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HMAS *Stirling* Radiological Environmental Monitoring Program (REMP): Baseline Assessment

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ASA

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Acknowledgement of Country

The Australian Submarine Agency (ASA) acknowledges the Traditional Custodians of Country throughout Australia. The ASA recognises their continuing connection to traditional lands and waters and would like to pay respects to Elders past and present, including those Aboriginal and Torres Strait Islander people who have contributed to the defence of Australia in times of peace and war.

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Glossary of Terminology

Term	Definition
Becquerel	A Becquerel (Bq) is an International Standard (SI) unit of radioactivity, which counts how many particles or photons (in the case of wave radiation) are emitted per second by a source. One Bq equals an average of one disintegration of a radionuclide per second.
Bioaccumulation factors	The ratio of the chemical concentration in an animal to the amount of chemical to which it is exposed through all routes, including the food chain.
Cosmic ray spallation	Cosmic ray spallation refers to the formation of chemical elements from the impact of cosmic rays on an object. It is a naturally occurring nuclear reaction.
Dosimeter	A device used to measure an absorbed dose of ionising radiation.
Gamma spectroscopy	A qualitative analysis process to detect the presence of artificial and naturally occurring radionuclides
Gamma spectrometry	A quantitative analysis process used to quantify the activity levels of gamma-emitting radionuclides in Bq/kg.
Gamma suite	This term reflects the suite of laboratory tests analysing for presence and concentrations of the following naturally occurring and artificial gamma emitting radionuclides: K-40, Co-60, Cr-51, Mn-54, Co-58, Fe-59, Zn-65, Zr-95, Nb-95, Sb-125, I-131, Cs-134, Cs-137, Hf-181, Ta-182, W-187, Pb-210, Ra-226, Ra-228, Th-232, Am-241
Half-life	The time taken for half of a group of radioactive atoms to decay. For example, after two half-lives a radionuclide have decayed such that only 25% of its original quantity remains. After five half-lives, just 3% of material remains and after 10 half lives, only 0.1% of the radioactive material remains. Every radionuclide has a unique half-life.
Ionising radiation	Ionising radiation refers to radiation that has enough energy to break an electron away from an atom, a process called ionisation.
Isotope	Atoms with the same number of protons but different numbers of neutrons are called isotopes. They share almost the same chemical properties, but differ in mass and therefore in physical properties. There are stable isotopes, which do not emit radiation, and there are unstable isotopes, which do emit radiation. The latter are called radioisotopes.
Marine invertebrates	Animal species that lack a true vertebral column (backbone) and primarily originate and diversify in marine environments.
Millisievert (mSv)	The millisievert (mSv) is a SI radioprotection unit measuring the radiation dose received either from a radioactive source or from other sources like X-rays in medicine. It is equal to 0.001 Sievert (Sv)
Minimum Detectable Concentration (MDC)	MDC is the level in which the Laboratory can identify the presence of a particular radionuclide activity level. The MDC varies from sample to sample and location to location due to differences in naturally

Term	Definition
	occurring radioactivity, differences in the weight of the sample, detection differences, and statistical fluctuations.
NORM	**N**aturally **o**ccurring radioactive **m**aterial, sometimes known as NORM, is the term used to describe any radioactive substance that exists naturally in the environment. NORM is found everywhere in the environment including soil, rocks, water, air and vegetation. It is also present in the human body and all living tissues.
Radionuclides	Radionuclides (or radioactive materials) are a class of chemicals where the nucleus of the atom is unstable. They achieve stability through changes in the nucleus. This process is called radioactive decay or transformation, and often is followed by the release of ionising radiation (beta particles, neutrons, or gamma rays).
Radionuclide of Interest	Refers to a nuclide that is the limiting nuclide in a mixture. Co-60 is the primary radionuclide of interest during maintenance of naval nuclear propulsion plants, due to its prevalence, long half-life and high radiological dose co-efficient.
Radiological Dose Co-Efficient	A quantity that, when multiplied by a measurement of radionuclide intake, air, particle, or environmental radioactivity concentration, will yield an organ equivalent dose or the effective dose to the exposed individual. The higher the radiological dose-co-efficient of a radionuclide, the higher the expected dose when exposed.
Secular Equilibrium	Secular equilibrium is state in which a number of radionuclides in a decay chain occur in proportional quantity to each other, indicating natural decay pathways. When used to classify naturally occurring radionuclides, this indicates no contamination from outside or artificially created sources. Contamination would be observed where specific radionuclides are out of secular equilibrium.

Introduction

1. The Australian Submarine Agency (ASA) engaged AECOM[1] to undertake an environmental baseline radiological contaminant assessment (hereafter referred to as baseline assessment) at HMAS *Stirling* (hereafter also referred to as the Site) to establish the levels of radionuclides (or radioactive materials) present in the environment. This has been conducted prior to the commencement of conventionally-armed, nuclear-powered submarine (NPS) visits by the United Kingdom (UK) and United States (US) under Submarine Rotational Force West (SRF-West) and AUKUS Pillar One.

2. The baseline assessment will inform the development of a Radiological Environmental Monitoring Program (REMP) which will be maintained over the life of the NPS program. This baseline assessment serves as a reference point for identifying any changes in radiation levels during NPS activities at the Site, to ensure the protection of the environment and health of personnel and the public [1]. The baseline assessment has been conducted in accordance with ASA's Commitment to Nuclear Safety and Australian Nuclear Mindset [2] and is consistent with international best practice.

3. In March 2023, AUKUS partners announced an Optimal Pathway to develop capability and technology for Australia's acquisition and safe operation of conventionally-armed NPS [3]. The Optimal Pathway includes increased NPS visits to Australian ports leading to the rotation and maintenance of UK and US NPS at *HMAS Stirling* from 2027 as part of SRF-West.

4. The baseline assessment of the Site at Garden Island, Western Australia (WA) establishes the baseline radiological profile of the area prior to commencement of SRF-W activities, and ahead of Australian NPS operating from *HMAS Stirling*. The ongoing REMP results will be compared to this baseline assessment to verify no discernible impact to quality of environment or risk to human health from NPS activities.

5. Table 1 provides a summary of the overall results of the baseline assessment; further details are in the results and discussion section.

[1] aecom.com – an infrastructure consulting firm specialising in areas including the provision of environmental services to achieve compliance, reduce or eliminate risks while protecting the natural environment.

Table 1: Summary of Results for the Baseline Assessment at HMAS Stirling and its Surrounds

Environmental Aspect	Findings
Shoreline Gamma Radiation Surveys	Results identified levels 15% *lower than* the average natural background radiation level for Australia.
Radon	Results identified levels which were *consistent with* the average natural background levels for Australia and globally.
Marine Water	Radionuclide analysis conducted on environmental media samples reported naturally occurring isotope concentrations, including tritium (H-3), that were low and *consistent with* expected natural background levels. Iodine-131 (an artificial isotope commonly used in nuclear medicine) was reported in one marine sediment sample with low concentrations (para 29). Cobalt-60 was reported in one sample of marine biota sample (seagrass) at very low levels (8 Bq/kg), however discarded as not a true detection (para 32). This result will be closely monitored in future sampling events.
Marine Sediment	
Marine Biota	
Area Monitoring (Dosimetry)	Results identified levels 30% *lower than* the average natural background radiation level for Australia.
Groundwater	Radionuclide analysis conducted on environmental media samples reported naturally occurring isotope concentrations that were low and *consistent with* expected natural background levels. No artificial isotopes were reported above detection limits.
Terrestrial Soil	

Location and Site

6. Garden Island has several historically significant sites that are of interest to the public and Defence members (Annexes A and B). Cliff Point, Careening Bay, Garden Island Batteries, J Gun Battery, the site of JF Mills' residence and the Z Force memorial have historical significance [4].

7. In addition to the historical sites, Garden Island has several environmentally significant species and the area surrounding the Island has several conservation areas shown in Annex A. These include the Carnac Island Nature Reserve located 3 km north, the Commonwealth marine environment situated 5.85 km west, Shoalwater Islands Marine Park located 600 m south and Shoalwater Island Nature Reserve located 2 km south of Garden Island. Additionally, Cockburn Sound contains commercial mussel farms approximately 4 km northeast of Garden Island. Annex B shows the different sectors. Species of plants and animals identified include:

a. **Causeway Sector** – Birds

b. **Careening Bay Sector** – Birds including Little Penguin nesting sites

c. **Helicopter Sector** – Birds

d. **Beagle Road Sector** – Tammar wallabies

e. **Fire Ground Sector** – Tammar wallabies and vegetation of environmental conservation significance

f. **Torpedo Sector** – Vegetation of environmental conservation significance

g. **RANAWED Sector** – Tammar wallabies, vegetation of environmental conservation significance and reptiles

h. **Herring Bay Sector** – Birds, Tammar wallabies, vegetation of environmental conservation significance and reptiles.

8. Garden Island, traditionally known as *Meeandip* in the Noongar language, and its surrounding waters holds a deep historical and cultural significance to the Noongar people. The area is part of the traditional lands of the Whadjuk Noongar people who have used the resources in this region for food, medicine, tools and other necessities [5]. Many of the identified species and areas of environmental significance are also areas and species of cultural significance to the Noongar people.

9. The Site is situated on the southern end of Garden Island approximately 2.5 km off the coast of Rockingham, WA and is connected to the mainland via a causeway. There are six types of flora on Garden Island that are listed as environmentally significant due to their limited distribution in other areas and there are several species of fauna that are of environmental interest due to their decline on the mainland [4]. The seagrass beds on the eastern shoreline of Garden Island hold significant marine ecology status due to their limited distribution [4]. Approximately 30 percent of the island is used by Defence. The remainder is open to public use and subject to environmental conservation [4]. The map in Annex C shows Defence restricted areas and the public use areas.

10. Within the *Stirling* designated zone[2], approximately 15 hectares have been identified where NPS Activities may be conducted and NPS Facilities may be constructed (area shown in red, in Figure 1). Approximately half of the Site is currently developed, with the remaining area consisting of natural bushland to be developed in support of Australia's NPS program over the next decade. The primary function of the Site is to provide operational, training, and logistics support to Royal Australian Navy ships, submarines and aircraft based in WA. It will be the main operational base for Australian NPS and will host visiting NPS.

[2] A 'designated zone' is a term defined under the *Australian Naval Nuclear Power Safety Act* 2024. The *Stirling* designated zone is described in the *Australian Naval Nuclear Power Safety Regulations 2025*, and refers to the entire island of Garden Island, and its surrounding waters.

Figure 1: HMAS Stirling with the red highlighted section indicating areas for planned NPS Activities and NPS Facilities

Existing Radioactivity Sources

11. **Naturally occurring radioactive materials (NORM).** NORM occur in various concentrations throughout the environment. Typically, this consists of uranium (U) and thorium (Th) decay series' radionuclides and potassium-40 (K-40). The concentration of these radionuclides (and the subsequent natural background radiation dose) varies throughout the world.

12. **Historical Radioactivity Sources.** Due to historical atmospheric nuclear weapons testing at Montebello Islands (1250 km North), Maralinga (1500 km East), nuclear accidents (e.g. Fukushima Dai-ichi Nuclear Power Plant) [6] and other historic atmospheric nuclear weapons testing in the Southern Hemisphere, there may be low concentrations of artificially produced radionuclides including caesium-137, plutonium-239 and plutonium-240 [7] [8].

NPS Radioactivity Sources

13. During the operation and maintenance phases of the NPS program there will be a number of future potential radioactivity sources, predominantly from waste products such as used personal protective clothing, ion exchange resins used to decontaminate liquids and redundant tools and equipment. All radioactive materials, including waste, will be strictly controlled to limit and contain any potential exposure. Activities associated with handling radioactive materials will be carefully planned, with control measures in place to keep potential exposure as low as reasonably achievable [9] [10].

14. **Radioactivity within coolant water.** NPS nuclear reactors use pressurised coolant water circulating through the reactor core and heat exchangers, with the offset heat creating steam in a secondary circuit to drive the propulsion plant. A number of radionuclides are formed within the coolant water from neutron activation. The vast majority of the activity in this coolant water is

accounted for by short-lived radionuclides including argon, nitrogen, fluorine, and manganese. The concentration of even the longest lived of these radionuclides decays to one-millionth of the initial concentration after 48 hours, which makes them undetectable and therefore would have no long-term discernible effect on the environment, even were it released.[3] A number of other longer lived radionuclides can also be produced from neutron activation of coolant water and componentry within the primary circuit, including:

a. **Cobalt-60 (Co-60).** Cobalt-60 is not naturally occurring in the environment. Due to its high-energy gamma emissions [11] this radionuclide is easily detectable via gamma spectroscopy. Cobalt-60 decays with a low energy beta resulting in a low dose coefficient and a long half-life of 5.27 years. It is also the most prevalent radionuclide found in NPS reactor coolants. For these reasons, cobalt-60 is the primary radionuclide of interest for environmental monitoring of NPS during its operational phase. The primary exposure pathways of interest for cobalt-60 are ingestion (drinking water and marine biota consumption), inhalation and external exposure when in close proximity.

b. **Tritium (H-3).** Tritium is a naturally occurring and abundant radionuclide, occurring from cosmic ray spallation[4] in the upper atmosphere. Tritium is also produced from neutron flux in the reactor coolant system. It does not bio-accumulate in humans or non-human biota. Tritium emits a weak form of radiation as a low-energy beta particle [12]. The tritium radiation does not travel very far in air or water [12] and cannot penetrate the skin. Tritium is usually found as tritiated water and can enter the body if people ingest food or water containing tritium, absorb it through breaks in the skin (open wounds, cuts etc.), or inhale it as a gas in the air [13].

c. **Carbon-14 (C-14).** Carbon-14 is produced naturally in the upper atmosphere from cosmic ray spallation and is abundant within the oceans. It is also produced through neutron bombardment of nitrogen and oxygen within the reactor coolant systems. Although carbon-14 has a long half-life of >5700 years, it is quickly excreted from living organisms and has a very low radiological dose coefficient for humans (5.8×10^{-10} Sv/Bq) [14]. For context, a human would need to consume approximately 10 million litres of water containing this equivalent radioactivity to receive a dose of one millisievert (mSv) from naturally occurring carbon-14. Due to its abundance in the oceans and low radiological dose co-efficient, it is not considered a radionuclide of interest for this assessment.

d. **Other Radioactive Corrosion Products.** In addition to cobalt-60, carbon-14 and tritium, radioactivity can also occur from trace quantities of corrosion and wear of activated surfaces within the reactor from contact with the cooling water. These include the radionuclides with half-lives of 24 hrs or more, for example tungsten-187, chromium-51, hafnium-181, iron-55, iron-59, nickel-63, niobium-95, zirconium-95, tantalum-182, manganese-54, zinc-65, antimony-125, and cobalt-59.

[3] Within 48h, these radionuclides will have decayed more than 20 half-lives. Any radionuclide, which has decayed more than 10 half-lives, will have a concentration so close to zero that it is considered practically zero.

[4] Cosmic ray spallation refers to the formation of chemical elements from the impact of cosmic rays on an object. It is a naturally occurring nuclear reaction.

Baseline Assessment

15. The baseline assessment was established using extant characteristics of the environment at Garden Island and location of SRF-West. Maps showing the monitoring sections are located in Annex D. A targeted sampling plan was implemented with the following considerations:

a. Potential for distribution of artificial radionuclides;

b. Sites known or considered to be potentially contaminated with radiological materials;

c. Sites where NPS will be located;

d. Locations used for recreational activities;

e. Conservation areas; and

f. Existence of current monitoring locations used for temporary NPS visits.

16. Radionuclides occur naturally in the atmosphere, and are present in almost every component of the environment around us, including in the air we breathe, the water we drink, the food we eat, and even within our bodies.

17. There are a number of pathways by which radionuclides are transported throughout the ecosystem, accumulate in the environment and potentially result in radiological doses to humans and non-human biota. The baseline assessment focused on the following:

a. **Background Radiation**. Background radiation from NORM accounts for the majority of the radiological dose to humans [15]. Establishing baseline monitoring at the boundary of the Site and the publicly accessible areas provides evidence of the existing background radiation levels for future comparison.

b. **Radon**. A naturally occurring radioactive gas, created as the radioactive decay product of radium. The radionuclide radon-222 is not generated through the NPS program, however it is extremely prevalent in the environment and one of the most common natural radionuclides on Earth, present in the air, soil and homes. Given its pervasiveness, radiation from radon-222 has the potential to impact on other measurements within the program. Establishing a baseline at the Site enables future comparison or delineation if required.

c. **Marine Water.** Radionuclides in marine waters are more bioavailable than those found within soils and sediments [16] due to being more readily dissolved and dispersed in the water column. Characterisation of radionuclide concentrations in water samples were conducted in areas where NPS will be docked and in surrounding areas at the Site.

d. **Marine Sediment and Terrestrial Soil**. Transport of radionuclides from soils into plant root systems can result in the bio-accumulation of radionuclides [17]. As local fauna ingest some of these species, this can result in radionuclide transfer throughout the ecosystem. Chemically mobile or leachable radionuclides can migrate from soils to other areas of the environment during rain and flooding events. Similarly, radionuclides in sediments can be bio-accumulated in seafloor dwelling flora and fauna. Typically, radionuclides in sediments are more bioavailable in comparison to soils, and therefore have a higher potential for contaminant transport into sensitive organisms. A sample is considered a marine sediment sample if it was collected from below the high tide line.

e. **Marine biota**. Measurement of radionuclides in marine biota is a critical step in developing a defensible radiological baseline. Measuring radionuclides in plants and animals is an important part of establishing a reliable picture of natural background radiation levels. This helps us understand how much radiation sensitive species may receive, and supports the protection of people, the environment and the ability to detect any changes over time. These species were chosen due to their ability to concentrate any artificially occurring radionuclides, should these be present. Marine bivalves (molluscs) have high bioaccumulation factors for radionuclides (compared to other biota) [18]; are consumed by the public and are commercially farmed within Cockburn Sound (approximately 4km away from the Site). Marine bivalves and seagrass from both the designated zone for NPS Activities and NPS Facilities (red area, figure 1) and surrounding areas were sampled and analysed. Due to animal ethics permits, and sample preparation requirements, all other invertebrate sampling was outside the scope of the baseline assessment.

18. The baseline assessment consisted of measuring radiation levels and analysing samples of marine water, marine sediment and marine biota. Marine water and marine sediment would be the most likely affected by releases of radioactivity. The environmental samples were analysed for cobalt-60 and other gamma emitting radionuclides. Cobalt-60 was specifically analysed because its presence in the environment can be solely attributed to liquid effluents from nuclear power plants or NPS operations. Specific testing parameters for each area of interest can be found at Table 2.

Table 2: Baseline Assessment Requirements

Media	Testing parameters	Analysis
Shorelines	• Dose rate survey • 3 sites, quarterly survey at each site	Areas of shoreline which are uncovered at low tide to determine if any radioactivity from bottom sediment has washed ashore.
Radon (outdoors)	• Passive radon detector • 2 sites, quarterly change at each site	Radon concentration measured to compare against regulatory limits.
Marine waters (filtered and unfiltered)	• Gamma Suite[5] • H-3 • Gross alpha and beta counting • 9 sites, quarterly collection at each site	Characterisation of radionuclide concentrations in both filtrate and residue fractions was conducted in areas where NPS will be docked and within Cockburn Sound.
Marine sediment	• Gamma Suite • 23 sites, quarterly collection at each site	Characterisation of radionuclide concentrations in sediment was conducted in areas where NPS will be docked and within Cockburn Sound.
Marine biota (molluscs and seagrass)	• Gamma Suite • Biannual sampling (end of summer and winter) at six locations	Biota collected biannually in areas where NPS will be docked and within Cockburn Sound to characterise any radionuclide concentrations.
Area monitoring	• Passive dosimeters • 19 sites, quarterly change at each site	Located across the site to monitor ambient radiation around the proposed Controlled Industrial Facility.
Groundwater	• Gamma Suite • Gross alpha and beta counting • One event, 10 samples	Samples collected from around the proposed Controlled Industrial Facility to characterise the concentration of radionuclides.
Terrestrial soil	• Gamma Suite • One event, 5 samples	Samples collected from above shoreline near the proposed Controlled Industrial Facility to characterise the concentration of radionuclides.

[5] Gamma suite is a laboratory suite of tests that screens for the following radionuclides: Co-60, K-40, Cr-51, Mn-54, Co-58, Fe-59, Zn-65, Zr-95, Nb-95, Sb-125, I-131, Cs-134, Cs-137, Hf-181, Ta-182, W-187, Pb-210, Ra-226, Ra-228, Th-232, Am-241

Results and Analysis

19. Overall, radionuclide data from this report demonstrates that the environmental media are consistent with background conditions for both natural and artificial isotopes within Australia. Specific details of results were as follows.

20. **Shoreline Radiation Survey**. The surveys were undertaken on a quarterly basis to establish a baseline level of activity and the results were compared against the natural background level of radiation within Australia. The average dose received from natural background radiation (from terrestrial and cosmic sources) in Australia is approximately 0.9 mSv/yr, which excludes contribution from inhalation of radon gas and radiation sources received through food consumption) [15]. The natural background radiation range varies significantly across the country depending on type of soil, latitude, and altitude.

21. Three key shoreline locations were selected to undertake measurements (Annex E):

a. **Armament Wharf** – this wharf is the key location of unloading and loading of armament (non-nuclear only). It has been established as the northern point of monitoring on the Island.

b. **Mid-shore Area (Careening Bay)** – this area is a main area of shoreline utilised by ADF personnel and their families primarily for recreational activities. No NPS related work has been or will be undertaken in this area; however, it will be an important reference for the movement of any radiological releases away from the primary NPS work area.

c. **South Shore Area (near the Causeway)** – this area is not a prominent work area; however; it will be an important reference for the movement of any radiological releases away from the primary NPS work area.

22. The annual dose rate average[6] across the assessment period for shoreline surveys is 0.77 mSv/yr. This result is approximately 15% lower than the Australian natural background levels (0.9 mSv/yr) [15] as shown in Figure 2. Australian natural background levels (excluding contribution from radon gas and food consumption) are quite low compared to the rest of the world, with global averages ranging from 1 to 13 mSv per year. [16]

[6] The meters used to undertake the measurements have an uncertainty factor of less than +/- 3% (Cs-137).

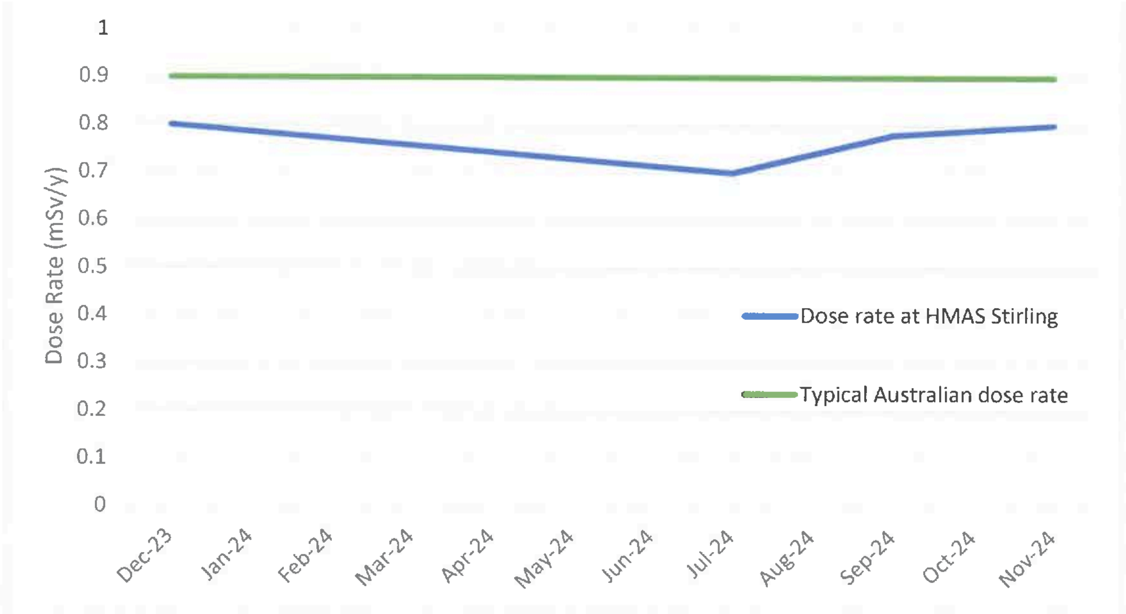

Figure 2: Shoreline radiological survey results

23. **Radon Measurements**. Atmospheric monitoring for radon occurred on a quarterly basis at two locations – the entrance to the Armament Wharf and the entrance to the Garden Island airfield. A map showing the location of these samples is located at Annex E (atmospheric monitoring – blue dots).

24. Radon levels across the monitoring period measured below 12 Bq/m^3. This is within the expected range for outdoor concentrations globally (5 - 15 Bq/m^3) [19] and for those in Australia (3 - 24 Bq/m^3) [20]. It is also well below ARPANSA's recommended screening value for domestic households of 200 Bq/m^3 or 1000 Bq/m^3 for workplaces [16]

25. **Radionuclides in Marine Waters.** Nine marine water samples were collected across the Site area each quarter, totalling 36 samples. A map showing the location of water samples is located at Annex F (figure 1).

26. The results of gamma spectroscopy and spectrometry of 36 marine water samples identified no artificial radionuclides above minimum detectable concentration (MDC)[7] in any samples, with results found at Table 3. Naturally occurring radionuclides were considered within the normal and naturally occurring ranges within Australia, not indicating contamination. These radionuclides will be monitored over the course of the program.

[7] See pages 5-6 for definition

Table 3: Results of artificial radionuclides in marine waters taken at Annex F (nil detected)

Radionuclides	No of Samples with Detectable Amount (n=36)	Range (Bq/kg)	Range of MDC (Bq/kg)
Cobalt 60 (Co-60)	0	<MDC	<0.05 – <0.3
Other artificial nuclides (Gamma Suite)[8]	0	<MDC	<0.1 – <2

27. Marine water samples were analysed for gross alpha and beta radioactivity, with results demonstrating low-levels of radioactivity and not indicating contamination. Additionally, water samples were tested for tritium (H-3), with results showing safe activity levels. Work previously undertaken by the CSIRO identified typical tritium levels in Australian seawater to be around 15 Bq/L.[9] Results for one sample showed a result of 40 (± 20) Bq/L, however this is within the error margin for what is considered normal in Australia and was only just outside the MDC ranges of 10–39 Bq/L. For context, the World Health Organisation Guideline for tritium is 10,000 Bq/L [21], meaning the levels detected were approximately 250 times lower than the internationally recognised safe drinking level.[10]

28. **Radionuclides in Marine Sediment**. Marine sediments were collected quarterly in areas along the dockside and Cockburn Sound, Garden Island and the anchorage point. A map showing the location of sediment samples is located at Annex F (figure 1). A total of 94 marine sediment samples were taken over the course of the year and analysed by gamma spectroscopy and gamma spectrometry.

29. No artificial radionuclides were detected with the exception of one sample, which detected iodine-131 (I-131) with a very low activity level of 2 Bq/kg. This value was lower than the MDC for all other samples (<3 to <5 Bq/kg), as seen in Table 4.[11] Given this extremely low activity level and iodine-131's short half-life in the environment of 8 days, this is likely not a true detection of iodine-131 but rather a sampling error. This does, however, serve as an indicator for the potential for iodine-131 to be present from sources such as medical isotopes, and will be monitored in future sampling. Iodine-131 is a common medical isotope, which can enter ocean waters primarily through sewage effluent from wastewater treatment plants [22] [23]. For context, should a human consume nothing but food containing an activity level of 2 Bq/kg of iodine-131 for an entire year, they would still only receive a

[8] See pages 5-6 for definition
[9] Tritium in Australian precipitation: A 50 year record - ScienceDirect
[10] Australian Drinking Water Guidelines do not specify a specific standard for tritium activity level in water, instead using exposure dose from all sources of radiation of 1 mSv per year. If all radiation within the water were tritium, the activity level for tritium in drinking water required to exceed 1 mSv per year would be 70,000 Bq/L.
[11] MDCs vary naturally from sample to sample, depending on the size, weight, location and naturally occurring background radiation in the area. This sample was detectable, however at a lower concentration than what was possible in all other samples.

dose rate of 0.5 mSv, which is the equivalent dose of approximately five chest X-rays or 166 hours of flying.

30. Table 5 shows the range of naturally occurring radionuclides in marine sediment. The ratio of radionuclide concentrations were all within the expected levels within Australia demonstrating secular equilibrium[12] and therefore a lack of contamination.

Table 4: Results of artificial radionuclides in Marine sediments from HMAS Stirling and its surrounds

Radionuclides	No of Samples with Detectable Qty (n=94)	Range (Bq/kg)	Range of MDCs (Bq/kg)
Cobalt 60 (Co-60)	0	<MDC	<0.2 - <3
I-131[13]	1	<MDC – 2	<3 – <5
Other artificial nuclides (Gamma Suite)	0	<MDC	<0.1 – <10

Table 5: Results of naturally occurring radionuclides in marine sediments

Radionuclides	Number of Detections (n=94)	Average value (Bq/kg)[14]	Range (Bq/kg)
Radium-226	94	7.9	3.8 - 16
Lead-214	94	8.5	4 - 17
Bismuth-214	92	7.4	3 - 15
Lead-210	80	20.1	5 - 60
Radium-228	80	8.7	1.5 - 16
Lead-212	93	7.9	2.6 - 18
Bismuth-212	36	15.2	7 - 30
Thallium-208	63	2.5	0.5 - 6
Potassium-40	88	76.2	21 - 170

31. **Marine biota and fauna.** A total of 12 seagrass samples (*Posidoinia sinuousa, Posidoinia australis sinuousa, Posidonia australis*) were collected across the area over two events during the

[12] See pages 5-6 for definition
[13] Detected in one sample, however in values lower than other MDCs therefore likely an error
[14] Ratios of radionuclides were consistent with the naturally occurring U-238 and Th-232 decay series, indicating secular equilibrium. This is considered normal and indicating a lack of contamination.

baseline assessment. The samples were collected in accordance with the exemption permit issued by Department of Primary Industries and Regional Development (DPIRD) for the activity, by using cut samples rather than removing the whole plant from the seabed. A map showing the location of flora samples is located at Annex F (figure 1).

32. The seagrass samples were analysed by gamma spectrometry. Results indicated a lack of artificial radionuclide contamination across all samples. One sample reported trace quantities of Co-60 (8 Bq/kg), however given its low value[15] and the lack of presence in equivalent samples in any other area from any other sample type, confidence in this being a true detection of Co-60 was low. It has therefore been discarded as a laboratory anomaly. This will however be noted and monitored in the future radiological environment monitoring program. Naturally occurring radionuclides were consistent with a lack of contamination.

33. A total of 12 marine fauna samples (mussels *Mytilus edulis*) were collected across the area over two sampling events in the year. The samples were collected in accordance with the exemption permit issued by DPIRD for the activity. A map showing the location of biota samples is located at Annex F (figure 1).

34. The primary marine fauna mussels were analysed by gamma spectrometry, with no artificial radionuclides detected. Naturally occurring radionuclide activity was consistent with a lack of contamination and with mussels found in other regions of Australia.

Table 6: Results of artificial radionuclides in marine biota and fauna from HMAS Stirling and its surrounds

Radionuclides	Seagrass (n=12)		Mussels (n=12)		Crustaceans (N/A)[16]	
	No of Detections	Activity (Bq/kg)	No of Detections	Activity (Bq/kg	No of Detections	Activity (Bq/kg)
Cobalt 60 (Co-60)	1 [17]	<MDC	0	<MDC	N/A	N/A
Other artificial nuclides (Gamma Suite)	0	<MDC	0	<MDC	N/A	N/A

35. **Area monitoring (dosimetry).** Ambient radiation levels were continuously measured using sensitive dosimeters, posted in the locations shown by the white dots in Annex F, Figure 1. These dosimeters formed a perimeter around key proposed berthing areas and operational sites. Readings were taken from the dosimeters quarterly. Two processing methods were employed; during Q1 and

[15] For context, if a human ate nothing but food containing the reported activity of Co-60 activity over the course of one year, it would result in the equivalent of less than 2% of recommended annual dose rate of 1mSv. It would be the equivalent radiation dose of flying for 50 hours.
[16] Outside of scope for baseline monitoring
[17] One sample detected Co-60 at 8 Bq/kg, however was discarded as a laboratory anomaly. It will be monitored during future environmental monitoring programs.

Q3, the dosimeters were processed for 'dose equivalent', while in Q2 and Q4 the dosimeters were processed for ambient exposure.

36. Results indicate an average annual dose rate of 0.64 mSv, which is approximately 30% lower than average natural background levels in Australia from terrestrial and cosmic sources (0.9 mSv [15]).

Table 6: Average net exposure results of Environmental Dosimetry, with annual results compared to average background levels

Dosimeter Number	Average Net Exposure (mSv)	Dosimeter Number	Average Net Exposure (mSv)
1	0.18	11	0.12
2	0.20	12	0.23
3	0.19	13	0.19
4	0.17	14	0.21
5	0.20	15	0.16
6	0.08	16	0.14
7	0.14	17	0.10
8	0.15	18	0.11
9	0.16	19	0.11
10	0.20	**Average Quarterly Exposure**	**0.16**
		Average Annual Exposure	**0.64**
		Average Background Level	**0.90**

37. **Groundwater**. A total of ten samples of groundwater were taken from on-site groundwater monitoring wells in the proposed area for NPS Activities and NPS Facilities during the baseline assessment. A map showing the location of samples is located at Annex F (Figure 2). All groundwater samples were analysed for the same artificial and naturally occurring radionuclides as marine sediments, as well as for gross alpha and beta activity.

Table 7: Results of artificial radionuclides in Groundwater samples (nil detected)

Radionuclide	No of Samples with Detectable Qty (n=10)	Range (Bq/kg)	Range of MDC (Bq/kg)
Cobalt 60 (Co-60)	0	<MDC	<0.1 – <0.4
Other artificial nuclides (Gamma Suite)	0	<MDC	<0.04 – <0.7

38. No artificial radionuclides were reported above detection limits in the groundwater samples analysed. Results can be found at Table 7.

39. For naturally occurring isotopes, all radionuclides were consistent with other groundwater samples in Australia [21] [24] [25]. Gross alpha and beta activity were the screening activity level of 0.5 Bq/L.

40. **Terrestrial Soil.** A total of five samples of terrestrial soil targeting the low tide line in the proposed NPS Activities and NPS Facilities area (red area, figure 1) and two to the southwest were taken during the baseline assessment and submitted for radionuclide analysis via gamma spectroscopy and spectrometry. A map showing the location of samples is located at Annex F (figure 3). No artificial radionuclides were detected above MDC (Table 8), and naturally occurring radionuclides were consistent with natural concentrations.

Table 8: Results of artificial radionuclides in terrestrial soil (nil detected)

Radionuclides	No of Samples with Detectable Qty (n=5)	Range (Bq/kg)	Range of MDC (Bq/kg)
Cobalt 60 (Co-60)	0	<MDC	<0.5 – <1
Other artificial nuclides (Gamma Suite)	0	<MDC	<0.1 – <10

Ongoing monitoring

41. The REMP will continue on an annual basis to provide confidence that the NPS Program and all activities at SRF-West will be carried out to the highest safety standards to protect our people, the community, and the environment. Results of ongoing monitoring will be compared to this baseline assessment on an annual basis for any substantive changes. Sampling inclusions in the REMP will be:

a. Marine water sampling;

b. Marine sediment sampling;

c. Marine invertebrates and seagrass sampling;

d. Environmental monitoring using passive dosimetry;

e. Shoreline radiometric surveys; and

f. Others as required if results indicate a need for further monitoring or the Site's future development identifies a need.

Conclusion

42. The baseline assessment has identified the background level of radiation at the Site. The radionuclide data demonstrates that the environmental media are consistent with background conditions for both natural and artificial isotopes within Australia.

43. Overall, the results of the baseline assessment indicate no risk of harm to our people, public or the environment, acknowledging the previous use of the area by Defence, including use by visiting United States' NPS, and the substantial industrial presence within close proximity to Garden Island and the Site.

44. The REMP will continue on an annual basis and the resulting reports will be published each year.

Applicable Documents

45. Standards and specifications referenced can be found in the References section at the end of this document.

Annexes:

A. Garden Island and Surrounding Environmental Conservation Areas

B. Garden Island WA Site showing Management Sectors and Major Features

C. Garden Island WA – Defence Areas and Public Access Areas

D. Radiation Monitoring Locations by Sectors

E. Shoreline Radiation Survey Measurement Locations

F. Monitoring Locations by Sample Type for Garden Island

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Annex A to:
BN96149861
Dated 22 Sep 2025

Garden Island and Surrounding Environmental Conservation Areas

Source: Australian Government, Department of Defence, "Garden Island Western Australia Heritage Management Plan (BN65633697)," Department of Defence, 2013

Garden Island WA Site Plans showing Management Sectors and Major Features

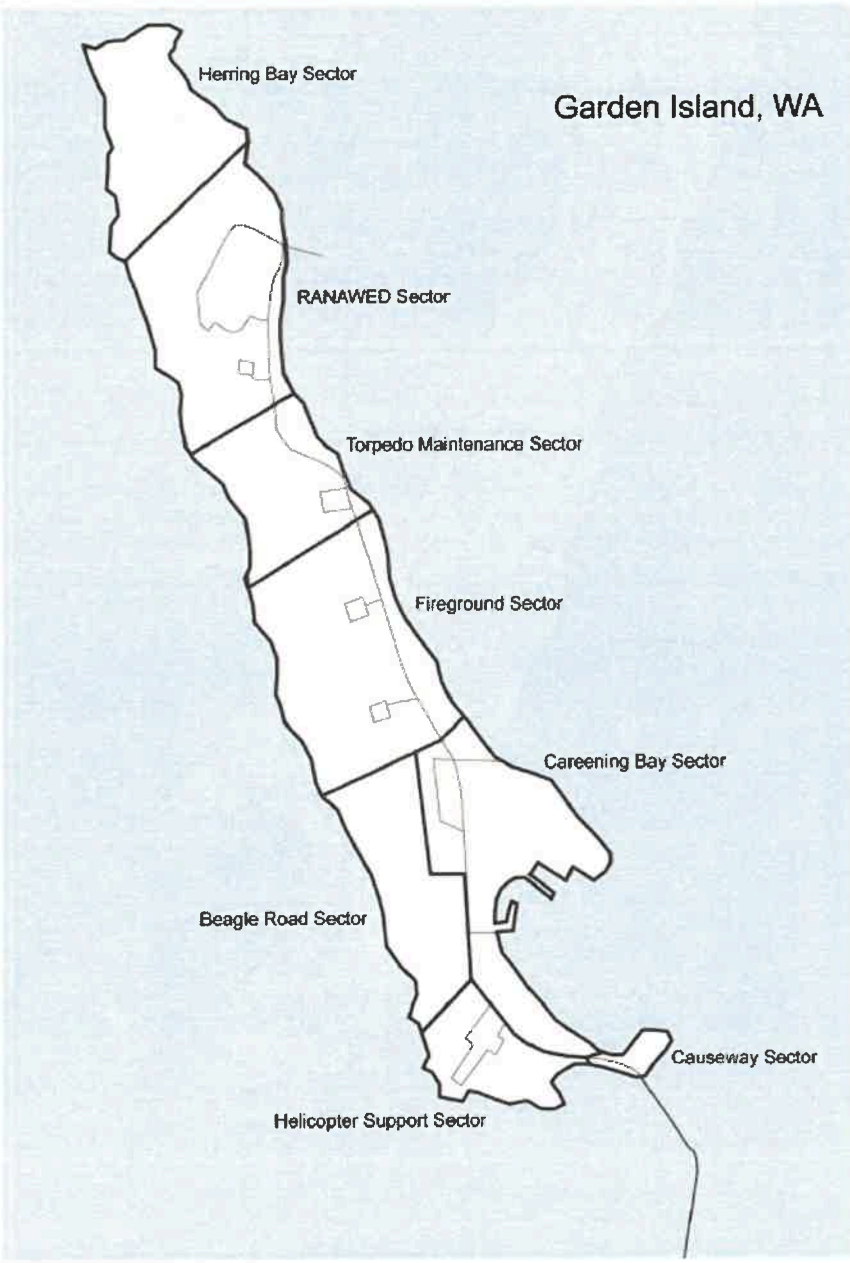


Figure 1. Management Sectors

Source: Australian Government, Department of Defence, "Garden Island Western Australia Heritage Management Plan (BN65633697)," Department of Defence, 2013

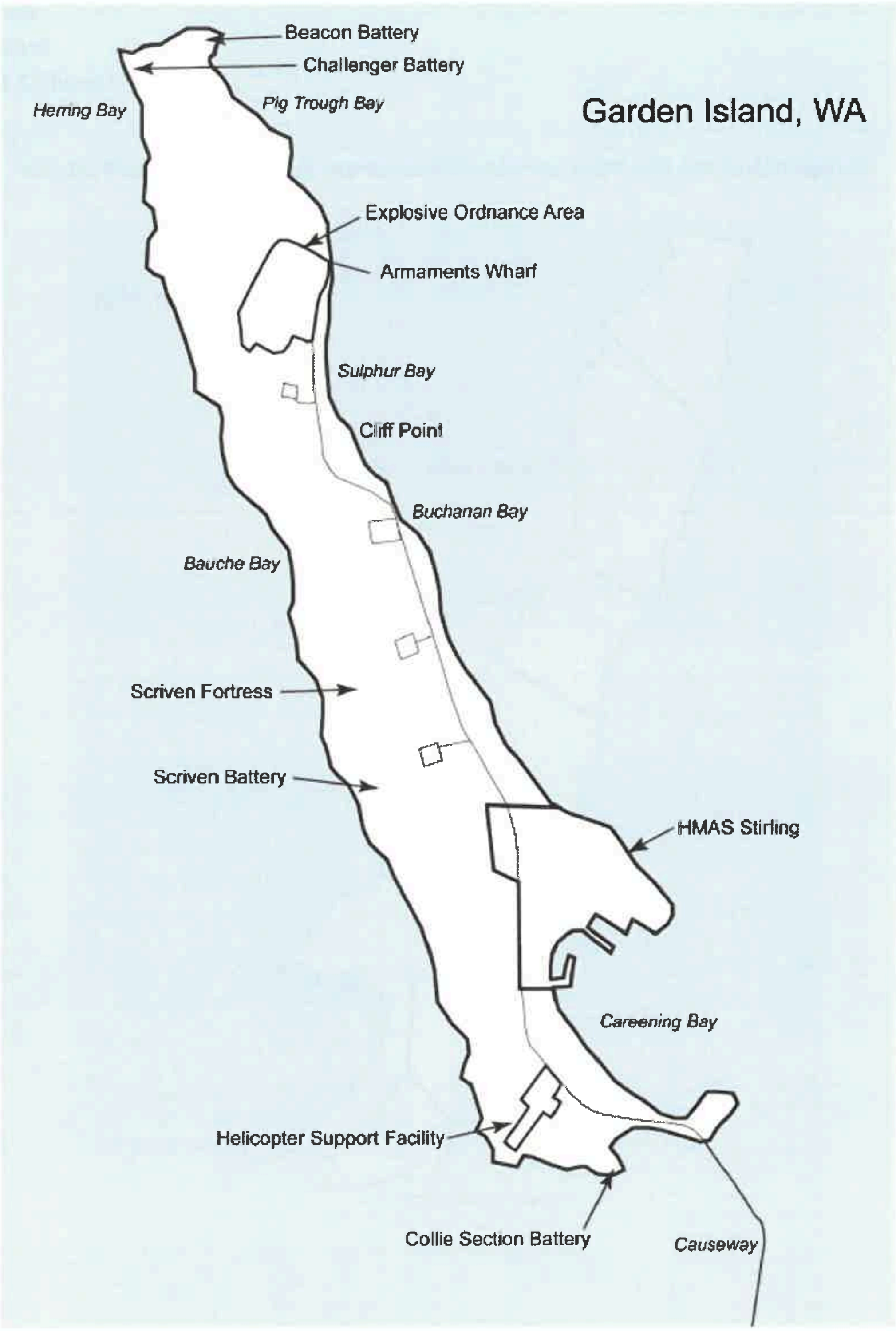
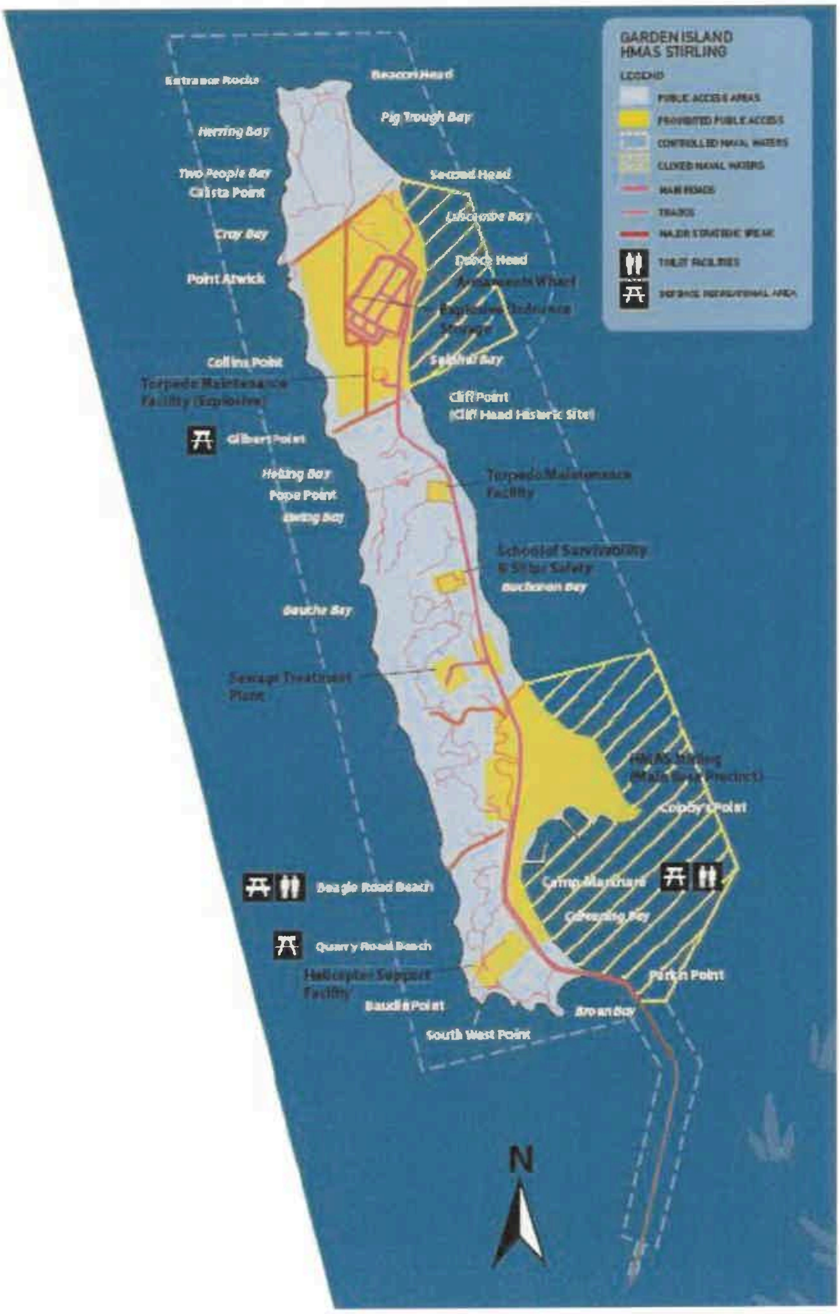


Figure 2. Major Features

Source: Australian Government, Department of Defence, "Garden Island Western Australia Heritage Management Plan (BN65633697)," Department of Defence, 2013

Annex C to:
BN96149861
Dated 22 Sep 2025

Garden Island WA – Defence Areas and Public Access Areas



Source: Australian Government, Department of Defence, "Garden Island Western Australia Heritage Management Plan (BN65633697)," Department of Defence, 2013

Environmental Monitoring Locations by Sectors

Figure 1. Northern Section Monitoring Areas

Figure 2. Southern Section Monitoring Areas

Annex E to:
BN9614986
Dated 22 Sep 2025

Shoreline Radiation Survey Measurement Locations

Figure 1. Armament Wharf

Figure 2. Mid-shore (Careening Bay)

Figure 3. South Shore (near Causeway)

Monitoring Locations by Sample Type for Garden Island

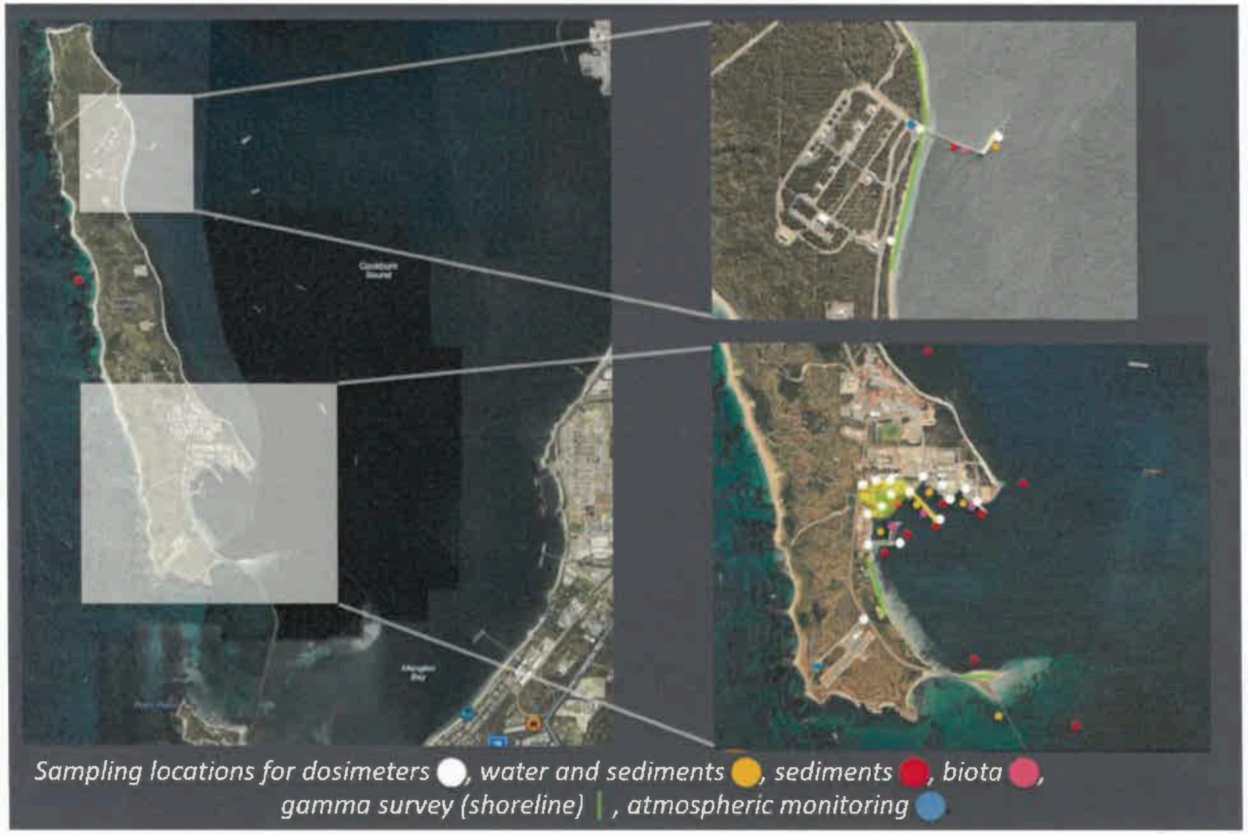


Figure 1. Sampling locations for environmental media (refer coloured dots legend)

Figure 2. Location of terrestrial soil sediment samples (courtesy of AECOM)

Figure 3. Location of ground water samples (courtesy of AECOM)