelling after all and added that this was because concerns about PWR-2reactors fitted with Core Type H had now been allayed.

"After extensive testing and examination of HMS Vanguard's fuel elements for corrosion and distortion, it is now clear that Core H is sound and HMS Victorious, the next boats due for refit will not have to be refuelled (neither will Vigilant or Vengeance at their subsequent refits)".

REF: https://www.navylookout.com/a-relief-for-the-submarine-service-hms-victorious-does-not-need-nuclear-refuelling/

4:24 On 1st of March 2024, the Royal Navy announced that HMS Victorious had docked in Devonport in late 2023 to undergo a "life extension package" overhaul, which would allow the boat to carry out her deterrent patrols until the next generation of submarines, the Dreadnought class, enter service.

REF: https://www.royalnavy.mod.uk/news-and-latest-activity/news/2024/march/01/20240301-hms-victorious-560m-refit-to-ready-her-for-future-operations

It remains unclear whether this life extension package included any work on the reactor or core.

4:25 Coming after the November 2023 announcement, the 1st March 2024 announcement appears optimistic. The Vanguard's first back-fitted Type H Core reactor failed to achieve its design life of 25 to 30 years. In that context it is relevant to note that Type H Core reactors back-fitted to the other boats of the class are still relatively young and must still undergo years of service. HMS Victorious, for instance was back-fitted with her first Type H Core reactor during a refit that ended in 2009, **this reactor is currently only half way (15 years) through its proposed design life.**

4:26 Detail of the life extension package has not been made public, however it is reported that it will cost £560 million, a considerable elevation of cost relative to other "normal" refits. Source close to the Navy commented that the cost of this refit was due to " the increased age of the boat and a realistic approach to a "costs for contract" model that provides performance incentives for Babcock *(the contractor)* to complete the project on time".

REF: https://www.royalnavy.mod.uk/news-and-latest activity/news/2024/march/01/20240301-hms-victorious-560m-refit-to-ready-her-for-future-operations.

4:27 **Conclusions: (Section 4):** On the basis of the available evidence, the 30-year, long-term viability of PWR-2 reactors fitted with the Type H Core remains unproven. In the context of the less than perfect record of PWR-1 reactors and their succession of core types, the prognosis for the success of H Core reactors fitted to both SSNB and SSN submarines remains unclear.

Despite security restrictions and PR spin from both Ministry of Defence and Navy sources it is evident that the most recent class of SSN attack submarines (Astute Class) have been fitted with the PWR-2 with 2 evolving/modified core types (G and H cores). H Cores have been publicised as having a working lifespan of 30 years and needing no-refuel/replacement core. However, the first PWR-2 reactors were fitted to the Vanguard Class SSBN boats, designed and built in advance of the Astute SSNs.

Section 4 has focussed on the experience with the Vanguard class because there is more historical data/reporting of their reactors. Section 5 focusses on the Astute class

Case study of the Vanguard class PWR-2 reactors reveals an inconsistent performance history of reactor+cores. As was the case with PWR-1 boats, the Vanguards had to undergo extensive planned maintenance periods consisting of updating of military equipment (sonar etc.) and repair, refuelling and back refit of new cores (originally fitted with Type G Cores and refitted with Type H Cores). Some of these boats required "unplanned maintenance" which usually required 2 years out of service, sometimes longer. In the case of the HMS Vanguard SSBN one "unplanned" maintenance outage lasted for 7 years (one year longer than the original build time). The cost of this refit was in excess of £400 million. "Unplanned" maintenance outages disrupted the programme of "planned" maintenance and clearly increased the wear-and-tear pressure on boats waiting for their planned maintenance.

The HMS Vanguard 7 year-long maintenance outage, referred to above, arose following a series of reports of observed H Core reactor misfunctions from the Naval Reactor Test Establishment (NRTE). In 2009 the NRTE reported that such misfunctions posed a risk of "potential failure of the reactor primary coolant circuit", leak of "highly radioactive fission products" and "significant risk to life in close proximity and a public safety hazard out to 1.5km from the submarine." In 2011 the NRTE discovered unexpected increases in radioactivity concentrations in the reactor cooling water attributed to microscopic cracking defects in the cladding of the fuel elements used in the reactor. These issues forced the Ministry of Defence and the Navy to send HMS Vanguard for an early and unplanned reactor refit. Review of the reporting of this HMS Vanguard second (unplanned) H Core refit revealed that the no-refuel H Cores were designed and constructed as sealed units, and that this has generated serious problems for the reactor engineers tasked with dismantling the reactor and replacing the suspect H Core. It was also revealed that, during the dismantling process, a number of bolts on the cooling system had been "sheared", but that, instead of being properly replaced, the sheared bolt heads had been re-attached with superglue.

In addition to the reactor issues, during the HMS Vanguard's 7-year outage it was also discovered that the entire tail section, including the rudder and the hydroplanes, was so badly damaged that it had to be virtually rebuilt. A similar problem had occurred with at least one of the predecessor SSNs.

I have been unable to find any further detail about the cause and remedy of the H Core reactor and fuel problems detected at the NRTE. Neither have I been able to identify any explanation for the decision to NOT replace the H Core reactors which were back-fitted to the other boats of the Vanguard class. In the aftermath of the NRTE reports of H Core reactor and fuel malfunction the UK Government and the Ministry of Defence took a surprise decision to close down the NRTE and to abandon empirical "lead" research on naval reactors in favour of computer modelling analysis of the performance of all new reactors and cores, including those intended for the UKs future SSBN fleet and the AUKUS SSNs.

5: ASTUTE CLASS SSN: PWR-2 WITH CORE TYPE H

5:1 The Astute class is the latest class of UK SSNs. The class is intended as the replacement for the Trafalgar Class SSNs. Seven boats will be constructed: Astute, the first of class, was launched in 2007, commissioned in 2010, and in operation May 2014. It is proposed that the Australian Navy take control of at least 1 Astute Class SSN while the first AUKUS Class SSNs are being built.

5:2 The Astute-class programme was initiated in February 1986 when the Ministry of Defence launched a number of studies intended to determine the capabilities and requirements for the replacement of the Trafalgar-class fleet submarines. The studies concluded that the new Class should be a revolutionary design, with significantly enhanced nuclear propulsion and firepower, and a more sophisticated "integrated sonar suite" and combat systems in order to keep abreast of developments within the Soviet N.Sub fleet

5:3 One of the significant design changes was a new and more powerful reactor, the PWR-2 which would be fitted with the Type H Core and designed to need no refuelling for an operational lifetime of 25-30 years. This reactor had originally been designed for the most recent Vanguard Class SSBNs. (SSBNs had always been bigger that SSNs).

5:4 Design and Build Issues: However, because the PWR-2 was approx. 30% larger than the PWR-1, the Astute class hull design could not be based on predecessor SSNs and had to be re-drawn to create a much larger boat (beam and length).

5:5 In November 1999, BAE Systems at Barrow-in-Furness became responsible for the final design and construction of the Astutes, by which time it had been approximately 20 years since the Vanguard SSBN class were designed, and the last of that class of boats had been launched. The workforce at the shipyard had fallen by about 10,000 to 3,000 and key skills in design and engineering had been lost. This generated major delays to the implementation of the Astute programme design and construction phases.

5:6 Additional delays and cost increases were caused by issues with 3D CAD software which had originally been promoted as an innovative cost-saving measure by greatly reducing man-hours. It was reported that one of the reasons for the delay was a lack of experienced designers able to use the software and its expanded tools.

5:7 Despite these problems, which included incomplete design drawings, the first boat of Class was laid down on 31 January 2001. Modular hull construction methods were used, with the boat being built in ring-like modules, each up to several metres in length, which were welded together using specially designed high-strength steel, and then fitted out. The Astute class is the first nuclear submarine to be designed using only 3D computer software.

5:8 In August 2002 an audit of the project determined that the Astute program was more than three years behind schedule, £700 million over budget and work was temporarily suspended. The crisis also resulted in orders for the second batch of vessels being postponed, pending the resolution of the production problems. In 2002 BAE and the Ministry of Defence admitted that they had underestimated the technical challenges and costs of the programme. In August of 2002 it was estimated that the Astute programme was running over three years late with cost over-runs of hundreds of millions of pounds over budget.

5:9 In December 2002, BAE Systems issued a profit warning as a result of the cost overruns and delays. BAE Systems and the Ministry of Defence subsequently renegotiated the contract, with an understanding that the Ministry of Defence would shoulder a percentage of the financial risks. In December 2003 a new contract was signed, with the Ministry of Defence agreeing to add another £430 million to the programme and BAE Systems taking on £250 million of the cost overruns.

5:10 In November 2009, the UK House of Commons Defence Select Committee found that delays due to technical and programme issues meant that the Astute class programme was 57 months late and 53% (or £1.35 billion) over-budget, with a forecast cost of £3.9 billion for the first three boats. The hand-over of boat 4 of class, HMS Audacious, was delayed from 2019 to 2021 due to "emergent technical issues". In February 2020, James Heappey, parliamentary under-secretary of state for defence, confirmed that the in-service date for the final SSN, HMS Agincourt, had slipped to 2026.

REF: https://www.seaforces.org/marint/Royal-Navy/Submarine/Astute-class.htm

5:11 Also in 2009, the safety assessment by the Defence Nuclear Safety Regulator concluded that PWR-2 reactor safety was significantly short of good practice in two important areas: loss-of-coolant accident and control of submarine depth following emergency reactor shutdown. The regulator concluded that PWR-2 was "potentially vulnerable to a structural failure of the primary circuit", which is a failure mode with significant safety hazards to crew and the public. Operational procedures have been amended to minimise these risks. (These issues, and others associated with the PWR-2 Type H Core, are discussed in following sections).

5:12 The first boat of class, HMS Astute, was launched in 2007, commissioned in 2010 and fully operational in 2014. This long lead time between launching and fully operational status may have been due to unusually extensive sea trails and crew training as the Astute Class SSNs are frequently characterised as the most sophisticated SSNs ever built and more complex than the space shuttle. It remains unclear if the proposed 25-30 year lifespan of the PWR-2 with Type H Core runs from launch date, commission date or the date of entry into operational status. Clarification of this issue will clearly have a major bearing on the "operational" life span of the reactors fitted to the Astute class boats.

5:13 Following the launch of HMS Astute, sea trials were carried out and a number of defect rectifications were conducted by the contractor at the Faslane operational base. A 44,000-tonne floating jetty constructed specifically for such work on the Astute boats at Faslane was not ready when HMS Astute arrived and they were initially supported by the forward-repair ship RFA Diligence moored in Gareloch. Two phases of Contractor's Sea Trials were conducted during 2010 with over 150 engineers and 20 shipyard staff involved in putting the boat's systems through around 700 test points and rectifying the problems.

5:14 The beginning of HMS Astute's career was marred by two incidents. She ran aground off the Isle of Skye in October 2010 due to navigational errors – highly embarrassing for the RN and the CO was subsequently sacked. The starboard hydroplane was damaged by a collision with the Coastguard tug sent to assist but Astute was eventually pulled off the sandbank at high tide with minimal other damage. In April 2011, while visiting Southampton and entertaining civic dignitaries on board, a disgruntled seaman went on a rampage armed with an SA80 rifle. Tragically Lt Cdr Ian Molyneux was killed and another officer wounded before the rating was disarmed by a civilian visitor.

5:15 In January 2023 it was reported that, during the operational trials process, serious faults were discovered in HMS Astute, the prototype vessel, that further delayed Astute's entry into service. Official comment was limited but the most serious issue was the mismatch between the powerful PW2 reactor and the steam turbines and gearbox derived from the Trafalgar class boats. This issue prevented Astute from reaching the top speed laid down in the original specification (probably more than 30 knots) although this problem has subsequently been resolved.

REF: https://www.navylookout.com/the-royal-navys-astute-class-submarines-part-1-development-and-delivery/

5:16 Some construction defects emerged that included corrosion and pipework exposed to full pressure made from the wrong metal that resulted in a leak while at depth and an emergency surfacing. Instrumentation in the nuclear reactor was defective because insufficiently pure lead had been used in the system. These kinds of issues are usually to be expected in a first-of-class vessel and were rectified in time. Astute was finally handed over to the RN in April 2013 and began her first operational deployment in early 2014, almost 15 years after the first steel had been cut.

REF: https://www.navylookout.com/the-royal-navys-astute-class-submarines-part-1-development-and-delivery/

5:17 By March 2021 the Astute project had cost £9.6 billion with boats delivered between 3-5 years behind the original schedule. This necessitated the extension in service of HMS

Trenchant, Talent and Triumph with the attendant costs of keeping ageing boats running. The first three Astutes cost a total of £3.53 billion, 21% more than the original £2.8 billion contract.

5:18 There were serious delays to boat four, HMS Audacious which had significant internal changes and improvements building on lessons learned from the first three boats. Details about the upgrades are limited but some aspects had already been de-risked and back-fitted to boats 1-3. Updates included changes to the combat system, the elimination of complexity where possible, more use of commercial off-the-shelf equipment and better access to make maintenance easier. The underlying causes of the delay to Audacious have never been properly explained to the public but it had a knock-on effect for the delivery of the last 3 boats. The 4 batch II boats were supposed to cost £5.86 billion but are now expected to total £6.7 billion. The final vessel, HMS Agincourt will cost an eye-watering £1.64 billion, although this compares reasonably well with the US$2.8 billion cost of a Block IV Virginia class SSN.

REF: https://www.navylookout.com/the-royal-navys-astute-class-submarines-part-1-development-and-delivery/

5:19 A January 2025 Technical Briefing implies that much of the delay to the maintenance/refurb programme for the UK SSN fleet and its successors is due to lack of availability of docking space. In late 2023 the MoD initiated programme to acquire two floating docks and associated infrastructure at Faslane. Named 'Programme EUSTON', this is officially described as a pathway to "resilient out-of-water engineering capability". In December 2024, the UK Defence Minister confirmed the project is ongoing, although it is still in the concept phase. Euston will likely be funded from the Defence Nuclear Enterprise (DNE) budget that is now ringfenced within the MoD's wider budget. This may give it some chance of surviving the round of cuts that looks likely in the coming defence review.
Euston is separate to the wider Clyde Infrastructure Programme (CIP) which is a major portfolio of works established in 2015 comprising 14 separate projects. This is primarily to upgrade facilities at Faslane and RNAD Coulport ready to support the Dreadnought-class and SSN AUKUS submarines.
The Clyde Infrastructure Programme is supposedly on track to be completed in April 2032 but costs have risen from the initial forecast of £1.585 billion to £1.869 billion and there is a struggle to attract enough qualified people to work on the project.
REF: https://www.navylookout.com/programme-euston-floating-dry-docks-for-royal-navy-submarines/
N.B.: It is evident that the Australian Navy/Defence Ministry will need to address design, and construct required maintenance dock space, heavy shiplift and resilient out of water engineering capability, ideally prior to taking reception of their first AUKUS SSN, if not prior to taking control of their proposed ASTUTE boat. Australia needs to be aware of the ever-increasing costs of such projects and remember that delay always leads to rising costs.
5:20 **Conclusions (Section 5)**: It is evident that the Astute programme has experienced very significant delays and cost over runs. Many of these problems have arisen as a result of national defence funding issues through periods of national and international financial problems, inflationary pressures, poor planning and indecision.

It is relevant to note that only six years after Astute's achievement of operational status in 2014, the confidence in the lifetime "no-refuelling" capability of the PWR-2 reactor with H Core was shown to be already outdated in the context of concern about emerging delays in the implementation of the programme for the follow on classes of both SSBNs (Dreadnought Class) and SSNs (AUKUS Class). Referring to the Astute Class SSNs on 28 April 2020, the *Navy*

Lookout publication stated that “It is … likely the first 3 boats HMS Astute, Ambush and Artful may undergo lengthy life extension refits and possibly refuelling.”

REF: https://www.navylookout.com/upgrading-the-royal-navys-nuclear-submarine-support-facilities/

5:21 The precise nature of such possible refuelling has not been expanded on by the Navy, the Ministry of Defence or the UK Government. However, the previous history of SSN refits implies indicates that such operations may require the back-fitting of a new core, shown to be both time consuming and very costly. There are now growing indications from sources close to the UK Government and Ministry of Defence that the AUKUS successor to the Astute class may be delayed (financial and technical issues) and not available until beyond the design life of the H Core. “HMS Astute was designed to have a 25-year life and will need to undergo nuclear refuelling and life extension if she is to be run beyond 2035. It’s early days for SSN (replacement) but the first boat is unlikely to arrive before the mid-2040s.”

REF: https://www.navylookout.com/the-royal-navys-astute-class-submarines-part-1-development-and-delivery/

5:22 The implications for the Australian Navy, re the proposed Astute transfer from UK to Australia require further investigation. To date I have been unable to identify any confirmation that the current PWR-2 reactors, with Type H Core, fitted to the Astute Class SSNs have been re-designed and manufactured to avoid the problems experienced by naval reactor engineers when dealing with the sealed unit H Core reactor fitted to the SSBN Vanguard during its prolonged refit of the replacement H Core reactor through the early 2020s.

Which Astute Class boat will operate on rotation from HMAS Stirling in WA? Will it have had a reactor and core refit? If so, what guarantees will be given regarding the success and safety of the refit? If not, how much of its original reactor design life will remain? Has the reactor been re-designed to avoid this problem? Will Australian nuclear dockyard staff be trained in the refit and maintenance of Astute Class PWR-2/H Core reactors? What guarantees does Australia have that UK built AUKUS SSNs will be delivered on schedule? Will the proposed AUKUS Class PW3, slated to have a 30-year no-refuel life-span, be a sealed unit reactor? Will there be any publication of its design and operating features? Does the Australian Navy have sufficient expertise to provide an independent critical analysis of the PWR-3?

5:23 Update: The first 6 Astute class boats have been fitted with the PWR2 + H Core used in the more recent predecessor SSN classes. The recently launched but not yet Patrol-operational ACHILLES is also reported to be fitted with a PWR2. Elsewhere this report documents some serious issues with this reactor/core combination which was first picked up by the Naval Reactor Test Establishment, now closed. It is reported that the PWR2/H CORE combination flaws have been overcome and no further problems have been reported. However, it should be noted that the detailed reporting of what occurs during maintenance periods of ASTUTE Class SSNs is now much reduced. In October 2024 and in the context of discussion of maintenance activities, a Royal Navy spokesperson said: “To maintain operational security, we do not comment on the details of submarine operations.”
REF: https://ukdefencejournal.org.uk/britain-finally-has-attack-submarine-at-sea-after-100-days/
N.B.: It is advised that Australian Navy/Defence Ministry ensure that they have full details of the maintenance, refit, refurb actions that have been carried out on all ASTUTE Class reactors including that fitted to their proposed boat.

5:24 Update: The *UK Defence Journal* (January 18, 2025) under the headline "Astute submarine programme 'overcoming challenges": summarises the 2023-24 Infrastructure & Projects Authority (IPA) Annual Report reporting of the ASTUTE programme as follows: "The report confirms that Boats 1 to 5 have already been delivered to the Royal Navy, with Boats 6 and 7 at advanced stages of construction at the BAE Systems shipyard. The project continues to make steady progress, achieving most of its build and commissioning milestones for the financial year."
However, the IPA's Delivery Confidence Assessment (DCA) remains at Amber, signalling significant risks that require close management. Two primary concerns are highlighted:
a: "Potential delays due to productivity rates: Current performance levels at the shipyard may impact time-lines. In-water phase delays for Boat 6: Challenges in this critical stage could affect the broader schedule."
b: "Financial Considerations: The programme's Whole Life Cost (WLC) increased from £10.827 billion in 2022/23 to £11.256 billion in 2023/24, primarily due to revised cost estimates accounting for inflation and the delivery pace at the shipyard. Additionally, a budget variance exceeding 5% reflects increased supplier pay settlements and rates, underscoring the rising financial pressures on defence infrastructure projects."
REF: https://ukdefencejournal.org.uk/astute-submarine-programme-overcoming-challenges/
5:25 Update: *Navy Lookout* reported in August 2024: "Almost a year ago we reported that none of the RN's attack submarines (SSNs) were at sea. There has been only limited SSN activity since but here we summarise the current situation and look forward to improving future availability. Of the RN's six SSNs currently in commission, only one has been to sea in the last 3 months."
The same article noted: "By the time the last boat is delivered, the Astute class programme will have cost over £10Bn in construction costs alone. While they are fine boats, their maintenance demands appear to be high with not enough attention paid to through-life sustainment during their design. This has been compounded by a lack of foresight and investment in submarine support infrastructure."
REF: https://www.navylookout.com/end-in-sight-for-royal-navy-attack-submarine-woes
5:26 Update: *Navy Lookout* reported in Jan. 2025 on a major fire in Oct. 2024 at the BAE system's yard at Barrow in Furness where N.Subs are built. After initial claims of no damage or delay to construction of ASTUTE class SSN attack subs, damage is now confirmed. The damage is inevitably going to cause delay to the construction programme. According to *Navy Lookout,* "it is believed sections of HMS Achilles may have been damaged by the fire that broke out on 30th October 2024 in the Devonshire Dock Hall at Barrow in Furness. Neither BAE Systems or the MoD will confirm if there will be delays to the submarine construction programme. Unverified reports say the fire started in portable equipment being used in the hall but spread to adjacent stored anechoic tiles and then to the hull of boat 7. How serious the damage was, if at all, is unclear. HMS Dreadnought also currently under construction in the DDH is believed to be unaffected."
REF: https://www.navylookout.com/agincourt-becomes-achillies-royal-navy-submarine-renamed/
N.B.: The fire damage to the SSN under construction is believed to be to hull section(s). Anechoic tiles are specially engineered from expensive specialist material. They absorb the sound waves of active sonar, reducing and distorting the return signal, thereby reducing its effective range and reduce the sounds emitted from the vessel, typically its engines, to reduce the range at which it can be detected by passive sonar. More than 39,000 acoustic tiles mask

the vessel's sonar signature, giving the Astute class a better stealth quality than any other submarine previously operated by the Royal Navy.
Update: After initial claims of no damage or delay to construction of ASTUTE class attack subs, damage was later confirmed and delays in the construction program are certain. The Office of Nuclear Regulation said that BAE's safety practices were "inadequate" and that BAE needs to demonstrate that suitable emergency arrangements in the event of a fire are in place by 12 September 2025.

5:27 Update: *Navy Lookout* reported in Feb. 2025: "Royal Navy Astute-class submarine, HMS Audacious was taken into number 15 dry dock in Devonport today. She arrived in Plymouth on 1st April 2023 for a refit that necessitates work on her hull, which could not begin until facilities had been upgraded. From early 2022 to March 2023, HMS Audacious spent 403 days away from the UK on patrol in the Eastern Mediterranean. While on this deployment, she underwent maintenance periods in Souda Bay (Crete) and Limassol (Cyprus). The RN revealed that during this time divers completed a demanding repair to ballast tanks that would usually be done in a dry dock."
REF: https://www.navylookout.com/hms-audacious-finally-dry-docked-in-devonport-after-22-month-delay/

5:28 Update: A UK Parliamentary Briefing issued in January 2025 stated that:
"There are longstanding concerns over manpower and skills shortages in the submarine service. manpower and skills shortage. Questions have also been asked over the impact that extended periods of maintenance have had on the availability of the Royal Navy's attack submarines and whether the fleet will be able to sustain both its current tasks and the additional deployments to Australia that are envisaged from 2026 under the AUKUS agreement. … All nuclear programmes and expenditure across the Ministry of defence (including all of the Royal Navy's nuclear-powered submarines), including annual in-service costs, have now been brought under one heading: the Defence Nuclear Enterprise (DNE). That spending has also been ringfenced within the departmental budget, reflecting the increasing interdependence between the nuclear deterrent and the Royal Navy's other conventional nuclear-powered submarine programmes, including the new AUKUS-SSN. This is particularly relevant to costs associated with basing, infrastructure and nuclear propulsion. DNE spend now appears as a single line in the departmental estimates. … The submarines will be built in the UK and Australia and work will begin by 2030, with a view to entering service toward the end of the 2030s (UK) and the early 2040s (Australia)."
REF: https://commonslibrary.parliament.uk/research-briefings/cdp-2025-0005/
N.B.: Clearly the major concerns raised throughout this report are still in place. In the longer terms the UK's problems with delayed construction, maintenance, skill shortage and recruitment provide a clear warning of the potential difficulties that may lie ahead for the Australian sector of the AUKUS programme.

5:29 Update: In a House of Commons debate on January 21, 2025, Graeme Downie MP raised questions about the UK submarine fleet's future capabilities, and the dismantling of retired submarines. Discussing future capabilities, Downie cited evidence from the Defence Committee's 2024 report, which raised doubts about the fleet's capacity to meet its growing commitments. "Even once all seven Astutes are in service, it is questionable whether the force will be able to sustain their current tasks and the additional deployments to Australia and wider region from 2026 onwards," Downie said, quoting from the Defence Committee record. Downie also expressed concern about the financial pressures on the defence nuclear

enterprise, noting that "the National Audit Office found key risks … relating to costs, skills, commercial relationships and delivery to schedule."
REF: https://ukdefencejournal.org.uk/uk-submarine-fleet-challenges-capabilities-and-plans/
Downie's concerns are confirmed by the official record of the Defence Committee from which he quoted.
REF: https://committees.parliament.uk/publications/43178/documents/214880/default/ (p.22)

6: REACTOR AND CORE TESTING: HMS VULCAN AND THE NAVAL REACTOR TEST ESTABLISHMENT

6:1 The Naval Reactor Test Establishment (NRTE) was located at Dounreay in the Caithness peninsula, in the far north east of Scotland**.** The Dounreay site is jointly operated by the UK Atomic Energy Authority and the NRTE. The NRTE site was run by Rolls Royce reactor division which designed and constructed all the reactors and cores for the Royal Navy and operated HMS Vulcan on behalf of the Ministry of Defence, and employed around 280 staff, led by a small team of staff from the Royal Navy. The NRTE had been operating since 1957, and housed and tested the prototypes of all of UK built nuclear propulsion plants of the reactors operated by the Royal Navy SSN and SSNB boats. It was a vital sector of the Royal Navy's nuclear propulsion programme, testing and proving the operation of five generations of reactor cores.

6:2 Each reactor and core type combination was sent to the Vulcan NRTE for testing to begin prior to deployment at sea, in order to detect any problems that may have existed in any design while the reactor was accessible, rather than built into an operational submarine. The age of the reactor being tested was always at least two years in advance of the operational units at sea thus allowing data to be gathered and fed back for prediction of actual operation, and to assist the design and development of new reactors and cores.

6:3 While the primary business of the NRTE was the testing of submarine reactors, it also ensured that relevant operating procedures were current and maintained with the tight safety parameters which applied to the operation of such equipment. The facility allowed operating procedures to be trialled in the same way as the reactors aboard submarines, to ensure changes and updates had been correctly incorporated. The facility also dismantled and examined the burnt-out reactor cores, checking them against predicted operating parameters and providing feedback to the engineers and designers working on the next generation of reactors.

6:4 It has been stated that reactors were run at higher levels of intensity than those on submarines under normal operation, with the intention of discovering any system problems before they might be encountered on submarines. It is stated that the NRTE reactors have significantly led the operational submarine plants in terms of operation hours, proving systems, procedure and safety.

6:5 However, presumably as a result of official policy, I have been unable to find any reporting of the intention and reasoning behind the evolution and development of the successive cores, some of which have been referred to as new "high powered" cores. No detail has been publicised to describe the technical/structural differences between the various core types. No detail has been made public concerning investigation of the status of the various core types after they had been removed from the test reactor or from the in-boat reactors to which they had been fitted. No detail has been provided about any remedial action taken to prevent the repeated leaks/cracking of reactor coolant system pipework discovered/observed during ongoing reactor and core type design and testing process and causing “unplanned” refit/refuel events. No detail has been provided about the results of study of the microscopic cracking in the fuel canisters used in H Core reactors, despite the fact that this was later considered not problematic enough to insist on the backfit of replacement H Cores to the Vanguards’ sister ships.

6:6 Dounreay Submarine Prototype 1 (DSMP1) went critical in 1965. This was the Rolls-Royce PWR-1 reactor plant which tested reactors fitted with Cores A, B and Z before being shut down in 1984. In 1987, the plant was recommissioned as LAIRD (Loss of Coolant Accident Investigation Rig Dounreay), a non-nuclear test rig, the only one of its kind in the world. LAIRD trials simulated loss of coolant accidents to prove the effectiveness of systems designed to protect the reactor in loss-of-coolant accidents.

6:7 Also in 1987, the second generation Rolls Royce reactor, PWR-2 was commissioned, and went critical with Core G the same year. That installation was shut down in 1996, when work began to refit the test plant with the current core, Core H, in February 1997.

6:8 Type H Core-set up work was completed in 2000 and after two years of safety justification the plant went critical in 2002. Vulcan Trials Operation and Maintenance, the programme under which Core H was tested, was completed and the reactor shut down on 21 July 2015. The reactor was then to be de-fuelled and examined, and post-operational work was intended to continue to 2022; the site was then to be decommissioned along with facilities at neighbouring UKAEA Dounreay.

6:9 A 2009 Safety Review reported that the testing of the Core H reactor had identified loss of coolant issues and inability to manage depth control during emergency reactor shut down. Later in 2011/12 it was reported that cracking/cladding degradation in nuclear fuel element canisters had caused a detectable and inappropriate increase in the radioactivity concentrations in reactor coolant water.

REF: https://www.nuclearinfo.org/wp-content/uploads/2020/09/Royal-Navy-Nuclear-Reactor-Test-Facility-Review.pdf

These discoveries led to HMS Vanguard SSBN being scheduled to be refuelled and contingency measures being applied to other Vanguard and Astute Class boats, at a cost of £270 million, before similar problems might arise on the submarines. This was not revealed to the public until 2014.

6:10 Despite repeated and positive reporting by the UK Government on the work of the NRTE, and the proven usefulness of the NRTE in discovering flaws in various previous core types, in 2015 the Secretary of State for Defence confirmed the UK Government’s decision to close down the HMS Vulcan NRTE and not to prototype the next generation PWR-3 reactor, due to be fitted in the UK successor SSBNs and the proposed AUKUS SSN fleet.

Noting that an expert panel had been asked to review the decision, the Secretary of State reported that the panel had concluded that it was a valid decision not to prototype and test the proposed PWR-3 and there was no practical course of action that would have enabled a prototype facility to be built ahead of the first Successor submarine.

6:11 The Secretary of State went on to report that “The panel have advised that, with no PWR-3 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 especially those elements that are unique to the UK. As such, I have agreed to their recommendation that the Department undertake a nuclear propulsion capability review to ensure the necessary capability and capacity is in place to sustain these requirements. This review will form part of the Department’s routine work to ensure that continuous at-sea deterrence can be sustained now and in the future.”

6:12 “The expert panel’s review confirms that the Vulcan Naval Reactor Test Establishment will not be required to support reactor core prototyping activity beyond 2015, as set out to Parliament on 2 November 2011, *Official Record*, column 37WS. It is anticipated that defueling and fuel management activities will continue at the site until 2022. The Vulcan defuel and decommissioning project is assessing detailed options which range from placing the prototype facilities into care and maintenance – while retaining the site’s strategic capabilities – to decommissioning the site and returning it to Nuclear Decommissioning Authority. Initial decisions on the future of the site are expected around 2016.”

REF: https://publications.parliament.uk/pa/cm201415/cmhansrd/cm150325/wmstext/150325m0001.htm

6:13 Despite the evident benefit of the previous empirical evidence of H Core, and other Core, malfunction, and the supposed improvements provided by HMS Vulcan testing regime, the Admiralty Naval Test Reactor at Dounreay, Rolls Royce, the Admiralty and the Ministry of Defence have agreed that the proposed new PWR-3 does not require reactor core prototype tests and instead “computational modelling” will be used.

6:14 It is proposed that Computer Modelling and “high confidence” in new reactor design means that physical testing is no longer necessary. Consequently, the NRTE was closed down and decommissioned in 2015. As a result, there is no longer any empirical research study of UK N.sub propulsion systems and future attempts to ensure design and operational integrity and safety will be highly reliant on hypothetical modelling without the benefit of any actual “lead” empirical experiential observation of the operational behaviour and function of future reactors as their deployment unfolds.

6:15 It may be deduced from the 2015 ministerial statement to the House of Commons that this radical departure from the empirical scientific method has been taken on two grounds:

1: Because there was no practical course of action that would have enabled a prototype facility to be built ahead of the first Successor submarine (not enough time to build a PWR-3 test rig and then run the reactor for a sufficient “testing” period in advance of fitting reactors in boats ready for launching); and

2: Cost: as it is self-evident that, in theory at least, the use of computational/hypothetical modelling will negate the need for ongoing construction and management of successive reactor and core test beds and the management and maintenance of a test facility such as the NRTE.

6:16 Since the decision to close down the NRTE, Rolls Royce and the Navy have continued with the development of a new reactor design which will be fitted to the proposed Dreadnaught class of successor ballistic missile boats. Known as the PWR-3 reactor, it is reported to cost about £50 million more per boat to purchase and operate compared to PWR-2 designs, but this is offset by its claimed PWR-3's longer life relative to the PWR-2 design.

6:17 On the basis of proposed Computer Modelling and "high confidence" in new reactor design Rolls Royce PR has claimed that PWR-3 design is superior to the PWR-2 for a number of reasons, principally because it too would have an operating lifespan of at least 30 years and no need for refuelling during it is expected service. Additionally, it is claimed that it has significantly lower maintenance requirements and costs due to the fact that it has 30% less component parts than the PWR-2 series. These optimistic claims have been made without the benefit of significant empirical/evidential support and are therefore largely hypothetical in nature.

6:18 *Nuclearinfo.org* published an analysis of an independent review commissioned by the UK Ministry of Defence in 2014. The Ministry of Defence review, while supporting the decision to close the NRTE on the grounds summarised in 6:15 to 6:17 above, also raised a series of concerns about the decision. *Nuclearinfor.org* noted that the Ministry of Defence review described the proposed PWR-3 as an adaption of earlier "proven technologies" (presumably this referred to the PWR-1 and PWR-2, both of which are shown to be characterised by multiple problems leading to "unplanned" maintenance issues, reactor cooling water leaks and corrosion problems necessitating unplanned withdrawals from operational service and ballooning costs.).

6:19 The *Nuclearinfo.org* analysis provided the following summary of the issues of concern: "The review also identified long-term risks to the naval nuclear propulsion programme and recommended remedies. It said the programme needed to address a loss of contingency and the fact that long-term activities had been deferred, that an ongoing research programme needed to be put in place, and that engagement with and learning from the civil nuclear sector also needed to be better. In some of the most damning comments, the review criticised what it called a 'culture of optimism' in 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".

REF: https://www.nuclearinfo.org/article/dreadnought-vanguard-astute-safety/dreadnought-prototype-review-exposes-flaws-naval-reactor

6:20 *Nuclearinfo.org* further commented that:

"The verification, validation and testing programme used for the PWR-3 reactor involved breaking its functions down into 45 subsystems, analysing and testing them separately before bringing them all together in a computer model. The methods used included extrapolating from current reactor designs and testing individual components and systems using a mix of existing, modified and all-new test rigs.

"The review did not examine at all the details of verification, validation and testing programme, but the authors had confidence in the programme based on the elements that they looked at. However, the review implies that they perceived a risk that work to verify the PWR-3 reactors through their whole in-service life could have its funding cut, and they emphasised that the programme would need to be run for a very long time in order to confirm the modelling assumptions used in the PWR-3 design. The lack of funding for such a programme is described as a "worry".

"The authors criticised the Ministry of Defence's record of investing in 'world-class' facilities, such as the test rigs used in the programme, then mothballing or closing them. They contrasted the stop-start funding of the naval nuclear propulsion programme with what they called the 'holistic' funding of the nuclear weapons programme, where AWE has an annual budget which allow it to continually run research, design and manufacture programmes. Their recommendation of work to verify the PWR-3 through its in-service life was in part motivated by a desire to put these facilities on a secure financial footing."

REF: https://www.nuclearinfo.org/article/dreadnought-vanguard-astute-safety/dreadnought-prototype-review-exposes-flaws-naval-reactor

6:21 *Nuclearinfo.org* further report that:

"The 'culture of optimism' criticised by the [Ministry of Defence] review meant problems, such as the fuel element breach, come as a surprise, even though such events are common in the civil nuclear sector. The authors of the review point out that optimism is probably misplaced in the light of the nuclear civil sector's record of delivery projects on time and to budget.

"They say that confidence in PWR-3 design has resulted in a reduction of operational contingency, as has the desire to drive down costs. They also say that the drive for cost reductions has caused long-term activities to be differed or abandoned, and that this short-termism and desire for savings is likely to lead to a "fractured and unsustainable capability base". Most ominously, they say that the potential risks inherent in this approach have not been addressed.

"The research side of the naval nuclear propulsion programme depends upon Technical Working Groups, which are described as "overly orchestrated, defensive and closed" in the review. Overall introspection is still considered to be an issue in the programme, with a failure to maintain links with and learn from the civil nuclear programme, though less so than in the past.

"The budget for research and technology within the programme was reducing at the time of the review and was planned to be reduced further. This was compounded by the fact that short term investigations, presumably related to the fuel element breach, had crowded out longer term work. The review supported the decision to continue operating the STF [Shore Test Facility] to gain more understanding of PWR-2 operations with a fuel element breach. However, work required to fully understand the condition of the PWR-3 reactors throughout their working life had not been completed, and might not happen at all. Similarly, the future of research on 'husbandry' of nuclear plant and future developments in nuclear propulsion was in doubt.

"The decline of the civil nuclear sector was also highlighted as causing problems for the programme. Previous naval reactor projects could incorporate data from a number of research reactors which were operational in the UK at the time. These have all been shut down as the civil nuclear sector contracted, and one of the review's recommendations is that the programme should seek access to other test reactors such as the University of Manchester's Dalton Cumbrian Facility and the National Nuclear User Facility."

REF: https://www.nuclearinfo.org/article/dreadnought-vanguard-astute-safety/dreadnought-prototype-review-exposes-flaws-naval-reactor

6:22 It is clear from the above, that despite their stated support for the closure of the UK NRTE and the cessation of the empirical naval test/lead reactor programme, the authors of the Ministry of Defence's 2014 Review expressed a series of major concerns about proposals to abandon empirical work in favour of reliance on computer modelling. Such was their concern that they conclude that oversight of the performance of the PWR-3 and successor reactors "had not been completed, and might not happen at all" and propose, as the remedy that the PWR-3 programme "should seek access to other test reactors." Which, because of the contraction of the civil nuclear industry, now appears to be whatever is available at Manchester University.

6:23 Conclusion: A summary review of the purpose and performance of the NRTE notes that the establishment had tested and analysed the operational efficiency and safety of multiple prototype naval reactor and core type combinations for the UK SSN and SSBN programmes over 50+ years. Throughout that period, testing at the NRTE had contributed empirical data to the evolution and development of a succession of what the UK Ministry of Defence and naval sources have repeatedly claimed as more efficient and powerful reactor/core combinations, and identified faults in both reactor and fuel function. After the NRTE had identified a number of potentially serious flaws in the functioning of the PWR-2 reactor/H Core combination through the years 2009 to 2011/12, a decision was taken to close down the NRTE and abandon all forms of empirical prototype reactor/core testing in favour of hypothetical computer modelling. In order to achieve best case accuracy and precision, computer modelling requires the input of the most accurate and detailed data inputs followed by verification against real life scenarios. Whether this can be achieved in the case of the entirely novel naval PWR-3/core combination to be fitted into the proposed AUKUS SSNs remains a matter of some doubt.

To date, no detail of the proposed computer modelling of future PWR-3 reactor performance has been provided by the UK Navy, the Ministry of Defence or Government. It may be assumed that this "model" has currently not been constructed and that any necessary data inputs remain unidentified and verification methodologies have not been discussed. The concept thus remains purely hypothetical.

Does the Australian Navy have sufficient expertise to critically examine the computer modelling?

7: REFIT, MAINTENANCE AND DISMANTLING OF UK NUCLEAR SUBMARINES

7:1 Refit, maintenance and decommissioning of nuclear submarines are complex procedures requiring both high-level technical facilities and a significant body of skilled workers. Updating of both the facilities and the worker skill-set are regular necessities in order to keep abreast of the latest scientific advances and the understanding of the radiological risks of such work to workers, local communities, and the environment. The UK experience clearly shows that such updating inevitably generates incremental cost increases over time as a result of multiple factors including inflation, the increasing complexity of the technology required and also because of the difficulties attached to updating outdated infrastructure.

7:2 With the exception of the most recently launched Astute Class SSNs, all of the UK SSNs have undergone at least two periods in dock for refit and maintenance. When planned, these are usually designated as LOPs (Long Overhaul Periods). A number of boats have also been forced to undergo unplanned maintenance and refit. In the case of all the previous boats, at least one of the LOPs has involved the refurbishment of the onboard reactors including the back-fit of a new (presumed updated) Core of a different type. Some boats have entered unplanned refit due to non-reactor issues, but others have entered unplanned refit specifically due to unexpected reactor problems.

7:3 Other maintenance and refit work on SSNs includes the repair and updating of surveillance, navigation and communication equipment and the onboard conventional weapons systems. This type of work is broadly similar to that required for non-nuclear powered submarines. By contrast, reactor repair, maintenance and refit work require radiologically specific planning, including the design and construction of specialist technology for the removal, handling, onsite storage and management of N.Sub derived radioactive wastes.

7:4 The UK experience has been that the evolution of N.Sub types and classes and their reactors has driven a commensurate evolution in the necessary repair/maintenance and refit facilities. I have not found any evidence that UK SSNs of any class have undergone any form of repair/maintenance or refit at dockyards other than those in the UK which have been purpose-built specifically for UK built boats.

7:5 Details of N.Sub dockyards and the evolution of facilities in response to the evolution of the N.Sub classes are available from multiple sources e.g.:
https://www.navylookout.com/upgrading-the-royal-navys-nuclear-submarine-support-facilities/

7:6 Conclusion: The UK experience is that the decommissioning, defueling, deradiation and scrapping of time-served N.Subs is fraught with technical problems and delays arising from those problems. It is also clear that these issues give rise to ever increasing costs.

In this context it is noted that, under the AUKUS agreement, it is proposed that Australia will take delivery of US Virginia Class SSNs and, eventually, AUKUS class submarines in addition to US and UK submarines operating on rotation from HMAS Stirling. As of yet there has been no discussion of the dock-related ramifications of the proposed Australian multiple class nuclear powered submarine fleet, nor of the long-term storage of decommissioned submarines. Given that some of the first generation of Australian owned SSNs will be “second hand” (i.e. Virginia and Astute Class) boats, the likely date of decommissioning is even less secure than it would be for “new” boats. *(See earlier comments for details of the early decommissioning of UK SSNs.)*

Details of N.Sub dockyards and the evolution of facilities in response to the evolution of the N.Sub classes are available from multiple sources e.g.:
https://www.navylookout.com/upgrading-the-royal-navys-nuclear-submarine-support-facilities/

Ministry of Defence sources are not publicly transparent or open about the costs involved in this work but the UK National Audit Office (NAO) has carried out and reported a number of investigations into the financing of UK nuclear powered submarine construction and refit activities. These NAO reports are publicly available. NAO reports focus on the financial costs of a range of Ministry of Defence and Naval activities but in doing so shine additional light on the nature of the repair/maintenance and refit demands of the UK SSN fleet.

8: NATIONAL AUDIT OFFICE REPORTING OF SSN DECOMMISSIONING

8:1 In 2019 the National Audit Office (NAO) published its report of an investigation, by the Public Accounts Committee of the UK House of Commons, into submarine defueling and dismantling. The investigation took place between 2017 and 2019.

REF: https://www.nao.org.uk/wp-content/uploads/2019/04/Investigation-into-submarine-defueling-and-dismantling-Summary.pdf

8:2 The NAO report noted that since 1980, the Ministry of Defence had decommissioned 20 submarines from service and replaced them with updated boats and that the Ministry of Defence had committed to handling the arising nuclear liabilities responsibly and disposing of submarines "as soon as reasonably practicable". (Disposal includes removing the irradiated nuclear fuel (defueling), safely storing defueled submarines (afloat), taking out the radioactive parts (dismantling), and then recycling the boat.)

8:3 However, by 2019 none of the 20 decommissioned boats had been disposed of and nine of them still contained irradiated fuel. The NAO noted that it was proposed to take a further three submarines out of service over the next decade (i.e. by 2029). The Department stores out-of-service submarines at dockyards in Devonport (Devon) and Rosyth (Fife), two sites which the nuclear regulators have assessed as safe.

8:4 The NAO report noted that the Public Accounts Committee had critiqued the lack of berthing space within the Devonport dockyard and recommended that the Ministry of Defence took steps to end the delays to submarine disposals. The Ministry of Defence confirmed that although it had deferred dismantling submarines on affordability grounds in the past, this was no longer acceptable on safety and reputational grounds. The Ministry of Defence confirmed its intention to fully dismantle its first submarine, HMS SSN Swiftsure, by 2023.

8:5 However, in August 2023 it was announced that "the British Submarine Delivery Agency (SDA) has achieved a significant milestone as the retired Royal Navy submarine HMS Swiftsure has docked at Rosyth for a pioneering dismantling process. This move marks the first step in what is set to become a historic accomplishment, as HMS Swiftsure is poised to be the inaugural UK nuclear-powered submarine to undergo a complete dismantling by the end of 2026.".

REF: https://defence-industry.eu/uk-final-dismantling-of-hms-swiftsure-nuclear-powered-attack-submarine-begins/

8:6 Conclusion: The 2019 NAO report noted that the Ministry of Defence had confirmed that it would "fully dismantle" its first nuclear submarine SSN Swiftsure by 2023. However, in 2023 the British Submarine Delivery Agency announced its intention to fully dismantle the Swiftsure by 2026. These announcements have, yet again, illustrated the speed with which the Ministry of Defence ambitions and claims have fallen behind the proposed time line for full dismantling of the first N.Sub and explains why many in the UK have low confidence in Ministry of Defence pronouncements on many N.Sub related issues, particularly those related to costings and timeline delays.

9: NUCLEAR LABILITIES OF THE UK NUCLEAR SUBMARINE PROGRAMME

9:1 A May 2022 report from the Defence Nuclear Organisation summarises the N.Sub related nuclear liabilities managed by the defence sector as follows:

a: 21 submarines that have left service and are awaiting dismantling, "this process has started at Rosyth Royal Dockyard where low-level radioactive waste has been removed from Swiftsure [SSN], Resolution & Revenge [SSBNs]. At Rosyth Royal Dockyard there are seven submarines stored afloat, all of which are defueled. At Devonport, there are 14 laid up submarines; four defueled, with plans to defuel the remainder."

b: Irradiated fuel defined as "submarine reactor fuel that has fulfilled its purpose for submarine propulsion and is either in a reactor awaiting defuel or is stored underwater in a purpose-built storage facility [at Sellafield]. Irradiated fuel includes prototype [from the Naval Reactor Test Establishment] and research fuel."

c. Sites and facilities: several sites (Rosyth, Devonport, etc) across the UK to support the defence nuclear programme. Each site manages nuclear liabilities and radioactive waste, but unlike the legacy civil nuclear sites, there is an ongoing requirement to keep most of the defence sites operational.

d. Radioactive wastes: covers management of radioactive wastes that are produced from submarine operations and decommissioning. The Defence Nuclear Organisation states that radioactive waste is predominantly Very Low-Level Waste and Low-Level Waste and that "We have Intermediate Level Waste but no High-Level Waste."

REF: https://assets.publishing.service.gov.uk/media/628e3534d3bf7f1f433ae20d/Nuclear_Liabilities_Management_Strategy.pdf

9:2 The nuclear fuel held in the un-defueled boats at Devonport and Rosyth is known as Irradiated Nuclear Fuel (INF) or Spent Nuclear Fuel (SNF). INF is characterised by the presence of a high amount of radioactive fission fragments and transuranic elements that are both very hot and very radioactive**.** At the N.Sub bases the fuel is stored afloat for the long term, usually over a decade, before defueling takes place and the removed fuel is taken to Sellafield for storage in a purpose built cooling pond.

9:3 It is relevant to report that the Defence Nuclear Organisation confirms that both Rosyth and Devonport are holding/managing decommissioned submarines containing used/irradiated reactor fuel while also stating that the Defence Nuclear Organisation holds "no High-Level Waste". There is a lack of clarity on the issue of characterisation of N.Sub INF/SNF. The Defence Nuclear Organisation does not provide a definition of High Level Waste, nor has it characterised the normal aggregate radioactivity of the INF/SNF removed from decommissioned SSNs. The IAEA has made the following general remarks concerning SNF: "Spent nuclear fuel is highly radioactive" and "high-hazard radioactive material, such as spent fuel".

REF: https://www.iaea.org/newscenter/news/fostering-the-safe-and-secure-transport-of-spent-fuel-in-the-united-kingdom

9:4 An *IAEA Bulletin* reports that "High Level Waste is characterized, of course, by high radiation levels but probably its most distinctive feature is that it requires special handling and considerations, such as thick biological shielding and engineered cooling systems because of the radio-decay heat load. The term also is extended to any matrix that contains a high enough concentration of fission products to require cooling, which, unless they are separated from the waste, includes the actinides (the alpha-emitting trans-uranium elements)."

REF: https://www.iaea.org/sites/default/files/21404640216.pdf

9:5 *Nuclear-power.com* states: "High-level waste, HLW, is primarily spent fuel removed from reactors after producing electricity. HLW is also a type of nuclear waste created by reprocessing spent nuclear fuel (e.g., waste formed by vitrification of high-level liquid waste)." This website further defines Spent Nuclear Fuel as "a nuclear fuel that has been irradiated in a reactor."

REF: https://www.nuclear-power.com/nuclear-power-plant/radioactive-waste/high-level-waste-hlw/

9:6 The *Nuclear-power.com* website further states that: "Due to the presence of a high amount of radioactive fission fragments and transuranic elements, spent nuclear fuel is very hot and very radioactive. Reactor operators have to manage the heat and radioactivity that remains in the "spent fuel" after it has been taken out of the reactor. In nuclear power plants, spent nuclear fuel is stored underwater in the spent fuel pool on the plant, and plant personnel moves the spent fuel underwater from the reactor to the pool. Over time, as the spent fuel is stored in the pool, it becomes cooler as the radioactivity decays away. After several years (> 5 years), decay heat decreases under specified limits so that spent fuel may be reprocessed or put into interim storage." This is precisely the strategy adopted for the INF/SNF from the UK Naval reactors.

9:7 The International Maritime Organisation (IMO), in conjunction with the IAEA, has classified the range of maritime radioactive cargos as either low level IMDG 7, or higher level INF. INF definitions include the following: "Irradiated nuclear fuel, material containing uranium, thorium and/or plutonium which has been used to maintain a self-sustaining nuclear chain reaction" and "High-level radioactive wastes".

9:8 The IMO, in conjunction with the IAEA, has identified three categories of INF as follows: Class 1 INF = cargo with an aggregate activity less than 4,000 TBq; Class 2 INF = cargo with an aggregate radioactivity less than 2x 106 TBq; Class 3 INF = cargo with no restriction of the maximum aggregate activity.

By international agreement, transport of any Class of INF, by sea, air or land, requires a much higher standard of packaging, security and transport mode arrangement than that required for IMDG 7 cargo transport.

9:9 **Conclusion**: Both the IAEA and the IMO recognise SNF as INF, a category of radioactive material similar to HLW. Some nuclear source definitions of HLW clearly include used reactor fuel either *in situ* in reactors or awaiting storage or reprocessing. It is evident that, despite the Defence Nuclear Organisation assertion that they "have NO High Level Waste", used reactor fuel held in decommissioned N.Subs fulfils the definition of HLW. It may be useful to submit FoI/EiR requests to the Australian authorities requesting further information on this issue in order to transparently characterise the nature of any INF/SNF arisings from the Australian deployment of N.Subs.

It appears inevitable that Australia must face the fact that, if it accepts ownership of US and UK SSNs and later undertakes construction of its own AUKUS Class boats, it will have to find ways to deal with the INF/SNF, intermediate-level wastes (ILW) and low-level wastes (LLW) arisings from those boats.

The Government of Australia will have to have management plans in place for all grades of N.Sub radioactive waste including:

a: the identification, design and construction of INF/SNF/HLW treatment and management facility/facilities and a long-term repository site.

b: ILW and LLW will require the identification, design and construction of similarly appropriate facilities and long term repositories.

c: design and construction of holding, transport and storage containers.

d: design and implementation of transport modes and routes for the carriage of all grades of radioactive arisings between dockyards and interim and long-term storage/repository sites

e: nuclear emergency reaction plans re nuclear dockyards and operational bases.

f: nuclear emergency response plans re transport mode and route incidents.

g: decisions on the distribution (or non-distribution) of radio-iodine tablets as part of emergency response planning.

10: DEFUELING NUCLEAR SUBMARINES

10:1 In May 2022 the UK Defence Nuclear Organisation (DNO) published its Nuclear Liabilities Management Strategy. The DNO report claims that its submarine reactor development has steadily increased reactor core life and the reactor cores currently being manufactured are designed to power a submarine for its entire lifetime. Still to be confirmed by working experience, this claim should result in fewer irradiated fuel cores per submarine and minimises the associated nuclear liabilities.

REF: https://assets.publishing.service.gov.uk/media/628e3534d3bf7f1f433ae20d/Nuclear_Liabilities_Management_Strategy.pdf

10:2 Early submarine cores, including the fuel assemblies, were removed from submarines during Long Overhaul Periods/refit at Chatham, Rosyth and Devonport dockyards. Chatham and Rosyth no longer carry out such work which is now focussed at Devonport. Early cores were transported overland to Sellafield and placed in the First-Generation Oxide Fuel Storage Pond (FGOFSP). In 2003, the UK commissioned a dedicated naval PWR fuel storage pond called the Wet Inlet Facility (WIF), also at Sellafield, designed to support the continued safe and secure storage of irradiated cores for several decades. Most of the submarine cores and irradiated/spent nuclear fuel stored in the FGOFSP have been transferred to the WIF, and under the current plans all cores are proposed for transfer to the WIF within a few years. This will include the prototype cores and irradiated/spent nuclear fuel from the Naval Reactor Test Establishment at HMS Vulcan.

REF: https://assets.publishing.service.gov.uk/media/628e3534d3bf7f1f433ae20d/Nuclear_Liabilities_Management_Strategy.pdf

10:3 The DNO programme summarised above and at section 9 has demanded the design and construction of high-tech dockyard and land transport facilities and skilled workforces at dockyards and at Sellafield. The DNO strategy proposes to develop the arrangements for the disposal of irradiated fuel working through the concept for Geological Disposal Facility (GDF) disposal of civil spent fuel as it matures. The DNO is working with the UK Nuclear Decommissioning Authority to agree on a packaging and conditioning arrangement for irradiated fuel that will meet the acceptance criteria for a GDF.

10:4 As of yet no site for a national GDF has been identified, despite financial sweeteners being offered to several UK communities located around sites where the geology appears to be potentially suitable. After decades of attempting to gain acceptance for entirely terrestrial GDF sites, the latest approach over the last few years has focussed on attempts to gain approval for sub-seabed GDF sites located several miles offshore, but accessed from tunnels with their openings onshore. These proposals are strongly opposed by local communities who express multiple concerns.

10:5 The DNO strategy proposes to deliver best value for money for the UK taxpayer and, dependent on the outcome of its irradiated/spent nuclear fuel disposability assessment, confirms that it will collaborate with the Nuclear Decommissioning Authority, at the appropriate time in the future, to use UK civil legacy spent fuel conditioning and packaging infrastructure for its irradiated fuel.

10:6 The DNO reports that UK naval PWR irradiated fuel is "dissimilar to other UK spent fuels and may require a bespoke disposal arrangement." However, the DNO does not explain how, or why, spent naval PWR fuel is dissimilar to other UK spent fuels, nor enlarge on the possible "bespoke arrangements".

The DNO confirms that "the current civil spent fuel disposal container concepts will be considered as part of the disposability assessment, a bespoke disposal container for our irradiated fuel will only be used if there are significant benefits in doing so. We anticipate placing the irradiated fuel into international safeguards at the point of disposal." It may be hypothesised that the dis-similarity arises from the fact the UK (and presumably the AUKUS) submarine fuels are manufactured from HEU (93.5%). Clearly these issues, as yet unexplained by UK authorities, require exploration and investigation in the context of the Australian engagement with the AUKUS project.

10:7 The DNO confirms that the "dissimilar" fuels, for future SSNs and SSBNs that have not yet been commissioned, are outside the scope of the strategy reviewed above. However, UK Government are "developing options" for the management of nuclear fuel from future boats and for the infrastructure, transport and lifetime management requirements of each option. As of April 2024, no detail of the design of AUKUS reactors, cores or fuel is publicly available.

10:8 The handling and management of reactor cores and irradiated/spent nuclear fuel during defueling operations is a complex process requiring equally high-tech facilities. At the Devonport N.Sub base, between 1999 and 2002, a new Reactor Access House (RAH) was constructed to move on rails in order to be aligned over the reactor compartment. Spent fuel can be raised up into the RAH and, if necessary, new fuel rods can be lowered into place. At the head of the dock, a Primary Circuit Decontamination and Alternative Core Removal Cooling (PCD/ACRC) system building was constructed. The PCD/ACRC building contains the plant used to cool the reactor, apply chemical decontamination and inject or remove boronated water reactivity suppressant. The building's equipment and plant are connected by over 20 km of pipework and 150 km of electrical cabling.

REF: https://www.navylookout.com/upgrading-the-royal-navys-nuclear-submarine-support-facilities/

10:9 **Conclusion**: The 2022 DNO report provides information on the defueling of UK N.Subs which is briefly summarised above. It is noted that the final, long-term disposal route option for the naval INF is the proposed UK national GDF, not yet identified despite many decades of investigation and fiercely opposed by communities adjacent to any sites tentatively identified as "possibles". It is noted that the DNO asserts that N.Sub INF is dis-similar from other PWR INF and may require "bespoke disposal containers", but that no detail of the asserted dis-similarity has been offered.

11: REMOVAL OF LOW-LEVEL WASTE

11:1 The UK policy has been to adopt a three-stage approach in which, following core and fuel removal and their transport to Sellafield, the second stage is the removal of all of the low-level waste (LLW) material prior to the removal of the intermediate-level waste (ILW). This policy has been adopted during the work on the SSN HMS Swiftsure, where 52 tonnes of LLW material, including large components such as steam generators and pressurisers, has been removed. In May 2022, the UK Government has reported that "all the dismantling work was completed safely, on time, within budget and minimising any environmental impact."

REF: https://www.gov.uk/guidance/submarine-dismantling-project

A detailed description of the work to remove LLW was publicised in 2014 as part of a consultation process.

11:2 In order to reduce ambient dose rates within the reactor compartment, removal of the steam generators (SG) is prioritised. Hull cuts are made above the SGs to allow them to be extracted vertically. A crane unit, fitted with integral containment, is positioned above the submarine hull to extract the SGs through the exit cut. When SGs are inside the containment the reactor compartment is resealed. The crane transfers each SG to a waiting transport vehicle. A turning frame is used to rotate the SG from vertical to horizontal orientation for loading on the vehicle and the item is then moved to a LLW store. Prior experience has been gained at dockyards, when SGs were removed during Long Overhaul Periods and a new set of SGs were fitted into a sea-going submarine.

REF: https://www.neimagazine.com/features/featurehow-babcock-plans-to-decommission-uk-nuclear-submarines-4177541/, 14 Feb 2014.

N.B.: It is evident that, despite their characterisation as LLW, the dose potential of items like Steam Generators is considered significant.

11:3 After the removal of SGs, removal of all LLW Nuclear Steam Raising Plant (NSRP) pipe work and small items of plant is completed. All LLW items are bagged and tagged/labelled prior to leaving the reactor compartment. Subsequently, the LLW is characterised and packaged into suitable containers or directly into ISO freight containers for dispatch to an appropriate recycling / disposal facility. It is likely that these activities will be undertaken in the Active Waste Accumulation Facility, in the covered dock area. Such operations have been carried out in the past and removing and replacing LLW items within the reactor compartment is a regular part of SSN routine refit activity. However, the scale of the work in removal of all the LLW is significantly greater.

REF: https://www.neimagazine.com/features/featurehow-babcock-plans-to-decommission-uk-nuclear-submarines-4177541/, 14 Feb 2014.

11:4 In the long run, N.Sub LLW is transported to a designated long-term LLW store. In the UK this is expected to be the national LLW repository at Drigg in Cumbria, a few miles from the Sellafield site. Such a transfer process entails overland transport of multiple LLW radioactive cargos by rail or road, through or past urban and industrial site via busy transport routes, posing a risk of accidents or other incidents giving rise to exposure/doses to the public and the environment.

11:5 Removal of ILW: The third and final step of the decontamination stage of the dismantling project is the removal of the Reactor Pressure Vessel (RPV), designated as ILW and reported to be about the size, or volume, of a double-decker bus. Submarine's RPVs must be stored for an interim period until they can be processed and sent to a proposed Geological Disposal Facility sometime after 2040. In 2016, after many years of procrastination, an interim storage site was identified at Capenhurst, close to the Irish Sea coast of north west England, a pre-existing licensed nuclear site where uranium-based fuels have been managed and conditioned for several decades.

11:6 Although the RPV itself has been designated as ILW, it is UK policy to identify the RPV "closure head" as LLW, and it must therefore be segregated from the RPV which is designated as ILW and has a different "disposal route". These reactor closure heads are radioactive steel domes three feet thick with a diameter of nine feet, weighing up to 28 tonnes. In order to carry out this segregation the RPV is filled with water prior to removal of the head to reduce dose rates in the working environment to acceptable levels. The RPV closure head is then removed vertically through a hull cut as in previous N.Sub refit and refuelling campaigns. The closure head is transferred to the on-site covered Active Waste Accumulation Facility for size reduction, packaging and transport off site to an authorised LLW repository facility along with the other LLW items.

11:7 N.B.: While this strategy clearly has the benefit of reducing the volume of ILW requiring management, storage and disposal, the process does generate an additional, undisclosed quantity of radioactively contaminated water requiring treatment, storage and eventual disposal. No detail is provided regarding the volume of the water involved, the degree/concentration of radionuclide contamination and the end/disposal fate of the liquids involved. It is also relevant to note that once the pre-existing RPV closure head has been removed as described above, "A replacement head [that is required to retain the RPV core barrel in place and provide shielding and containment of the RPV internals] is imported through one of the SG hull penetrations and manoeuvred into place on the RPV using a rail / trolley arrangement. Once the replacement head is secured the shielding water is pumped out and the RPV internals dried using a dehumidifier."

REF: https://www.neimagazine.com/features/featurehow-babcock-plans-to-decommission-uk-nuclear-submarines-4177541

11:8 To date I have found no information on the radiological characterisation of such "replacement heads" (ILW or LLW?) after their deployment onto the RPV, nor on their eventual fate and disposal route during or after the subsequent removal and treatment of the Reactor Pressure Vessel, with its attached replacement head.

11:9 UK N.Sub RPVs are suspended in a primary shield tank (PST) which contains approximately 25 tonnes of carcinogenic potassium chromate 0.2% solution. The RPV must be separated from the PST before it can be removed from the submarine. Prior to removal of the RPV more of the hull must be removed in order to allow access to the top of the RPV and provide a removal route. Following demonstration that the RPV is disconnected from the PST the crane is connected to an RPV lifting frame and the RPV is transferred to a transport container within the dock bottom. Once loaded and secured in the transport container the complete package is rotated to a horizontal orientation using a turning frame provided with the container. The horizontal package is then lifted to a waiting transporter on the dockside and transferred to the Active Waste Accumulation Facility building for temporary storage on the transport trailer.

11:10 The PST is an integral part of the submarine structure and is separated by cutting the lower hull and Reactor Compartment forward bulkhead which make up the front and bottom of the PST. The PST is then removed via the same access point as the RPV itself, but is lifted, by the crane, directly onto a transporter on the dockside. From the dockside the PST is transferred to a size reduction facility within the Active Waste Accumulation Facility where it will be cut up, characterised, packaged and consigned for disposal / recycling as appropriate. The RPV will be stored in its transport container on the road trailer / Self Propelled Modular Transport (SPMT) in the Active Waste Accumulation Facility. If necessary, temporary shielding will be erected around the RPV to reduce dose uptake by workers in the area.

11:11 After arrival of the PST in the Active Waste Accumulation Facility, samples will be taken from the complex structure of the PST for analysis to further inform its radionuclide inventory. Expected yields of radioactivity in the PST are unknown. "Any residual potassium chromate solution will be removed. The PST will then be reduced to suitable sized pieces to allow disposal via approved recycling / disposal routes. Precautions will be implemented to minimise the risks associated with residual chemicals, including working within a fully bunded area. Radiation protection measures will be implemented as necessary. During PST size reduction operations, the feasibility of size reducing the PST within the empty reactor compartment will be investigated and assessed."

REF: https://www.neimagazine.com/features/featurehow-babcock-plans-to-decommission-uk-nuclear-submarines-4177541/

11:12 "Consistent with the UK national waste hierarchy, the DNO [Defence Nuclear Organisation] report explains that the submarine disposal programme has successfully diverted radioactive waste from near surface disposal by using specialist metal melting treatment for recycling. The characterisation and targeted size-reduction of submarine ILW components in future will minimise the volumes for storage and eventual disposal to the UK's Geological Disposal Facility."

REF: https://assets.publishing.service.gov.uk/media/628e3534d3bf7f1f433ae20d/Nuclear_Liabilities_Management_Strategy.pdf, page 8.

11:13 The specifics of such "specialist metal melting treatment" has not been discussed in any of the documents referenced above but other sources, in the radiological context, refer to the recycling of radiologically contaminated material by the Studsvik Co of Sweden.

REF: https://www.studsvik.com/key-offerings/waste-management-technology

Issues of concern around the transport of such material have been discussed in the following document: *https://www.nuclearpolicy.info/docs/news/NFLA_PR_Berkeley_transport.pdf* and re lessons learned from package breach radiation leak:
https://resources.inmm.org/system/files/patram_proceedings/2004/1-7_210.pdf

11:14 **Conclusion**: A summary review of Defence Nuclear Organisation description of proposals for the removal of N.Sub LLW notes various stages of LLW removal and disposal, including the technically complex strategy for removing the steam generator, and notes that the removal of around 52 tonnes of LLW had been successfully removed from the SSN Swiftsure by 2022. Such waste is/will be characterised and sorted, packaged and dispatched to the UK's national LLW depository near Sellafield. Similarly, the Defence Nuclear Organisation report describes proposals for the removal of Intermediate Level Waste (ILW) including the bulky and heavy submarine Reactor Pressure Vessels (RPVs).

The long term intended disposal destination for the submarine RPVs is the proposed national Geological Disposal Facility (site not yet identified). In 2019, after decades of procrastination, an interim storage site was identified at an existing licensed nuclear facility. However, as of April 2024 no RPVs have been removed from any decommissioned N.Sub and, in order to confirm access/use of the identified interim storage site the Ministry of Defence is paying an estimated £1.5 million a year to reserve storage at the site which it currently expects to use from the mid-2020s.

12: THE UK NATIONAL AUDIT OFFICE REPORTING OF COST ISSUES ARISING FROM DECOMMISSIONING, DEFUELING AND DECONTAMINATION OF UK NUCLEAR SUBMARINES

12:1 In 2019 the UK National Audit Office (NAO) published its report "Investigation into submarine defueling and dismantling", based largely on the outcomes of the examination of UK Ministry of Defence officials by sessions of the House of Commons' Committee of Public Accounts through the years 2017-2019. This report provided a highly critical analysis of the failings of the Ministry of Defence submarine dismantling progress supported by considerable detail of its financial failings

REF: https://www.nao.org.uk/wp-content/uploads/2019/04/Investigation-into-submarine-defueling-and-dismantling.pdf

12:2 Retired submarines generate three levels of radioactive material, which influences how parts can be handled, transported and stored. The types of radioactive materials to be removed include:

a: irradiated/spent nuclear fuel from within the submarine's reactor core. As it continues to generate heat, fuel will be stored under water at the Nuclear Decommissioning Authority's (NDA's) Sellafield site, after which it will be sent to a disposal facility;

b: intermediate-level waste, primarily the Reactor Pressure Vessel (RPV) and other parts from within the reactor compartment, which had been close to the nuclear fuel. This waste comprises about 1% (50 tonnes) of the boat and is stored and then disposed of in designated facilities; and

c: low-level waste that needs to be handled and disposed of within the regulatory framework but does not meet the criteria for intermediate-level waste. This covers the remainder of a submarine's reactor compartment such as pipework and comprises around 4% (176 tonnes) of the boat, which will be disposed of in a low-level waste repository.

12:3 At 2019, the NAO report estimated that it would cost an estimated £96 million to fully dispose of a single submarine. However, there is considerable uncertainty about these costs given the high rate of inflation and overall rising costs since 2019 and the fact that, as of 2019, the Ministry of Defence still needed to confirm and approve how it will remove and transport intermediate-level waste. N.B.: The figure reported by the NAO did not include the costs associated with the Ministry of Defence establishing the required facilities and infrastructure, and disposing of nuclear waste at the end of its storage period.

12:4 Regulatory responsibilities are principally divided between two organisations. The Office for Nuclear Regulation (ONR) regulates the contractor-owned and operated sites. It aims to ensure that the nuclear industry controls its hazards effectively, continually improves its practices and maintains high standards. It oversees the transportation of certain nuclear materials and the design, build, operation and decommissioning of nuclear facilities. The Defence Nuclear Safety Regulator (DNSR) regulates nuclear activities and facilities at Ministry of Defence owned and operated sites. It reports independently to the Defence Secretary and regulates the transport of defence nuclear materials. N.B.: There may be some conflict of interest between these two organisations. DNSR is focussed entirely on Defence work and interests and reports to the Secretary of State for Defence. ONR is focussed on the civil nuclear industry and now reports solely to the Secretary of State for Department for Work and Pensions, though recently also worked closely with the now defunct Department of Energy & Climate Change.

12:5 The NAO noted that the proposed costs should be regarded as "estimates" because they are based on multiple uncertain assumptions including that the Ministry of Defence will maintain existing practices for long-term berthing and the number of maintenance periods for operating submarines, the varying rates of inflation, ever-increasing costs (wages and materials), the necessity to upgrade facilities and respond to "unplanned" submarine refits/repair, etc.

12:6 The NAO report noted that despite the 20-year-old Ministry of Defence commitment to dispose of the 20 submarines it had decommissioned since 1980, none had been completely dismantled by 2019 and that, as a result the Ministry of Defence now stored twice as many nuclear submarines as it operated, with seven of them having been in storage for longer than they had been in service.

12:7 The NAO noted that, in 1995, the Ministry of Defence had committed to dismantle all of its decommissioned submarines "as soon as reasonably practicable", that it did not start serious consideration of disposal until 2000, first aimed to have an operational process agreed by 2011 but did not actually begin dismantling its first submarine until 2016. Having commenced dismantling its first submarine in 2016 the Ministry of Defence proposed to roll out its approach across other submarines by 2026. During that time span the Ministry of

Defence had spent an estimated £0.5 billion on maintaining and storing its retired submarines since 1980.

12:8 As of 2019, the NAO report noted that the Ministry of Defence had set aside a £7.5 billion liability in its 2017-18 accounts for maintaining and disposing of its out-of-service submarines. Of this figure, £2.2 billion was intended for the maintenance of the 20 submarines currently out-of-service and the costs of using the Devonport site. The Ministry of Defence also provided £1.5 billion to dispose of these boats and the remaining three Trafalgar-class SSNs and four Vanguard-class SSBNs currently in service. The Ministry of Defence did not need to provide for the liabilities associated with storing and disposing of submarines not yet in operation. In the case of its newly launched Astute Class SSNs, the Ministry of Defence increased its liability by an average £100 million for each of the Astute-class boats brought into service. Potential changes to HM Treasury's discount rates, which contributed significantly to the 50% (£2.5 billion) increase in the provision from 2016-17 to 2017-18, had a significant effect on the size of the Department's liability, as did inflationary pressures.

12:9 The NAO reported that the Ministry of Defence's ability to dispose of its submarines depended largely on one private contractor and also on the UK government more widely. It noted that Babcock International Group plc (Babcock) was the Ministry of Defence's sole supplier capable of undertaking most of the defueling and dismantling requirements, that Babcock owned the nuclear-licensed dockyards and facilities in both Devonport and Rosyth and also provided aspects of the related projects. This policy limited the Ministry of Defence's ability to obtain the most favourable contracts. The Ministry of Defence was also reliant on (RWM) Radioactive Waste Management, a wholly owned subsidiary of the Nuclear Decommissioning Authority, to provide the Geological Disposal Facility. This is expected to be available to receive submarine-related intermediate-level waste from the 2050s. The Ministry of Defence currently contributes 6% of the total annual cost of Geological Disposal Facility development, equivalent to £2 million in 2017-18.

12:10 The defueling facility project: The NAO report also noted that, as of 2019, the Ministry of Defence had not defueled any submarines since 2004 and did not have a fully funded plan to restart defueling. Nine of the 20 out-of-service submarines contained irradiated fuel requiring the use of dock facilities approved by the UK nuclear regulator. This was because, in 2004, the Office for Nuclear Regulation (had reported that those facilities did not meet the latest required standards and the Ministry of Defence had to postpone all defueling activity until the facilities had been uprated. The Ministry of Defence estimated that defueling might take two years per boat. It had not yet allocated a defueling budget as part of its long-term financial planning and would have to consider this alongside other priorities.

12:11 The NAO reported that, as a result of the Office for Nuclear Regulation report, the Ministry of Defence defueling facility project was delayed by 11 years, with a £100 million (57%) increase in costs. In 2007, the Ministry of Defence approved the intention to restart defueling in 2012. Then, in 2013, it delayed the start date to 2017 as, although this project remained the best option, it did not represent value for money given commercial and technical issues. This represented the latest departmental approved start date. The NAO reported that there had been further delays meaning that the Ministry of Defence's latest planning estimate, subject to ongoing scrutiny and departmental approval, was to start defueling in 2023.

12:12 Further delays arose from the Ministry of Defence's decision in 2014 to undertake the unplanned refuel of HMS Vanguard SSBN (with Type H Core), and then in 2016 deciding to pause its Devonport infrastructure upgrades for two years, apparently to avoid overspend of the annual budgets. As a result of that decision defueling could not restart, and the facilities project, which was an estimated 90% complete, was suspended. To control further costs and delays, in 2018 the Ministry of Defence contracted with Babcock to maintain necessary skills during the suspension. The NAO 2019 report noted that, as result of these decisions, the Ministry of Defence now expected to pay more to complete this project than in 2016 and that, as a result of problematical commercial negotiations (arising from the policy of retaining a single contractor), regulatory permissions and financial approvals, uncertainties remained over the project timeframes.

12:13 Delays to the defueling facility project had wider cost, risk and dock space implications. As of 2019 the Ministry of Defence paid an estimated £12 million a year to maintain and store the nine fuelled submarines then stored in Devonport. The NAO noted that maintaining floating fueled, rather than unfueled, submarines generated a number of additional technical uncertainties and affected dock availability. It contributed to space pressures in Devonport and put the Ministry of Defence at risk of not meeting its commitment to inspect, clean and repaint stored submarines at least every 15 years, and not having space to prepare the SSN Torbay, which left service in 2017, for long-term storage. Until submarines are defueled and dry docked the Ministry of Defence must keep them partially crewed, which potentially affects its ability to redeploy its personnel. In 2017, the Department initiated a £1.5 million project to design a storage preparation process that could be conducted in the water, rather than a dock.

12:14 The NAO report noted that, as of 2019, the Ministry of Defence had begun to dismantle two submarines and was developing its designs into approved processes to complete the work. In December 2016, the Ministry of Defence started dismantling Swiftsure (SSN) (which left service and was defueled in 1992) by removing its low-level waste. It completed this in August 2018, on time and within the £13 million budget. In December 2018 the Ministry of Defence began a similar process for Resolution (SSBN). Following its 2011 and 2014 public consultations on the dismantling approach, the Ministry of Defence committed to removing the intermediate-level waste, such as the Reactor Pressure Vessel, from the submarine intact and then transporting it to the interim store in Capenhurst in Cheshire. However, as of 2019 the Ministry of Defence had not yet approved the technical processes for removing and transporting this waste and was therefore paying an estimated £1.5 million a year to reserve storage at the Capenhurst site which it currently expects to use from the mid-2020s. N.B.: Removal of intermediate-level waste from SSN Swiftsure has (as of March 2024,) not taken place or begun, and is currently proposed to commence in 2025 and be completed in 2026/27.

REF: https://www.navylookout.com/project-to-dismantle-ex-royal-navy-nuclear-submarines-inches-forward/

12:15 The 2019 NAO report noted that the dismantling project had been delayed by 15 years, with the whole-life cost increasing by £0.8 billion (50%). The delay follows changes to the requirements and temporary suspension of the project. In May 2000, the Ministry of Defence began to consider a submarine dismantling process intended to be operational by 2011. Given the lack of progress, which included a four-year deferral to make savings and the need to consider evolving government nuclear waste policy, it rescoped the project in 2009 and then again in 2013, resulting in an aim to have a tried and tested approach by 2024. The Ministry of Defence had to restart its waste transportation procurement after it did not receive any viable bids, which caused a further two-year delay. The Ministry of Defence later re-estimated that it would roll out its approach by 2026.

12:16 The 2019 NAO report observed that the delays had created cost, capacity and reputational risks beyond the project, but had given the Ministry of Defence an opportunity to re-assess its submarine dismantling approach. Given developments in the civil nuclear sector and, having gained a better understanding of how to remove and transport waste, the Ministry of Defence had reconsidered its approach to intermediate-level waste. Concurrent with the annual maintenance, the Department had committed to removing one or more submarines from the water at least every 15 years for more detailed maintenance in dock. It recognised a £2.2 billion liability for this within the overall £7.5 billion liability included in its 2017-18 accounts. If this work took 24 months, rather than the assumed 18 months, and there was a two-year delay in dismantling the submarines, this could increase liabilities by an estimated £0.9 billion. Delays also put pressure on dock space, with Devonport expected to run out of space for retired submarines in the mid-2020s.

12:17 In the two years prior to the compiling of the NAO report, the Ministry of Defence had revised its governance arrangements which it was continuing to develop. In 2018, the Defence Nuclear Organisation established a dedicated nuclear liabilities project board and set project-wide objectives. It also developed its first strategic overview of projects and their inter-dependencies, alongside encouraging more routine senior-level engagement. From April 2019, the Defence Nuclear Organisation became responsible for all disposal-related projects, including those previously within the Royal Navy's remit. It accepted that there was a high risk due to the failure to manage its nuclear liabilities coherently and had assessed itself as not yet having fully developed plans in place to meet 67% of its submarine defueling and dismantling objectives.

12:18 The NAO noted that, in order to meet its commitments to Parliament, the Ministry of Defence had set itself a series of milestones. In particular, in order to dismantle its first submarine by 2023, the Ministry of Defence assessed that by December 2019 it needed to have decided its approach to removing and transporting intermediate-level waste. It would then design the process, and demonstrate that it can do this work, alongside contracting for the transport and ensuring it has the budget in place. Beyond this, the Ministry of Defence current estimates included:

a: Completing the defueling-related projects in 2023 in order to start defueling submarines at that date, although there remain uncertainties around this time frame;

b: Removing the intermediate-level waste from Swiftsure between 2023 and 2024 to test its chosen approach to dismantling (*This uncertainty has been confirmed by more recent announcements (see section 12:14)*; and

c: Rolling out a dismantling approach in 2026, after having tested it on one submarine. *N.B.: This remains an aspiration only. On 12th of June 2023 the Secretary of State for the Ministry of Defence stated that the first stage of dismantling, which includes the removal of all low-level radioactive waste, had been completed for four submarines: 1 SSN (Swiftsure) and 3 SSBNs (see section 12:14).*

REF: https://ukdefencejournal.org.uk/progress-steady-in-decommissioning-old-uk-nuclear-subs/

12:19 **Conclusion**: The 2019 NAO Report offers the following "Key Facts" regarding the 20 out-of-service submarines stored by the Ministry of Defence:

- 19: average number of years submarines out-of-service, against 26 years in-service
- £0.5 billion: estimated total cost to the Ministry of Defence of maintaining retired submarines since 1980 to 2017
- £96 million: estimated cost to the Ministry of Defence of fully disposing of one submarine
- £7.5 billion: Ministry of Defence's future liability for maintaining and disposing of its 20 stored and 10 in-service submarines, as of March 2018
- 11: number of years' delay in re-establishing an ability to defuel submarines, moving from 2012 to a current planning estimate of 2023 *(decommissioned submarines still NOT defueled March 2024)*
- 57% (£100 million): budget increase for re-establishing a defueling capability from £175 million (2007) to £275 million (2018)
- 9: average number of years fuelled submarines have been stored as at 2019
- 15: number of years delay rolling out a tested submarine dismantling approach, moving from 2011 to a current planning estimate of 2026
- 50% (£0.8 billion): increase in the cost of the project from £1.6 billion (2002) to £2.4 billion (2016)
- £0.9 billion: estimated increase in the Ministry of Defence's longer-term financial liabilities related to submarine dismantling should it take six months longer to remove intermediate-level waste from boats dismantled in two stages than the expected 18 months; and a similar delay dismantling the remaining submarines.

REF: https://www.nao.org.uk/wp-content/uploads/2019/04/Investigation-into-submarine-defueling-and-dismantling.pdf

Looking to the future, the NAO Report concluded that the Ministry of Defence had not fully considered its approach to disposing of all its operational and future submarines. As of 2019, the Ministry of Defence did not have a fully developed plan to dispose of the later SSN and SSBN (Vanguard, Astute and Dreadnought) class submarines, which have different types of nuclear reactors, but it had identified suitable dock space which, if used, would need to be maintained. The NAO noted that within the civil nuclear sector, organisations are under an obligation to consider nuclear waste disposal during the design stage of power stations and nuclear infrastructure. The Ministry of Defence does not have a similar obligation.

13: NUCLEAR SUBMARINES AND ROYAL NAVY CANNIBALISATION OF SPARE PARTS

13:1 A National Audit Office report by the Comptroller and Auditor General Ministry of Defence, "Investigation into equipment cannibalisation in the Royal Navy", published in 2017

(HC 525 SESSION 2017–2019, 1 November 2017), reported that Royal Navy cannibalisation of spare parts from other boats had become increasingly frequent over recent years and that House of Commons committee inquiries had uncovered the followings “key facts”:

- 3,230 instances of ship and submarine cannibalisation had occurred between April 2012 to March 2017.
- A 49% increase in cannibalisation had occurred between April 2012 to March 2017.
- 0.3%–1.4% of all parts provided by Defence Equipment & Support (DE&S) were cannibalised across the main ship and submarine types, April 2012 to March 2017.
- 26% instances where the same part was cannibalised three or more times.
- 71% of cannibalised parts were valued at less than £5,000 between April 2012 to March 2017.
- The average number of cannibalisations per each Astute-class submarine in 2016-17 was 59.
- £92 million estimated maritime support funding was removed in-year from 2015-16 and 2016-17 budgets that could increase the need to cannibalise parts.
- 34% of part demands were unsatisfied past their required delivery date with no forecast due date for their receipt.
- A 21% shortfall in trained and qualified staff within the DE&S navy supply teams.
- 5% of part demands where parts identified as obsolete.

13:2 Some 40% of ships and submarines receiving cannibalised parts needed them so they could be ready for operations or training. In these cases, cannibalisation rectified issues that would have reduced the operational capability of ships and submarines. The remaining 60% of ships and submarines did not need the parts for operations or training. Instead, in some cases the parts were required to complete planned maintenance work to a specified schedule so as to avoid potential delays and additional costs.

13:3 New Astute-class submarines experienced the highest average number of cannibalisations across ships and submarines, with 59 instances per submarine. They also experienced more defects than older equipment, with a third of these defects resolved through cannibalised parts.

13:4 The need for cannibalisation is exacerbated by both a lack of information about when parts will be delivered, and delays in receiving parts on time. In March 2017, the DE&S Ships Operating Centre met 55% of part demands from ship and submarine crews by the required date (target 75%). The Submarine Operating Centre met 63% of demands (target 80%). At the same point, of 17,038 ship part demands already past their required delivery date, 34% had no recorded forecast delivery date. Identifying a forecast delivery date can be more difficult where the Ministry of Defence has contracted-out support arrangements. The Ministry of Defence has undertaken a number of initiatives to improve ship and submarine supply chain management.

13:5 Each instance of cannibalisation can delay programmes, create additional engineering risks and add to the work of staff, affecting morale. Cannibalisation has a number of impacts the Ministry of Defence needs to manage including: programme delays: In the past five years, the number of cannibalisations from the Astute-class submarine production line increased 43%, from 77 instances in 2012-13 to 110 in 2016-17. Cannibalisation caused a 42-day delay and led to the Department having to pay an additional £4.9 million in relation to HMS Artful (Boat 3), and has also affected other boats.

13:6 Other impacts requiring management by the Ministry of Defence included Engineering risk: Cannibalised parts, along with additional parts that must be removed to gain access to them, may be damaged while being removed, transported or reinstalled. An estimated 11% of the parts recorded by ships as having shortcomings in their material, design or documentation were cannibalised. Testing: As well as additional work to remove cannibalised parts, engineers need to test systems on both the donor and recipient equipment, reducing the time available for routine maintenance. In addition, the 2017 Navy risk register identified a lack of spare parts as a risk to operational capability given its demoralising effect on personnel.

13:7 **Conclusion**: A 2017 National Audit Office (NAO) investigation has reported that cannibalisation (re-use of used parts scavenged from other boats) is endemic throughout the UK Navy and that the N.Sub force is not exempt from this issue. The NAO investigation confirms that the most recent SSN (Astute) Class boats are heavily impacted by this practice, with a 43% increase in cannibalisation incidents between 2012/2013 and 2016/2017. The NAO confirmed that cannibalisation caused a 42-day delay and led to the Ministry of Defence having to pay an additional £4.9 million in relation to HMS Artful (Boat 3), and has also affected other boats. The NAO noted that cannibalisation generated engineering risks, the need for extra testing of used parts and demoralising effects on personnel. The revelation that such cannibalisation occurs is a clear indication of the problems that can impact the safe and effective management of an SSN fleet.

Can Australia implement an SSN "spare parts" industry in sufficient time to be able to support its proposed "home built" fleet of AUKUS SSNs and, before that, second-hand US Virginia SSNs? Will Australia, at any stage, be reliant on others for spare parts for its AUKUS fleet?

14: "INTERACTIONS": UK SSNS AND SSBNS: SINKING OF CIVILIAN VESSELS, COLLISIONS, NEAR MISSES, GROUNDINGS

14:1 Various campaign and citizens groups have attempted to catalogue and report the interactions between N.Subs and civilian vessels since the establishment of the Clydeside/Faslane base HQ of the N.Sub force. These efforts have usually been relatively localised and not widespread. In the UK the most comprehensive records were compiled by the Celtic League, an Isle of Man based organisation benefitting from a central position between the two most active N.Sub bases Faslane and Devonport. Between 1982 and 2015 the Celtic League collated a dossier of information on 170 such "interactions" including net "snaggings", collisions, near misses and at least 30 suspicious unexplained sinkings.

REF: https://www.celticleague.net/submarine-narrowly-misses-fishing-boat-off-coast-of-ireland/

14:2 Relevant Areas of submarine activity, UK and Irish waters: the greatest intensity of incidents is found relatively close to submarine bases where regular patrols from

a: Faslane Clydeside/Glasgow are moving to and from north and Central Atlantic via Clyde approaches, using deep water areas, close to the coasts of Northern Ireland and the west coast of Scotland in order to avoid detection ASAP.

b: Devonport (south west England): patrols moving to and from central Atlantic via western approaches and accessing deep water ASAP in order to avoid detection.

14:3 N.Subs from both bases also use the Irish Sea regularly to access both North and Central Atlantic, because despite limited areas of deep waters: there is a deep water trench running the entire length of the Irish Sea. Nuclear submarines from the French base at Ile Longue, Finisterre use similar routing strategies (deep water channels and trenches) to access the deep open ocean.

14:4 Submarine and surface fleet naval war gaming exercises also generate greater concentrations of both sub-surface and surface activity at the approaches to submarine ports, deep water "hideouts" (e.g. Beaufort Trench in the Irish Sea: 200 to 300 metres deep and lying across the Cairn Ryan/Belfast ferry route), mid-ocean hideouts and other areas selected for such exercises. Examples of the latter include the northern polar oceans, Iceland/Greenland Gap: once a cold war strategy: now revised to fit contemporary scenarios and involving new vessel and threat types. Recent exercises (Western Scotland and SW Coast) April/May 2019 involving UK and NATO submarines almost certainly drew in Russian nuclear submarines as "observers" and "trackers".

14:5 Other areas likely to increase the risk of negative interactions with N.Subs include submarine training areas, or those characterized as "straits" or "choke points", the concentration of shipping in maritime traffic lanes approaching ports and harbours, busy "fishing grounds", areas of offshore installation (wind farms, oil fields, aggregate/deep sea mining), areas designated for current of historical chemical or explosive weapons and radioactive waste dumping.

14:6 **Major parameters likely to lead to incidents/interactions.** Due to security considerations, there is never any pre-voyage publication of voyage details and therefore civilian vessels remain completely unaware of N.Sub activity. The deployment of the N.Sub force is based around the maximum possible degree of concealment. To that end both SSNs and SSBNs will submerge to periscope depth as soon as practical in order to become less visible to surface, aircraft and satellite sensing. Civilian surface vessels are at a further disadvantage as soon as this occurs, due to the vastly reduced surface visibility of the submarines. On very rare occasions periscopes or surface waves may be visible.

14:7 The intensity and concentration of submarine activity in UK waters increases during national and international/NATO military naval war gaming exercises. Thus, during the anti-submarine exercise "Exercise Joint Warrior", through April and May of 2019, there were 35 surface warships and 5 NATO submarines (undisclosed number of which were N.Subs) operating off the western coast of Scotland and Irish Sea coasts of south west Wales. Ministry of Defence and naval sources concur that such exercises tend to "draw in" non-allied/hostile submarines to observe and record the capability of allied boats and the identifying acoustic pattern of their engines. Reported "enemy incursions" and intensifications of the international political/military situation also give rise to increased N.Sub activity.

14:8 Submarine training exercises, readying for patrol exercises and post refit/maintenance sea trials generally take place in pre-defined, but still extensive areas, marine "training" areas which are marked on mariners' charts. Notices to shipping and mariners are broadcast and published, usually at fairly short notice to warn that a training exercise is under way. However, in accord with security considerations, the location and routes of boats undergoing such training or trials within the training area are not provided and it is the sole responsibility of the submarine commander to avoid contact/interaction with civilian vessels.

14:9 Compared to Motor Fishing Vessels (MFVs), nuclear powered submarines are much larger, faster and more powerful. Net drag: full astern: must be classed as very dangerous to the MFV and crew: deployed nets become snagged by an N.Sub which, proceeding "full ahead", tows the MFV stern first resulting in very rapid swamping and total loss sinking (from the stern) of the MFV. A number of such incidents have led to the death by drowning of crew members. Such incidents lead to total loss of boat and gear with considerable financial implications to the affected fishing community.

1982: **MFV Sheralga**: Fishing 30 miles off Dublin coast with nets deployed: Nets snagged and boat dragged backwards at high speed (10+ knots) despite engines powering forwards. Took water over stern and sank quickly. All crew escaped. Eyewitnesses and survivors claimed "only a submarine could have been responsible …" Initial official denial from Ministry of Defence (no admission of liability/responsibility = no legal claim possible). Several weeks later an official admission of responsibility. The Irish government refused to act as a "party" in support of fishermens' claim. Irish government pushed for "submarine free" Irish fishing grounds (not gained). Survivors did eventually win compensation through a Belfast court

14:10 **Net drag: from the beam**: must also be classed as very dangerous to the MFV and crew: deployed nets have become snagged by N.Subs which, proceeding full ahead while crossing the track of the MFV, generates a very rapid (sideways) capsize and rapid sinking with attendant loss of vessel, gear and, in a number of recorded cases, loss of life.

MFV Antares trawler: (15 metres: 34 tons) Carradale. Nov 1990. Fishing in Arran Trench: sudden disappearance. Wreck eventually identified: crew (4) all drowned. Inquiry found that HMS Trenchant SSN (85 metres: 5,300 tons) on exercise in the area with other NATO vessels. Initial denial of involvement from Ministry of Defence, but later official inquiries demonstrated that: SSN Trenchant was in the area and submerged at the time of the incident, Trenchant had snagged nets set at 60 metres depth while Antares turning. Antares pulled sidewise as Trenchant continued on course. Antares capsized: turned upside down and sank rapidly. Trenchant's officers reprimanded.

14:11 **Surface wave capsize**: because of their relatively large size and the power of their nuclear propulsion systems, compared to most MFVs working inshore and coastal waters, N.Subs travelling at periscope depth or less can create very large bow waves and "wakes".

1988: MFV Inspire (Fishguard: Pembs) working in calm weather/low winds. Capsized and swamped by large freak wave off Pembrokeshire coast. 3 crew dead, 1 survivor rescued after 11 hours in water. Rapid official (Ministry of Defence) denials of presence of UK or NATO subs in the area. Ministry of Defence refusal to confirm/deny presence of non-NATO subs. Local witnesses reported surface presence of submarines in the area at the time (this area close to deep water southern Irish Sea trench). Inquiry/inquest: Expert witness proposed no "natural" cause of wave: Expert witness proposed most likely cause was bow wave of semi-submerged submarine travelling at speed. No alternative explanation offered by any other source. Ministry of Defence, Navy critiqued due lack of transparency, refusal to provide details of submarine movements in the sea area. 1991 inquest conclusion blamed "unknown submarine" and recorded a verdict of "unlawful killing": No other verdict or legal conclusion. Because "guilty party" not identified, no compensation was offered to survivor or relatives.

14:12: **Collision incidents** reported have usually involved collision of a surface vessel with submerged or partially-submerged submarine. **MFV Pescado**: Feb 1991. Scallop Dredger: sudden disappearance while fishing 15 miles off Cornish coast during a NATO maritime exercise. 6 crew dead/drowned. Wreck identified by camera inspection: vessel upright (but tilted) on sea bed, dredges NOT deployed (i.e. boat NOT fishing), large “six ft dent punched” into underside of the Pescado’s painted hull, 2 long “smears” of black paint running away from the dent. Samples of black paint analysed: demonstrated similarities to paint taken from UK submarine: no link to Pescado’s paintwork.

Ministry of Defence consistently denied presence of subs in the area at the time. Local witnesses consistently reported the presence of submarines in the area at the time. Ministry of Defence eventually forced to admit that subs were in the area at the time, but continued to deny liability or involvement. Unofficial position is that Pescado was either struck from underneath by submerged and speeding sub, or was struck during emergency surfacing procedure: vessel turned turtle and sank very quickly. Ministry of Defence, Navy critiqued due lack of transparency, refusal to provide details of submarine movements in the sea area. No ID established of culpable party. No verdict, no compensation awarded.

14:13 **Non-MFV interaction incidents:** Emergency surfacing manoeuvre: sub sinks vessel (multiple civilian mortalities). In 2001: Hawaii: Japanese Fishery High School Training Ship “Ehime Maru”(ex-trawler: 58 metres: 741 tonnes) was sunk by USS Greenville nuclear powered SSN (110 metres: 6,000 tons) on a training and demonstration mission when the USS Greenville performed an Emergency Ballast Blow Surfacing manoeuvre. The manoeuvre propelled the submarine from 120 metres to surface in less than 10 seconds. At the culmination of the manoeuvre the SSN struck the underside of Ehime Maru, the SSN Greenville’s rudder ripped a massive gash in Ehime Maru’s hull. The submarine surfaced a few seconds later, right next to the Ehime Maru which sank within five minutes of the impact, with the loss by drowning of nine of the crew and students aboard. There were many witnesses from other vessels in the area and the US Navy admitted full responsibility and the Greenville’s commander was retired**.**

14:14 **Collisions and Crashes (major damage/costs to one or both vessels)**: In 2010 the Ministry of Defence admits 16 “crashes” involving UK N.Subs since 1988.

Grounding: Nov 2002 HMS Trafalgar: travelling 50 metres below the surface at 14 knots (24km/hr): ran aground on a small island near Skye, £5 million repair bill, 2 officers reprimanded.

Dual-Subsurface Collision: Feb 2009 HMS Vanguard and French N.Sub Triomphant collide in “open” north Atlantic (Both nuclear-powered and nuclear-armed). Triomphant reported they had hit a submerged object, perhaps a sunken cargo container: £50 million repair bill for both. Officers reprimanded.

Grounding: Oct 2010: HMS Astute (nuclear-powered hunter/killer) ran aground in Broadford Bay, Skye, several hundred metres outside charted and marked safe route through Skye Bridge: officers reprimanded: Astute refloated by Anglian Prince tug: but then collided with Anglian Prince causing damage to Astute.

14:15 HMS Ambush – MV Andreas, July 2016, HMS Ambush (Astute class SSN), nuclear powered and fully armed with Tomahawk cruise missiles (non-nuclear): At periscope depth in Straits of Gibraltar. Ambush could "see" Hydrocarbon product tanker MV Andreas which was fully loaded, but when maneuvering to avoid another vessel, Ambush struck MV Andreas. Both Ambush and Andreas were damaged, but Ambush was more severely damaged at conning tower (£2.1 million). Commander of Ambush reprimanded and downgraded.

Nov 2002: USS Oklahoma SSBN (nuclear powered and nuclear armed) collides with loaded LNG Tanker in Strait of Gibraltar: Clear risk of major explosion. Commander sacked and 3 others reprimanded.

2005: nuclear powered sub USS Philadelphia hit a Turkish merchant vessel in the Straits of Hormuz: damage slight. Vessel missions not interrupted.

14:16 2007: Nuclear powered and nuclear armed USS Newport News: submerged and navigating at periscope depth in approaches to Straits of Hormuz, collided with Japanese super-tanker "Mogamigawa" (300,000 tonnes). USS Newport News damaged at bow, forced to surface and could not submerge until after dry dock repairs completed (patrol security severely compromised). Mogamigawa damaged at stern (hull and props) but proceeded to port under own power. US Naval Inquiry report found that passage of the tanker over the submerged submarine had created a "Venturi" or “sucking force” that pulled the submarine upwards and into the bottom of the tanker. Some reports of chemical and radiation leaks but these denied by US Navy.

14:17 April 2015: During NATO Exercise Joint Warrior: Northern Irish trawler the *Karen* was fishing 18 miles off the coast of County Down when it was suddenly pulled backwards at a speed of around 10 knots (11.5 mph). The crew had to rapidly scramble to cut the steel wires connecting the 60-ft trawler to the submerged nets in order to free the vessel. In an interview with the BBC the skipper said that the incident had caused £10,000 worth of damage to his vessel and caused him the loss of two tons of catch. Navy sources denied responsibility and claimed that a Russian submarine was responsible, and insisted that one of their submarines would have surfaced to check on the welfare of the submarines in British waters. Five months later in September 2015, the Ministry of Defence admitted that it was a British submarine which caught the nets of the Karen.

14:18 In October 2015 a report by the Marine Accident Investigation Branch criticised the Royal Navy for its lack of transparency and for taking five months to admit liability and made the following statement: “This investigation was conducted without the full co-operation of the Royal Navy. The involvement of a submarine was not revealed until nearly 5 months after the accident and it took 10 months for the Royal Navy to submit evidence to the investigation team. These delays impeded the progress of the independent investigation, and the evidence submitted was insufficient to determine all the causal factors.” Part of the “insufficient evidence” was the Navy’s refusal to provide the name or class of the submarine, though it did confirm that the home port of the boat was HMNB Clyde/Faslane, (the home port of the UKs SSBNs fleet) and that the boat was on military operations.

14:19 The report found that the Royal Navy submarine crew incorrectly believed they were passing underneath a cargo vessel, meaning they did not leave enough room to avoid the nets of the *Karen*. The Royal Navy was found to have failed to “fully engage in the subsequent investigation” and the report expressed concern that lessons learned following the sinking of the *Antares* in 1990 were being forgotten and that the Royal Navy would have to work to “rebuild trust with the fishing industry.”

REF: https://assets.publishing.service.gov.uk/media/57fe2e2ee5274a496200000a/MAIBInvReport20_2016.pdf

14:20 6th November: 2018. Stena Ferry/N.Sub interaction: Stena Ferry (en route Cairn Ryan to Belfast: Irish Sea: transiting a declared submarine training area, but not aware of vicinity of N.Sub travelling at patrol speed) reports "close proximity" sighting of sub at "periscope depth". RN/Ministry of Defence report that a N.Sub had "sighting" of a Stena Ferry. Public reporting initially restricted: Incident only became "public" 4 months later (Feb' 2019) UK Marine Accident Investigation Boad agreed that an investigation of the incident should take place.

14:21 "Close proximity" is an archaic term with no apparent precise modern definition: in the days of sailing warships, it had the same meaning as "close quarters" and was defined as "yard arm to yard arm" (i.e. very close). Periscopes on submarines may be as long as 100 feet (30.5 m). When a submarine is submerged to a depth not deeper than the length of the periscope, it is considered to be at "Periscope Depth." There is a consensus that a submarine travelling at "Periscope Depth" can create a large and powerful "bow wave" and that both bow wave and periscope may be visible from other vessels: this was the case with the Stena ferry, where a crew member spotted the periscope and its wake approaching on collision course and alerted the ferry's bridge officers who took immediate evasive action. The Marine Accident Investigation Branch enquiry found that the officers on board the submarine were solely responsible, did not observe the immediacy of the situation, took "confused" and delayed decisions.

14:22 General/usual pattern of official UK response: Initial denial of UK submarine involvement. If public pressure (media reportage and public concern) maintained: often an eventual admission that submarines were in the area. Denial of impact or "contact" between MFV and UK N.Subs almost always maintained. Presence of "hostile" N.Subs often implied (without supporting evidence). General refusal to disclose details on grounds of national security. Implications that sunk/total loss boats were badly maintained or manned by in-expert crews. Antares/Trenchant and Stena Ferry incident a rare example of admission and attached "responsibility".

14:23 **International Maritime Organisation (IMO) submarine codes**: IMO has no power to enforce or mandate. IMO Resolution A15: 599: adopted November 1987 "Recommends that a submerged submarine, if information of the presence of a fishing vessel and its fishing gear is available, should, as far as possible, keep out of the way of that fishing vessel and any fishing gear connected to it unless the submarine is disabled."

14:24 IMO Submarine Code: second Resolution: A17:709: adopted 1991 "Recommends that a submerged submarine, if information of the presence of a fishing vessel and it's fishing gear is available, should, as far as possible, keep out of the way of that fishing vessel and any fishing gear connected to it unless the submarine is disabled."

"Invites governments

a: to bring the above recommendation and the concern expressed in this resolution to the attention of authorities, commanders and officers responsible for operating submarines

b: to develop local arrangements to establish procedures to promote safety of fishing vessels and submarines in areas considered prone to mishaps between fishing vessels and submerged submarines (exclusion areas: stop and help protocols etc)

c: to ensure that submarines navigating through areas where vessels are known to fish use all reasonably available means for determining the presence of such vessels and their fishing gear to avoid endangering such vessels and their gear."

14:25 IMO Protocols re non Motor Fishing Vessels (MFVs). Feb. 2019 email inquiries (on behalf of UK NFLA) to IMO asking for details of protocols for N.Sub interaction with non MFV vessels were responded to (29th May 2019). IMO response states "not aware of any IMO instruments related to safety of (non-MFV) ships related to submarines". IMO response also states "submarines can only be considered when emerged on the sea surface which are then, for the purpose of COLREGS [collision regulations], considered like any other …. vessel." IMO response also states "It is the navies that would have to provide standard procedures" for collision avoidance protocols with merchant ships. Last 2 IMO responses (above) to NFLA appear to contradict both IMO Resolution A15: 599 & IMO RESOLUTION: A17:709: referenced above. in which a set of protocols for interaction between submerged N.Sub and MFVs is agreed between IMO and Ministry of Defence and presented (by the IMO).

14:26 Defence Nuclear Safety regulation: A number of publications specify the Defence Nuclear Safety Regulations of the UK Defence Nuclear Enterprise comprising the Nuclear Propulsion Programme and the Nuclear Weapon Programme for UK Ministry of Defence. These regulations do not address the management of "at-sea" risks and tend to focus on onshore and dockside issues likely to impact the areas around N.Sub bases. In the context of those issues DSA03-DNSR is a guidance document and should be read in conjunction with the regulation document DSA02-DNSR. The goal of the regulations is to ensure that the management of safety and environmental protection of defence nuclear activities can achieve outcomes as good as those governed by the UK and international legislation. Full documentation can be viewed at the following.

REF: https://www.gov.uk/government/collections/defence-nuclear-safety-regulations-dnsr

Detail of site-specific regulations can be found at Appendix 2, below.

14:27 **Conclusion**: A summary review of interactions between N.Subs and civilian vessels illustrates that N.Sub patrol routes, exercise and training areas present major risks to the safety and operation of civilian vessels and their crew, ranging from small inshore commercial fishing boats up to super tankers. The available evidence clearly shows that these threats include the risk of loss of life, total loss of vessels and significant damage to gear and vessels.

It is clear that, despite the best attempts of both civilian and Defence authorities the secrecy surrounding N.Sub operations makes risk avoidance that much more complex, with notification of N.Sub movements not publicised and the details of patrol and training strategies not divulged to judicial or government agency inquiries.

On a number of occasions civilian stakeholder groups (fishers etc.), local authorities and citizens campaigns have attempted to initiate improved protocols for submarine activity by interacting with the International Maritime Authority (IMO). However it has become clear that the IMO, which cannot mandate action, does not have the power to mandate a set of standard procedures to prevent damaging interactions between civilian vessels and the N.Subs forces of sovereign nations . Evidently it will be the responsibility of the Australian Defence Department and Australian Navy to draw up a set of protocols for the protection MFVs, and other civilian vessels, their crews, passengers and cargo from the risks generated by the deployment of N.Subs.

Cleary the IMO does not have the power to mandate a set of standard procedures to prevent damaging interactions between civilian vessels and N.Subs. Evidently it will be the responsibility of the Australian Defence Department and Australian Navy to draw up a set of protocols for the protection of MFVs, other civilian surface vessels and their crews, passengers and cargo from the risks generated by the deployment of N.Subs.

APPENDIX 1: DISCHARGES OF RADIOACTIVITY FROM UK NUCLEAR SUBMARINE BASES

1:1 Radioactive discharges to the environment from N.Sub bases: UK sites require the discharge of radioactive effluent to both the atmosphere and the marine environment. The Government, advised by its regulatory agencies, permits licensed discharges of a number of specifically named nuclides which it considers significant. Other nuclides are not individually analysed for, but are analysed *en masse* and reported as “other radio nuclides”, or in the case of alpha and beta emitters as “total alpha” or “total beta”.

1:2 To date, I have been unable to find a detailed quantification of the radioactive inventory of N.Sub liquid effluent destined for discharge to the marine environment. I assume this is because such information is not made widely available for security reasons. However, such an inventory for civilian PWRs is available, from which it is evident that PWR liquid discharges may contain at least 60 species of radionuclide, including low concentrations of long-lived alpha emitters including Pu-238, Pu-239/240 and Am-241. It is assumed that naval PWR liquid effluents will be broadly similar.

1:3 Three radionuclides discharged during the refit process, Carbon-14, Cobalt-60 and Tritium, are generally reported in their named individual concentration. However, a smaller volume of other irradiated “activation” products (derived from metallic structural components of the reactor, primary cooling system pipework, etc.) such as radioactive iron, copper, manganese, nickel, zinc are also present in naval PWR wastes. As referenced above, low levels of long-lived alpha emitters are also present in PWR wastes. These are rarely referenced in detail and generally covered in monitoring reports under headings such as “other radionuclides”, “total alphas” or “total betas”.

1:4 The Ministry of Defence, UK Government and relevant Government funded/sponsored Agencies tasked with regulation, monitoring, radio-analysis and dose assessments have always reported their opinion that, based on their science, doses to local populations around these bases are low (in the less than ten microgram range).

1:5 Government agencies ensure that, at all sites, samples of fin fish, shellfish, marine algae and sediment are analysed for a range of specific radionuclides. Some radionuclides are admitted to be present as a result of N.Sub base activity, others are reported due to weapons test fallout, Chernobyl and Sellafield, e.g. long-lived alpha emitters, Cs-137 and Sr-90.

1:6 Excepting tritium (as tritiated water) and Carbon-14, the principal source of radioactivity in naval PWR liquid waste discharges comes from trace amounts of corrosion and activation/wear products from reactor plant metal surfaces in contact with reactor coolant water. A variety of radioactive elements, or radionuclides, is produced. The other predominant radionuclide with a half-life greater than one day is cobalt-60, which has a half-life of 5.3 years.

1:7 Naval PWR reactor coolant also contains radionuclides with very short half-lives ranging from seconds to hours. This group includes such species as Nitrogen-16 (7 second half-life), Argon-41 (1.8-hour half-life), and Manganese-56 (2.6 hour half-life). For the longest-lived of this group, the concentration in water is reduced, within about 24 hours, to one-thousandth of the initial concentration.

1:8 Both Tritium and Carbon-14 figure highly in UK government sponsored annual marine environmental radioactivity monitoring reports from N.Sub bases at Devonport, Rosyth etc, which provide details of the estimated/calculated amount discharged from each site.

1:9 Tritium is a characteristic radionuclide of both gaseous and liquid effluents from nuclear sites and it is widely recognised that PWRs generally produce more tritium (especially in their liquid effluents) than other reactor types. It is no surprise to note that these reports confirm that tritium is always the most significant radionuclide discharged to sea from UK naval Defence sites, in terms of the annual, aggregated TBq discharge.

1:10 In 2020, despite the reduction of discharges due to greater effort at the site, it was reported that the estimated discharge of liquid Tritium to sea from the Devonport base was over 8.4 billion Bqs, Carbon-14 had the second most significant annual aggregated discharge (18 million Bqs) , Cobalt-60 was third (1.67 million Bqs) and the aggregated annual discharge of "other radionuclides" was reported as 4.49 million Bqs.

REF: "Radioactivity in Food and the Environment, 2020" RIFE-26, Environment Agency et al'. 2021, p.322.

1:11 The relatively high Tritium burden in the liquid radioactivity discharged from the Devonport naval site is largely attributed to the fact that N.Subs cannot discharge their liquid wastes while on patrol because it might lead to their detection. As a result, the cooling/moderating water must be recycled repeatedly during patrol activity, during which process the concentration of radioactivity is increased. This cooling water presents, with its elevated concentrations of radioactivity, presents additional management problems during refit and maintenance periods and when released to the environment in the vicinity of dockyards and bases.

1:12 At UK civilian PWR sites, radionuclides discharged to sea usually enter the marine environment in liquid soluble form or as particulate material. Discharged particulate material may originate from within the reactor system and include micro-particles of nuclear fuel and fuel cladding, particles of metal from the reactor structure itself and the ancillary pipework/pumping equipment etc., and as contaminated pipework "scale" which has adsorbed/absorbed radioactivity from the discharge liquids during discharge.

1:13 Discharged particulates may vary in size depending on the performance of site filtration and pipeline technology (at most UK sites filters finer than 5 microgram mesh are NOT fitted because they tend to clog and inhibit the discharge of liquid wastes). Much pipeline scale is formed below/beyond site filtration infrastructure (i.e. there is no END of pipe filtration). Very few UK nuclear sites with permitted discharges to sea have undergone investigation of the end-of-pipe environments. At the few sites where studies have been carried out, such particles have been found. Post laboratory analysis confirms that many such particles have a high (elevated) radioactivity yield and pose significant dose risks via contact, dietary or inhalation exposure. There is no evidence that this is NOT the case at naval PWR refit bases. N.B.: As mentioned elsewhere in this report, defence security considerations restrict access to relevant data.

1:14 A number of the radionuclides discharged in "soluble" form (Plutonium, Americium) once in the marine environment, preferentially leave the soluble phase and ADsorb to the outer surfaces of sedimentary, silty and organic micro-particles suspended in the marine water column. Suspended particles of mineral origin are usually most concentrated in coastal and inshore waters and are transported through the marine environment on the regionally dominant currents. Organic micro-organisms are most concentrated in nutrient rich waters.

1:15 Where conditions are suitable, particulate material precipitates out of the water column and forms major intertidal (mangrove areas, coastal and estuarine mud bank and salt marsh) and sub-tidal deposits, which can be significantly enriched in radioactivity, relative to the ambient seawater.

1:16 Other radionuclides, such as Caesium-137, Tritium and Carbon-14, show a more pronounced tendency to remain in solution in the water column. However, this is by no means an absolute rule and these and other more "soluble" radionuclides become absorbed into organic material and sedimentary deposits where they may be found in the interstitial/pore water.

1:17 The sea to land transfer of radionuclides: sea spray, marine aerosols and sedimentary particles. Studies of the sea to land transfer of five anthropogenic radio nuclides (Plutonium-239 & 240, Plutonium-238, Americium-241 and Caesium-137) by the UK Atomic Energy Authority have confirmed that the sea to land transfer of these radionuclides was observed in airborne samples of both sea spray and micro-droplets of marine aerosol generated by bubbles bursting in breaking waves both off shore and in the inshore surf zone.

REF: "Studies of Environmental Radioactivity in Cumbria Part 5: The Magnitude and Mechanisms of Enrichment of Sea Spray with Actinides in West Cumbria" J.D. Eakins et al'. UKAEA: AERE HARWELL. March 1982. Paras: 2:1, 5:5 and 5:6

1:18 The UKAEA study clearly confirmed that, in all samples of airborne material, the great bulk of all three Plutonium and the one Americium nuclides were found to be attached, by ADsorbtion, to the outside surface of suspended fine (average size: 1 to 2 microns) clay mineral, organic and sedimentary micro-particles which had been suspended in the ambient water column and ejected in micro bubbles into the coastal airstream when bubbles burst.

1:19 The study reported that the process of marine aerosol micro-droplet production generated enriched concentrations of the Plutonium and Americium nuclides in airborne samples, relative to the concentrations in the ambient water from which they were derived, with EFs (Enrichment Factors) of several hundred being reported relative to filtered ambient seawater thus confirming the relevance of microparticles

1:20 By contrast the observed EFs for Caesium-137 were much lower (generally in the region of around 2 to 2.5) and this was attributed to the fact that Caesium nuclides tend to be more conservatively associated with the water fraction of marine aerosols rather than the particulate fraction.

1:21 Bio-concentration of alpha emitters by marine micro-organisms: The term micro-organism (or microbes) refers to organisms small enough to be measured in the micron/micrometre range (one millionth of 1 metre and smaller). Most micro-organisms are around 1 micrometre (micron) in size. Viruses are typically $1/10^{th}$ that size. Animal cells are typically around 10 micrometres in size.

N.B. There is a wide consensus that organisms and other particles smaller than 10 micrometres are inhalable (can enter the lungs), and are potentially problematic for human health, while particles and organisms greater than 10 micrometres are far less likely to be inhaled into the lungs, but get trapped in the nose or throat, where they may also cause health impacts.

1:22 The 1982 UKAEA study (see 1:17 above) on the sea to land transfer of radioactivity adsorbed to airborne marine particles derived from bubble bursting in the surf zone, reported that these particles (consisting of both sedimentary particles and organic micro-organisms) were largely in the 1 to 2 micrometre diameter range.

1:23 Marine micro-organisms include bacteria, viruses, fungi (yeasts and moulds) and animal and plant plankton species. There is a consensus that micro-organisms make up about 70% of the biomass in the ocean and that as many as 10 to 100 million micro-organisms can be present in a teaspoonful of sea water. Most marine micro-organisms can thrive in warmer temperatures and their numbers may increase markedly during periods of increased water column temperatures. Micro-organisms are also capable of expanding their habitat as they follow warming waters and altered ocean currents. A 1989 paper noted that the concentration of bacteria in jet drops and film drops ejected from bursting bubbles generated by breaking waves “can be several hundred times that in the bulk water”.

1:24 The 1982 UKAEA study (see 1:17 above) confirmed that marine micro-organisms can become enriched with actinides and reported that very high concentration factors (260 – 26,000) for Pu 239/249 and Am 241 had been observed in micro-algae in the open sea. The study further noted that these micro-organisms could become concentrated at the sea surface (as algal blooms/red tides etc) and that subsequent suspension in high winds was possible, the implication being that they may be susceptible to sea to land transfer.

1:25 The 1982 UKAEA study further reported that empirical field investigation of sea to land transfer of marine radioactivity on the Cumbrian coast had clearly demonstrated the presence of micro-organisms in sea spray crossing the surf line during periods of onshore wind. One particular sample set proved that a high loading of micro-organism particulates was closely linked to highly elevated (compared to ambient sea water) concentrations of Pu 239/240.

1:26 Extent of inland penetration of airborne, marine derived radioactivity: A (pre-1986/pre-Chernobyl) research study carried out by a medical team reported that a Scottish island, about 330kms/117 sq. miles in area, held elevated levels of Sellafield derived, sea discharged Caesium-137 which had transferred from the sea to the land in marine aerosols and sea spray, blown onshore by winds from all compass directions. It was reported that the Cs-137 was found in all types of island coastal and inland environment, despite the fact that the discharge source point was over 250 kms distant.

1:27 The medical team did not model or estimate doses, but arrived at their Cs-137 dose data via empirical radio-analysis of foodstuffs, consumers urine and whole-body analysis at the Kilbride Reactor Centre. It was demonstrated that those individuals who ate a traditional “island diet” of locally grown foodstuffs had higher body concentrations of the Cs-137 than those who ate imported “shop food”. The highest body burden of marine sourced Cs-137 in “island diet” consumers was measured in an islander who ate no sea foods.

1:28 Some of the study subjects were shown to have higher body burdens of sea to land transferred marine Cs-137, than the body burdens of multiple radionuclides calculated for some Critical Group sea food consumers and residents living adjacent to licensed sea disposal radio-active effluent discharge pipelines.

REF: "Body concentration of Caesium-137 in patients from Western Isles of Scotland" CG Isles et al'. BMJ: June 29: 1991

Through 1987-1988 a UK Local Authority carried out a radiological survey which discovered Sellafield sea-discharged Caesium-137 on agricultural produce samples approximately 10 miles inland from the coast of west Wales, at over 200 kms distant from the discharge point.

REF: "RADMID: Radiation Monitoring in Dyfed:" 1987-: First Report: Dyed County Council. Carmarthen. Wales

1:29 Advice presented to the Authority by BNFL and UKAEA representatives confirmed that the Cs-137 was from Sellafield sea discharges and that it had transferred from the sea to the land by the mechanisms first noted by the UKAEA study referenced above (see 1:17 above).

2: Radiological impacts of coastal flooding

2:1 Marine radioactivity is also transferred from the sea to the land during periods of (spring or super-tide) high tide, storm waves and coastal flooding thus exposing coastal zone populations to inhalation doses arising from airborne sun-dried microscopic particles and contact doses from handling seaweed, driftwood, flotsam and jetsam contaminated/coated with micro-organisms.

2:2 Such events deliver dietary doses of marine originating radioactivity to humans, following their incorporation into foodstuff products from seasonally inundated tide washed food growing areas. This mechanism is reported by UK government and nuclear industry funded regulatory authorities and monitoring/sampling agencies. It is relevant to note that the vital importance of agricultural/horticultural, artisanal gathering use of coastal mangroves/marshland/sea washed harvest areas is a common feature of low lying coastal and estuarine communities.

REF: Annual RIFE (Radioactivity in Food and the Environment) Reports: CEFAS. UK

2:3 Such inundation events have also impacted coastal settlements on a frequent basis, but most such events are poorly reported and usually characterised by a refusal, or failure, to investigate the potential radiological impacts. In 1990, the town of Towyn on the north Wales coast suffered a major storm surge which breached the coastal defences and flooded streets, homes, businesses and holiday caravan sites. Many residents were evacuated and could not return to their homes for some time. One of the characteristics of this event was the sea to land transfer of thousands of tonnes of marine fine sediment from the muddy inshore zone of the Liverpool Bay area of the northern basin of the Irish Sea. An independent citizen (not associated with government regulatory agencies) took samples of the flood sediment and had them analysed by an independent radioanalytical laboratory.

2:4 The consultant author of the lab report noted that radiation warning limits had been overtopped and warned that the presence of high concentrations of both Caesium and Americium-241 strongly implied the very high likelihood that similar levels of Plutonium radionuclides were present in the sediment. The consultant stated that "The values obtained suggest that, when the sediment dries out, there is a possible radiation hazard due to the inhalation of radioactive dust containing the isotopes of Americium and Plutonium."

REF: "Radiation Survey of Towyn": March 1990. Dr R.F. Wheaton. Edinburgh Radiation Consultants

2:5 Routine radiological monitoring and analysis of marine samples in the UK generally shows low levels of radioactivity in marine samples in the vicinity of N.Sub bases. However, there are a number of potential weaknesses/flaws in the sampling and analytical procedures used in the UK and these, since they are based on widely accepted IAEA 'guidances', may be replicated by Australian regulatory agencies.

2:6 Twice-a-year sampling of marine environmental samples (fin fish, shellfish, crustaceans, marine algae, sea water and sediment) is the standard in the UK. Fin fish may include both pelagic and demersal species. Adult demersals may spend more time in the regional waters than pelagics like mackerel etc. which are annually migratory, so demersals may provide a more representative characterisation of local and downstream radiological conditions. Adult shellfish and crustaceans generally spend most of their life spans in one place. Resident species are far more likely to provide regionally and locally specific data on food chain dose pathways. Sample numbers are generally low, rarely more than 3 from any specific site, at any specific sample collection. Similarly, only a few water column samples are taken, usually only one or two samples are recovered, per sampling excursion from near the discharge outfall.

2:7 "Sediment" sampling is generally incoherent with regard to the choice of sample sites, which are not regularly spaced geographically or representative of local and regional characteristics. In marine geophysical terms "sediments" are characterised by the Whitworth Scale ranging from very fine micro-particles composed of organic, clay and silty mud through to sands, gravels and cobbles.

2:8 In the UK such samples are widely reported as "sediment" and relatively few are specifically defined as mud/silt. It is assumed that a number of "sediment" samples consist of sand and/or gravels with some admixture of fine sediments, but, for the majority of samples this remains unclear. Precise characterisation of such samples is important because many academic studies, reported in peer reviewed journals, report that finer sediments generally have elevated concentrations of anthropogenic radioactivity due to the partioning and ADsorbtion effect referenced above (any given volume of silt holds far more particles, and hence surface area, than a similar volume of sand or gravel ... thus generating elevated concentrations of ADsorbed radioactivity).

2:9 In the UK it is also the case that most sampling sites for marine sediment and marine algae are easy to access from the roadside, boatyards, slipways, tourist beaches, etc. Such sites may not be fully representative of the regional coastline. Sample sites are focussed almost exclusively on the coastal environment while estuarine environments and the tidal reaches of rivers (which may extend many miles inland) are generally NOT sampled. Such environments are often associated with relatively dense population centres. The failure to sample them means that population dose estimates etc may not be fully representative. Estuaries and the tidal reaches of river systems are generally repositories of fine sediments in mud bank, salt marsh and mangrove environments. As explained above, such fine sediments can hold concentrations of anthropogenic radioactivity significantly elevated above those found in sand, gravel or cobble environments. This could generate elevated doses, via contact, dietary or inhalation doses. If such potential pathways remain un-investigated, the doses to adjacent populations cannot be estimated.

2:10 Over the last 10 years I have initiated and led a number of research field work campaigns with UK coastal citizens groups investigating coastal radioactivity issues along the coast of the Bristol Channel. This work has shown that marine discharged radioactivity can penetrate at least 17 miles inland from the coast along the tidal reaches of rivers. It was also observed that such river corridors, and their associated tidally transported radioactivity, pass through riverbank towns and villages and that, in the interest of flood management, such rivers are subjected to dredging, with dredge wastes dumped on the river bank or applied to agricultural land. Until this work was carried out the dose implications had not been referenced or discussed.

2:11 As mentioned above, UK analytical protocols are based on widely accepted IAEA guidance. Such guidance references a focus on gamma analysis with a relatively reduced focus on the alpha and beta emitters. Gamma radio-analysis tends towards the use of short counting times because it is less expensive. Short count (approx. 15 hour) gamma analysis for subjects such as Cs-137, Co-60 etc is the widely used and preferred method in the UK.

2:12 However, academic papers published in peer reviewed journals clearly indicate that longer term counts provide more precise analytical outcomes with lower "less thans" (i.e. below detection level) and higher "maximums" or "peaks" of radionuclide concentration than are returned by short count analysis. My own work initiating, designing and leading Citizens Science sampling and analytical research with Citizens Campaign groups in the UK, has confirmed that when operating an 80-hour / 3-day count the academic advice is indeed correct. The 80-hour count generates lower "less than" and elevated "maximum" radiological outcomes than the short term count. This clearly implies that short count gamma analysis generates a less accurate quantification of the radioactivity in each sample. When such data is fed into dosimetry models it inevitably generates a less accurate quantification of dose.

2:13 Regulatory agency sampling and analytical work of sea to land transfer issues is minimal. Site specific sampling of salt marsh grazing and post-inundation populated areas is never undertaken. Quantification and investigation of sea to land transfer via marine aerosols and sea spray pretty much ceased after the run of UKAEA studies came to an end in the mid-80s after it was calculated that the radiological impacts were minimal and localised to the foreshore/beach.

2:14 In the UK there is no evidence of any government agency attempt to gather empirical evidence on the actual body burden of anthropogenic radioactivity of individuals or communities adjacent to, or downstream of, N.Sub bases. Body burden and dose assessments are modelled using the data gathered by government agencies/regulators. The only such empirical work has been carried out by independent teams (e.g. the Hebridean sea to land transfer study referenced above) where whole body monitoring and urine sampling were undertaken.

3: Dose Pathways: it can be argued that many of the inadequacies in the official regulatory and nuclear industry sampling and analytical sampling work are based on an inadequate understanding of marine environments.

3:1 In the case of the UK, Sellafield's radioactive discharges were initiated under pressure from the UK's 'need' to produce weapons grade materials, as far as I can ascertain the decision to carry out the discharges was ratified under an Order of Council without a vote in either of the Houses of Parliament. The understanding of marine environments and parameters was relatively poor compared to current knowledge. But, once discharges of radioactivity had begun there was no going back. It is clear that, at that stage, there was no understanding of how the sea discharged radioactivity behaved in marine environments. This was admitted in a speech by a BNFL scientist John Dunster who referred to the sea discharge of man-made radioactivity as a great experiment.

3:2 The official position in the UK is that doses of sea discharged radioactivity to humans are derived from contact with the skin, ingestion/dietary or inhalation. Critical groups and individuals (those most likely to be exposed) are identified on the basis of their habits, diet and work, and their time on the sea shore and the intertidal zone is assessed. This can include commercial and sport fishermen, dog walkers, houseboat dwellers, holiday makers, sailor, surfers *et al*. Such work is focussed very much at the shoreline. It may be supported by various air monitoring installations at the nuclear sites.

3:3 A prime example of the inadequate understanding of marine and coastal environments is the issue of sea to land transfer. Annual UK Radioactivity in Food in the Environment (RIFE) reports provide publicly available data on the radioactivity concentrations in marine and coastal environments adjacent to point sources of radioactive effluent discharges. It is clear from these reports that the regular annual sampling and analysis work at UK N.Sub bases do not extend beyond a radius of 12 to 15 miles from the point source.

3:4 Radioactivity in Food in the Environment reports fail to address the issue of sea-to-land transfer of sea-discharged radioactivity via marine aerosols and sea spray, the evidence of its transfer deep inland (at least 10 miles), its subsequent deposition on pasture grass, arable, horticultural, foraged food and open fresh water sources, or the fact, that in some regions, transfer capable onshore winds blow for 50% of the year. All of these parameters generate a number of additional exposure pathways not addressed by official sampling and analysis and subsequent dose modelling. Dietary, lung inhalation and contact doses of marine discharged radioactivity to communities in the terrestrial coastal zone are currently not recognised or investigated by official regulators and monitoring agencies.

3:5 N.Subs cannot discharge radioactive wastes to sea while operational for security reasons. As a result, some radionuclides become concentrated in the N.Sub PWR coolant to a greater degree than in civilian PWR reactors. It is clear from analysis of the records of discharges from sites like the Devonport base that discharges are intermittent and pulsed and reflect the degree of radiological concentration/contamination, which is, in itself, a reflection of the duration of the at-sea patrol time of boats in dock for refit, renovation and maintenance.

3:6 Tritium represents both the largest volume, and the largest aggregated amount, of radioactivity discharged from N.Sub bases. Recent research (Feb. 2023) published in a peer reviewed journal confirms work published in a specialist journal that Tritium discharged to sea (as tritiated water from a French reprocessing site) can be transferred to the atmosphere by evaporation from the sea surface and is then available for transport on to terrestrial environments during episodes of onshore wind. The results of the study, based on 18 field research campaigns, were then used in hypothetical modelling exercises in an attempt to generate quantification of the extent of this process. The outcomes of the modelling suggested that, when 1 litre of seawater containing between 20 to 100 Bq of tritium evaporated off the sea surface, it injected between 2 to 15 Bq of tritium into the atmosphere.

REF: "Flux of tritium from the sea to the atmosphere around a nuclear reprocessing plant: Experimental measurements and modelling for the Western English Channel": O.Connan et al: Journal of Environmental Radioactivity. Vol 257 Feb. 2023

The above work is highly relevant to N.Sub bases carrying out maintenance, refurb, repairs and re fuelling work.

3:7 The study authors also reported that the model estimated that at least 1% of the total tritium discharged to sea from the French site returned to the atmosphere after evaporating from the sea area from the discharge point to 10 km downstream. It was noted that likely variations in the rate of evaporation would be dependent on air and water temperatures. It is assumed that the estimated 1% is an average or mean figure and may be higher depending on the site-specific parameters. Water and air temperatures and the rates of evaporation in the Gulf of St Vincent will not replicate those in the English Channel.

3:8 **N.B.: The study's authors concluded that evaporation of tritium from the sea surface should not be ignored because it could lead to under-estimation of atmospheric dose pathways to sea users and coastal communities. This is particularly relevant because such dose delivery pathways may operate on a daily basis downstream from N.Sub bases during discharges associated with refit, maintenance and decommissioning/dismantling operations. In periods of prevailing onshore winds exposure may give rise to chronic/long term doses delivered over extended timescales**

3:8 From the above it can be deduced that significant amounts of tritium, C14, Co60, alphas and "other radionuclides" will blow ashore during the dumping/discharge of N.Sub cooling water treated water, generating inhalation, dietary and contact doses to downstream coastal zone, island and marine Critical Groups. This dose pathway has been totally ignored by the IAEA and by regulatory authorities in all of the 'nuclear' states .

3:9 The evidence summarised above confirms the earlier argument, first advanced in the immediate wake of the Fukushima disaster, that the sea-to-land transfer of radioactivity dose pathways represent a significant group of exposures and that the inhalation dose, by virtue of its magnitude and its duration (number of hours/days per year), represents the most important.

3:10 We know that a number of other anthropogenic radionuclides, including Cs-137, C14, the Pu nuclides, are also found in soluble form. None of these have been investigated to determine their evaporative characteristics. Given the lack of data to be found in the academic literature on such issues, it may be assumed that the solubility of many of the radionuclides discharged from N.Sub sites has not yet been so characterised.

3:11 In-depth investigation of regional marine hydro-dynamics, coastal geo-morphology, sedimentation and sediment transport, estuarine parameters, and sea to land transfer processes (coastal inundation, marine aerosoling, evaporative processes from sea surface and exposed intertidal zones), regional meteorology (onshore winds, storm frequency, coastal wave height etc.) in conjunction with analysis of both tidal and residual near surface water movements, are highly recommended prior to the development of any N.Sub base.

3:12 There is no indication in any of the UK literature relating to the pre-construction proposals and plans to build UK N.Sub bases that these issues were given any consideration in the planning and strategic decision-making stage. In the case of UK defence establishments, the priority has been to get the base built, do not complicate the issue, and only consider the implications to local/regional populations and the environment once the base is operational.

3:13 As a result, consideration of the radiological implications and the programmes are, of necessity, bolt-on, after-thought appendices to the construction of the base. In this context, it is relevant to note that UK annual Radioactivity in Food and the Environment (RIFE) reports always state that their purpose is to “re-assure” the public that radioactivity levels around nuclear sites are within legal limits.

4: N.Sub radioactivity and Duplicate diet study: In the run up to the UK’s first Hinkley C nuclear power station inquiry held in the 1980s, the UK Ministry of Agriculture Fisheries and Food (MAFF) was ordered to undertake “special studies to measure the intake of radionuclides using a duplicate diet technique”.

4:1 Such studies are aimed at populations close to nuclear sites licensed to discharge liquid and gaseous radioactive wastes, and, in particular to those individuals who eat fresh locally produced foodstuffs. Such studies require participants to prepare an exact duplicate of everything they eat over a 7-day period. This is then subjected to radio-analysis in order to identify the significant radionuclides present and attempt quantification of the dietary dose.

4:2 The MAFF Hinkley duplicate diet study was initiated in 1987 with a summer diet phase and a following winter diet phase proposed for 1988. Forty individuals (half adult and half juveniles) were selected from within a six-mile radius of the Hinkley Point nuclear power station site. A control population of 20 people consuming locally grown vegetables was identified from residents around the Kingsbridge Estuary in south Devon, an area identified by MAFF as being distant from any nuclear site and any associated liquid and gaseous discharges.

4:3 All dietary items were individually analysed for a range of radionuclides. Samples were then bulked according to their geographical location (Hinkley or Kingsbridge Estuary). Results from phase 1 (1987 summer diet) were then presented to the Hinkley C Inquiry in 1988 before complete empirical dose assessments were carried out and before phase 2 had been carried out. However, “estimates” of summer diet maximum doses were attached. These were universally low (Hinkey diet=14.3 micro Sv, Kingsbridge diet=16.3 micro Sv), representing a small percentage of the UK “permitted dose”.

4:4 The MAFF representative who presented this work to the inquiry argued that its outcome conclusively proved that the dietary pathway doses received by Hinkley residents from locally grown produce was lower than that received by the distant “control” residents at Kingsbridge, that this proved that radioactivity concentrations around the Hinkley A and B reactors were less significant than those at sites distant from nuclear discharges and that any additional dietary doses derived from the proposed Hinkley C PWR reactors were unlikely to be significant.

4:5 However, my analysis of the results reached the following conclusions:

a: Standard UK gamma analytical methodology uses a 15-hour count period. Multiple academic studies report more precise analytical outcomes with lower “below detections” and higher maximums, my own work with citizens campaigns using a 3-day (72) hour counting time has universally confirmed the academic work.

b: I proposed that a similar standard approach, vis-a-vis alpha analysis, had been used in the duplicate diet study.

c: Doses were “estimated” by hypothetical modelling and NOT based on empirical data (whole body monitoring, urine analysis etc).

d: The radionuclide making the greatest contribution to the elevated Kingsbridge dose was Co-60. Co-60 is produced by nuclear fission occurring as a result of steel degradation in naval PWR reactors. UK government reporting of sampling/analytical work on UK submarine marine samples states that "the nuclide of main importance being cobalt 60".

REF: "Radioactivity in surface and coastal waters of the British Isles, 1988". Aquatic Environment Monitoring Report: Number 21. Ministry of Agriculture Fisheries & Food. 1989.

5: The closest source of Co-60 to the Kingsbridge estuary is the Devonport nuclear submarine base (approx. 30 miles upstream of the Kingsbridge estuary) where N.Sub PWR maintenance, refit and defueling/refuelling was carried out as required.

6: The residual (long-term) general near-surface marine water body movement from the Devonport base trends west to east from Devonport towards the Kingsbridge estuary.

4:6 In my role as the Research Director of the citizens science research group, the Irish Sea Project, my response evidence on the Duplicate Diet Study to the Hinkley Inquiry concluded that the conclusions provided by the UK Government's Duplicate diet studies were:

a: based on inadequate/imprecise analysis of the radionuclide concentrations in the diet and that the (hypothetically) modelled estimated doses intakes, based on that analysis, were therefore similarly inadequate and imprecise;

b: radioactivity discharged to the marine environment from the N.Sub work at Devonport was carried eastwards towards and into the Kingsbridge estuary;

c: that Cobalt-60 was transferred from the marine to the terrestrial environment via a number of sea-to-land pathways including marine sea spray, marine aerosols, coastal flooding and the use of seaweed as a fertiliser which gave rise to contact doses to plant material via contact with seaweed fertilised soil and from wind-blown (deposition) radioactive marine seasprays and aerosols;

d: that in this context it was relevant to recognise that the population of the Kingsbridge Estuary included an elevated proportion of organic gardeners because it was a national centre of "alternative" philosophy and lifestyle.

4:7 The second stage (winter diet) was not reported and I understand that it was not completed. Had it been completed it might have shown an elevated radioactivity dose because the general north western European winter diet consists of a greater percentage of root crops, which have a longer growing period and thus spend longer in contact with ambient radioactivity. My evidence to the inquiry was not responded to, or refuted, by any Government or nuclear agencies and the issue of the Hinkley/Kingsbridge Duplicate Diet study was not raised again at the inquiry.

5: Probable impact of N.Sub base radioactive discharges on Australian marine and coastal environments and populations:

5:1 The Gulf of St Vincent is recognised for its diversity with many species of crustaceans and polychaete worms, sea quirts and sea urchins. The seabed is largely composed of a soft sediment shelf, with species of seagrass around the mouth of the Port River. A Cardinal fish, genus Vincentia, gets its name from Gulf of St Vincent where the type specimen of its species was first identified and collected. The Gulf of St Vincent coastline incorporates the Adelaide International Bird Sanctuary National Park and also a large network of coastal protected areas off the northern shoreline, including the Adelaide Dolphin Sanctuary, the Upper Gulf of St Vincent Marine Park and Light River Delta Sanctuary, as well as two Aquatic reserves: Barker Inlet-St Kilda and St Kilda-Chapman Creek.

5:2 It is reported that Gulf of St. Vincent is 145 km in length, has an average depth of 21 m and two connections to the adjacent continental shelf. Investigator Strait is bounded by the northern coastline of Kangaroo Island and the south facing coastline of Yorke Peninsula and has an average depth of 34 m. Backstairs Passage is a narrow (13 km wide) opening between Kangaroo Island and the south- western tip of Fleurieu Peninsula and has maximum depths of 35–40 m. The adjacent continental shelf has water depths of 100–150 m.

5:3 The Gulf is recognised as a “low energy”, semi-enclosed waterway, where wave action is limited and flushing exchange with the open ocean is seasonally (summer) severely restricted. Modelling studies indicate that the Upper Spencer Gulf has flushing times of between 1 and 2 years. Near-field studies imply that dilution of anthropogenic effluent discharge water may be substantially reduced in the absence of tidal mixing during weak neap “dodge” tides.

REF: “Hindcasts of the fate of desalination brine in large inverse estuaries: Spencer Gulf and Gulf St. Vincent, South Australia”: Jochen Kemp et al’: Desalination and Water Treatment 2 (1) February 2009

5:4 The coastline of the Gulf of St Vincent supports some of the greatest area of largely intact, connected coastal native vegetation and habitats in the South Australia region. It is characterised by extensive tidal areas of fine sediment mangrove environments and mudflats, samphire and saltmarsh communities and river estuaries. It is reported that, in the Adelaide area, suspended sediments and nutrients do not readily move offshore. If there are discharges to the marine environment, they stay in the nearshore zone moving backwards and forwards along the coast for some time before they are dispersed.

REF: https://www.epa.sa.gov.au/files/477425_acws_physical.pdf

5:5 There is no evidence that the implications of the proposed nuclear submarine maintenance and construction facility at the Osborne Naval Dockyard have been investigated. Such investigation, particularly in the context of the likely discharges of nuclear effluents to sea from such a facility, are strongly indicated by the brief summary of relevant environmental parameters presented above. Such parameters are strongly associated with the long-term presence and environmental re-concentration, in biota and estuarine and near coastal fine sediments and water body, likely to give rise to doses of N.Sub marine radioactivity via the pathways described above.

5:6 **The Stirling Naval base** on the eastern/inland facing coast of Garden Island, inside the Cockburn Sound, and already the major submarine base of the Australian Navy, is proposed as the operational base for both the AUKUS fleet and their proposed predecessor boats. Garden Island and the man-made causeway from Cape Peron have made the enclosed Cockburn Sound into a semi-enclosed marine area with a restricted flushing exchange with the open ocean. In that context some of the environmental parameters summarised above re Gulf of St Vincent may be relevant to the potential for radiological pollution in the context of routine N.Sub operations at the Stirling Naval base.

5:7 Submarines approaching and leaving the Stirling Naval Base must traverse the shipping lanes leading to both Fremantle and Kwinana ports. Fremantle Harbour, at the mouth of the Swan River to the north of Garden Island, is Western Australia’s largest and busiest general cargo port, handling containerised shipping, car carriers, livestock carriers, and cruise ships on a 24 hour/day basis. Kwinana is situated inside the Cockburn Sound on the mainland coast, almost directly opposite the Stirling naval base. Kwinana port handles bulk cargo grains, petroleum, LPG, mineral sands, fertilisers, sulphur, alumina and other bulk cargos. There is a deep-water anchorage at the Gage Roads lying offshore between Rottnest Island and the mainland.

5:8 The area adjacent to the Stirling Naval Base clearly represents an area of peak risk for negative interactions between N.Subs and civilian vessels. There is already a high concentration of civilian and merchant vessel traffic, both anchored and under way, much of it consisting of very large "bulkers", gas carriers, oil tankers and container ships, which requires a complex traffic management system, with designated routes for each port and dock bay, "in" and "out" traffic lanes, complex manoeuvring patterns and pilotage.

5:9 The addition of nuclear-powered submarine traffic, with its inherent requirement to submerge as soon as is practicable, coupled with the necessity for a designated training area and training patrols will clearly exacerbate an already complex regional scenario. Many of the parameters contributing to negative interaction scenarios are present in the vicinity of the Stirling Naval Base proposed N.Sub operational HQ. **N.B.: This issue has not been addressed in any detail to date, if at all. It is absolutely vital that the development of both the Osborne and the Stirling N.Sub bases should not proceed until such issues have been thoroughly investigated, researched and consulted on and contingency plans have been designed, analysed and tested under many different scenarios**.

5:10 Update: A November 2024 Press briefing from CND UK reported that:
"Radioactive air emissions have been increasing year-on-year at Coulport one of Britain's nuclear submarine bases in Scotland. Emissions of radioactive tritiated water vapour had doubled at the Royal Navy's nuclear weapons storage depot at Coulport on Loch Long between 2018 and 2023. According to the Scottish Pollution Release Inventory, tritiated water vapour emissions at Coulport were 1.7 billion becquerels (units of radioactivity) in 2018, rising steadily to 4.2 billion units in 2023. Tritiated water vapour is harmful when inhaled, ingested or absorbed through the skin as its radiation causes cancer and cardiovascular diseases including strokes."
The investigation also found that eight miles from Coulport at Faslane, where Britain's nuclear submarines are based, tritiated water containing over 50 billion units of radioactivity had been dumped into the Gareloch. The level of dumping peaked in 2020, when 16.6 billion units were discharged.
The CND briefing reported that in 2019, the Scottish Environment Protection Agency (SEPA) "changed the rules to allow certain tritium-contaminated effluents from nuclear submarines at Faslane to be discharged into the Gareloch." Both SEPA and the MoD claim these emissions are within official safety limits.
However, Dr Ian Fairlie, CND's science advisor, states that these limits are unreliable, as official estimated doses from tritium contain "large uncertainties."
REF: https://cnduk.org/radioactive-pollution-is-increasing-at-britains-nuclear-bases/
Data presented in the annual RIFE Reports (Radioactivity Food & the Environment) produced by UK Government Agencies, confirms an ongoing increase in the volume of radionuclides discharged to air from the Scottish nuclear submarine sites.
Refurbishment, maintenance and dismantling operations (and associated radioactive waste discharges to sea and air) at N.Sub sites fluctuate in intensity and show a wide variation in annual emissions of radioactivity from such sites. Recently, pressure from Government Audit offices, Defence Committee members, MPs and the public have increased pressure on the

MoD and the various submarine taskforces to increase productivity. The increases tabulated below are clearly a result of such pressures.

Table: Evolution of Radionuclide discharge to Air from Scottish N.Sub bases (Bqs)

	2018 RIFE-24	2023 RIFE 29 Rosyth
Tritium	Nil	1.25E +04
C14	Nil	3.11E +03
Others	Nil	3.97E +04
Coulport		
Tritium	1.77E +09	4.22E +09

N.B.: Radioactivity in Food and the Environment (RIFE) reports provide the results of annual analysis (by Government agencies) of environmental samples from around UK licensed nuclear sites. The reports are online at: *https://www.food.gov.uk/research/radioactivity-in-food-and-the-environment*

APPENDIX 2: RADIATION EMERGENCY: EXCLUSION ZONES AND IODINE TABLETS

See below for extracts from the current UK standard emergency responses at Ministry of Defence N.Sub bases as current. Full texts are available from the following references:

https://www.argyll-bute.gov.uk/sites/default/files/migrated_files/consequence_reports_amalgamated-ac.pdf

https://www.highland.gov.uk/download/downloads/id/23033/loch_ewe_offsite_emergency_plan.pdf

https://www.gov.uk/government/publications/post-nuclear-emergency-response-exercise-reports

https://www.gov.uk/government/publications/jsp-471-defence-nuclear-accident-response

https://www.plymouth.gov.uk/sites/default/files/2024-12/Devonport-Offsite-Emergency-Plan.pdf

Ministry of Defence emergency response: Consequences Reports

HMNB Clyde, RNAD Coulport and Loch Goil Operational Berth

HMNB Clyde

Part 1 – Factual Information

1. Regulation 7(3) Schedule 4 Clause 1(a) - Name and address of the operator:

a. Naval Base Commander Clyde (NBC(C)). b. Her Majesty's Naval Base Clyde, Faslane, Helensburgh, Argyll and Bute, G84 8HL.

2. Regulation 7(3) Schedule 4 Clause 1(b) - Postal address of the premises where the radioactive substance will be processed, manufactured, used or stored, or where the facilities for processing, manufacture, use of storage exist: a. Her Majesty's Naval Base Clyde, Faslane, Helensburgh, Argyll and Bute, G84 8HL.

3. Regulation 7(3) Schedule 4 Clause 1(c) - The date on which it is anticipated that the work with ionising radiation will commence or, if it has already commenced, a statement to that effect: a. HMNB(C) Faslane has worked with ionising radiation to provide technical, logistic and administrative support to nuclear-powered warships since 1963.

Part 2 – Recommendations

1. Regulation 7(3) Schedule 4 Clause 2(a) - The proposed minimum geographical extent from the premises to be covered by the local authority's off-site emergency plan: a. The proposed minimum geographical extent from the premises to be covered by the local authority's detailed emergency plan is an area extending to a distance of 1.5 km from a submarine berth. b. An outline planning zone of 5 km has been determined for HMNB(C) Faslane by the Secretary of State for Defence in accordance with regulation 9(1)(c).

2. Regulation 7(3) Schedule 4 Clause 2(b) – The minimum distances to which urgent protective actions may need to be taken, marking against each distance the timescale for implementation of the relevant action; and Clause 3(a) – The recommended urgent protective actions to be taken within that zone, if any, together with timescales for the implementation of those actions. a. 200 m from the submarine in all directions - controlled evacuation of the immediate area around the submarine (NB: No member of the public would be expected to be within this area).

b. 400 m from the submarine in all directions – personnel to shelter indoors within the first few hours. The following distances are recommended for the urgent protective actions of evacuation, sheltering and stable iodine tablets. These are the largest distances determined by detailed consequence assessment of a range of source terms and include consideration of a range of weather conditions and populations.

c. 1.5 km from the submarine in the downwind sector - provision and consumption of stable iodine tablets within the first few hours. (Note: The provision and consumption of iodine tablets within the first few hours is only a requirement for radiation emergencies involving the naval reactor plant.)

d. 1.5 km from the submarine in the downwind sector - sheltering indoors within the first few hours. It is recommended that the declaration of an Off-Site Nuclear Emergency by the operator to the local authority is the trigger for implementing the off-site emergency plan and initiating all of the above recommended urgent protective actions.

Consequences Reports

HMNB Clyde, RNAD Coulport and Loch Goil Operational Berth

3. Regulation 7(3) Schedule 4 Clause 3(b) – Details of the environmental pathways at risk in order to support the determination of food and water restrictions in the event of a radiation emergency:

a. A release of radioactive material from the submarine could create the requirement for food and water restrictions. For a submarine, this can take the form of an airborne release and/or a marine release.

b. For an airborne release, radioactive material will be dispersed downwind. A proportion of this material will fall to the ground - this material will be available for uptake into the terrestrial food chain via ingestion of contaminated foodstuffs. Radioactive material released to the air may also make its way into the freshwater environment either through run-off or direct deposition on open water.

c. For a marine release, radioactive material will be deposited in the area surrounding the submarine - this may affect the marine food chain and pose a hazard via ingestion of contaminated seafoods.

1. Regulation 7(3) Schedule 4 Clause 4 – The rationale supporting each recommendation

a. Controlled evacuation of the immediate area around the submarine to 200 m in all directions is to protect against the direct gamma radiation hazards from the submarine, in accordance with the lower emergency reference level (ERL) for evacuation of 30 mSv.

b. Sheltering indoors up to 400 m in all directions from the submarine is to protect against the direct gamma radiation hazards from the submarine, in accordance with the lower ERL for shelter of 3 mSv.

c. Consumption of iodine tablets in the 1.5 km downwind zone is to protect against an uptake of radioactive iodine to the thyroid, in accordance with the lower ERL for stable iodine of 30 mSv.1

d. Sheltering within the 1.5 km downwind zone is to protect against contamination following a release of radioactive material, in accordance with the lower ERL for shelter of 3 mSv.

e. The recommendation to shelter and consume iodine tablets out to 1.5 km in the downwind sector differs from the previous recommendation of 1.2 km due to the consideration of a wider range of weather conditions in accordance with Schedule 3. This is in line with the current emergency arrangements, and ensures the public are protected from a full range of possible consequences identified.

f. The Secretary of State for Defence has determined an outline planning zone distance of 5 km.

2. Regulation 7(3) Schedule 4 Clause 5(a) – The rationale for its recommendation on the minimum distances for which urgent protective action may need to be taken: a. The minimum distances recommended are based on a full range of possible consequences of the identified radiation emergencies evaluated in the consequence assessment made in accordance with regulation 5(1). These consequences were subsequently compared with the ERLs listed in PHE-CRCE-049 May 2019.

3. Regulation 7(3) Schedule 4 Clause 5(b) – The rationale for agreement that no off-site planning is required. a. This clause does not apply to HMNB(C) Faslane.

Consequences Reports

HMNB Clyde, RNAD Coulport and Loch Goil Operational Berth

RNAD Coulport

Part 1 – Factual Information

1. Regulation 7(3) Schedule 4 Clause 1(a) - Name and address of the operator:

a. Naval Base Commander Clyde (NBC(C)).

b. Her Majesty's Naval Base Clyde, Faslane, Helensburgh, Argyll and Bute, G84 8HL.

2. Regulation 7(3) Schedule 4 Clause 1(b) - Postal address of the premises where the radioactive substance will be processed, manufactured, used or stored, or where the facilities for processing, manufacture, use of storage exist:

a. RNAD Coulport, PO Box 1, Cove, Argyll and Bute, G84 0PD.

3. Regulation 7(3) Schedule 4 Clause 1(c) - The date on which it is anticipated that the work with ionising radiation will commence or, if it has already commenced, a statement to that

effect: a. HMNB(C) RNAD Coulport has worked with ionising radiation to provide technical, logistic a and administrative support to nuclear-powered warships since 1968.

Part 2 – Recommendations

1. Regulation 7(3) Schedule 4 Clause 2(a) - The proposed minimum geographical extent from the premises to be covered by the local authority's off-site emergency plan:

a. The proposed minimum geographical extent from the premises to be covered by the local authority's detailed emergency plan is an area extending to a distance of 1.5 km from the Explosives Handling Jetty (grid reference NS 2112 8965).

b. An outline planning zone of 5 km has been determined for HMNB(C) RNAD Coulport by the Secretary of State for Defence in accordance with regulation 9(1)(c).

2. Regulation 7(3) Schedule 4 Clause 2(b) – The minimum distances to which urgent protective actions may need to be taken, marking against each distance the timescale for implementation of the relevant action; and Clause 3(a) – The recommended urgent protective actions to be taken within that zone, if any, together with timescales for the implementation of those actions.

a. 200 m from the submarine in all directions - controlled evacuation of the immediate area around the submarine (NB: No member of the public would be expected to be within this area).

b. 400 m from the submarine in all directions – personnel to shelter indoors within the first few hours. The following distances are recommended for the urgent protective actions of evacuation, sheltering and stable iodine tablets. These are the largest distances determined by detailed consequence assessment of a range of source terms and include consideration of a range of weather conditions and populations.

c. 1.5 km from the submarine in the downwind sector - provision and consumption of stable iodine tablets within the first few hours.

d. 1.5 km from the submarine in the downwind sector - sheltering indoors within the first few hours.

It is recommended that the declaration of an Off-Site Nuclear Emergency by the operator to the local authority is the trigger for implementing the off-site emergency plan and initiating all of the above recommended urgent protective actions.

Note: The provision and consumption of iodine tablets within the first few hours is only a requirement for radiation emergencies involving the naval reactor plant.

Consequences Reports

HMNB Clyde, RNAD Coulport and Loch Goil Operational Berth

3. Regulation 7(3) Schedule 4 Clause 3(b) – Details of the environmental pathways at risk in order to support the determination of food and water restrictions in the event of a radiation emergency:

a. A release of radioactive material from the submarine could create the requirement for food and water restrictions. For a submarine, this can take the form of an airborne release and/or a marine release.

b. For an airborne release, radioactive material will be dispersed downwind. A proportion of this material will fall to the ground - this material will be available for uptake into the terrestrial food chain via ingestion of contaminated foodstuffs. Radioactive material released to the air may also make its way into the freshwater environment either through run-off or direct deposition on open water.

c. For a marine release, radioactive material will be deposited in the area surrounding the submarine -this may affect the marine food chain and pose a hazard via ingestion of contaminated seafoods.

Part 3 - Rationale

1. Regulation 7(3) Schedule 4 Clause 4 – The rationale supporting each recommendation:

a. Controlled evacuation of the immediate area around the submarine to 200 m in all directions is to protect against the direct gamma radiation hazards from the submarine, in accordance with the lower emergency reference level (ERL) for evacuation of 30 mSv.

b. Sheltering indoors up to 400 m in all directions from the submarine is to protect against the direct gamma radiation hazards from the submarine, in accordance with the lower ERL for shelter of 3 mSv.

c. Consumption of iodin tablets in the 1.5 km downwind zone is to protect against an uptake of radioactive iodine to the thyroid, in accordance with the lower ERL for stable iodine of 30 mSv.1

d. Sheltering within the 1.5 km downwind zone is to protect against contamination following a release of radioactive material, in accordance with the lower ERL for shelter of 3 mSv.

e. The recommendation to shelter and consume iodine tablets out to 1.5 km in the downwind sector differs from the previous recommendation of 1.2 km due to the consideration of a wider range of weather conditions in accordance with Schedule 3. This is in line with the current emergency arrangements, and ensures the public are protected from a full range of possible consequences identified.

f. The Secretary of State for Defence has determined an outline planning zone distance of 5 km. This is to assist for planning for extremely unlikely events involving all sources of radioactive materials at RNAD.

Coulport

2. Regulation 7(3) Schedule 4 Clause 5(a) – The rationale for its recommendation on the minimum distances for which urgent protective action may need to be taken: a. The minimum distances recommended are based on a full range of possible consequences of the identified radiation emergencies evaluated in the consequence assessment made in accordance with regulation 5(1). These consequences were subsequently compared with the ERLs listed in PHE-CRCE-049 May 2019.

3. Regulation 7(3) Schedule 4 Clause 5(b) – The rationale for agreement that no off-site planning is required. a. This clause does not apply to HMNB(C) Faslane.

Consequences Reports

HMNB Clyde, RNAD Coulport and Loch Goil Operational Berth

Loch Goil Operational Berth

Part 1 – Factual Information

1. Regulation 7(3) Schedule 4 Clause 1(a) - Name and address of the operator:

a. Assistant Chief of Naval Staff Submarines. b. Command Building, HMNB Clyde, Faslane, Helensburgh, G84 8HL.

2. Regulation 7(3) Schedule 4 Clause 1(b) - Postal address of the premises where the radioactive substance will be processed, manufactured, used or stored, or where the facilities for processing, manufacture, use of storage exist: a. QinetiQ Loch Goil, Douglas Pier Loch Goil, Lochgoilhead, PA24 8AE.

3. Regulation 7(3) Schedule 4 Clause 1(c) - The date on which it is anticipated that the work with ionising radiation will commence or, if it has already commenced, a statement to that effect: a. Loch Goil Operational Berth has worked with ionising radiation in berthing nuclear-powered warships for over 45 years.

Part 2 – Recommendations

1. Regulation 7(3) Schedule 4 Clause 2(a) - The proposed minimum geographical extent from the premises to be covered by the local authority's off-site emergency plan:

a. The proposed minimum geographical extent from the premises to be covered by the local authority's detailed emergency plan is an area extending to a distance of 1.5 km from the Loch Goil Operational Berth (grid reference NS 2050 9800).

b. An outline planning zone of 5 km has been determined for Loch Goil Operational Berth by the Secretary of State for Defence in accordance with regulation 9(1)(c).

2. Regulation 7(3) Schedule 4 Clause 2(b) – The minimum distances to which urgent protective actions may need to be taken, marking against each distance the timescale for implementation of the relevant action; and Clause 3(a) – The recommended urgent protective actions to be taken within that zone, if any, together with timescales for the implementation of those actions.

a. 200 m from the submarine in all directions - controlled evacuation of the immediate area around the submarine (NB: No member of the public would be expected to be within this area).

b. 400 m from the submarine in all directions – personnel to shelter indoors within the first few hours.

c. 1.5 km from the submarine in the downwind sector - provision and consumption of iodine tablets.

The following distances are recommended for the urgent protective actions of evacuation, sheltering and stable iodine tablets. These are the largest distances determined by detailed consequence assessment of a range of source terms and include consideration of a range of weather conditions and populations. (Note: The provision and consumption of iodine tablets within the first few hours is only a requirement for radiation emergencies involving the naval reactor plant.)

d. 1.5 km from the submarine in the downwind sector - sheltering indoors within the first few hours. It is recommended that the declaration of an Off-Site Nuclear Emergency by the operator to the local authority is the trigger for implementing the off-site emergency plan and initiating all of the above recommended urgent protective actions.

………

Other sites: from media reports

Nearly 13,000 anti-radiation (iodine) pills have been handed out at Barrow in Furness (where both SSNs and SSBNs are manufactured and fitted with their reactors which are then trialled "in-boat" by BAE Systems) in case of the 'unlikely event' of a nuclear emergency.

Records reveal that childcare facilities and care homes situated near BAE Systems have received iodine tablets should submarine reactors go into meltdown. Authorities and shipyard bosses emphasise that the possibility of radiation ever being released is unlikely. 12,020 anti-radiation pills have been sent to various childcare facilities, including: nurseries, schools, colleges and daycares located around the shipyard. The medication was issued between 2016 and 2021. 930 tablets have been distributed to care homes, including day centres and adult residential care, in the area surrounding BAE.

Iodine tablets help protect the thyroid gland against harmful radioactive iodine exposure in the event of a nuclear accident.

Records show that a further 84,000 stable iodine tablets were pre-issued to people in Devonport, Plymouth and Portland (an occasional N.Sub berth) from 2016-21 to protect them from radiation. Medicine went to nurseries, schools, care homes and clinics near naval docks.

Pre-distributed iodine: Information from a number of countries indicates that Belgium, Canada, the Czech Republic, Finland, France, Germany, Luxembourg, Sweden and Switzerland have pre-distributed iodine in the vicinity of nuclear reactors – the area covered has ranged from 4 km to 20 km radius of the nuclear reactors. In the UK, the decision to pre-distribute rests with the local authority and it has only occurred in a limited number of cases and a 3 km radius has tended to be used.