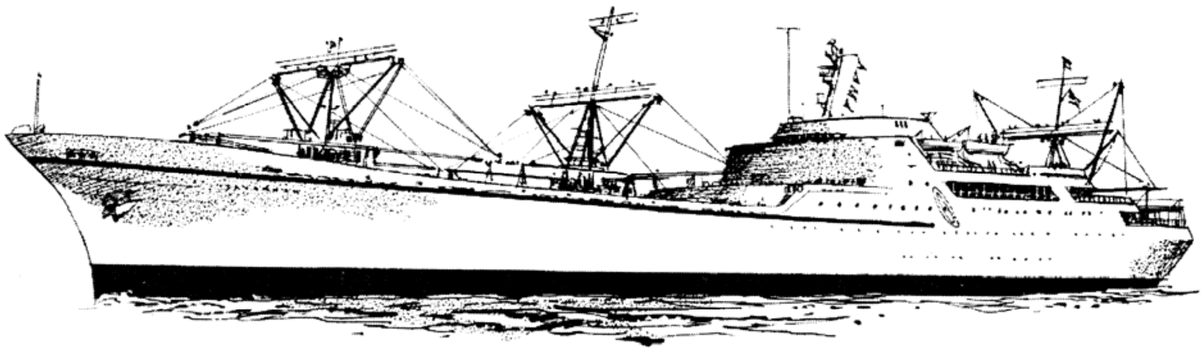

Nuclear Ship SAVANNAH

Radiological and Non-Radiological Spaces Characterization Survey Report

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Prepared for

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Maritime Administration
Office of Ship Operations**

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Radiological and Non-Radiological Spaces Characterization Survey Report Addendum

This is the first revision issued for the Radiological and Non-Radiological Spaces Characterization Survey Report

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1. EXECUTIVE SUMMARY

The N/S SAVANNAH (NSS) Characterization Project is intended to provide the Maritime Administration (MARAD) with a profile of radiological and non-radiological contaminants on the ship in radiological spaces. The scope of work was to perform a radiological and environmental hazard characterization program of the radiological spaces to document the location and extent of radiological and environmentally hazardous materials within these spaces preceding the decommissioning effort. In addition, a number of smears and samples were taken in non-radiological spaces to facilitate future analyses. The information obtained from this project will enable MARAD to develop appropriate decommissioning strategies and to estimate associated costs.

This characterization task was not intended to document a Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)–compliant termination survey that would be subjected to the rigors of a Nuclear Regulatory Commission (NRC) review. The intent of the characterization program was to provide a basis for which the government could estimate the cost of performing the decommissioning. In addition, the end state of the ship is expected to be complete free release and therefore a MARSSIM based survey is not required. Only those locations and equipment/structures that were expected to be radioactive were surveyed in depth to determine the extent and types of radioactive materials present. The remaining areas (principally aft of the engine room, forward of the reactor compartment, and in the mid-ship-house and public areas) were surveyed less rigorously than radiological areas but in sufficient detail to confirm that no radioactive materials reside in those locations. The characterization program conducted from March 20, 2005 to April 25, 2005 did not include the radiological characterization of the reactor vessel, internals, or neutron thermal shield tank.

The characterization effort was implemented in accordance with a preestablished Characterization Plan that included project-specific procedures encompassing radiological aspects of the project.

The following sampling was performed during the characterization program:

- 1423 smears surveys
- 26 paint scrapings
- 14 metal samples
- 6 secondary containment concrete core bores

- 10 crud (solids) samples from the primary system
- 4 primary water samples from the steam generators
- 1 water sample (chromated water over-rinse residue) from the empty neutron shield tank
- 11 air samples for radioactive contaminants

A representative number of paint, metal, and core bores were sent to General Engineering Laboratories (GEL) in Charleston, S.C. for confirmatory analysis, including detection of tritium in core bores, which was not possible with any shipboard instrumentation. The results of the confirmatory analyses performed by GEL confirmed the finding of the shipboard instrumentation.

Findings of this characterization effort are as follows:

- Confirmed the absence of fission products (other than trace quantities of cesium-137), uranium and its daughter isotopes, as well as transuranics (e.g., plutonium), indicating no discernable fuel failures.
- Minimal crud contribution to total curie content.
- No contamination found in the non-radiological spaces.
- Minimal contamination found in radiological spaces.
- Overall dose rates much lower than expected.
- Previously radiologically identified sites found uncontaminated.
- Containment vessel systems, structures. and equipment exceptionally radiologically clean.

In conclusion, the N/S SAVANNAH is in very good condition from a radiological perspective to support decommissioning. The data gathered during this exercise, and subsequently verified by a certified, independent laboratory, would allow MARAD to develop comprehensive decommissioning strategies along with bounding the costs.

2. HISTORY/STATUS OF NUCLEAR SHIP SAVANNAH

In 1955, President Eisenhower proposed that the United States build the world's first atomic-powered merchant vessel to demonstrate America's peaceful use of the atom. In 1956, Congress authorized construction of the Nuclear Ship SAVANNAH as a joint project of the Maritime Administration and the Atomic Energy Commission. After the ship was commissioned, MARAD took title to and responsibility for the ship.

The reactor plant achieved initial criticality in December 1961 and operated from 1962 to 1970 at an average plant thermal power of 30%, resulting in 2.4 effective full power years of irradiation on the structures inside the containment vessel (CV). The NSS is currently moored along side the Nuclear Barge STURGIS in the James River Reserve Fleet (JRRF) near Fort Eustis, Virginia.

On 29 January 1973, the U. S. Atomic Energy Commission issued Amendment 13 to the Technical Specifications associated with NSS license NS-1. This amendment acknowledged that the NSS's reactor was no longer operational. This decision was based on the fact that all nuclear fuel had been removed from the ship, and the reactor and associated systems had undergone certain modifications to ensure that they were no longer operable.

The following radioactive material/equipment had previously been removed from the ship:

- All fuel elements (32)
- Main coolant pumps and integral motors (4)
- Loose radioactive material (components and waste)
- Fission chambers and start-up source
- Demineralizer resin tanks

The reactor vessel is closed with the head in place (held by six tensioned studs). The control drive system is disconnected mechanically, hydraulically, and electrically.

The primary system was initially thought to be drained of water, though it was estimated that approximately 1100 gallons of water remained in the lower plenum of the reactor vessel below the inlet nozzles. This estimation was performed by the contractor who was responsible for dewatering the primary system in 1976. During the opening of both port and starboard steam generator primary system inlets, water was observed in both steam generators. It is anticipated that water may also be in the pressurizer surge line. The status of the water level in all of the primary components, which is being evaluated under a change order to this contract, will be documented elsewhere.

3. RADIOLOGICAL CHARACTERIZATION

Materials onboard the NSS might contain radioactivity from both activation and contamination processes. Activation is a process by which a material is made radioactive through neutron bombardment produced by the fission of uranium fuel. Radioactivity is induced throughout the material such that the material may be considered radioactive. While an activated material such as steel cannot be cleansed of its radioactive nature, the radioactivity cannot be transported unless the steel itself is degraded (e.g., through corrosion, cutting, or abrasion) and transported.

Activation products in stainless and carbon steel–based reactor and primary system components could include iron (Fe-55), cobalt (Co-60), and nickel (Ni-59 and Ni-63). With only 2.423 effective full power years of irradiation time, none of these nuclides reached saturation (highest activity attainable by an isotope in a specific neutron flux, i.e., rate of production = rate of decay). Fe-55, with the shortest half-life of the principal nuclides, reached 46% of saturation; Co-60 reached 27%. Ni-59, with a half-life of 7.5×10^5 years, attained less than 0.003% of saturation, while Ni-63 reached 1.7%. Fe-55 would have been present in large quantities on the NSS at final shutdown but has since decayed through more than 13 half-lives and is now present in only trace quantities. Concrete may contain tritium (H-3). Radon was noted in many of the vessel's enclosed areas and was identified during air sampling.

Radioactive surface contamination generally refers to loose or fixed radioactive material that is transported and deposited onto a surface. This contamination may result from processes such as abrasion, oxidation, or erosion of fission and activation products. Radioactive surface contamination may be easily transported from surface to surface through direct contact. It is important to make the distinction that activated materials present a greater external exposure concern to the human body, while contaminated materials are a greater internal exposure concern to the human body. In addition, during characterization or remediation activities such as cutting, grinding, coring, and other intrusive techniques, the potential for internal exposure is increased.

Chemical action of the coolant water flowing through the core can cause gradual corrosion of the materials forming the reactor pressure vessel (RPV), internals, primary piping, steam generators, and pressurizer. These corrosion products, referred to as "crud," have been or will be activated by neutron irradiation and will circulate with the coolant until they decay or are deposited at locations of low water velocity or stagnation flow or are removed by purifiers, leaks, or routine replacements of water. Crud would normally be retained in the primary loop unless leaks in the steam generator tubes caused crud carryover to the secondary loop.

Potential airborne radioactivity areas, which might exceed regulatory limits for concentration and could require the use of respiratory protection, were identified early in the characterization program.

The large number of sample categories and locations identified in the Characterization Plan reflects the significance of both activation and surface contamination in the selection of safe, cost-effective decommissioning processes.

4. RADIOLOGICAL CHARACTERIZATION TECHNICAL APPROACH

4A. RADIOLOGICAL CHARACTERIZATION METHODOLOGY

The following describes the methodology that was used to characterize radiological hazards in sufficient detail for MARAD to develop decommissioning strategies. As previously stated, this characterization program was abbreviated in scope compared to the final MARSSIM-based survey, which will be required in preparation for the NRC license termination following decommissioning.

- Containment vessel structures and internal structures may contain trace amounts of radioactivity due to induced activity from exposure to neutron radiation during operation. Samples of the structural metal were taken, and activated nuclides, if any, were identified.

- The reactor vessel, internals, and neutron shield tank were previously characterized by WPI, based on current material standards, actual plant operating data, and the latest analytical computer code (ORIGEN-ARP Version 2.00) accepted by the NRC. This characterization is available in the report entitled, “Nuclear Ship Savannah Reactor Vessel, Internals, and Neutron Shield Tank Characterization and Classification Assessment, revision 0 dated April 3, 2004”. The results of the analyses concluded that the reactor vessel, internals, and neutron shield tank satisfied the radionuclide inventory waste acceptance criteria (WAC) for the Barnwell disposal site. To confirm or refine the earlier analytical results, external reactor vessel dose measurements were obtained from inside the neutron shield tank at the elevation of the core mid-plane.

- The containment vessel rests on a support frame surrounded by a concrete shield lined on the inside with a painted carbon steel plate liner. While no contamination or induced activity was expected in the concrete behind the liner, that assumption was confirmed by drilling through the liner at strategic locations with a hole saw and core boring the concrete with a magnetic base core boring machine to obtain appropriate samples for off-site evaluation.

- Several specific locations were investigated, such as the inside surfaces of the primary system (by opening the primary inlet of each steam generator). Other systems were opened as necessary by removing valve bonnets, heat exchanger manways, pipe flanges, etc. to gain access and samples. All system openings were closed to an airtight (but not hydrostatically tested) condition. Air-handling systems (shut down and in use) were opened and investigated

- The steam plant (secondary side) was characterized by opening the condenser near the steam jet air ejector (SJAE) and the port inspection point steam generator steam drum.

- WPI's extremely knowledgeable and experienced staff identified areas of concern and approached the effort in a thorough and efficient manner. Personnel biographies are contained in Appendix A.

4B. INSTRUMENTATION

4B.1 Calibration

Radiation detection instruments used for the project were either rented from an approved vendor or provided by MARAD. Upon arrival, the instruments were checked for function and condition; all instruments were determined to be in good working condition. Calibration data sheets were reviewed, matched to each instrument, and accepted.

All instrument rentals and calibration sources were procured under WPI's NQA-1 program, which is an NRC-compliant Quality Assurance Program.

Air samplers, on loan from MARAD, were also used on this project. A copy of the calibration data sheet was provided for each air sampler. These were verified as current for each air sampler and accepted.

4B.2 Daily Source Checks

To permit daily checks of the instrumentation, operational check sources for alpha and beta instruments were used. These sources were as follows:

- thorium-230 (alpha emitter) 339 Bq (9.16 nCi)
- technetium-99 (beta emitter) 75.8 Bq (2.05 nCi)

Each portable instrument was checked daily for proper background. This background value was established when the instrument was first put into service on this project. A source count value using an appropriate check source was established initially for the portable instruments. From this initial count, a ±20% range was established for each instrument. On a daily basis or more frequently if appropriate, the appropriate check source was counted with each portable instrument and a count value obtained. The daily source count was entered on the Instrument Source Check Log for each instrument and verified to be within this ±20% range.

No gamma source was provided. An alternative method to source-check the portable radiation detectors (Ludlum 19 μR meters) was a stateroom commode with porcelain glaze. This glaze contained enough naturally occurring radioactive material (NORM) to provide a reading of 6–9 μR. The reasons for this method are discussed in Section 4C.2, Frisking. This approach provided a suitable gamma source for a daily source check of the μR meters. Natural background on the NSS was 2–3 μR.

The Teletector, a gamma detector with 17-foot telescoping capability, was checked daily, when used, by comparing readings in radiological areas with a Ludlum 19 μR meter, a method that provided assurance that the Teletector was functioning properly.

A 20-minute average background count was established for the 2929 counters; a daily 20-minute background was performed, and the range verified as ±10% of the average. These daily background values were entered on the Instrument Source Check Log for each instrument.

The 2929s count both alpha and beta simultaneously. Using the Th-230 and Tc-99 check sources, an average 5-minute count value was obtained for each counter when first put into operation for this project. Based on this initial count, a ±10% range was established. Daily count values were obtained from the 2929s using both check sources. These source count values were entered in the Instrument Source Check Log for each 2929 counter and verified to be within this ±10% range. These values were verified by using National Institute of Standards and Testing (NIST) traceable check sources and documented on Instrument Check Source Logs for each instrument.

Copies of the daily source check and background count are included in Appendix B.

4B.3 Instrument Use

Two Radeco Low-Volume Air Samplers were used to detect airborne radioactive particulates. These battery-powered, computer-controlled, totalizer-type air samplers can run for approximately 3 hours on a full battery charge. In addition, augmented battery service was provided through two 800-amp/hour marine batteries purchased for this effort. Air samples were obtained prior to entry into an area without respiratory protection and when opening the primary system.

Ludlum 19 µR meters were used to monitor for low-level gamma radiation upon first entry into radiological areas and for measuring dose rates up to 5 mR throughout the radiological areas.

Ludlum 3, 12, and 2221 count rate meters with pancake probes were used to monitor for very low levels of beta/gamma contamination throughout the ship and were also used to monitor individuals upon exiting radiological areas.

A Ludlum 2221 count rate meter with an alpha probe was used to monitor for alpha contamination in selected areas of the containment vessel and labs.

One teletector telescoping instrument was used in radiological areas above 5 mR/hour, almost exclusively in containment and shipboard laboratories.

Two Ludlum 2929 scalers with 43-10-1 probe were used to count the smears, air samples, metal samples, and paint scapings taken during this project.

Table 4B.3-1 lists shipboard nuclear instrumentation used during the project.

Table 4B.3-1
N.S. Savannah Characterization Project Instrument List

Instrument model	Serial number	Probe model	Probe serial number	Radiation detected	Readout units
Ludlum 3	97416	44-9 pancake	NA	Beta/gamma	cpm
Ludlum 12	75809	44-9 pancake	NA	Bata/gamma	cpm
Ludlum 12	91037	44-9 pancake	NA	Beta/gamma	cpm
Ludlum 19	42972	Internal scintillator	NA	Gamma	µR/hour
Ludlum 19	95499	Internal scintillator	NA	Gamma	µR/hour
Ludlum 19	95469	Internal scintillator	NA	Gamma	µR/hour
Ludlum 2221	197766	43-5 scintillator	127385	Alpha	cpm
Ludlum 2221	94954	44-9 pancake	NA	Beta/gamma	cpm
Ludlum 2929	102001	43-10-1	103276	Beta/gamma	cpm
Ludlum 2929	160019	43-10-1	167229	Beta/gamma	cpm
Teletector 6112D	28991	NA	NA	Gamma	mR/hour
Radeco H-810DC	0864	Air sampler	NA	Air particulate	NA
Radeco H-810DC	0865	Air sampler	NA	Air particulate	NA
Canberra high resolution gamma spectrometer*	S/N 96-5740	Base unit/detector	SAM 935 (90163/S SR593)	Gamma	Kev/Mev

* SERAT team provided.

4C. RADIOLOGICAL SAMPLING LOGISTICS

To adequately characterize the existing radiological conditions aboard the NSS, seven different types of data were collected: smears for surface contamination including samples taken from the interior of the primary system to estimate the extent of crud buildup (or plate-out) in the reactor vessel, frisking for fixed contamination, dose rate measurements, paint scrapings, metal samples for induced activity, core bores for shielding wall samples, and air samples to identify airborne radioactivity.

4C.1 Dose Rate Measurements

Dose rate measurements (primarily in µR/hour) were taken in rooms and compartments throughout the ship to determine the radiation levels from any residual radioactive materials or contamination.

4C.2 Frisking

Frisking measurements (in counts per minute) generally preceded the smear samples to identify any locations with fixed or loose radiological contamination. Frisking is the process of detecting radioactive material on personnel or equipment/structures.

Frisking readings and dose surveys in selected commodes and sinks exhibited slightly elevated readings (typically 7–10 μR/hour) compared to background (2–4 μR/hour). Investigation of this anomaly revealed that prior to the mid-1970s, a glaze commonly used in the manufacture of porcelain products could contain trace amounts of uranium and/or thorium. Use of a portable energy spectrometer did confirm the presence of thorium in some of the porcelain furnishings.

4C.3 Smears

Smears are 10- × 10-cm (4- × 4-inch) samples taken by rubbing a fixed-size sample paper (nominally a circle about 2.5 cm (1 inch) in diameter on a contiguous area). The area may be any set of dimensions that equals 100 cm^2. The smear paper is protected from cross-contamination and numbered as to the area and sequential sample number. The smear is then placed in a shielded detector, and any radioactive emissions which occur from decay are "counted" by the detector.

The number of "counts" is an indication of the amount of residual radioactivity (removable) on the originally sampled area. Count rates for all smears above background were converted to the standard nomenclature for radioactive surface contamination, disintegrations per minute (dpm)/100 cm^2. Surface contamination levels above 10CFR20 regulatory limits (1,000 dpm/100cm^2 for beta/gamma activity) were posted with appropriate warning signs. In all, 1423 smears were taken during the categorization effort depicted on the radiological survey forms in Appendix C.

In determining the sample distribution in an area, emphasis was given to those areas identified by frisking as being potentially contaminated such as sumps, door sills, contaminated systems pipe flanges, any location with evidence of leakage, etc.

In those areas of the ship not expected to be contaminated, such as staterooms, dining and recreation areas, crew quarters, offices and galleys, predetermined smear locations included door sills, door knobs, ventilation ducts, bathroom floors, and sinks. As shown in Appendix C, these areas exhibited radiation levels at or below background.

Smears of the interior piping of the primary system were taken at the inlet to the steam generator and on the inlet side of the tube sheets. Smears of the primary system contamination were obtained via inspection ports located on the steam primary side of the steam generators that were subsequently reinstalled. The principal isotope in the crud was confirmed to be Co-60 through use of gamma spectroscopy. Using the highest activity smear (tube sheet entrance) and assuming this crud level to be uniformly distributed over the interior surface of the RPV, a total crud activity level of 1.1 mCi was obtained. In our 3 April 2004 report, the total RPV crud activity level in 2007 was estimated to be less than 0.3 Ci of Co-60. A gamma energy spectrometer was used to confirm that the principal isotope in the crud was Co-60. Details of the crud analysis are provided in Appendix B. The difference in crud levels are due to the fact that one was an estimate based on a dose rate that was obtained in 1971 at the primary inlet piping where an assumption was that the dose rate was totally Co-60. A conservative estimate was developed assuming this dose rate was an infinite line source. Now the evaluations should be based on actual data obtained during the characterization efforts.

4C.4 Paint Samples

Paint samples were taken using a rasp or scraper to remove all levels (coats) of paint in recognition of the fact that early contaminated coats of paint may have been overcoated with fresh paint and would be impervious to smears. Paint samples included only paint and undercoatings but no metal. Preference was given to locations containing multiple layers of paint and in areas near or around radiological laboratory sinks and any other location with potential for contamination. While the same area planning philosophy as for smears was followed, the paint sampling locations were also selected on the basis of accessibility. Based on the absence of any activity levels above background in the passenger and crew living spaces, as well as other non-radiological portions of the ship, paint samples were taken only in the radiological portions of the ship as shown in the radiological survey forms in Appendix C. The activity levels were nonexistent based on actual results from dose rates and smear samples. Obtaining paint samples in the non-radiological portions of the ship would add no new information to the extensive data base already compiled through dose surveys and smear collection.

The NSS Health Physics staff detected radioactivity levels above background in some samples. Six samples, which showed activity levels above background using shipboard instrumentation, were sent to GEL, a WPI-approved vendor, for confirmatory analysis. Results of GEL's analysis indicated the presence of Co-60 and Cs-137 in the picocurie (pCi) range where 1 pCi=10^{-12} Curies. Co-60 activity levels ranged from 2.61 to 109 pCi/gm with the highest level at the foundation of the RPV and primary containment wall. Cs-137 activity levels ranged from 2.58 to 342 pCi/gm with the highest level at the interior of the primary vent duct, where airborne Cs-137 would tend to concentrate. The detection of Co-60 and Cs-137 confirmed findings of the onboard characterization effort involving smear collection/counting and portable gamma spectroscopy.

A trace amount of Pb-212, which is a decay product of naturally occurring Th-232, was detected (1.81 pCi/gm). K-40, a naturally occurring isotope in elemental potassium that accounts for about one-third of the external and internal whole body dose resulting from natural sources, was detected at a trace level of 2.76 pCi/gm. Details of GEL's analysis are provided in Appendix C.

4C.5 Metal Samples

To identify radiation sources resulting from the neutron activation of metal components during reactor operation, small metal samples (less than 1 square inch) were cut from metal components/structures with saws, drills, or other bulk metal–removal equipment. The objective was to obtain only metal with no paint, coatings, or other foreign materials. Sample locations were determined based on physical structure type and location in the CV. A set of samples was taken from structural components in close proximity to and in direct line-of-sight of the core mid-plane, where maximum neutron irradiation during power plant operation would have occurred. Another set of samples was taken in structural components near the outer wall of the CV at core mid-plane locations to determine the activation of the CV wall, if any. The activity (if any) was measured to determine curie concentration of the activated metal.

Neutron activation in the CV ceased following reactor final shutdown. Fe-55, the principal isotope of radiological concern in structural steel, has since decayed through thirteen half-lives ($T½$ = 2.7 years) and is currently present in only trace quantities.

Though the metal samples showed no activity above background in the NSS Health Physics Lab, four samples were sent to GEL for confirmatory analysis. Results of GEL's analysis indicated no detectable radiation levels except naturally occurring K-40, a radioactive isotope of elemental potassium, that measured 2.97 pCi/gm. Details of GEL's analysis are provided in Appendix C.

4C.6 Core Bores

Six core borings were taken through the steel inner liner of the secondary area and into the shield wall to determine the extent to which the concrete external to the steel wall is contaminated or induced activity exists. In addition, the concrete shielding was considered the only credible location for tritium (H-3), other than residual water in the RPV and primary system piping/steam generators. Selection of core bore locations was based on expected maximum activity levels as well as boring equipment accessibility.

It was also necessary to provide drilling water to the core boring machine, which required use of a water recovery system. Core bores were removed and identified as to orientation (outer and inner end and location). The steel plug removed from the core bore access hole in the wall also provided an induced activity sample. The core bore holes in the steel liner were restored by sealing with a sealing material.

Two of the core bore samples, including the steel plugs, were sent to GEL for analysis, including determination of the presence of tritium, whose characteristic low beta energy (20 keV, max) without accompanying gamma emissions was beyond the detection capabilities of any shipboard instrumentation. GEL's analysis indicated no detectable levels of tritium in either of the two samples. Both samples contained trace amounts (< 1 pCi/gm per isotope) of naturally occurring Th-232 decay products (Ac-228, Pb-212 and Tl-208) and naturally occurring U-238 decay products (Bi-214, Pb-214 and Th-230). The isotope, K-40, a naturally occurring isotope in building materials such as concrete, was present at activity levels in the 12-14 pCi/gm range, a factor of 4-5 higher than the K-40 content measured in paint or metal. This finding confirms the higher concentration of K-40 that would be expected in concrete versus either metal or paint. The broad array of naturally occurring isotopes (K-40, U-238 and Th-232 daughter products) detected in the bore samples are entirely consistent with the predictable isotopic content of a concrete structure.

The steel plugs exhibited no detectable radioactivity, which is an indication of negligible levels of neutron activation at those locations during reactor operation. This finding is corroborated by the absence of any detectable radioactive material except naturally occurring isotopes in either of the bore samples. Details of GEL's analysis are included in Appendix C.

4C.7 Air Samples

Airborne radioactive material was determined through the use of RADECO low-volume air samplers followed by quantitative analysis of residual radioactivity retained on the air filters inserted at the flow intake of the samplers. The high initial alpha levels followed by decay to background levels within 24 hours indicated the presence of naturally occurring radon (Ra-222) on the ship. These findings are consistent with likely sources of shipboard radon that include concrete, floor tiles, and porcelain furnishings. Likely sources of radon include concrete, floor tiles, and porcelain furnishings. Air sampling identified no other sources of airborne radioactivity and the results are included in Appendix C.

4C.8 Water Sample

One water sample (chromated water over-rinse residue) was collected from the empty neutron shield tank. No radioactivity was detected using onboard instrumentation. This finding was verified by GEL's analysis that found no detectable levels of radiation in the water sample. Details of GEL's analysis are included in Appendix C.

4D. SAFETY PRECAUTIONS

WPI implemented the N/S SAVANNAH Preliminary Accident Prevention and Health and Safety Plan that had been previously prepared and accepted by MARAD under another contract. This plan established comprehensive procedures for all feasible issues associated with the characterization effort. In addition, MARAD supplied a marine chemist, who released confined spaces, secondary containment, and primary containment for general access. Upon initial opening, the primary containment was oxygen deficient prior to ventilation being established. The Gas-Free Certificate is provided in Appendix D. Appendix E contains Project Exposure information for the team. All work in radiological areas was performed in accordance with a Radiation Work Permit (RWPs). The RWPs are provided in Appendix F.

4E. WASTE MANAGEMENT

Waste management was performed in accordance with project procedures described in Appendix G. All trash removed from radiologically controlled areas was frisked prior to determining its release status. If an item frisked clean, it was disposed of as normal trash following a confirmatory survey prior to leaving the vessel. If an item was found to contain radioactive material, it was bagged and stored onboard the NSS. In addition, before trash was removed from the NSS, the bags were frisked again as a precaution.

5. RADIOLOGICAL CHARACTERIZATION RESULTS

5A. RADIOLOGICAL PROFILE

One hundred eighty-five areas of the NSS were evaluated for radioactivity, including nine decks and seven compartments or areas that span decks vertically. In excess of 1400 smears were taken in these areas. One hundred and one surveys were documented and are included in Appendix C. Many of these surveys included multiple areas; as an example, five staterooms were usually documented on one survey. Summarizations of these areas are included in Tables 5A.3-1 through 5A.6-1.

5A.1 Dose Rates

For radiological areas outside of primary or secondary containment, general area dose rates ranged from background to 50μR/hour. Contact readings on some pipes reached 2mR/hour.

In non-radiological areas, general area dose rates were at or below background, with one exception in Cargo Hold 4, where shine from the Cold Chemistry Lab produces approximately 250μR/hour at the Cargo Hold 4 aft wall. Shine is radiation emanating from another location on the ship but being measured remotely.

Inside secondary containment, dose rates in the upper levels of secondary containment were essentially background. In lower secondary containment, general area dose rates varied 0.3–1.6 mR/hour, with contact readings of up to 221 mR/hour.

Inside CV general area dose rates varied 0.1–10 mR/hour, with the highest contact reading around the “U” tube end of the steam generators of 35 mR/hour.

Inside the steam generator primary side inlet plenum dose rates were a maximum of 344 mR/hour in the mid-plane of the plenum and the highest contact reading was 812 mR/hour, on the tube sheet.

A dose rate summary is included in the following sections.

5A.2 Radiological Contamination

No loose radiological contamination was found in unexpected places. Very little contamination was found in areas where it was expected. Several stateroom toilets, sinks, and floor tiles were found to contain NORM. A summarization of these areas is included in the following tables.

5A.3 Non-Radiological Areas

The non-radiological areas were clear of detectable radiological contamination. The non-radiological areas evaluated are summarized in the following table.

Table 5A.3-1
Non-Radiological Area Summary

Deck/compartments	Number of areas evaluated	Dose rate found	Contamination found
Navigation Bridge Deck	8	Background	All < background
Boat Deck	10	Background	All < background
Promenade Deck	2	Background	All < background
"A" Deck	20	Background	All < background
"B" Deck	44	Background	All < background
"C" Deck	31	Background	All < background
"D" Deck	11	Background	All < background
Weather Deck ("A" Deck) fwd and aft	15	Background	All < background
14' Flat Deck	5	Background	All < background
Hold Deck	6	38 μR/hour*	All < background
Cargo Hold Number 4 (aft)	5	250 μR/hour**	All < background
Machinery Casing, boat to "C" Deck	4	Background	All < background
Engine and Control Rooms	8	Background	All < background
Hold Number 5, engineering space	2	Background	All < background

*Hold Deck had a pipe running under the deck plate in the passageway that read 38 µR/hour on contact. This pipe ran through a portion of the crossover area also. The pipe is for the waste transfer system. Lower dose rates were recorded at various areas of the passageway above the deck plates.

**Hold Number 4, "D" Deck Starboard, had readings on the aft wall up to 250 µR/hour. This appears to be shine from the Cold Chemistry Lab.

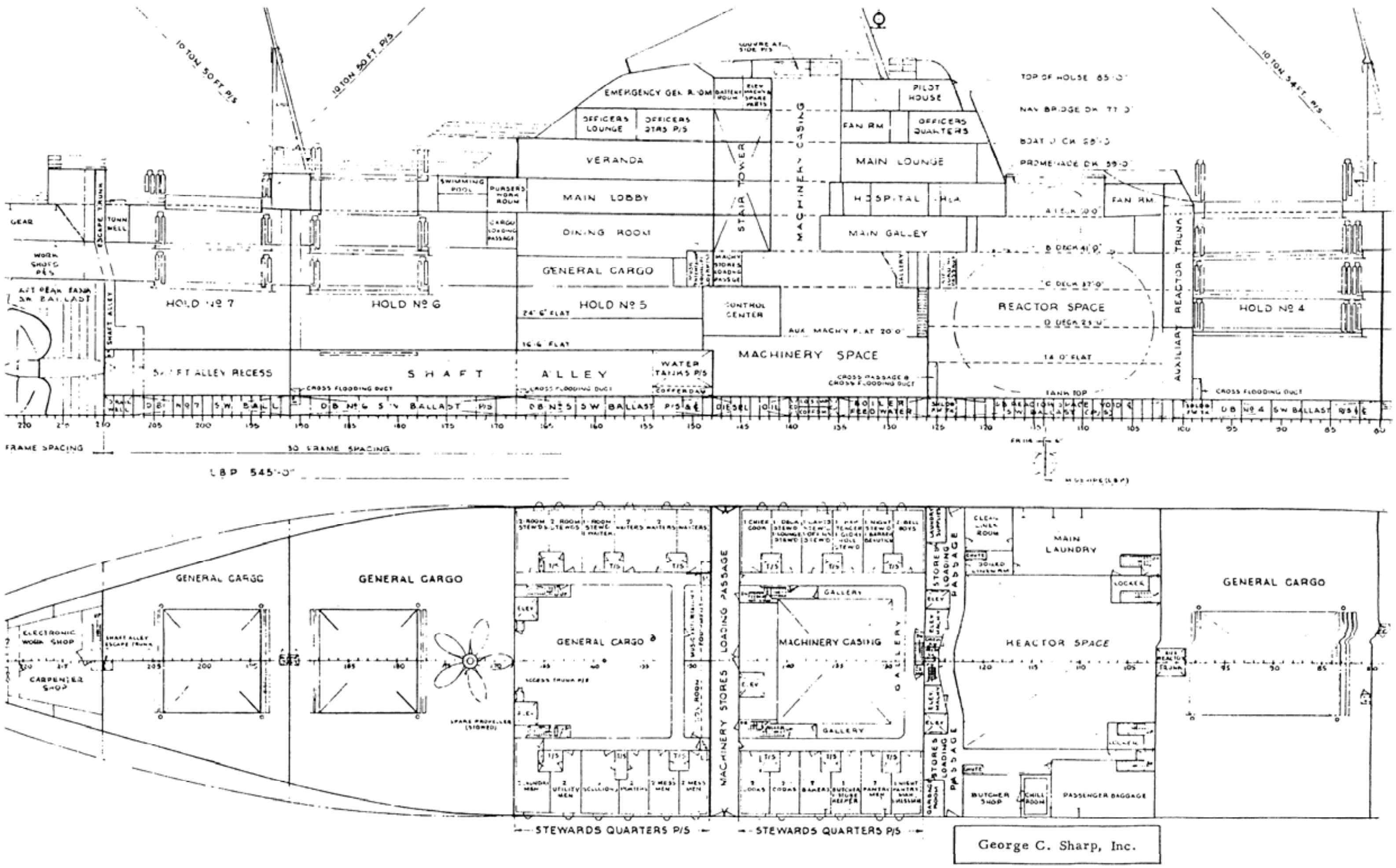
5A.4 Radiological Areas

Table 5A.4-1 provides a summary of radiological condition found during the evaluation of radiological areas excluding containment. The values listed are maximums. Figure 5A.4-1 provides a cross-sectional view of the NSS radiological area. Brief summaries are provided below with detailed information on the Survey Sheets in Appendix C.

Table 5A.4-1
Radiological Area Summary

Deck/compartments	Dose rate found	Contamination found dpm/100cm^2
Hot Chemistry Lab, "D" deck off of the control room	Background	< 1000
Port Forward Stabilizer Room, upper level off of 14' flat	8 µR/hour	All < background
Port Forward Stabilizer Room, lower level	150µ R/hour	All < background
Fan Room "B" Deck, starboard side	Background	All < background
Stateroom B-1 (radiological waste storage)	Background	All < background
Cold Water Chemistry Lab, upper level	50 µR/hour	All < background
Cold Water Chemistry Lab, lower level	2000 µR/hour	Max 3904
Hold #4, "D" Deck, starboard	250 µR/hour	All < background
Charge Pump Rooms, port and starboard	180 µR/hour	All < background
Health Physics Lab., "A" Deck	5 µR/hour	Max 1221
Hold Deck, outside containment, port-to-starboard crossover passage	25 µR/hour	All < background
Hold Deck, outside containment, port and starboard passages	38 µR/hour	All < background

Figure 5A.4-1
N/S SAVANNAH Cross Section, Frames 80–270



Hot Chemistry Lab, "D" Deck off of the Control Room

No radiological readings were found. Two locations had detectable contamination < 1000 dpm/100cm^2. See survey number NSS-0081. Detectable contamination was noted from smear samples taken at the drains in the hot lab. No radiological dose readings were noted above background.

Port Forward Stabilizer Room, upper level off of 14' flat

General area dose rates at mid walkway were 8 μR/hour. Forward of this at end of walkway dose rate was 5 μR/hour. Both appear to be shine from lower level. No radiological contamination was found. See survey number NSS-0059.

Port Forward Stabilizer Room, lower level

General area along walkway ranged 5–50 μR/hour. Green piping (waste transfer piping) on either side of walkway ranged 20–150 μR/hour on contact. No radiological contamination was found. See survey number NSS-0060.

Fan Room "B" Deck, starboard side (connects to Cold Chem. Lab)

No radiological readings were found. No radiological contamination was found. See survey number NSS-0062.

Cold Water Chemistry Lab, upper level, "C" Deck (port entrance)

The lab extends from port to starboard between stairwells. The general area dose rate on the port side is 4 μR/hour. A large, continuous air-monitoring unit covered with lead is stored in the starboard side. Dose rates of 4–50 μR/hour were found in and around this monitor. No radiological contamination was found. See survey number NSS-0064.

Cold Water Chemistry Lab, lower level, access is from upper level

Filter canisters located on port side of room read 200–600 μR/hour on contact. Overhead pipes on starboard side read 2000 μR/hour on contact. One location showed smearable radiological contamination. The sample sink inside the hood was 3904 dpm/100 cm^2. See survey number NSS-0070.

Hold #4, "D" Deck, starboard

The aft portion of this deck in Hold #4 has radiation readings 6–250 μR/hour. An overhead vent pipe has a reading of 38 μR/hour. The highest readings appear to be shine coming from the Cold Chemistry Lab, which is on the other side of the bulkhead. No radiological contamination was found. See survey number NSS-0063.

Charge Pump Rooms, port and starboard, lower level of engineering space

General area dose rate was background (2–4 μR/hour). On contact with the charge pumps, a maximum reading of 180 μR/hour was recorded. No radiological contamination was found. See survey number NSS-0086.

Health Physics Lab, “A” Deck at Hospital

General area in lab was background (2–4 μR/hour). Inside sink dose rate was 5 μR/hour. Frisker read 350 cpm in bottom of sink. Radiological contamination was found in bottom of sink at 1221 dpm/100 cm^2. See survey number NSS-0068.

Hold Deck, outside containment, port to starboard crossover passage

A reading of 25 μR/hour was found on the floor of the passage, port side. No radiological contamination was found. See survey number NSS-0066.

Hold Deck, outside containment, port and starboard passages, for and aft

Slightly elevated dose rate readings were found on the containment wall (7 μR/hour) on the starboard side. On the port side, a reading of 38 μR/hour on contact with a pipe under the deck plate was found. Tracing the pipe for to aft, elevated readings on the deck plate were found from 4 μR/hour to 18 μR/hour. No radiological contamination was found. See survey number NSS-0065.

5A.5 Secondary Containment

Table 5A.5-1 summarizes radiological conditions found during the evaluation of Secondary Containment. The values listed are maximums. Consult the write-ups below the table and survey sheets for details.

During initial entries and during other entries, outer shoe covers and outer gloves were frisked to determine whether radiological contamination was present. No contaminated shoe covers or gloves were found.

Table 5A.5-1
Secondary Containment Radiological Summary

Deck/compartments	Dose rate found*	Contamination found (dpm/100cm²)*
"B" Deck, access area aft of reactor	Background	All < background
"B" Deck, area forward of reactor	Background	All < background
"C" Deck forward, access from "B" deck	Background	All < background
"A" Deck around cupola	Background	All < background
Top of Cupola	4 μR/hour	All < background
Aft Mezzanine, mid level between "C" and "D" Decks	3–5 μR/hour	All < background
Lower level of Secondary Containment	221 mR/hour	All < background

*See write-up below for details.

"B" Deck, access area aft of reactor

Dose rates in this area were background (2–4 μR/hour). Frisking showed no locations above background (20–40 cpm). No radiological contamination was found. See survey number NSS-0067. No smearable contamination was noted. Dose rates were present due to activated material or contamination inside of other systems.

"B" Deck, area forward of reactor

Dose rates in this area were background (2–4 μR/hour). No radiological contamination was found. See survey number NSS-0072.

"C" Deck forward, access from "B" Deck

Dose rates in this area were background (2–4 μR/hour). No radiological contamination was found. See survey number NSS-0071.

"A" Deck around cupola

Dose rates in this area were background (2–4 μR/hour). No radiological contamination was found. See survey number NSS-0073.

Top of Cupola

No radiological contamination was found. See survey number NSS-0090.

Aft Mezzanine, mid level between "C" and "D" Decks and decon shower on "C" Deck

General area dose rates were 3–5 μR/hour. No radiological contamination was found. See survey number NSS-0075.

Lower level of Secondary Containment, access down ladder tube only

General area starboard side 300–1000 μR/hour, 1400–1600 μR/hour head high. Overhead yellow line emits 221 mR/hour on contact. These lines are posted. Starboard forward general area is 400–500 μR/hour. Port side general area was 60–80 μR/hour. No radiological contamination was found. See survey number NSS-0076.

5A.6 Primary Containment

Table 5A.6-1 provides a summary of radiological condition found during the evaluation of Primary Containment. The values listed are maximums. Consult the write-ups below the table and survey sheets for details. Figures 5A.6-1 through 5A.6-5 provide a layout of the primary containment by elevations and plan views.

During initial entries and during other entries, outer shoe covers and outer gloves were frisked to determine whether radiological contamination was being spread. No contaminated shoe covers or gloves were found.

Table 5A.6-1
Primary Containment Radiological Findings

Deck/compartments	Dose rate found	Contamination found (dpm/100cm^2)
Primary Containment, upper hatch closed	15 μR/hour	All < background
Primary Containment, upper hatch open	400 μR/hour	All < background
Primary Containment, 1ST level	500 μR/hour	1200
Primary Containment, inside shield tank upper ring	7 mR/hour	All < background
Primary Containment, 2nd level	3 mR/hour	All < background
Primary Containment, 3rd level	10 mR/hour	< 1000
Primary Containment, 3rd level, area over U-tube steam generator	35 mR/hour	< 1000
Primary Containment, 4th level	3 mR/hour	All < background

Figure 5A.6-1
Primary Containment Equipment Layout

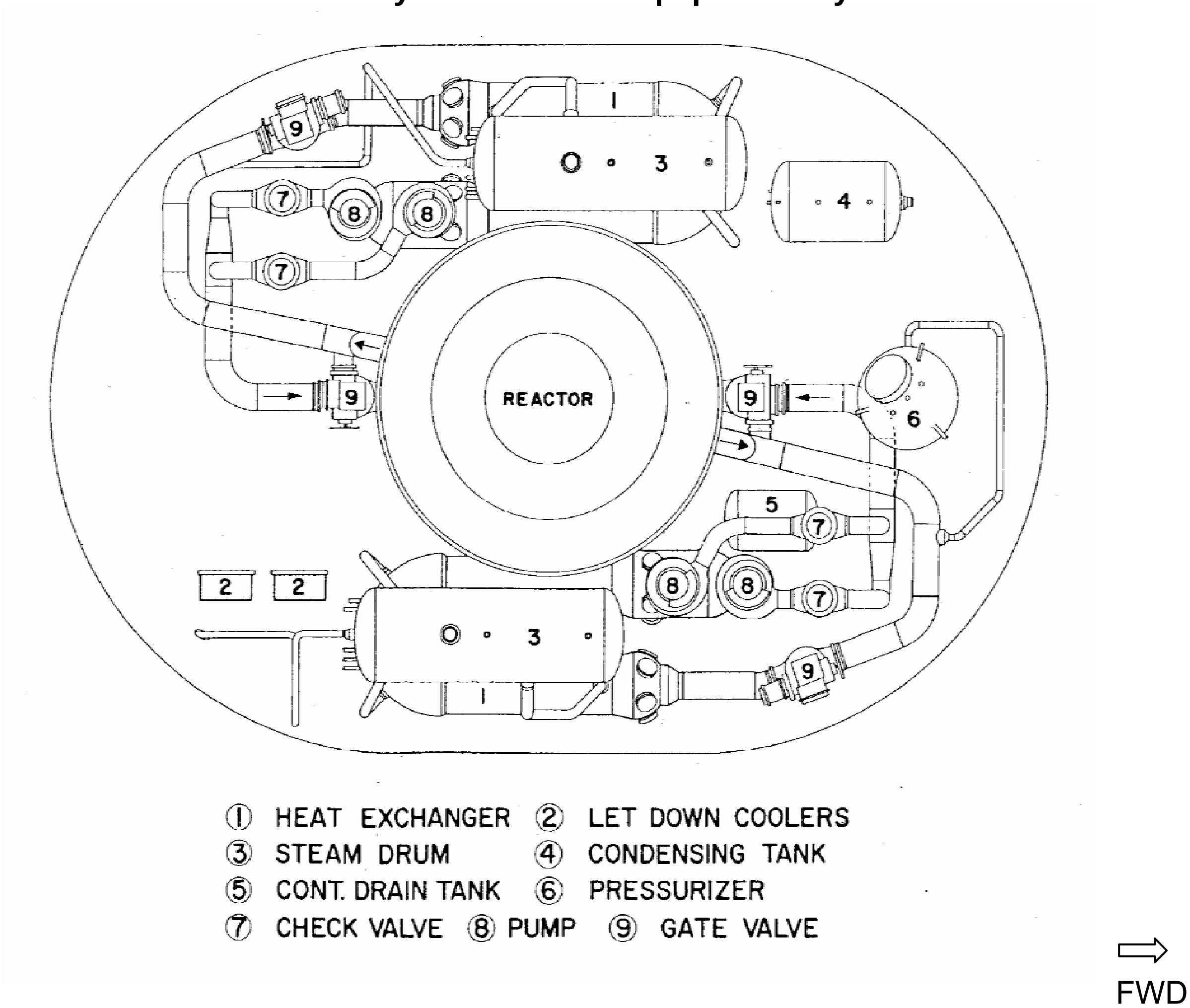


Figure 5A.6-2
Primary Containment Level 1 (Top)

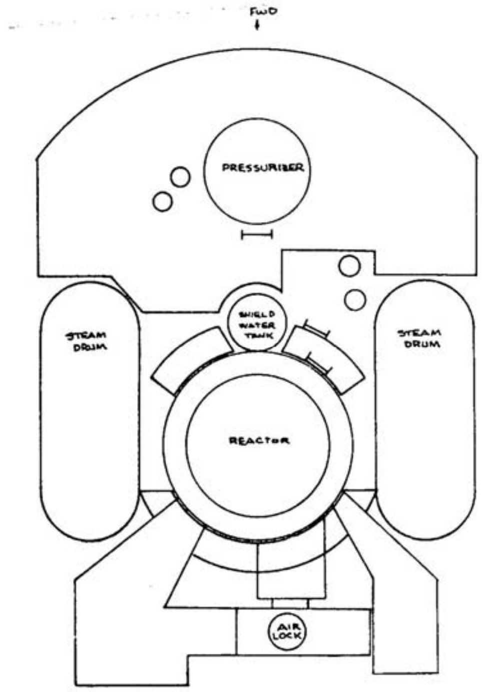


Figure 5A.6-3
Primary Containment Level 2

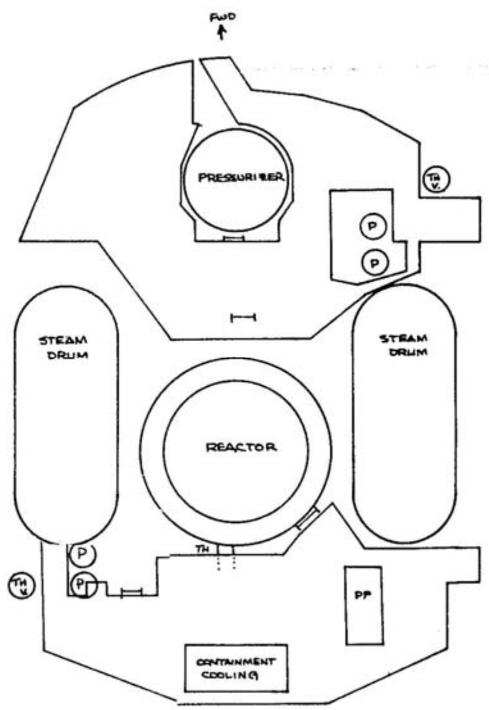


Figure 5A.6-4
Primary Containment Level 3

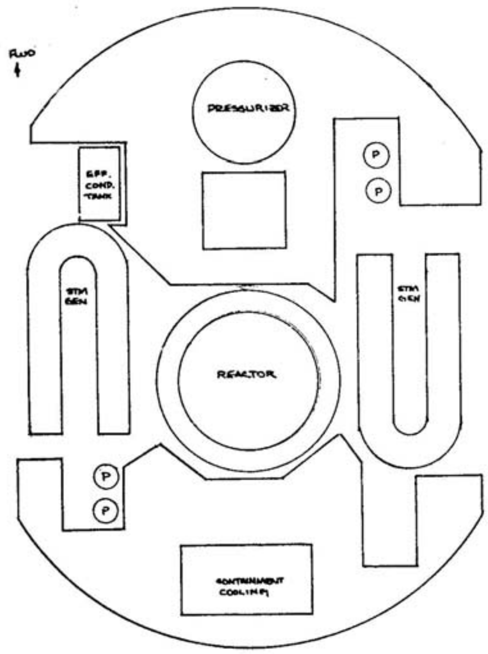
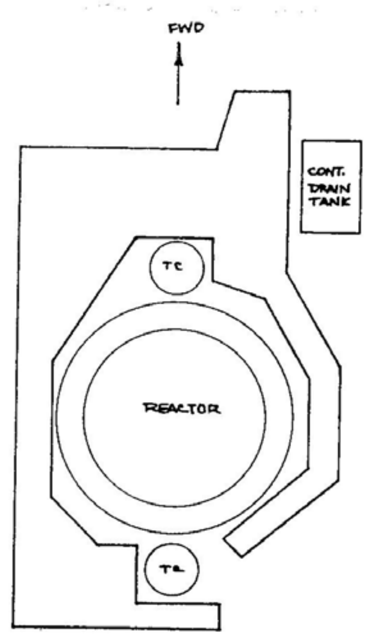


Figure 5A.6-5
Primary Containment Level 4 (Bottom)



Primary Containment, upper hatch closed, after plug removal

Dose rate at gauge on upper hatch 15 µR/hour. No radiological contamination was found. See survey number NSS-0069. No smearable contamination was noted. Dose rates were present due to activated material or contamination inside of other systems.

Primary Containment, upper hatch open

Dose rate in airlock 400 µR/hour. No radiological contamination was found. See survey number NSS-0074 and NSS-0077. No smearable contamination was noted. Dose rates were present due to activated material or contamination inside of other systems.

Primary Containment, 1ST level

The aft area of 1st level general area dose rate is 0.1–0.5 mR/hour. Next to and forward of the reactor, dose rates vary, with the highest being on the starboard side of the pressurizer at 0.7 mR/hour. Radiological contamination found in several locations <1000 dpm/100cm^2. One location to right of pressurizer has radiological contamination at 1200 dpm/100cm^2. See survey numbers NSS-0087, NSS-0079, and NSS-0083.

Primary Containment, inside shield tank upper ring, neutron wells, and inside neutron shield tank access area

General area dose rate 300–500 µR/hour. Readings were taken in neutron detector wells that extend down next to the reactor wall inside the neutron shield tank. There is lead shielding installed on the OD of the neutron detector wells.

Neutron well	Midpoint reading	Bottom reading
Aft well	2.2 mR/hour	3.4 mR/hour
Forward well	2.4 mR/hour	3.7 mR/hour

There is a personnel hatch into the neutron shield tank. Reading taken 7 feet down from flange (core mid-plane) was 7 mR/hour. No radiological contamination was found inside the shield tank upper ring or inside the shield tank. See survey number. NSS-0087 and NSS-0091.

Primary Containment, 2nd level

Dose rates on Level 2 vary 0.1–3 mR/hour. Highest reading is forward starboard near steam drum. No radiological contamination was found. See survey number NSS-0084.

Primary Containment, 3rd level

Dose rates on Level 3 vary 0.1–10 mR/hour. Highest reading is aft starboard near U-tube steam generator. Radiological contamination was detected up to 300 dpm/100cm^2 in two locations. See survey number NSS-0085.

Primary Containment, 3rd level, area over U-tube steam generators

Starboard steam generator dose rate between down-comers was 24 mR/hour. Port steam generator dose rate between down-comers was 35 mR/hour. Radiological contamination was detected ~150–~650 dpm/100 cm^2 in six locations between the down-comers on the U tube steam generator, starboard side. See survey number NSS-0089.

Primary Containment, 4th level

General area dose rate was 1–3 mR/hour. No radiological contamination was found. See survey number NSS-0082.

Primary Containment, 3rd level, opening primary system of steam generator

Port and starboard generators were opened. Unexpectedly, both had significant water in them, which was not indicated to be the case when the plant was originally dewatered.

Dose rates	**Starboard steam generator (mR/hour)**	**Port steam generator (mR/hour)**
Outside inner cover seal	32	34
At opening plane	45	NA
At mid plenum	275	344
At tube sheet	525	812
	Survey number NSS-0096	Survey number NSS-0097

Contamination levels	**Starboard steam generator (dpm/100cm^2)**	**Port steam generator (dpm/100cm^2)**
Inside, top of plenum	14,798	22,000
Inside, left of access opening	13,183	6,096
Inside, right/below of access opening	51,682	4,144
Plenum tube sheet	166,730	378,673
Inside surface of SS	10,211	7,654

cover seal		
	Survey number NSS-0096	Survey number NSS-0097

Surveys after work was performed showed smearable radiological contamination of <500 dpm/100cm^2 in work areas. This is well below the regulatory limit of 1000 dpm/100cm^2.

From the RPV dose rate information taken at the RPV external wall near the core mid-height location, the following is known. The actual reading of 7 mR/hour that is about an order of magnitude lower than expected is attributable to the residual Co-60, which was estimated from previous analytical analysis to be 1108 curies distributed throughout the internals and structural components of the RPV. Though other nuclides are known to reside in the RPV, only the gamma radiation from Co-60 (1.17 and 1.32 MeV) are sufficiently energetic to penetrate the thermal shields, core barrel, and RPV wall resulting in measurable doses above background external to the RPV.

An estimate of dose rate at the exterior of the vessel was made using a point source approximation along the centerline of the vessel at mid-core height as outlined in Appendix B. This analysis gave a dose rate of 85 mR/hour. The higher estimated versus measured dose suggests an overprediction of the total RPV curie content in the original analysis. The difference between measured and calculated is likely attributable to one or more of the following factors:

- overprediction of thermal neutron flux in the core internals
- use of high natural cobalt (Co-59) content (0.141%) for analysis (maximum ASTM values)
- underprediction of Co-60 gamma shielding/absorption by the heterogeneous arrangement of core internals and structural components that tend to depress neutron flux during normal operation.

5A.7 Air Samples

To reduce the time project members spent wearing respirators and to protect them from potential inhalation of radiological material, air samples were taken on initial entry into radiological areas and during evolutions with potential radiological consequences. A total of 11 air samples were taken. Locations are listed below.

All of the air samples were heavy with radon when counted right after sample acquisition. All samples required several counting periods with the last count in excess of 72 hours to thoroughly demonstrate the lack of any airborne radioactivity other then radon. This resulted in excess respirator time for some of the project members. Refer to Appendix H for respiratory protection discussion.

After the last count for each air sample was completed, all samples showed negative for airborne radioactivity. See Appendix C for individual air sample data.

Air sample locations:

- Cold Chemistry Lab, initial
- Access to Secondary Containment
- Charge Pump Room starboard
- Airlock for Primary Containment
- Primary Containment, 1st level
- Charge Pump Room, follow-up
- Cold Water Chemistry Lab, follow-up
- Primary Containment, 2nd level
- Secondary Containment, lower level
- Primary Containment, 4th level
- Primary Containment, 3rd level at port U-tube steam generator access hatch

6. ENVIRONMENTAL CHARACTERIZATION (HAZMAT)

6A. SCOPE

The objective of the NSS hazardous materials characterization program was to support MARAD in its decommissioning planning, cost estimating, radiological engineering, and scheduling efforts. To this end, hazardous materials (e.g., PCBs, lead, asbestos, etc.), which potentially may impact the decommissioning activities and/or downstream waste management will be identified. Under this scope, hazardous materials associated with fixed surfaces on the ship were surveyed and identified in both radiological and non-radiological spaces on the vessel

Personnel used existing vessel data, visual surveys, and sample collection/chemical analysis as part of the hazardous material characterization effort. All efforts were conducted in a manner consistent with the Characterization Plan and specified elements of Quality Assurance Project Plan. Prior to the sampling effort, personnel reviewed available details of the vessel's infrastructure and operational equipment for potential sources, amounts, and relative hazards of potential contaminants. Target sampling items and locations were indexed and located on vessel schematics.

6A.1 Asbestos-Containing Material

Using available information and visual surveys, potential asbestos-containing materials (ACM) were identified, indexed, and mapped. This effort took place within both the radiological and non-radiological parts of the ship. Within the radiological spaces, samples of potential ACM were collected, mapped, and photographed. These samples were analyzed by an off-site laboratory (Aerosol Monitoring and Analysis, Lanham, Md.) to identify asbestos content. Within non-radiological spaces, representative samples of potential ACM were acquired, mapped, and photographed. These samples were placed in labeled bags and left aboard the ship for potential future analysis, as necessary.

Subsequent to the receipt of analytical results of samples collected from the radiological areas of the ship, quantities of ACM were estimated based on observations, data, and available maps of the ship. Personnel did not revisit the ship subsequent to the receipt of the analytical data to develop more accurate estimates of ACM quantities on those surfaces that tested positive for asbestos (i.e., Chrysotile or Amosite).

6A.2 Lead-Based Paint

The lead-based paint (LBP) testing was performed with a Radiation Monitoring Device (RMD) Model LPA-1 X-ray fluorescence analyzer (XRF). The XRF contains a small radioactive (cobalt-57) source, which emits radiation when pressed against a surface and the trigger is depressed. If the paint contains lead, the radiation stimulates the lead atoms to emit characteristic X-rays, which are sensed by a detector in the unit. The XRF then converts these signals to a final reading in milligrams per square centimeter. The LPA-1 XRF is capable of achieving a 95% confidence level in readings to a depth of 3/8-inch.

Calibration of the RMD LPA-1 was conducted in accordance with the manufacturer's instructions. Prior to obtaining readings from suspect surfaces, three calibration readings were collected on a National Institute of Technology (NIST) Level III Standard

Reference Material paint film. The LAP-1 must calibrate to 1.0 mg/cm^2 with a tolerance of ±0.3 mg/cm^2 for the average of the three readings. If the calibration readings fell outside of this range, the equipment was rechecked and recalibrated before use.

For this survey, the XRF was set to a default value of 1.0 mg of lead per square centimeter of surface area tested. The Virginia Lead-Based Paint Activities Regulations, 18 VAC, 15-30-20, defines a lead-containing substance as any coating, paint, plaster, or surface encapsulation material containing greater than or equal to 1.0 mg/cm^2 of lead.

6A.3 Liquids

The location of equipment and tanks which potentially contain fuels, lubricants, and coolants were identified and noted on vessel schematics, and an index was compiled. Samples of liquids identified on the ship were collected for material characterization to assist in future decommissioning activities. This effort included both aqueous samples and oils. Samples from the non-radiological portion of the ship were labeled and left on the vessel for potential future analysis. Liquid samples from the radiological areas of the ship were transferred to a WPI-approved vendor for analytical testing.

6A.4 PCBs

Electrical equipment that potentially contains PCB-containing dielectric and electrical conduit was identified through review of vessel information and visual survey.

6A.5 Mercury

As part of the hazardous materials characterization, thermometers and switches were inspected in an effort to determine whether they potentially contained mercury. As these units were sealed, no samples were collected.

6B. RESULTS

Results of the hazardous materials characterization of the NS Savannah are presented below. With the exception of lead-based paint testing, the multimedia samples collected from the non-radiological areas of the ship were not analyzed. Those samples, which were collected, were transferred to MARAD for potential future analysis. These samples from the non-radiological spaces were not within the scope of the project. The samples were gathered for future analysis if desired.

Table 6B-1 provides an analytical summary of the results of the water and oil samples obtained in the radiological spaces.

Table 6B-1
Radiological Spaces Liquid Sample Summary

Sample ID	**Units**	**Secondary Containment Sump (oil)**	**Secondary Containment Sump (water)**	**Primary Containment (hydraulic oil)**	**Stabilizer Rooms (hydraulic oil)**	**Stabilizer Rooms (lube oil)**
Metals						
Cadmium	mg/L	NA	0.02	NA	NA	NA
Chromium	mg/L	NA	0.3	NA	NA	NA
Mercury	mg/L	NA	0.00027	NA	NA	NA
Lead	mg/L	NA	0.5	NA	NA	NA
PCBs						
Aroclor 1016	mg/kg	76	NA	1180	28	BQL*
Aroclor 1260	mg/kg	197	NA	430	12	BQL*
Total halogens	mg/kg	107	NA	242	73	BQL*

* BQL = below the quantification limit.

6B.1 Asbestos-Containing Materials

To asses the asbestos content of materials on the ship, samples of potential ACM were collected from both the radiological and non-radiological areas. Samples collected from the radiological sections of the ship were submitted to Aerosol Monitoring & Analysis, Inc. (AMA) for analysis. Samples collected from the non-radiological areas of the ship were secured in labeled zip-lock bags, documented on field log sheets, and stored in a box on the vessel for potential future analyses, as determined by MARAD.

Asbestos samples were collected using appropriate coring devices and proper wetting techniques to minimize potential fiber release. Average sample size was approximately 0.5 $\times$ 0.5 inches. The samples were placed in sealed bags and labeled with a unique sample identification number (ID). All sample locations were encapsulated using duct tape and labeled with the appropriate sample ID Number. Sample locations were recorded on the arrangement drawings, and a digital photograph of each sample was taken. Sample location maps and the photographic documentation are presented in Appendix I and Appendix J, respectively.

Three bulk samples of each homogeneous material were taken. Samples taken from the non-radiological areas of the ship were provided to MARAD for cataloging purposes and potential future analysis. Samples taken from the radiological areas were analyzed via polarized-light microscopy (PLM) by AMA. A material that contains ≥1% asbestos is considered an ACM. A material is not considered to be an ACM if the three samples of the homogeneous material contain <1% asbestos. Field datasheets and sampling results are given in Appendix K and Appendix L, respectively. Most of the samples analyzed from the radiological areas of the vessel contained asbestos (i.e., both Chrysotile and Amosite). Subsequent to receipt of the laboratory data, personnel estimated quantities of ACM from the radiological areas of the ship. This rough estimate was based on observations made during sample collection and room dimensions obtained from vessel maps. Personnel did not revisit the ship subsequent to receipt of the lab data to refine these estimates of ACM quantities. The listed estimates in Appendix L are rough orders of magnitudes.

In addition to sample collection logs and diagrams of each deck showing the location of each ACM sample, photographs of all the sample locations were obtained. These photographs are included in Appendix J.

6B.2 Lead-Based Paint

On-site XRF technology was employed for rapid lead content quantification in paints throughout the vessel. Representative locations were analyzed to quantify lead content in real-time using XRF techniques. Excluding calibrations, 523 readings on the accessible painted interior and exterior surfaces of the NS Savannah were collected. WPI was assisted in this task by ERM and AMA of Lanham, Md.

Of the 523 readings, 57 were ≥1.0 mg/cm^2. As noted previously, this is the value at which the state of Virginia classifies materials as “lead-containing.” Results for each measurement taken during the screening can be found in the field forms attached in Appendix M. In addition, Tables 1 and 2 within Appendix M summarize the positive analytical readings collected in the radiological and non-radiological areas of the ship, respectively. Tables 1 and 2 in Appendix M also summarize the analytical results obtained from paint chips collected on the ship and analyzed at the AMA laboratory for quality control purposes. Selected photographs of the lead-based sampling effort throughout the ship are presented in Appendix N.

6B.3 Liquids

As part of the ship characterization effort, liquids that remain in the radiological and non-radiological areas of the boat were sampled for characterization. Samples were collected using a dedicated plastic bellows-type sampler and placed in laboratory supplied bottleware. Once collected, the samples were sealed in zip-lock bags and placed in a cooler with ice. Liquids collected from the radiological areas of the boat were analyzed by Froehling & Robertson (F&R), a Virginia-certified environmental laboratory located in Richmond. Liquid samples collected from the non-radiological areas of the boat were documented and placed in a cooler that remained on the ship for analysis at a later time, if desired.

Samples collected from the non-radiological areas of the ship include hydraulic oils from the winches and steering gear, and lubricating oils from the boat emergency generator. Liquid samples collected from the radiological area included water and oil from the sump in the lower Secondary Containment area, hydraulic oil from the Primary Containment area, and lube oil and hydraulic oil collected from the ship stabilizer compartments. These samples were analyzed to assist in the characterization of these materials for the purpose of future disposal options by a decommissioning contractor.

Oils were analyzed for total halogen content and PCBs, and the water sample was analyzed for volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and metals. Analytical results for the liquid samples collected from the radiological areas of the boat were analyzed, and the results are included in Appendix O. Halogens and PCBs were detected in the Secondary Containment sump oil, Primary Containment hydraulic oil (oil from control rod drive mechanisms), and Stabilizer Room hydraulic oil. Metals were detected in the Secondary Containment sump water. It should be noted that volumetric estimates of the liquid samples could not be obtained, as the size of the liquid containment for the various liquids was not discernable.

6B.4 PCBs

In addition to the liquid oil samples collected for PCB analysis, power transformers on the ship were inspected to evaluate PCB content. According to personnel knowledgeable about historic ship operations, power transformers on the boat were all dry-type transformers. The vessel was checked for liquid-containing transformers by those involved with the characterization and none were found. However, based on the date of ship construction, it is likely that capacitors in the fluorescent light ballasts present throughout the ship contain small quantities of PCBs. These ballasts ended using PCBs content in 1978. Samples of light ballasts and electrical wiring were not collected for analytical testing as part of the characterization.

Polychlorinated Biphenyls (PCBs) are a concern for ships of the SAVANNAH's vintage. WPI characterized several liquids but the description of the non-liquid items that may contain PCBs was a bit brief. Section 6A.4 provides general information related to dielectric and electrical conduit, but you should be aware that PCBs may also be in paint coatings as well as other non-liquid media.

Painted surfaces that contain $\geq$ 50ppm PCBs may not be torch cut. Combustion of PCBs is prohibited per 40 CFR 761.50. If the decommissioning entails the cutting of painted surfaces, the paint should be analyzed for PCBs or presumed to contain regulated concentrations. "Regulated" painted surfaces must be mechanically removed at and around the burn line to prevent heating of the paint.

The reader should be aware that PCBs may be found in non-liquid media aboard the vessel. "High probability" non-liquid media includes: electrical cable, ventilation gaskets, grease, rubber applications such as electrical channel rubber and pipe hanger liners, adhesives, and caulking/grouting. If these items are removed during the decommissioning, they must be handled and disposed of in accordance with 40 CFR 761 et seq.

6B.5 Mercury

As part of the hazardous materials characterization, thermometers and switches throughout the ship were inspected in an effort to determine the potential presence of mercury-containing materials. Based on the inspection, and in accordance with WPI sources knowledgeable of the ship, no mercury-containing thermometers or switches were documented on the boat. Visual observations of the thermometers did not suggest that any thermometers contained mercury. Based on the year of construction and years of operation, it is possible that some fluorescent light bulbs on the vessel contain mercury.

7. QUALITY ASSURANCE

The characterization effort was performed in accordance with the Quality Assurance Project Plan. WPI's Nuclear QA program was applied to data/sample management, vendor analyses, and instrument calibration/use. Project implementing procedures were developed and followed during the implementation of the project.

8. SERAT REPORT

Thomas Jefferson National Accelerator Facility (Jefferson Lab) entered into an agreement with the MARAD to provide support for the SERAT. Commensurate with its role of health physics support for Savannah Emergency Response Assessment Team (SERAT) efforts, Jefferson Lab conducted a series of measurements to confirm the primary nuclides of concern remaining in the reactor systems of the NSS. The report detailing these findings is contained in Appendix P.