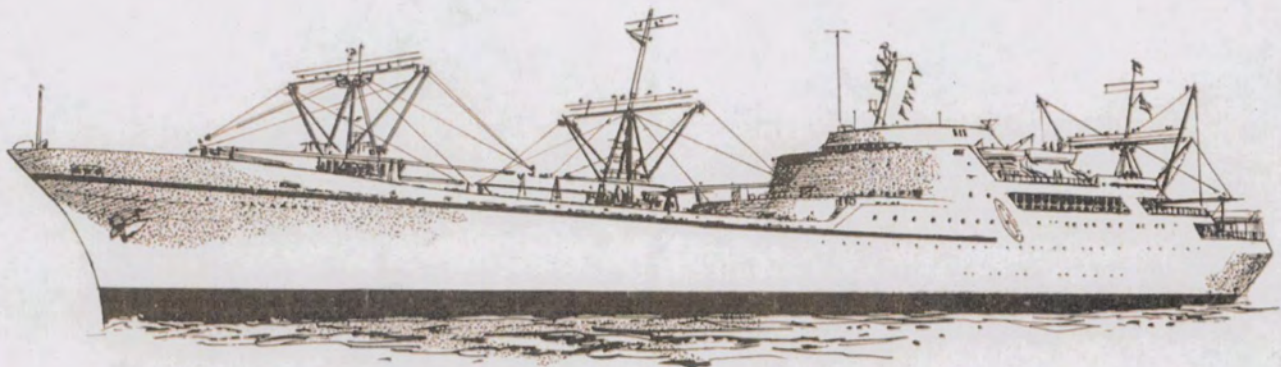




**U.S. Department of Transportation  
Maritime Administration  
Office of Ship Operations**



***N.S. SAVANNAH***

**LICENSE TERMINATION PLAN**

**STS-004-003**

**Revision 1**

Approved:

Date: September 4, 2025

Senior Technical Advisor

**Prepared by:  
NSSS, LLC**



## ABSTRACT

The Nuclear Ship *SAVANNAH* (NSS) is believed to be the first federally-designated historic property to undergo decommissioning under the provisions of a Nuclear Regulatory Commission (NRC) utilization facility license. It is also the only waterborne and mobile NRC-licensed site. For these and other reasons, this decommissioning project contains characteristics that uniquely differentiate it from conventional landside nuclear power facilities. This License Termination Plan (LTP), while following NRC prescribed format and content requirements, seeks to define, explain, and propose solutions to the challenges and opportunities that arise from *SAVANNAH*'s unique characteristics, while meeting the overarching objective to terminate the NS-1 license without restrictions.

Certain characteristics may simplify the nature of NSS decommissioning and license termination. These include the compact nature of the NSS site and its construction features that isolate it from much of the surrounding environment. Other characteristics may be considered complications, including the aforementioned compact and mobile (i.e., transient) site and also those resulting from NSS' designation as a National Historic Landmark (NHL). As a federally-owned NHL, it is incumbent upon the U.S. Department of Transportation, Maritime Administration (MARAD) to undertake such planning and actions (emphasis added) as are necessary to minimize harm to the landmark – which is a higher standard than is typically imposed on decommissioning projects, even when they involve properties with historic significance. Among the earliest agency stated goals for NSS decommissioning was a preference that the ship not be destroyed, but instead preserved if practical, following the license termination. This goal strongly influenced the design choices made by MARAD when planning decommissioning; however, in practice these choices were found to neatly complement and address some of the significant challenges that the compact and mobile site posed. The preservation goal also challenged decommissioning in that the disposition of NSS would necessarily come after the license termination by NRC. This left the eventual end state of the facility open and unknown during the decommissioning process. The LTP includes detailed discussions and analyses of three distinct end state scenarios, all of which are shown to meet the radiological criteria for unrestricted release. In this regard, MARAD has chosen to adopt the Environmental Protection Agency's 15 mrem per year standard, as MARAD's administrative limit described within the LTP. The administrative limit includes *as low as reasonably achievable* (ALARA) considerations.

Since 2018, MARAD has formally consulted with several parties under the provisions of Section 106 of the National Historic Preservation Act of 1966, as amended. This consultation ultimately resulted in a Programmatic Agreement (PA) covering both decommissioning and disposition as a single Undertaking. The PA, whose signatories include MARAD, the Advisory Council on Historic Preservation, Maryland State Historic Preservation Officer, and the NRC, was executed in March 2023. It is no longer uncommon for licensed facilities to enjoy extended operating periods which, when combined with some period of SAFSTOR, result in facilities that become historically significant with the passage of time. It seems probable that future decommissioning projects will involve facilities that possess significance to the extent that they become federally-designated historic properties (i.e., listed on the National Register of Historic Places). To that end, MARAD hopes that this LTP provides an example for what can be accomplished when two otherwise contradictory processes are thoughtfully managed and executed in a harmonious manner.



**License Termination Plan – (STS-004-003)**

---

**RECORD OF REVISIONS**

| <b>Revision</b>         | <b>Summary of Revisions</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| STS-004-003, LTP Rev. 0 | Original. Approved January 27, 2025.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| STS-004-003, LTP Rev. 1 | <p>Revision 1, per 10 CFR 50.71(e), includes the responses to requests for additional information (RAIs). The revision simply consolidates the RAIs into a single document.</p> <p>Each RAI is located in the appropriate section of the LTP and each is annotated by the parenthetical phrase (RAI response).</p> <p>Responses to some RAIs required deleting text in Sections 5.5.3.1, 5.7.1.3, 5.7.2.5 and 5.8.1, There are no change bars for deletions.</p> <p>A new chapter 11 was added to list submittals supporting LTP approval.</p> |

**LIST OF EFFECTIVE PAGES**

| <b>Page No.</b>           | <b>Rev. No.</b> | <b>Page No.</b> | <b>Rev. No.</b> | <b>Page No.</b> | <b>Rev. No.</b> |
|---------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Title Page<br>and ii - xx | 0               | 1-214           | 0               |                 |                 |



## TABLE OF CONTENTS

|                                                                                          |      |
|------------------------------------------------------------------------------------------|------|
| Abstract.....                                                                            | ii   |
| Record of Revisions .....                                                                | iii  |
| List of Effective Pages .....                                                            | iii  |
| Table of Contents.....                                                                   | iv   |
| List of Tables .....                                                                     | ix   |
| List of Figures .....                                                                    | xii  |
| Foreword.....                                                                            | xiii |
| Acknowledgments.....                                                                     | xiv  |
| Abbreviations and Acronyms .....                                                         | xix  |
| 1 GENERAL INFORMATION .....                                                              | 1    |
| 1.1 Identifying Information.....                                                         | 1    |
| 1.2 Introduction.....                                                                    | 1    |
| 1.3 Purpose.....                                                                         | 2    |
| 1.4 Decommissioning Objectives .....                                                     | 3    |
| 1.5 Plan Summary.....                                                                    | 3    |
| 1.5.1 Chapter 1, General Information .....                                               | 3    |
| 1.5.2 Chapter 2, Site Characterization.....                                              | 3    |
| 1.5.3 Chapter 3, Identification of Remaining Site Dismantlement Activities.....          | 4    |
| 1.5.4 Chapter 4, Remediation Plans .....                                                 | 4    |
| 1.5.5 Chapter 5, Final Status Survey Plan.....                                           | 4    |
| 1.5.6 Chapter 6, Compliance with the Radiological Criteria for License Termination.....  | 4    |
| 1.5.7 Chapter 7, Update of the Site-Specific Decommissioning Costs .....                 | 5    |
| 1.5.8 Chapter 8, Supplement to the Environmental Report.....                             | 5    |
| 1.5.9 Chapter 9, Portions of the Facility that were Released prior to LTP Approval ..... | 5    |
| 1.5.10 Chapter 10, Regulatory Notifications of Changes.....                              | 5    |
| 1.6 Facility and Site Description.....                                                   | 5    |
| 1.6.1 Port of Baltimore General Description.....                                         | 14   |
| 1.6.2 Surrounding Area of the NSS Site .....                                             | 15   |
| 1.6.3 Operational Background .....                                                       | 23   |
| 1.7 Confirmation of Information (RAI Response).....                                      | 25   |
| 1.8 References.....                                                                      | 25   |
| 2 SITE CHARACTERIZATION.....                                                             | 27   |
| 2.1 Introduction.....                                                                    | 27   |
| 2.1.1 Operations and Final Shutdown Summary.....                                         | 28   |

## License Termination Plan – (STS-004-003)

|       |                                                                                |    |
|-------|--------------------------------------------------------------------------------|----|
| 2.1.2 | Current Site Radiological and Non-Radiological Conditions .....                | 28 |
| 2.1.3 | Chronology of Decommissioning Planning and Characterization .....              | 29 |
| 2.1.4 | Other Considerations Regarding Site Characteristics and Characterization ..... | 30 |
| 2.2   | Historical Site Assessment.....                                                | 32 |
| 2.2.1 | Introduction .....                                                             | 32 |
| 2.2.2 | Methodology .....                                                              | 32 |
| 2.2.3 | Results .....                                                                  | 33 |
| 2.3   | Characterization Activities.....                                               | 33 |
| 2.3.1 | Activation Analysis in 2004.....                                               | 33 |
| 2.3.2 | WPI Characterization in 2005 .....                                             | 34 |
| 2.3.3 | RPV, Reactor Internals and NST Sampling in 2005 .....                          | 40 |
| 2.3.4 | Characterization Activities in 2018.....                                       | 41 |
| 2.3.5 | Characterization Activities in 2019.....                                       | 48 |
| 2.3.6 | Survey of Exterior Hull in 2019.....                                           | 56 |
| 2.3.7 | Sampling NST lead (Pb) in 2021 .....                                           | 60 |
| 2.3.8 | Engine Room Survey in 2022 .....                                               | 62 |
| 2.4   | Initial Classifications .....                                                  | 62 |
| 2.4.1 | Systems .....                                                                  | 62 |
| 2.4.2 | Structures.....                                                                | 64 |
| 2.5   | References.....                                                                | 69 |
| 3     | IDENTIFICATION of REMAINING SITE DISMANTLEMENT ACTIVITIES .....                | 70 |
| 3.1   | Introduction.....                                                              | 70 |
| 3.1.1 | Dismantlement Scope and Planned Final Ship Configuration .....                 | 70 |
| 3.1.2 | Completed Dismantlement Activities .....                                       | 72 |
| 3.1.3 | Coordination of Activities and Unreviewed Safety Questions.....                | 73 |
| 3.1.4 | Proposed Methods to Prevent Recontamination .....                              | 73 |
| 3.2   | Remaining Activities .....                                                     | 75 |
| 3.3   | Waste Projections.....                                                         | 75 |
| 3.4   | Occupational Exposure .....                                                    | 77 |
| 3.5   | Major Project Milestones .....                                                 | 77 |
| 3.6   | References.....                                                                | 77 |
| 4     | REMEDIATION PLANS .....                                                        | 79 |
| 4.1   | Remediation Actions and ALARA Evaluations .....                                | 80 |
| 4.2   | Remediation Actions.....                                                       | 81 |
| 4.2.1 | Pressure Washing.....                                                          | 81 |
| 4.2.2 | Needle Guns .....                                                              | 81 |
| 4.2.3 | High Pressure Water Blasting .....                                             | 81 |
| 4.2.4 | Laser Ablation.....                                                            | 84 |
| 4.2.5 | Chemical Strippers .....                                                       | 84 |
| 4.2.6 | Grinding .....                                                                 | 84 |
| 4.2.7 | Sponge and Abrasive Blasting .....                                             | 84 |
| 4.3   | Remediation Activities Impact on the Radiation Protection Program .....        | 85 |



## License Termination Plan – (STS-004-003)

|       |                                                                         |     |
|-------|-------------------------------------------------------------------------|-----|
| 4.4   | ALARA Evaluation .....                                                  | 86  |
| 4.4.1 | ALARA Evaluation (RAI response) .....                                   | 87  |
| 4.5   | Summary of Remediation Techniques, Procedure and Issues .....           | 89  |
| 4.6   | References .....                                                        | 89  |
| 5     | FINAL STATUS SURVEY PLAN .....                                          | 91  |
| 5.1   | Introduction .....                                                      | 91  |
| 5.2   | Scope .....                                                             | 92  |
| 5.2.1 | Final Status Survey Organization .....                                  | 92  |
| 5.2.2 | Final Status Survey Administrative Procedures .....                     | 93  |
| 5.3   | Summary of the Final Status Survey Process .....                        | 93  |
| 5.4   | Survey Planning .....                                                   | 97  |
| 5.4.1 | Data Quality Objectives .....                                           | 97  |
| 5.4.2 | Survey Units .....                                                      | 99  |
| 5.4.3 | Reference Coordinate Systems .....                                      | 100 |
| 5.4.4 | Area Preparation: Isolation and Control .....                           | 101 |
| 5.4.5 | Selection of DCGLs .....                                                | 101 |
| 5.5   | Final Status Survey Design Elements .....                               | 103 |
| 5.5.1 | Selecting the Number of Fixed Measurements and Locations .....          | 105 |
| 5.5.2 | Judgmental Assessments .....                                            | 108 |
| 5.5.3 | Data Investigations .....                                               | 108 |
| 5.6   | Survey Protocol for Non-structural Systems and Components .....         | 110 |
| 5.7   | Survey Implementation and Data Collection .....                         | 110 |
| 5.7.1 | Survey Methods .....                                                    | 111 |
| 5.7.2 | Survey Instrumentation .....                                            | 114 |
| 5.7.3 | Survey Considerations for Structures and Equipment .....                | 120 |
| 5.8   | Survey Data Assessment .....                                            | 120 |
| 5.8.1 | Sign Test .....                                                         | 121 |
| 5.8.2 | Unity Rule .....                                                        | 121 |
| 5.8.3 | Data Assessment Conclusions .....                                       | 122 |
| 5.9   | Notes on Structure and System Surveys .....                             | 122 |
| 5.9.1 | Exterior Hull Survey .....                                              | 122 |
| 5.9.2 | Neutron Shield Tank / Fuel Transfer Tank .....                          | 123 |
| 5.9.3 | Steam Generators .....                                                  | 123 |
| 5.9.4 | Pressurizer .....                                                       | 123 |
| 5.9.5 | Double Bottom Tanks .....                                               | 123 |
| 5.10  | Final Status Survey Release Records and Reports .....                   | 124 |
| 5.11  | Quality Assurance and Quality Control Measures .....                    | 124 |
| 5.12  | References .....                                                        | 126 |
| 6     | COMPLIANCE with the RADIOLOGICAL CRITERIA for LICENSE TERMINATION ..... | 127 |
| 6.1   | Introduction .....                                                      | 127 |
| 6.2   | Proposed Radiological Criteria for License Termination .....            | 128 |

## License Termination Plan – (STS-004-003)

|        |                                                                        |     |
|--------|------------------------------------------------------------------------|-----|
| 6.3    | Potential End State Conditions .....                                   | 128 |
| 6.3.1  | MARAD Ship Disposal Program.....                                       | 130 |
| 6.3.2  | Ship Conditions at License Termination .....                           | 132 |
| 6.4    | Radionuclides for Evaluation.....                                      | 133 |
| 6.5    | Documents for Guiding Calculations.....                                | 137 |
| 6.6    | Exposure Scenarios Evaluated .....                                     | 138 |
| 6.7    | Dose Rate Equations for Remediation and Component Removal Workers..... | 139 |
| 6.8    | Tools Used for Calculations and Analyses .....                         | 141 |
| 6.9    | Inputs to the Scenario Calculations.....                               | 142 |
| 6.9.1  | Tour Guide on Ship .....                                               | 142 |
| 6.9.2  | Remediation Worker on Ship .....                                       | 144 |
| 6.9.3  | Component Removal Worker on Ship .....                                 | 148 |
| 6.9.4  | Scrap Steel Scenarios in NUREG-1640 .....                              | 151 |
| 6.9.5  | "ModelRisk 4.0" (RAI Response).....                                    | 154 |
| 6.10   | Analysis and Results .....                                             | 162 |
| 6.11   | Reefing.....                                                           | 166 |
| 6.11.1 | Diver on a Reefed Ship .....                                           | 167 |
| 6.11.2 | Consuming Fish from a Reefed Ship .....                                | 167 |
| 6.12   | Area Factors .....                                                     | 171 |
| 6.13   | Radionuclides of Concern and Insignificant Dose Contributors.....      | 171 |
| 6.14   | Surrogate DCGLs (RAI Response).....                                    | 174 |
| 6.15   | Additional Considerations Concerning Preservation .....                | 174 |
| 6.16   | References.....                                                        | 178 |
| 7      | UPDATE of the SITE-SPECIFIC DECOMMISSIONING COSTS .....                | 180 |
| 7.1    | Introduction.....                                                      | 180 |
| 7.2    | Estimated Remaining Decommissioning Costs .....                        | 181 |
| 7.2.1  | Previously Docketed Decommissioning Estimates.....                     | 181 |
| 7.2.2  | Current Site-Specific Decommissioning Cost Estimate.....               | 182 |
| 7.3    | Decommissioning Funding .....                                          | 184 |
| 7.3.1  | Funds Available to Complete Decommissioning .....                      | 184 |
| 7.3.2  | Comparison to Estimated Remaining Costs.....                           | 184 |
| 7.4    | Regulatory Commitments .....                                           | 185 |
| 7.5    | Future Escalation of Estimates.....                                    | 185 |
| 7.6    | References.....                                                        | 185 |
| 8      | SUPPLEMENT to the ENVIRONMENTAL REPORT .....                           | 186 |
| 8.1    | Introduction.....                                                      | 186 |
| 8.2    | Purpose.....                                                           | 189 |
| 8.3    | Initial Environmental Assessment .....                                 | 189 |
| 8.4    | Post-Shutdown Decommissioning Activities Report.....                   | 189 |
| 8.5    | Supplement Environmental Assessment.....                               | 190 |



## License Termination Plan – (STS-004-003)

---

|       |                                                                 |     |
|-------|-----------------------------------------------------------------|-----|
| 8.5.1 | Proposed Action and Alternatives Evaluated in the SEA .....     | 191 |
| 8.5.2 | Conclusion of the SEA and FONSI.....                            | 194 |
| 8.5.3 | RAI Responses .....                                             | 195 |
| 8.6   | Impact to PSDAR .....                                           | 199 |
| 8.7   | Environmental Considerations Regarding Vessel Disposition ..... | 199 |
| 8.8   | Conclusion .....                                                | 199 |
| 8.9   | References.....                                                 | 200 |
| 9     | PORTIONS of FACILITY RELEASED prior to LTP APPROVAL .....       | 201 |
| 10    | LTP AREAS that cannot be changed without NRC APPROVAL .....     | 202 |
| 10.1  | References.....                                                 | 203 |
| 11    | Submittals Supporting LTP Approval.....                         | 204 |
| 11.1  | References.....                                                 | 204 |

## LIST OF TABLES

|            |                                                                                                                       |    |
|------------|-----------------------------------------------------------------------------------------------------------------------|----|
| Table 1-1  | Principal Characteristics of the N.S. <i>SAVANNAH</i> .....                                                           | 12 |
| Table 1-2  | Chronology of Significant Licensing Events .....                                                                      | 23 |
| Table 2-1  | Barnwell Waste Acceptance Criteria Classification of the RPV and Reactor Internals .....                              | 34 |
| Table 2-2  | 2005 Characterization Project Instrument List.....                                                                    | 36 |
| Table 2-3  | 2005 Non-Radiological Area Summary .....                                                                              | 37 |
| Table 2-4  | 2005 Radiological Area Summary .....                                                                                  | 38 |
| Table 2-5  | 2005 Reactor Compartment Radiological Summary.....                                                                    | 39 |
| Table 2-6  | 2005 CV Radiological Summary .....                                                                                    | 40 |
| Table 2-7  | Summary of the RPV and Internals Activities .....                                                                     | 41 |
| Table 2-8  | 2018 Areas Surveyed .....                                                                                             | 42 |
| Table 2-9  | 2018 Maximum Results by Measurement Type.....                                                                         | 44 |
| Table 2-10 | NSS 2018 Characterization Summary Table A.....                                                                        | 45 |
| Table 2-11 | NSS 2018 Characterization Summary Table B.....                                                                        | 46 |
| Table 2-12 | 2019 Baseline Survey Measurement Summary (Quantity Collected).....                                                    | 49 |
| Table 2-13 | Fixed Position Alpha ( $\alpha$ ) Beta ( $\beta$ ) Sensitivity in Highest $\alpha$ $\beta$ Background per Survey Area | 50 |
| Table 2-14 | Off-site Laboratory Smear Composite Gamma Spectroscopy Results .....                                                  | 51 |
| Table 2-15 | Steam Generator Composite Smear Results Compared to Screening DCGLs.....                                              | 52 |
| Table 2-16 | Pressurizer Composite Smear Results Compared to Screening DCGLs.....                                                  | 53 |
| Table 2-17 | Containment Drain Tank Composite Smear Results Compared to Screening DCGLs.....                                       | 53 |
| Table 2-18 | RC Exhaust Ventilation Composite Smear Results Compared to Screening DCGLs .....                                      | 54 |
| Table 2-19 | Primary Loop RC IX Piping Composite Smear Results Compared to Screening DCGLs ...                                     | 54 |
| Table 2-20 | Component Activity and Classification Summary.....                                                                    | 55 |
| Table 2-21 | Hull Survey Units.....                                                                                                | 56 |
| Table 2-22 | Descriptive Statistics, Beta Static Measurement Data, Background Corrected .....                                      | 59 |



**License Termination Plan – (STS-004-003)**

---

|            |                                                                                        |     |
|------------|----------------------------------------------------------------------------------------|-----|
| Table 2-23 | NSS Hull MARSSIM Survey Summary .....                                                  | 60  |
| Table 2-24 | Initial Classification of Systems.....                                                 | 63  |
| Table 2-25 | Initial Classification of Structures or Rooms .....                                    | 66  |
| Table 3-1  | Projected Remaining Waste Quantities as of September 30, 2023 .....                    | 75  |
| Table 3-2  | Summary of Waste Disposed from Ship through September 30, 2023 .....                   | 76  |
| Table 3-3  | Radiation Exposure - Project Total and Estimate to Complete Remaining Activities ..... | 77  |
| Table 3-4  | General Project Milestones .....                                                       | 77  |
| Table 4-1  | Summary of System End States at License Termination (RAI Response) .....               | 82  |
| Table 5-1  | Survey Unit Surface Area Limits .....                                                  | 100 |
| Table 5-2  | Investigation Levels (RAI Response) .....                                              | 108 |
| Table 5-3  | Traditional Scanning Coverage Requirements .....                                       | 112 |
| Table 5-4  | Available Instruments and Associated MDCs (RAI Response).....                          | 118 |
| Table 6-1  | Samples for Hard to Detect Analyses .....                                              | 134 |
| Table 6-2  | Initial Suite of Radionuclides.....                                                    | 134 |
| Table 6-3  | Offsite Laboratory Results of Sample Analyses .....                                    | 135 |
| Table 6-4  | Radionuclide Fractions of the Sample Analyses .....                                    | 136 |
| Table 6-5  | Radionuclide Sum of Fractions and Normalized Sum of Fractions .....                    | 137 |
| Table 6-6  | Scenarios Evaluated for Calculation of Surface Contamination DCGLs.....                | 139 |
| Table 6-7  | Parameters for Tour Guide on Ship Calculations.....                                    | 144 |
| Table 6-8  | Parameters for Remediation Worker on Ship External Dose Calculations .....             | 145 |
| Table 6-9  | Parameters for Remediation Worker on Ship Ingestion Dose Calculations.....             | 146 |
| Table 6-10 | Parameters for Remediation Worker on Ship Inhalation Dose Calculations .....           | 147 |
| Table 6-11 | Parameters for Component Removal Worker on Ship External Dose Calculations .....       | 148 |
| Table 6-12 | Parameters for Component Removal Worker on Ship Ingestion Dose Calculations .....      | 149 |
| Table 6-13 | Parameters for Component Removal Worker on Ship Inhalation Dose Calculations.....      | 150 |

### License Termination Plan – (STS-004-003)

|            |                                                                                                                 |     |
|------------|-----------------------------------------------------------------------------------------------------------------|-----|
| Table 6-14 | Non-Radionuclide Input Parameter Distribution Summary for Both Worker Scenarios (RAI Response)                  | 156 |
| Table 6-15 | Component Removal Worker Output Parameters (RAI Response)                                                       | 157 |
| Table 6-16 | Remediation Worker Output Parameters (RAI Response)                                                             | 159 |
| Table 6-17 | Percentile Distributions of Total Dose factor for Each Worker Scenario and for Key Radionuclides (RAI Response) | 161 |
| Table 6-18 | 95 <sup>th</sup> Percentile EDE from All Pathways - Scrap Yard and Foundry Worker                               | 163 |
| Table 6-19 | 95 <sup>th</sup> Percentile EDE from All Pathways - Leachate ( $\mu\text{Sv/y}/(\text{Bq}/\text{cm}^2)$ )       | 164 |
| Table 6-20 | Scenario Results ( $\text{mrem/y}/(\text{dpm}/\text{cm}^2)$ )                                                   | 165 |
| Table 6-21 | Surface Contamination Limits (DCGLs)                                                                            | 166 |
| Table 6-22 | Reefing Diver Dose Rate Coefficients and DCGLs                                                                  | 167 |
| Table 6-23 | Concentrations of the Residual Nuclides in the Containment Volume                                               | 170 |
| Table 6-24 | Activity Fractions/DCGLs                                                                                        | 172 |
| Table 6-25 | Relative Dose Fractions                                                                                         | 173 |
| Table 6-26 | Radionuclides of Concern (ROCs) and Insignificant Dose Contributors (IDCs)                                      | 173 |
| Table 6-27 | Activity Fractions Remaining Over Time                                                                          | 177 |
| Table 6-28 | Annual Dose Over Time ( $\text{mrem}$ )                                                                         | 178 |
| Table 7-1  | Estimated Remaining Decommissioning Costs as of September 30, 2023                                              | 182 |
| Table 8-1  | Summary of Impacts                                                                                              | 193 |



## LIST OF FIGURES

|             |                                                                                  |     |
|-------------|----------------------------------------------------------------------------------|-----|
| Figure 1-1  | NSS at Pier 13 in 2023 .....                                                     | 6   |
| Figure 1-2  | Containment, Reactor Compartment and Engine Room (Frames 99-148) .....           | 6   |
| Figure 1-3  | Arrangement of Principal Components in Containment .....                         | 7   |
| Figure 1-4  | General Arrangement – Inboard Profile .....                                      | 8   |
| Figure 1-5  | General Arrangement - Decks - Top of House to A Deck .....                       | 9   |
| Figure 1-6  | General Arrangement - Decks - B and C .....                                      | 10  |
| Figure 1-7  | General Arrangement - Decks - D and Tank Top .....                               | 11  |
| Figure 1-8  | NSS Location from Google Maps, with an approximate one-mile radius overlay ..... | 13  |
| Figure 1-9  | NSS at Pier 13 from Google maps satellite view, circa 2009 .....                 | 14  |
| Figure 1-10 | NSS at Pier 13, September 2023, looking northward .....                          | 18  |
| Figure 1-11 | NSS at Pier 13, September 2023, looking northward .....                          | 19  |
| Figure 1-12 | NSS at Pier 13, September 2023, looking northwest .....                          | 19  |
| Figure 2-1  | NSS Starboard Survey Units .....                                                 | 57  |
| Figure 2-2  | NSS Port Survey Units .....                                                      | 57  |
| Figure 2-3  | Neutron Shield Tank .....                                                        | 61  |
| Figure 3-1  | Remaining License Termination Activities .....                                   | 74  |
| Figure 4-1  | Comparison of Cape John to NSS .....                                             | 88  |
| Figure 4-2  | Results of Equations N-1 and N-2 .....                                           | 89  |
| Figure 5-1  | FSS Organization .....                                                           | 94  |
| Figure 6-1  | Receptor and Sources for RESRAD-BUILD Model .....                                | 143 |

## FOREWORD

This License Termination Plan (LTP) has benefitted from the accrued experience of commercial industry and the Nuclear Regulatory Commission (NRC) since the first LTPs were submitted some twenty years ago. In preparing the LTP, MARAD carefully considered the LTP approval histories for several of the more recent commercial projects, including among others, LaCrosse, Humboldt Bay, and Zion; the Plum Brook federal site operated by the National Aeronautics and Space Administration was also considered. In general, Requests for Additional Information (RAI) generated during the LTP review and approval process tended to be grouped into similar categories. Many, if not the preponderance, of the RAIs involved environmental affects that are not germane to N.S. *SAVANNAH* (NSS). Examples include the effects of groundwater and subsurface soil contamination, and other factors related to onsite and potential offsite terrestrial conditions. As described in the LTP, NSS is isolated from both the terrestrial and marine/aquatic environments, and so MARAD anticipates no such RAIs. Another common category of RAIs involved the location of information within the LTP itself. MARAD believes this category exists because the three NRC guidance documents, although consistent with themselves and the underlying regulations at 10 CFR 50.82, differ from each other in certain respects. The three guidance documents are:

1. Regulatory Guide 1.179, *Standard Format and Contents for License Termination Plans for Nuclear Power Reactors*, Rev. 2, July 2019
2. NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, Rev. 2, April 2018, including Appendix A
3. NUREG-1757, Volume 2, *Consolidated Decommissioning Guidance – Characterization, Survey, and Determination of Radiological Criteria*, Rev. 1, September 2006

Before actual writing of the LTP started, MARAD developed an internal working document that collected, in a single location, all the NRC LTP acceptance criteria. We arranged this document in chapter format, laying out the requirements from each of the guidance documents in sequential order, beginning with R.G. 1.179, and followed by NUREGs 1700 and 1757 in that order. No attempt was made to consolidate duplicate or duplicative content. The MARAD document became the working shell for the LTP. As LTP sections were written, they were inserted into the appropriate location(s) of the shell. Later, a tracking matrix was developed which served as a quality control / quality assurance mechanism for authors and reviewers. The matrix is called the **Acceptance Criteria Review Matrix (ACRM)**. As the LTP matured into a final narrative construct, the editors used the ACRM to carefully control the consolidation of duplicative content.

MARAD has included the final ACRM in the License Amendment Request that submits the LTP to NRC. It is our hope that the matrix will serve a similar purpose for NRC reviewers as it has for the MARAD authors and reviewers, and that it proves useful to NRC in the NSS LTP approval process.



## ACKNOWLEDGMENTS

This License Termination Plan (LTP) is more than the collective work of several authors, editors, and reviewers. In a very real sense, it represents the culmination of decades of work and service by many individuals too numerous to name, who conceived, designed, constructed, operated, and finally decommissioned the world's first nuclear-powered merchant ship. It thus comes with no small irony that as the N.S. *SAVANNAH* (NSS) licensed lifecycle nears conclusion, the world maritime community is embracing with renewed interest and vigor, the potential use of commercial nuclear propulsion to significantly reduce carbon and other greenhouse gas emissions from merchant ships. While this objective was not part of the NSS program, meeting the objective must, of necessity, draw upon the experiences and precedents that NSS established, and which were further developed by West Germany's *Otto Hahn*. To that end, MARAD looks forward to preserving and disseminating the collected knowledge and experience of the NSS program, so that it can be used for its original purpose – to advance the development of nuclear-powered merchant ships for the benefit of humankind. In this way, we hope to continue and expand the legacy of the outstanding group of men and women who put the once outrageous idea of using the power of the atom to propel a peaceful, commercial ship into practical effect, who then explored all the many unforeseen challenges associated with the idea, and who ultimately safeguarded both the ship and its knowledge base through the long decades of protective storage and decommissioning. This LTP, as the culmination of their work and legacy, is dedicated to them.

I will take the liberty of exercising my prerogative as signatory to acknowledge the contributions of my contemporary staff, mentors and predecessors. It seems inevitable that some persons will be missed in the narrative; and in some cases, others may not be named out of narrative clarity; any such omissions are my own. In many respects, the NSS lifecycle is bracketed by two careers; my own, and that of Zelvin Levine. Zel graduated from Georgia Tech with a Doctorate in Chemical Engineering, and having completed the then-newly created School of Reactor Technology at Oak Ridge. He joined Babcock & Wilcox in 1955, and was one of the first employees assigned to the NSS project. In that sense, his career with NSS began virtually at the beginning of the program. Zel was responsible for significant engineering designs and safety analyses to support operating authorizations and licensing. He left B&W for the Martin Company on the STURGIS project before joining MARAD in 1969, and worked through several progressively more senior positions until he was named Assistant Administrator for Research and Development. He acted as MARAD's NSS licensee from about 1975 until his retirement at the end of 1998. I joined MARAD in 1991, and was assigned to the NSS in 1993 to supervise its removal from the Patriots Point Naval and Maritime Museum. I became the project engineer on a staff of about three persons, the other being Joseph Seelinger, at the time the Chief of the Division of Ship Maintenance and Repair, and a former NSS Reactor Operator from the 1963-1964 MARAD backup crew. I worked directly with Zel as MARAD formulated the license amendment request associated with the relocation of NSS, and the removal of Patriots Point as co-licensee. Zel, Joe and I continued to act as the MARAD licensee organization until Zel's retirement. Joe then became licensee, and I followed five years later when Joe retired in January 2004. By that time, the NSS DECON project had been authorized, and a small nucleus staff had been stood up. Baring anything unforeseen or untoward, I expect to complete my tenure as licensee upon the license termination.

Maritime Administrator Bill Schubert must be credited with the executive act of authorizing decommissioning in February 2002. He is followed immediately by Jim Caponiti, our Associate Administrator for National Security at the time, who championed the project and sought the resources necessary to develop it. Credit is also due to Bill Trost, the Director of the Office of Ship Operations, who had programmatic responsibility for NSS, and who endorsed the creation of the dedicated *SAVANNAH* Technical Staff (STS) organizational unit in 2005. Their successors, and others in MARAD senior



## License Termination Plan – (STS-004-003)

---

management have continued to support NSS operations, and to advance the cause of decommissioning after the late 2006 suspension described in the PSDAR. To that end, credit is due to Administrator Paul Jaenichen, who sought the resumption of decommissioning beginning in 2013, and Associate Administrator Kevin Tokarski who also championed the project and supported the staff.

The immediate STS organization has never numbered more than five direct MARAD employees at any time. In addition to myself, our original staff included John Wiegand, Decommissioning Program Manager, Greg Thornton, Facility Site Manager, and Rick Volkmann, Marine Surveyor, and technical writer. Our Contracting Officer was Gene Simmons from 2003 to his retirement in 2013. In the four short years of 2003 to 2007, we brought together contractors and federal partners to create a licensee organization virtually from scratch, design the DECON-LT project, and resurrect the ship itself from the doldrums of the James River Reserve Fleet. The strength of the initial planning is evidenced by the fact that the DECON-LT project started in 2017 is fundamentally unchanged from the 2006 design. Only the administrative and contracting details have changed. Other MARAD STS staff have included Robert Falk and Caleb Soeun as DPM, and Jim Brown as FSM.

By design, the STS is a blended organization that includes contractors in key roles, and partner organizations supporting decommissioning activities and providing oversight. We established long-term relationships with the Department of Energy's Argonne National Lab and the DOT Volpe Center in that period of 2003 to 2007. Larry Boing, Mike Buonopane, Bill Halloran, and Chris Zevitas were the principals from those organizations, along with Chuck Felhauer. Our initial decommissioning planning contractor, WPI, was represented by Jon Stouky, a pioneer in the decommissioning industry, and himself a former NSS program participant as the operator of the servicing barge *Atomic Servant*, and in the post of Nuclear Advisor. John Bowen and Franco Godoy were part of the WPI team. Jon and John would remain with the NSS program well beyond the completion of the WPI contracts in 2007. Both served in the contractor key positions of Nuclear Advisor, and John later served as the contract Project Manager during the TOTE Services bridge contract from 2018 – 2021.

We added Areva Federal Services as our Engineering and Management Oversight Services contractor in 2007, along with Radiation Safety and Control Services as our radiological protection and emergency response contractor. Keystone Shipping Company was assigned as our General Agent for ship husbandry, custodial care, conversion and modifications, and marine services. Areva was hired to perform the detail design for DECON, but that focus turned to SAFSTOR when the budgetary suspension struck. Harvey Story, Don McGee, Doug Roberson, Skip Litterer, Lars Flink and Trevor Nancarrow represented these companies, with Doug, Don and Trevor returning over the course of time. Doug and Don are both active with the project today.

In 2005 and 2006 MARAD acquired "license technical support" services from Sayres and Associates – a relationship which ran until September 2012, and which produced the most significant long-term staffing relationships, with John Osborne as Licensing & Compliance Manager, Art Paynter as Quality Assurance Manager, and Bob Sheranko as Business and Risk Manager. Both John and Art continue in their roles, while Bob retired in 2019. In the position of Nuclear Advisor were first Jon Stouky, and then Pat McConnell. Among them and together with the direct staff, and incumbent contractors, MARAD created a contemporary licensing program by reconstituting our fundamental basis documents, modernizing the Technical Specifications via license amendment requests, and crafting an administrative and technical procedures program based on industry standards and best practices. Our current decommissioning program could not exist without the hard work and dedication of these individuals and companies.

The non-profit N/S SAVANNAH Association was created as a successor to the informal crew reunion organization that had existed from the early 1980s. The NSSA provided considerable assistance to decommissioning planning efforts, including sponsoring a reunion onboard NSS in 2008 during which



many interviews were conducted in support of the Historic Site Assessment. The NSSA continues to support NSS operations to this day, with our appreciation and gratitude.

Considering the importance and standing of NSS as a National Historic Landmark, and its place within the LTP, I would be remiss in omitting the persons who helped with our consultative efforts. Barbara Voulgaris, recently retired as MARAD's Senior Historian and Federal Preservation Officer, guided the consultation effort. She was aided by Thomas Shepherd, formerly of MARAD's Office of Chief Counsel, and Rand Pixa, MARAD's recently retired Deputy Chief Counsel. Ainsley Parrish, Justin Valentino, and Wendy Coble support the ongoing execution of the Programmatic Agreement. I am assisted by Anne Jennings, as a contractor with Sustainable Design Consortium. Argonne National Lab's Konnie Westcott and Dan O'Rourke also made significant contributions to MARAD's NHPA compliance effort. MARAD also appreciates the support provided by the PA signatories and concurring parties, especially with respect to the decommissioning activities portion of the NHPA Undertaking as described within the LTP.

In the period between 2008 and 2017, other contracts were awarded to support STS and NSS operations. The first integrated management contract was awarded in 2013 to Tote Services. This contract combined the formerly separate ship husbandry, radiological protection, and license technical support functions. The Phase I decommissioning effort began in the final year of this contract, and continued under a bridge contract from 2018 to 2021. Principals during this period included Tom McIntyre and John Bowen as Project Manager, Jim Byrne and John Bowen as Nuclear Advisor, Cliff Marks in several positions, and Herb Evans as Radiation Safety Officer.

Two engineering support contracts are in place to provide independent engineering review and oversight, field inspection services, and multidisciplinary regulatory support. Under the B2Z Engineering Contract are John Wiegand, retired from MARAD and drawing upon his many years of *SAVANNAH* experience, and Don McGee of Orano Federal Services (successor to Areva). Sustainable Design Consortium provides the field inspection services with Tony Margan and Robbie McCready, and independent review with Jim Reese and Bruce Reynolds, both via Tidewater.

Under the 2021 DECON-LT integrated services contract, the current key personnel include Matt Arsenault, Project Manager, Nick Waltz, Nuclear Advisor and BRM, Jerry Toumey, Decommissioning Manager, Scott Ginter, RSO, Art Paynter, QAM and John Osborne, LCM. Jay Tarzia, Ron Thurlow and Todd Eiler are the principal representatives of the joint venture partners RSCS and ESFS. The current MARAD senior management and headquarters staff with programmatic responsibility for NSS operations include Deputy Associate Administrator for Federal Sealift Doug Harrington, Director of Fleet Program Management Melinda Simmons-Healey, Program Manager Laila Linares, Director of Acquisitions Bruce Markman, Contracting Officer Ken Egbuna, and Contracting Specialist Lisa Miles. And of course, the MARAD senior leadership team including Maritime Administrator Ann Phillips, Deputy Administrator Tamekia Flack, and Executive Director Jack Kammerer, provide continuing leadership and support to NSS activities, including the license termination effort.

With respect to the LTP itself, I wish to thank the authors, contributors, and reviewers for their equally hard work and dedication. The LTP development team was led by Eric Darois of RSCS. John Osborne and Robert Falk developed the Acceptance Criteria Review Matrix. The principal LTP author / editor is John Osborne, and contributors include Robert Falk, Pete Hollenbeck, Heath Downey, Rob Grant, Art Paynter, and Caleb Soeun. Independent reviews were provided by Dave Fauver (RSCS), Don McGee (Orano via B2Z Engineering), John Wiegand (B2Z), James Reese (Tidewater), Robert Yetter (EnergySolutions), and Cameron Davis (ES). Three formal pre-submittal meetings were held and included among MARAD attendees not named above Jay Tarzia of RSCS.

For the entirety of the current NSS program, Cynthia Bearor has stood alongside me as a charter and integral member of the STS. Her organizational title of Documentation and Administrative Support

### **License Termination Plan – (STS-004-003)**

---

Manager belies her importance; it is a holdover from the early days. Among many other things, she functions as the MARAD Site Safety Officer, and serves as either the Contracting Officer's Representative, or ACOR, for all our active contracts. For a long time, she and I were the only MARAD direct employees on the STS. To say that this project rests equally on her shoulders as mine would be an understatement because it fails to acknowledge how deeply I have come to rely on Cindy's support.

On November 8, 2022, we held a ceremony immediately before the Reactor Pressure Vessel lift. The ceremony commemorated our colleagues and program partners who did not live to see the day. A magnetic plaque was affixed to the RPV canister, and remains attached at Clive. Regrettably, we added another member to the list earlier this year. In their honor, I will end this acknowledgement by repeating their names herein.

Erhard W. Koehler  
October 2023



**SAVANNAH TECHNICAL STAFF  
IN MEMORIAM  
2002 – 2023**

**Helen Delich Bentley  
Wayne Britz  
Robert Falk  
Lars Flink  
Marvin Gordon  
CAPT Moses Hirschowitz  
Fred Hoffman  
Dr. Zelvin Levine  
Walt Mathers  
RADM Lauren S. McCready  
Bob Moody  
Joseph H. Seelinger  
Gene Simmons  
Harvey Story  
Jon Stouky  
Stanley D. Wheatley**

## ABBREVIATIONS AND ACRONYMS

**Note to Reviewers: Acronyms will be redefined on first use in each chapter.**

ACRM - Acceptance Criteria Review Matrix  
AEC - Atomic Energy Commission  
ALARA - As Low As Reasonably Achievable  
c/d - counts per disintegration  
CEQ - Council on Environmental Quality  
CRD - Control Rod Drive  
CV - Containment Vessel  
DCF - Dose Conversion Factors  
DCGL - Derived Concentration Guideline Level  
DQA - Data Quality Assessment  
DQAP - Decommissioning Quality Assurance Plan  
DQO - Data Quality Objective  
EA - Environmental Assessment  
EAF - Electric Arc Furnace  
EDE - Effective Dose Equivalent  
EPA - Environmental Protection Agency  
FSS - Final Status Survey  
GEL - GEL Laboratories, LLC  
HSA - Historical Site Assessment  
HTD - Hard to Detect  
IDC - Insignificant Dose Contributors  
ISOCS - In Situ Object Counting System  
LAR - License Amendment Request  
LBGR - Lower Bound of the Gray Region  
LLBP - Less Likely but Plausible  
LLRW - Low Level Radioactive Waste  
LTP - License Termination Plan  
MARAD - U.S. Department of Transportation, Maritime Administration  
MDA - Minimum Detectable Activity  
MDC - Minimum Detectable Concentration



### License Termination Plan – (STS-004-003)

---

MDCC - Minimum Detectable Corrected Counts per minute  
N/A - Not Applicable  
NEPA - National Environmental Policy Act  
NHL - National Historic Landmark  
NHPA – National Historic Preservation Act  
NRC - Nuclear Regulatory Commission  
NRHP – National Register of Historic Places  
NSS - Nuclear Ship *SAVANNAH*  
NST - Neutron Shield Tank  
OSHA - Occupational Safety & Health Administration  
PPDA - Patriots Point Development Authority  
PSDAR - Post Shutdown Decommissioning Activities Report  
RASS - Remedial Action Support Survey  
RAI -Request for Additional Information  
RCA - Radiologically Controlled Area  
ROC - Radionuclide of Concern  
SCM - Surface Contamination Monitor  
SEA - Supplemental Environmental Assessment  
SOF - Sum of the Fractions  
USN - U.S. Navy  
VSP - Visual Sample Plan  
WRS - Wilcoxon Rank Sum

# 1 GENERAL INFORMATION

## 1.1 Identifying Information

Facility: Nuclear Ship *SAVANNAH*; License NS-1; Docket No. 50-238  
 Location: Baltimore City, Maryland  
 Address: Pier 13 Canton Marine Terminal; 4601 Newgate Ave; Baltimore, MD 21224  
 Owner / Licensee: Maritime Administration, U.S. Department of Transportation  
 Responsible Official: Erhard W. Koehler, Senior Technical Advisor, N.S. *SAVANNAH*

## 1.2 Introduction

This License Termination Plan (LTP) is submitted by the Maritime Administration (MARAD) as licensee for the Nuclear Ship *SAVANNAH* (NSS) on October 23, 2023 and approved on January 30, 2025. Revision 1 includes the responses to requests for additional information (RAI). Each is located in the appropriate section or in a new section of the LTP and each is annotated by the parenthetical phrase (RAI response).

As described more fully in the *Updated Final Safety Analysis Report* (UFSAR) [Reference 1-1], NSS is the world's first nuclear-powered merchant ship. It was conceived and constructed during the Eisenhower Administration as a signature element of the *Atoms for Peace* Program and remains a powerful symbol of this nation's commitment to advance the peaceful uses of nuclear technology for the betterment of humankind. After successfully completing its programmatic goals and objectives, NSS was removed from service in 1970, defueled in 1971, and made permanently inoperable by 1976, as represented by issuance of a Possession-only License.

NSS was operated as a museum from 1981 to 1994, during which time the State of South Carolina, acting through the Patriots Point Development Authority (PPDA), was a co-licensee with MARAD.<sup>1</sup> During the museum period, NSS was first named to the National Register of Historic Places (NRHP, 1983), and then designated as a National Historic Landmark of the United States (NHL, 1991). In seeking to complete the NSS licensed lifecycle through decommissioning and license termination, MARAD has been sensitive to NSS' historic significance, and taken affirmative steps (see Section 1.4 of this chapter, and Section 3.1.1 of Chapter 3) to meet the objectives of the National Historic Preservation Act (NHPA) of 1966, as amended, with particular emphasis given to minimizing harm to NSS.<sup>2</sup> As should be apparent, the statutory requirement to minimize harm to the landmark does not clearly align with the traditional approaches taken in power reactor decommissioning and license termination. MARAD formally addressed this conflict in its *2008 Post Shutdown Decommissioning Activities Report* (PSDAR) [Reference 1-2]. Whereas the PSDAR postulated methods by which the NHPA objectives might be met, this LTP uses detailed discussions of end-state scenarios and approaches towards meeting license termination radiological criteria to describe how MARAD will meet its NHPA objectives.

<sup>1</sup> A 1981 statute authorized MARAD to bareboat charter NSS to the State of South Carolina for use as a museum ship at the Patriots Point Naval and Maritime Museum in Mount Pleasant. A bareboat charter is a form of lease employed in the maritime industry. The museum was (and still is) operated by the Patriots Point Development Authority (PPDA), a state corporation. Because NSS was still licensed by NRC, the statute allowed for PPDA to become a co-licensee to exercise physical custody and control of the ship (as the NRC licensed site), and to manage NRC-required radiological protection and emergency response requirements. MARAD held title to NSS and was responsible for underwater hull maintenance. The charter and museum service ended in May 1994 when MARAD removed NSS for drydocking and underwater hull repairs. PPDA was removed as a co-licensee by Amendment 12 in July 1994.

<sup>2</sup> Section 110(f) of the NHPA provides as follows: "Prior to the approval of any Federal undertaking that may directly and adversely affect any National Historic Landmark, the head of the responsible Federal agency shall to the maximum extent possible undertake such planning and actions as may be necessary to minimize harm to the landmark."



MARAD believes that the NSS decommissioning project is a first, in that the subject of the project is already a federally designated historic structure, as opposed to a structure deemed eligible for designation. MARAD and NRC are signatories, along with the Advisory Council on Historic Preservation (ACHP) and the Maryland State Historic Preservation Officer (MD SHPO), to a *Programmatic Agreement* (PA) [Reference 1-3] covering the combined decommissioning and disposition of NSS as an NHPA Undertaking. This LTP supports both aspects of the Undertaking, by describing how MARAD can meet the license termination criteria, and demonstrating how that license termination supports the potential NSS disposition end-states, including preservation. Reviewers should bear this in mind when reading the LTP.

This plan has been developed to address the license termination requirements of 10 CFR 50.82 and the radiological release criteria of 10 CFR Part 20, Subpart E. This plan is a supplement to the UFSAR [Reference 1-1] and is provided as an enclosure to License Amendment Request 2023-001. In preparing the LTP, MARAD followed the requirements of the Nuclear Regulatory Commission (NRC) guidance documents listed below:

1. Regulatory Guide 1.179, *Standard Format and Contents for License Termination Plans for Nuclear Power Reactors*, Rev. 2, July 2019 [Reference 1-4]
2. NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, Rev. 2, April 2018, including Appendix A [Reference 1-5]
3. NUREG-1757, Volume 2, *Consolidated Decommissioning Guidance - Characterization, Survey, and Determination of Radiological Criteria*, Rev. 1, September 2006 [Reference 1-6]

### 1.3 Purpose

The purpose of the LTP is to demonstrate compliance with NRC decommissioning and license termination requirements. MARAD has prepared the LTP in accordance with References [1-4], [1-5] and [1-6] to demonstrate that its decommissioning and license termination project meets the intent of the applicable NRC regulations. Regarding the regulations, the LTP:

- Satisfies the content requirements of 10 CFR 50.82(a)(9)(i) and (ii), as described in Chapters 1 through 9; and,
- Satisfies applicable portions of the requirements of 10 CFR Part 20, Subpart E, Radiological Criteria for License Termination. Specifically, the LTP satisfies the requirements of the following:
  - 10 CFR 20.1401 General provisions and scope; and,
  - 10 CFR 20.1402 Radiological criteria for unrestricted use.

Furthermore, MARAD affirms its understanding that the license cannot be terminated in fewer than two years from submittal of this LTP, in accordance with 10 CFR 50.82(a)(9)(i). MARAD anticipates requesting license termination to be effective in December 2025, provided all prerequisite actions are complete at that time.

By following References [1-4], [1-5] and [1-6], MARAD is confident that NRC will approve the LTP in accordance with 10 CFR 50.82(a)(10) after finding that:

- Completing the remainder of decommissioning activities will be performed in accordance with NRC regulations;
- Completing decommissioning will not be inimical to the common defense and security;
- Completing decommissioning will not be inimical to the health and safety of the public; and,
- Completing decommissioning will not have a significant effect on the quality of the environment.



#### 1.4 Decommissioning Objectives

MARAD's principal decommissioning objective is to terminate license NS-1 without restrictions. Although postulated in the PSDAR [Reference 1-2], MARAD does not intend to request license termination under restricted conditions or by using alternate criteria.

MARAD will conduct remediation and survey operations such that it can submit a request to the NRC for unrestricted release of the site in accordance with Subpart E of 10 CFR Part 20 after meeting the requirements of 10 CFR 20.1402, Radiological Criteria for Unrestricted Use. The LTP documents the process that will be used to demonstrate that the dose from residual radioactivity that is distinguishable from background radioactivity does not exceed 25 mrem/year<sup>3</sup> to the Average Member of the Critical Group (AMCG) from all applicable pathways over a 1,000-year period and that residual radioactivity has been reduced to levels that are "As Low As Reasonably Achievable" (ALARA).

At the time of LTP submittal, MARAD has essentially completed all planned dismantlement activities (see Chapter 3), and can state with confidence that it has achieved its NHPA objectives to conduct decommissioning activities in a manner that respects (i.e., preserves, maintains, and minimizes impacts to) the historic fabric of the ship, such that decommissioning does not negatively impact potential future preservation uses. Subject to confirmation by NRC, the end-state condition of the nuclear power plant structures and components (See Section 3.1.1. of Chapter 3) also meets the NHPA objective to minimize harm to the character-defining features of the nuclear power plant, without preventing their radiological release or subsequent disposal via either shipbreaking or artificial reefing.

#### 1.5 Plan Summary

The LTP is arranged in ten (10) chapters, as described below.

##### 1.5.1 Chapter 1, General Information

LTP Chapter 1 describes the process used to meet the requirements for terminating the 10 CFR Part 50 license and to release the NSS for unrestricted use. The LTP has been prepared in accordance with the requirements in 10 CFR 50.82(a)(9) and is submitted both as an enclosure to support License Amendment Request (LAR) 2023-01 for the NRC to approve the LTP and as a supplement to the UFSAR.

##### 1.5.2 Chapter 2, Site Characterization

LTP Chapter 2 discusses the Historical Site Assessment (HSA) and characterization activities that have been conducted to determine the nature and extent of radioactive contamination on the ship prior to remediation. The information obtained from the characterization provided guidance for decontamination and remediation planning.

Data from subsequent characterization may be used to change the original classification of an area, within the requirements of this LTP, up to the time of Final Status Surveys (FSSs), as long as the classification reflects the level of residual activity existing prior to any remediation in the area. This chapter satisfies the underlying intent of 10 CFR 50.82(a)(9)(ii)(A).

---

<sup>3</sup> As described elsewhere in the LTP, MARAD has adopted a 15 mrem/year standard as an administrative limit for NSS. This administrative limit includes *as low as reasonably achievable* (ALARA) considerations. Within the LTP, direct citations of regulations (i.e., 25 mrem/year) should be interpreted to mean 15 mrem/year unless stated otherwise. Additionally, MARAD is considering the post-LT life cycle for NSS to be 70 vice 1,000 years.



### 1.5.3 Chapter 3, Identification of Remaining Site Dismantlement Activities

LTP Chapter 3 identifies the remaining site dismantlement and decontamination activities. The information includes those areas and equipment that need further remediation and an assessment of the potential radiological conditions that may be encountered. Estimates of the occupational radiation dose and the quantity of radioactive material to be released to unrestricted areas during the completion of the scheduled tasks are provided. The projected volumes of radioactive waste that will be generated are also included. This chapter satisfies the underlying intent of 10 CFR 50.82(a)(9)(ii)(B).

### 1.5.4 Chapter 4, Remediation Plans

LTP Chapter 4 discusses the various remediation techniques that may be used during decommissioning to reduce residual contamination to levels that comply with the release criteria in 10 CFR 20.1402. This chapter also discusses the ALARA evaluation and the impact of remediation activities on the Radiation Protection Program (RPP). It satisfies the underlying intent of 10 CFR 50.82(a)(9)(ii)(C).

The selected remediation methods used are dependent upon the contaminated material and extent of contamination. The principal materials that may be subject to remediation are structural surfaces.

Note that there are no embedded pipes, soils, surface water or groundwater at NSS. Remediation techniques that may be used for structural surfaces include standard and high pressure washing, wiping, grit blasting, chemical stripping, grinding, and other methods.

### 1.5.5 Chapter 5, Final Status Survey Plan

LTP Chapter 5 presents the final survey process used to demonstrate that the NSS complies with radiological criteria for unrestricted use specified in 10 CFR 20.1402 (i.e., annual dose limit of 25 mrem/year to AMCG plus ALARA). This chapter also describes proposed control mechanisms to ensure areas are not re-contaminated. This chapter satisfies the underlying intent of 10 CFR 50.82(a)(9)(ii)(D).

The FSS Plan describes use of the Data Quality Objectives (DQO) process in designing surveys, survey methods and instrumentation, data collection and processing, and data assessment and compliance.

### 1.5.6 Chapter 6, Compliance with the Radiological Criteria for License Termination

LTP Chapter 6 presents the radiological information and methods used to demonstrate compliance with the radiological criteria for license termination and to release the NSS for unrestricted use. Chapter 6 discusses the following:

- Radionuclides potentially present and mixture fractions;
- Exposure pathways;
- Computational models used for dose modeling;
- Sensitivity analysis and deterministic parameter selection;
- Derived Concentration Guideline Level (DCGL) and Dose Factors; and,
- Basis for the selected reasonably foreseeable and less likely but plausible scenarios.

This chapter satisfies the underlying intent of 10 CFR 50.82(a)(9)(ii)(E).

#### 1.5.7 Chapter 7, Update of the Site-Specific Decommissioning Costs

LTP Chapter 7 provides a detailed discussion of MARAD's primary decommissioning services contract, other remaining costs, and available decommissioning funding that satisfies the underlying intent of the 10 CFR 50.82(a)(9)(ii)(F) to demonstrate that sufficient resources are available to complete the remaining decommissioning activities and release the NSS for unrestricted use.

#### 1.5.8 Chapter 8, Supplement to the Environmental Report

LTP Chapter 8 describes MARAD's evaluations of the environmental impacts of decommissioning and license termination, including its *2008 Environmental Assessment* [Reference 1-7] and *2019 Supplemental Environmental Assessment* [Reference 1-8]. As a federal agency, MARAD is required by the *National Environmental Policy Act of 1969* to evaluate the proposed action of decommissioning and terminating the license of the NSS, independent of any such evaluation by NRC. MARAD has determined that there are no significant environmental impacts for decommissioning the NSS. Furthermore, MARAD affirms that there is no new information or significant environmental changes associated with the site-specific termination activities up to the submission of the LTP that is not contained in its 2008 and 2019 assessments; nor does MARAD expect there to be any new information or significant environmental changes in the period leading to license termination. This chapter satisfies the underlying intent of 10 CFR 50.82(a)(9)(ii)(G)

#### 1.5.9 Chapter 9, Portions of the Facility that were Released prior to LTP Approval

LTP Chapter 9 describes the portions of the facility that were released for use before approval of the LTP under 10 CFR 50.82(a)(9)(ii)(H). No parts of the facility were released for use before approval of the LTP.

#### 1.5.10 Chapter 10, Regulatory Notifications of Changes

LTP Chapter 10 lists the LTP areas that cannot be changed without NRC approval. The LTP areas applicable to NSS are derived from Appendix B of NUREG 1700 [Reference 1-5].

### 1.6 Facility and Site Description

The NSS was an 80 MW<sub>th</sub> pressurized-water nuclear reactor. MARAD is owner and licensee of NSS. The MARAD Headquarters is located at 1200 New Jersey Ave., SE, Washington, DC. The NSS is located at Baltimore Harbor, Pier 13 in the Canton industrial district of the port, near the Seagirt Marine Terminal in Baltimore, Maryland. Note that the City of Baltimore is an independent jurisdiction surrounded by the similarly-named Baltimore County. The street address is 4601 Newgate Avenue, Baltimore, MD 21224.

The site is licensed under Possession-only License No. NS-1, Docket No. 50-238. The licensed site of the NSS is the boundary defined by the ship's hull (see Figures 1-1 through 1-7). There have been no changes to the original site boundary. The site (i.e., the ship) contains no soils or ground water. Given that the site is bounded by the ship's hull, there is no map that shows the detailed topography of the site.

Because the NSS is mobile and waterborne, the off-ship characteristics of the site vary with the location of the vessel. The ship's principal characteristics are shown in Table 1-1 (see page 12).





Figure 1-1 NSS at Pier 13 in 2023

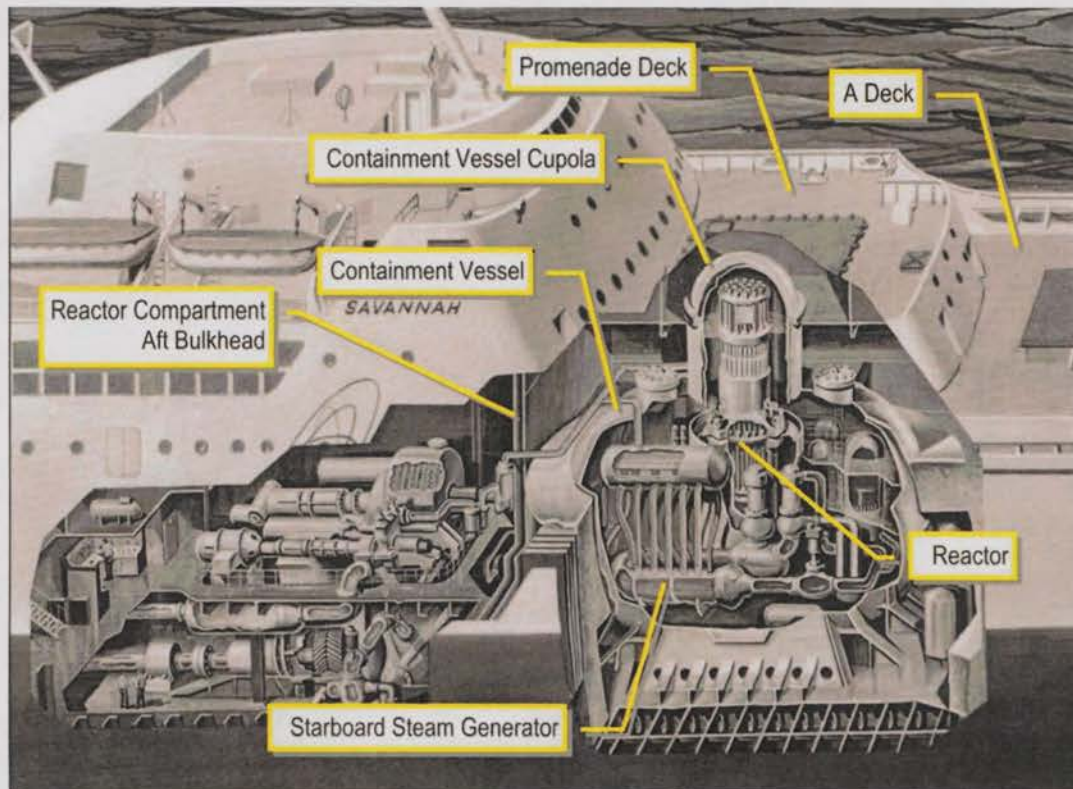
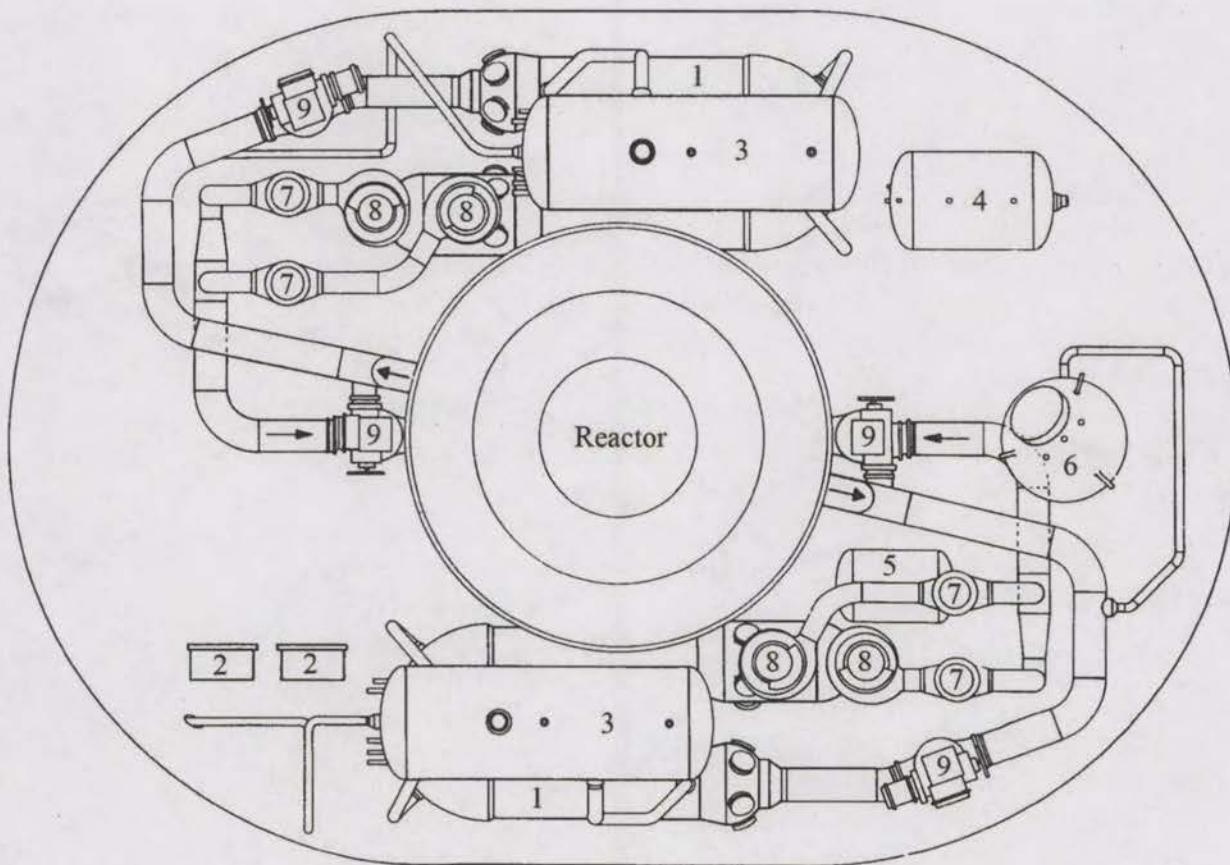


Figure 1-2 Containment, Reactor Compartment and Engine Room (Frames 99-148)



**Figure 1-3 Arrangement of Principal Components in Containment**

|   |                                                |   |                        |   |                              |
|---|------------------------------------------------|---|------------------------|---|------------------------------|
| 1 | Heat Exchanger (Steam Generator U-tube bundle) | 2 | Let Down Cooler        | 3 | Steam Drum (Steam Generator) |
| 4 | Effluent Condensing Tank                       | 5 | Containment Drain Tank | 6 | Pressurizer                  |
| 7 | Check Valve                                    | 8 | Primary Pump           | 9 | Gate Valve                   |



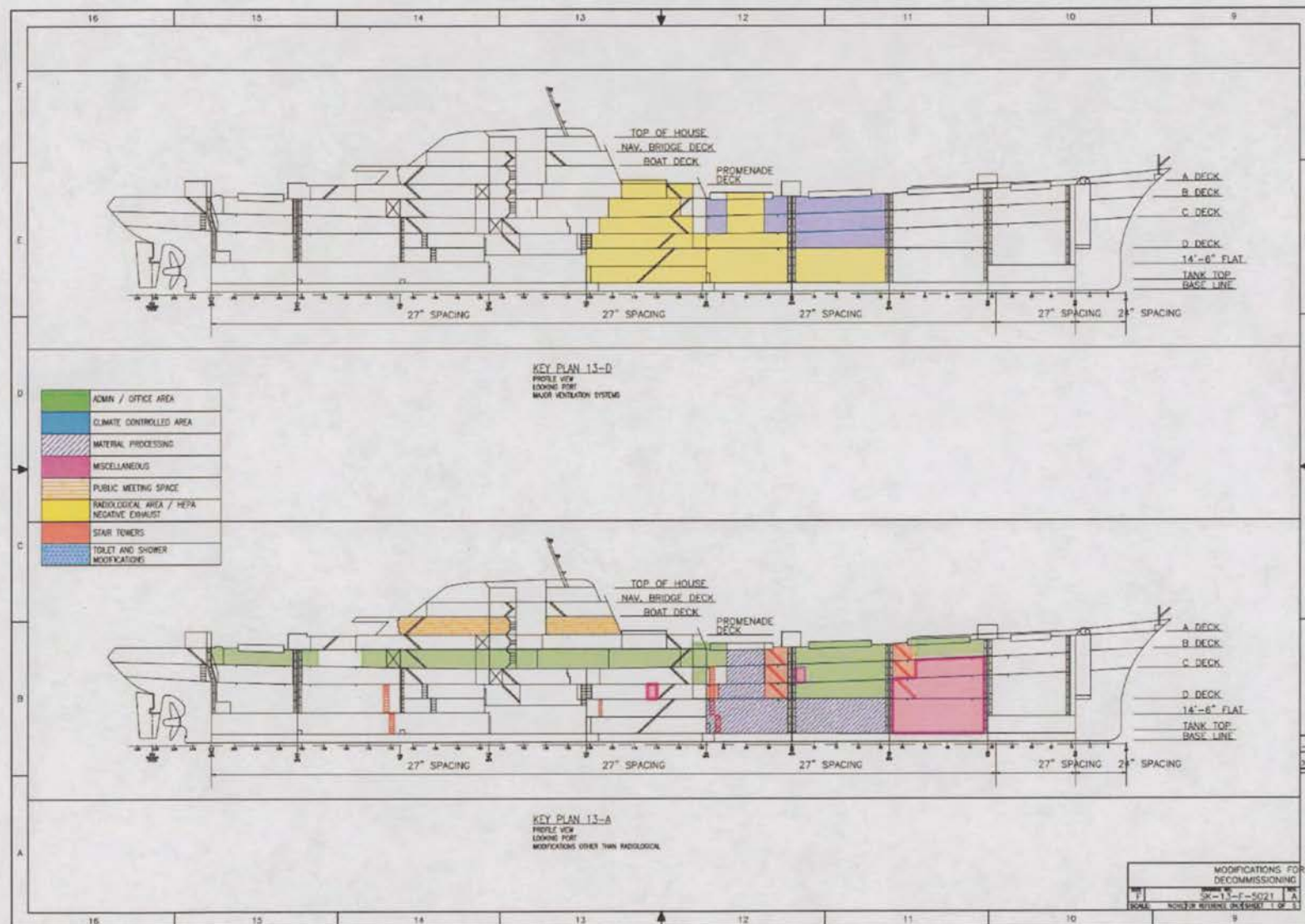


Figure 1-4 General Arrangement – Inboard Profile

# License Termination Plan – (STS-004-003)

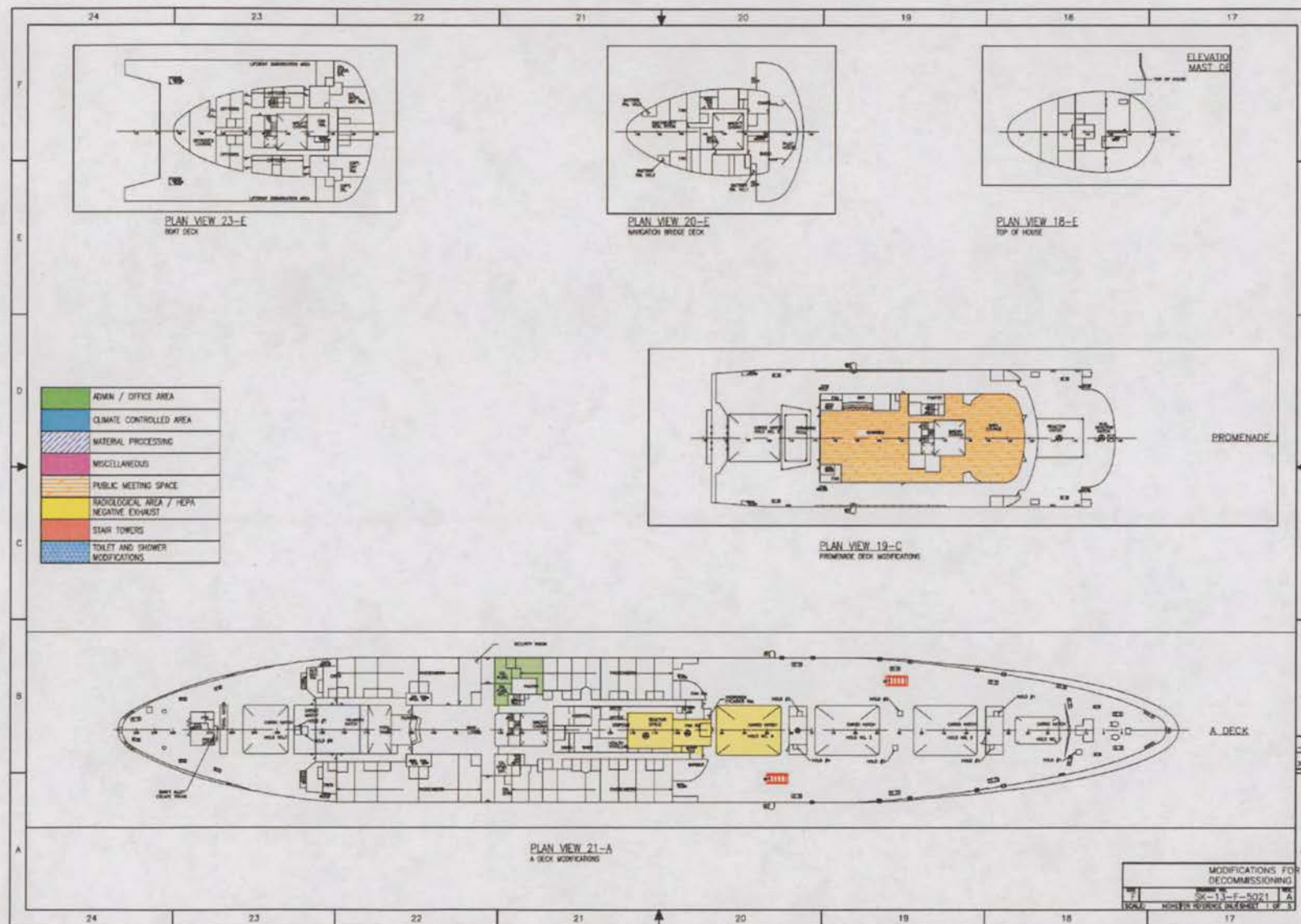


Figure 1-5 General Arrangement - Decks - Top of House to A Deck



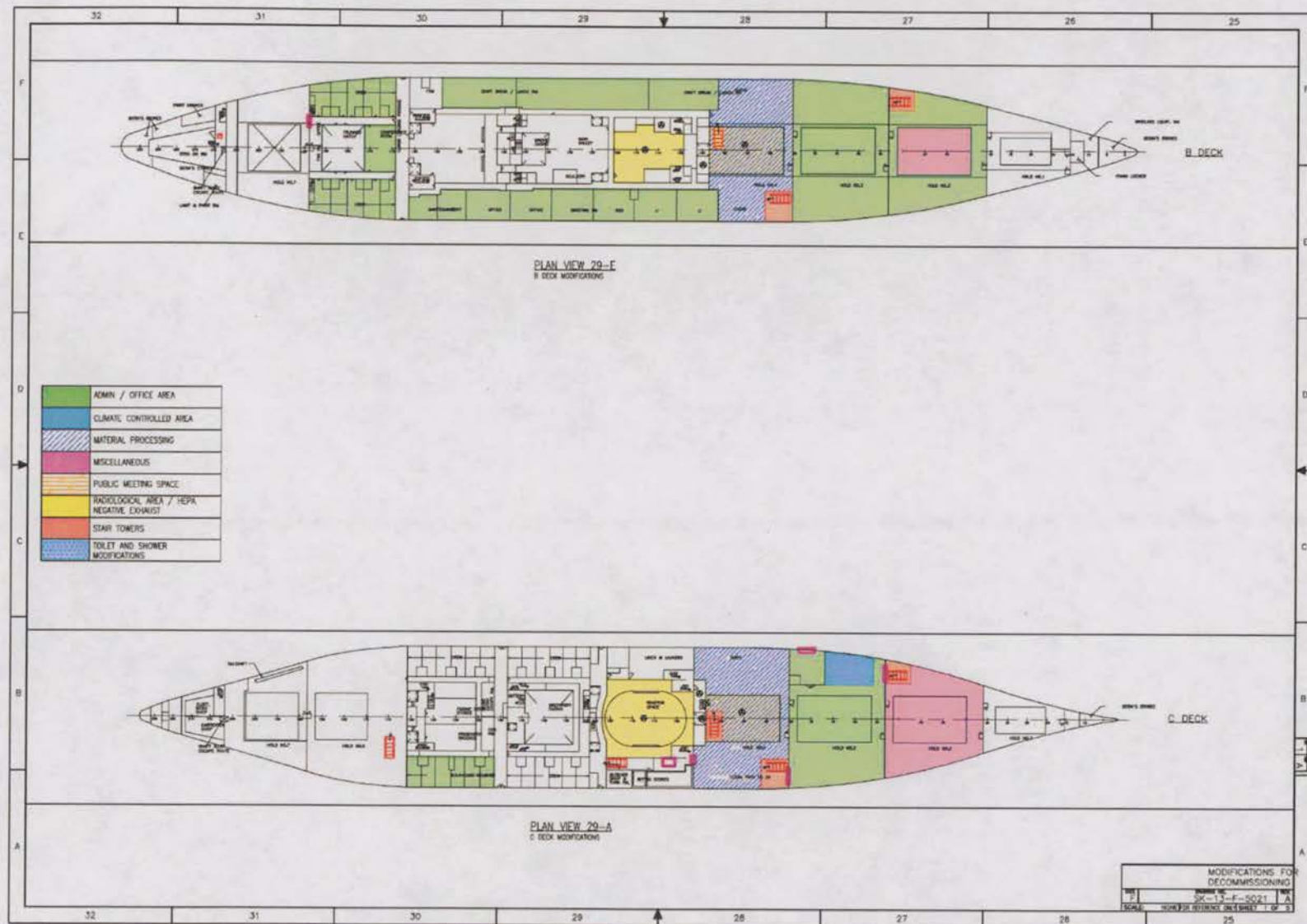


Figure 1-6 General Arrangement - Decks - B and C

# License Termination Plan – (STS-004-003)

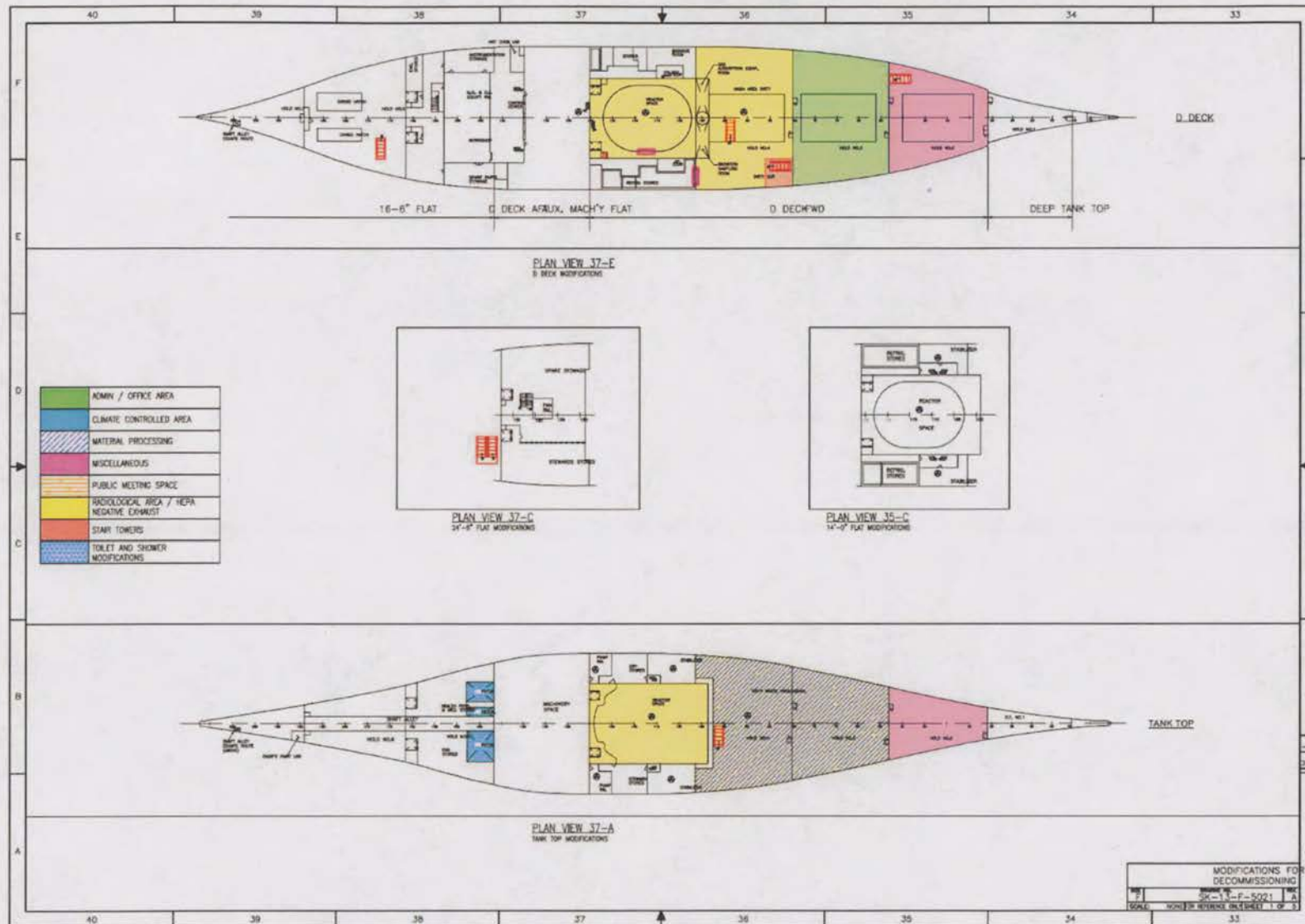


Figure 1-7 General Arrangement - Decks - D and Tank Top



**Table 1-1      Principal Characteristics of the N.S. *SAVANNAH***

| <b>Dimensions</b>                            | <b>Feet</b> |
|----------------------------------------------|-------------|
| Length Overall                               | 595.5       |
| Length Between Perpendiculars                | 545         |
| Beam, Maximum                                | 78          |
| Height, baseline to weather deck (A-deck)    | 50          |
| Height, baseline to top of house             | 85          |
| Draft, design                                | 29          |
| Draft, light ship (approximate)              | 18.33       |
| <b>Displacement and Tonnage in Long Tons</b> |             |
| Net carrying capacity, total deadweight tons | 9,656       |
| Full load displacement, tons                 | 21,990      |
| Light ship, tons                             | 12,334      |

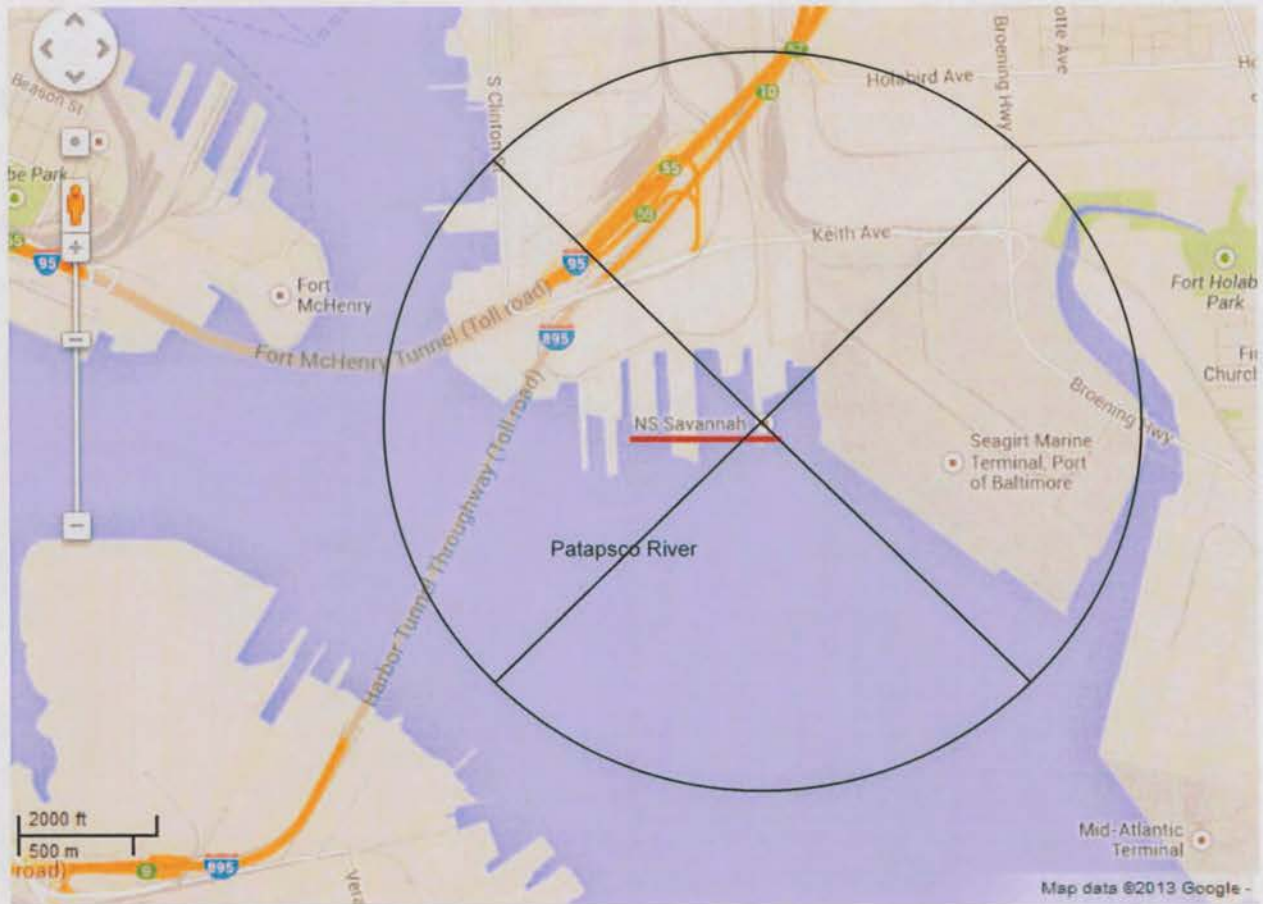
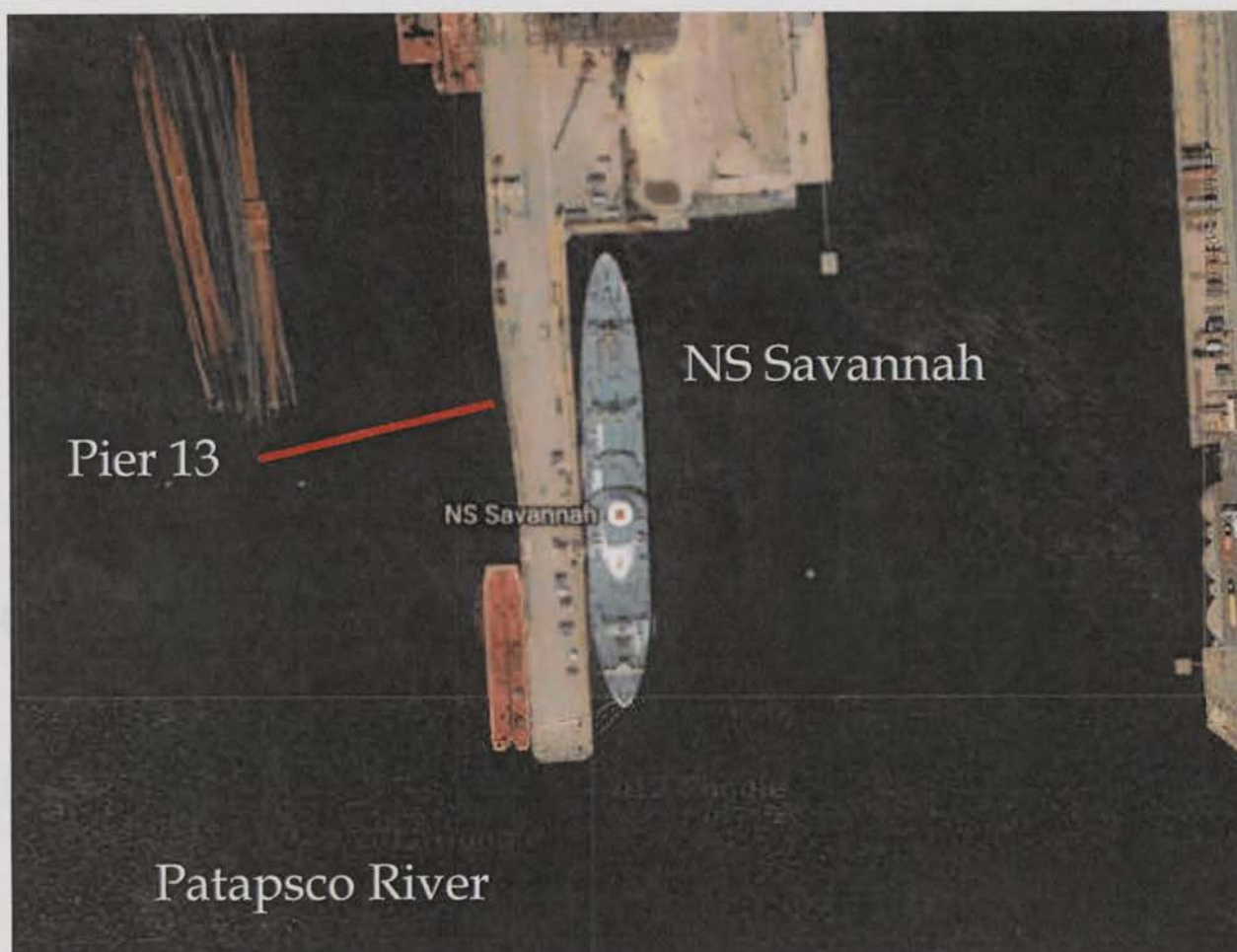


Figure 1-8 NSS Location from Google Maps, with an approximate one-mile radius overlay





**Figure 1-9 NSS at Pier 13 from Google maps satellite view, circa 2009**

The west wall of the Seagirt Marine Terminal appears at the right margin of the image.

#### 1.6.1 Port of Baltimore General Description

Baltimore, one of the major ports of the United States, is at the head of tidewater navigation on the Patapsco River. The mid-harbor point, at the intersection of Fort McHenry and Ferry Bar Channels 0.6 miles southeast of Fort McHenry, is 8 miles from the mouth of the river, 150 miles above the Virginia Capes, and 62 miles from the Delaware River.

The terrain in the Baltimore vicinity is relatively low and flat, with no wind channeling effects. There are no natural hazards in the Chesapeake Bay enroute to Baltimore. The route is void of man-made obstructions such as lift bridges, locks and traffic control points. The following information has been taken from Coast Pilot 3 - Chapter 15 - Edition 52, 2019.

##### 1.6.1.1 Anchorages

General, dead ship and small-craft anchorages are in Baltimore Harbor. (See 33 CFR 110.1 and 110.158 for limits and regulations.)

##### 1.6.1.2 Tides and Currents

The mean range of tide is 1.1 feet at Baltimore; daily predictions are given in the Tide Tables. Prolonged winds of constant direction may cause substantial variation in the tide. Currents in the harbor are 0.8 knot on the flood and ebb. (See the Tidal Current Tables for daily predictions.)



#### 1.6.1.3 Weather

Baltimore is in a region about midway between the rigorous climates of the North and the mild climates of the South. It is adjacent to the modifying influences of the Chesapeake Bay and Atlantic Ocean to the east and the Appalachian Mountains to the west. January is the coldest month, and July, the warmest. Winter and spring have the highest average wind speeds.

Baltimore Harbor is frozen over during severe winters, but the icebreakers and the larger power-driven vessels keep the dredged channels open so that self-propelled vessels seldom have difficulty entering the harbor. Ice conditions in the main channel are most severe in the vicinity of Seven Foot Knoll Light, where ice moving from the northern end of Chesapeake Bay tends to collect in packs.

#### 1.6.1.4 Repairs

Baltimore has extensive facilities for wrecking and salvage. In addition to equipment especially designed for salvage operations, heavy hoisting facilities are available.

### 1.6.2 Surrounding Area of the NSS Site

As noted in Section 1.4, the site itself is the NSS, with its boundary formed by the exterior surface of its hull, superstructure, and tophammer.<sup>4</sup> Everything exterior to the ship itself is an offsite area.<sup>5</sup> This includes the water in which the ship floats, the structure to which the ship is attached when at berth (i.e., Pier 13 in the current condition), and the land to which that structure is attached. There have been no changes to the site boundary since original construction.

As shown in Figure 1-1, NSS is berthed at an existing industrial facility in the Canton Industrial District of the Port of Baltimore. The current facility was constructed as a grain elevator, primarily for export service, by the Northern Central Railway, a subsidiary of the Pennsylvania Railroad (PRR), in 1922. Portions of the current facility were constructed in 1905, and similar facilities were located on the site beginning in the 1880s. The elevator ceased operations in 1994. Elevated portions of the grain discharge equipment were removed from the finger pier (Pier 13) at an indeterminate date. During the late 1990s, MARAD temporarily layberthed two general cargo ships at Pier 13. Immediately to the east of Pier 13 is the bulk unloading facility of the National Gypsum (dba Gold Bond) Company's wallboard plant on Newkirk Street, and beyond that is the Maryland Port Administration's Seagirt Marine Terminal. To the west are the remains of the PRR bulk ore pier (Pier 12; only the pier head remains in use, with remnants of the removed finger pier still attached), and the active general cargo and coal export facilities of the Canton Marine Terminal (Pier 11) and the CNX Marine Terminal. Other commercial facilities and extensive rail trackage lie to the north of Pier 13, with Baltimore Harbor to the south. In 2019 the Pier 13 complex was sold to Berg Demolition, who proceeded to demolish the remaining structures of the former grain elevator; that work was completed in the summer of 2020. In 2021, the facility was purchased by National Gypsum, who expanded the bulk gypsum storage onto portions of the former grain elevator footprint. The remaining footprint was converted into a parking area, which is leased to Hildebrandt Trucking for temporary storage of flatbed trailers serviced by dray trucks. Other tenants on Pier 13 include Moran Towing, with three (3) ship-assist tugs stationed near the head of the pier, and Project Liberty Ship which berths the historic S.S. *John W. Brown* along the west wall. Figures 1-10 through 1-15 depict NSS at Pier 13 in context with its surrounding area.

---

<sup>4</sup> Masts, spars, booms, rigging, boats, etc. In general, all the fixed items of outfitting that are not part of the ship's hull or superstructure.

<sup>5</sup> The only exception to this rule occurs when the ship is drydocked. Current procedures define the drydock floor and its access points to be owner-controlled areas for purposes of access and work control; however, this does not involve a literal expansion of the licensed site boundary. Similar access controls are employed when divers work on the underwater hull with the ship afloat.



The layberth facility is constructed on fill and contains no ground water. There are no off-site wells used by nearby communities; potable water for residential and commercial use is supplied by municipal systems fed by distant reservoirs in northwest Baltimore City and further beyond in Baltimore County.

1.6.2.1 Within a One Mile Radius (all Baltimore, MD 21224)

There are numerous industrial and commercial facilities within an approximately one-mile radius of the ship including (arranged alphabetically):

- A.H. Gardner & Son Trucking, 2207 Newkirk Street
- B&E Storage, 2500 Broening Highway
- BWI2 Amazon Fulfillment Center, 2010 Broening Highway
- Canton Railroad Co., 1841 South Newkirk Street
- Canton Stevedoring Inc. (Pier 11 Canton Marine Terminal), 3800 Newkirk Street
- CNX Marine Terminal Inc. (Consol Energy – export coal), 3800 Newgate Avenue
- George Hilderbrandt Trucking Inc., 4600 Newgate Avenue
- Gold Bond Building Products, Baltimore Gypsum Board Plant (and adjacent marine terminal), 2301 South Newkirk Street
- Heidelberg Materials Corp. (formerly Lehigh Cement Co.), 3100 Mertens Street
- Maryland Port Administration, Seagirt Marine Terminal, 2600 Broening Highway
- Maryland Transportation Authority, 2310 Broening Highway; also 3990 Leland Avenue
- Moran Towing Corp. (Ship Assist Tugs and Maintenance Facility), Pier 13, 4601 Newgate Avenue
- Moran Towing Corp. (Operations Center and Dispatch Office) 4616 Newgate Avenue
- MTC Logistics, 4851 Holabird Avenue
- PGT Trucking / CT Transportation, 2150 S. Newkirk Street
- Point Breeze Business Center, 2200 Broening Highway
  - U.S. State Department - US DESPATCH
  - All State Career Center
  - IDEMIA North America
- Project Liberty Ship SS *John W Brown*, Pier 13, 4601 Newgate Avenue
- Sherwood Lumber Co. (formerly Middle Atlantic Wholesale Lumber, Inc.), 2150 Newkirk Street
- Ruckert Terminals Corp, 2300 Broening Highway

Transportation

- Interstates 895 (Harbor Tunnel) and 95 (Ft McHenry Tunnel) pass within 4000 feet of the ship

- CSX and Norfolk Southern Railroads have extensive trackage within the one-mile radius. CSX maintains a ready track for locomotives inside the Seagirt Marine Terminal at the foot of New Vail Street

There are no residences within 1 mile.

#### 1.6.2.2 Within a Two-Mile Radius

Within the two-mile radius to the east are significant residential areas of Canton and Dundalk that include:

##### Medical

- Johns Hopkins Community Physicians - Greater Dundalk, 2112 Dundalk Avenue, Dundalk, MD 21222
- Johns Hopkins Home Care Group, 5901 Holabird Avenue Baltimore, MD 21224

##### Parks

- Saint Helena Playground, corner of Rails Avenue and Parnell Avenue, Dundalk MD 21222
- Fort McHenry National Monument and Historic Shrine, 2400 East Fort Avenue, Baltimore, MD 21230
- Latrobe Park, East Fort Avenue, Baltimore, MD 21230

##### Schools

- Fort Holabird Park, at Oak Avenue Baltimore, MD 21224
- Dundalk Elementary School, 2717 Playfield Street, Dundalk MD 21222
- Saint Rita's School, 2907 Dunleer Road, Dundalk MD 21222
- Canton Middle School, 801 South Highland Avenue, Baltimore, MD 21224
- Archbishop Borders School, 3500 Foster Avenue, Baltimore, MD 21224
- Holabird Elementary, 1500 Imla Street, Baltimore, MD 21224
- John Ruhrah Elementary School, 701 Rappolla Street, Baltimore, MD 21224
- Graceland Park/O'Donnell Heights Elementary School, 6300 O'Donnell St., Baltimore, MD 21224

##### Senior Care

- Baltimore County, 101 Center Place, Dundalk MD 21222
- Park View At Dundalk, 103 Center Place, Dundalk, MD 21222
- CSI Support & Development Services 3600 O'Donnell St Baltimore MD 21224
- Future Care Canton Harbor, 1300 South Ellwood Avenue. Baltimore, Maryland 21224
- Heritage Center, 7232 German Hill Road, Baltimore, MD 21222

#### Just Outside of 2 Miles

##### Schools

- Dundalk Middle School, 7400 Dunmanway, Dundalk MD 21222
- Dundalk High School, 1901 Delvale Avenue, Baltimore, MD 21222



- Community College of Baltimore County, 7200 Sollers Point Road, Dundalk, MD 21222
- Logan Elementary School, 7601 Dunmanway, Dundalk MD 21222
- Highlandtown Elementary School, 3223 East Pratt Street, Baltimore, MD 21224
- Patterson High School, 100 Kane Street, Baltimore, MD 21224
- Francis Scott Key Elementary/Middle School, 1425 East Fort Avenue, Baltimore, MD 21230

Senior Care

- Olf Senior Housing Inc., 6424 E Pratt Street. Baltimore MD 21224
- Cove Point Apartments, 7801 Peninsula Expressway, Dundalk, MD 21222

Hospital

- Johns Hopkins Bayview Medical Center 4940 Eastern Avenue. Baltimore MD 21224

Downtown Baltimore is 4 miles north northwest of the ship.



**Figure 1-10 NSS at Pier 13, September 2023, looking northward**

From left to right appear the head of the Canton Marine Terminal (Pier 11), storage piles for export coal, the remnant head of Pier 12, the Pier 13 Canton Marine Terminal centered in foreground showing S.S. John W. Brown and NSS, the National Gypsum (Gold Bond) terminal, and ending with the west wall of the Seagirt Marine Terminal at far right. An expanded image appears below.



**Figure 1-11 NSS at Pier 13, September 2023, looking northward**



**Figure 1-12 NSS at Pier 13, September 2023, looking northwest**

At the top left in background is the coal loading pier of the of the CNX Marine Terminal (vessel at berth marked "TRANSBULK"), closer to NSS is the Pier 11 Canton Marine Terminal facility operated by Canton Stevedoring, Inc. Downtown Baltimore City appears in the center background.





**Figure 1-12 NSS at Pier 13, September 2023, looking westward**

Like Figure 1-12, this image shows the CNX Marine Terminal finger pier with a vessel loading at berth, and the Canton Stevedoring project cargo facility immediately beyond NSS. At upper left is the Fairfield section of Baltimore, while the middle harbor area appears to the left.



**Figure 1-13 NSS at Pier 13, September 2023, looking northeast**

The National Gypsum (Gold Bond) wall board plant appears in upper left, with the expanded gypsum rock storage area below. To the right is the west boundary of the Seagirt Marine Terminal and its container storage yard. The warehouse building in the background is the Amazon Fulfillment Center on Broening Highway.





**Figure 1-14 NSS at Pier 13, September 2023, looking eastward**

The berth area in left center is part of the National Gypsum facility. To the east is the Seagirt Marine Terminal operated by PortsAmerica Chesapeake for the Maryland Port Administration. The Dundalk area of Baltimore County appears beyond the terminal.



**Figure 1-15 NSS at Pier 13, September 2023, looking southward**

The broad expanse of the Baltimore Harbor appears astern of NSS, with the I-695 Francis Scott Key memorial bridge in the upper-left corner.



### 1.6.3 Operational Background

The NSS was designed, constructed and operated as a joint research and development project of the U.S. Department of Commerce, Maritime Administration and the U.S. Atomic Energy Commission (AEC). In general, MARAD's contribution was the ship while the AEC's was the nuclear fuel, reactor and related nuclear systems. The program was managed by a Joint Group established by MARAD and AEC in 1956, which also included the U.S. Coast Guard and U.S. Public Health Service. The Joint Group was disbanded in 1965 effective with the issuance of operating license NS-1; from that date forward MARAD managed the NSS alone.

Table 1-2 presents a chronology of significant licensing events. As noted in the table, the NSS was no longer operational after 1971. Since then, it has been moved by towing.

**Table 1-2      Chronology of Significant Licensing Events**

| <b>Date</b>            | <b>Event Description</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| April 1955             | President Eisenhower announced a proposal to build a nuclear-powered merchant ship to demonstrate peaceful uses of the atom.                                                                                                                                                                                                                                                                                                                                                                 |
| October 1956           | Contract to Babcock & Wilcox to design and construct the reactor.                                                                                                                                                                                                                                                                                                                                                                                                                            |
| January 22, 1957       | Memorandum of Understanding (MOU) established between MARAD and AEC to perform tasks related to design development, testing, initial operation and international acceptance of nuclear merchant ships.                                                                                                                                                                                                                                                                                       |
| April 1957             | Contract to George Sharp to design hull.                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| December 10, 1957      | Contract to New York Ship building to construct ship.                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| May 22, 1958           | Keel laid.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| July 21, 1959          | Ship launched, crew training began.                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| July 24, 1961          | Authorization of AEC fueling and operation for test and demonstration purposes.                                                                                                                                                                                                                                                                                                                                                                                                              |
| December 21, 1961      | Initial criticality.                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| March 1962             | Initial sea trials at Camden, NJ and Yorktown, VA.                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| August 1962            | Commencement of initial voyage. First voyage to commercial port Yorktown, VA to Savannah, GA. Demonstration phase of operations began with voyage from Savannah, GA to Norfolk, VA.                                                                                                                                                                                                                                                                                                          |
| August 1965            | AEC Operating License (NS-1) issued.                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| August to October 1968 | Commercial marine refueling at MARAD Refueling Facility, Todd Shipyards, Galveston, TX. During the last voyage before the Fuel Shuffle Outage, evidence of a minor fuel failure was detected. It appeared that small amounts of fission products were released to the primary coolant whenever there was a significant change in reactor power level. Post shuffle operation indicated that the situation still existed; however, it did not limit operation or access anywhere on the ship. |
| July 25, 1970          | Commercial Operations ended.                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| November 6-8, 1970     | Final Voyage to Pier "E" Todd Shipyards, Galveston, TX from annual                                                                                                                                                                                                                                                                                                                                                                                                                           |



**License Termination Plan – (STS-004-003)**

| <b>Date</b>       | <b>Event Description</b>                                                                                                                                                                                                                                                                                 |
|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                   | drydocking 10/30 through 11/06 at Todd Shipyards, New Orleans, LA.                                                                                                                                                                                                                                       |
| November 8, 1970  | Final Reactor shutdown at 5:50 PM and established Cold Iron condition at Todd Shipyard, Galveston, TX per FAST-21.                                                                                                                                                                                       |
| December 3, 1971  | Permanent cessation of operations established by completing Layup Procedure LU-9. As part of defueling, primary pump motors and impellers were removed.                                                                                                                                                  |
| December 21, 1972 | Thirty-six spent fuel elements (32 plus the four replaced during the fuel shuffle) (Core I and Ia) were shipped from Galveston, TX to AEC - Savannah River Plant, Aiken, SC for reprocessing. (September 21, 1973, Operations Report).                                                                   |
| May 19, 1976      | Possession-only License issued (License Amendment 8) and recognized the ship was in a state of protective storage. Total estimated residual activity 1.09E+5 Ci.                                                                                                                                         |
| August 14, 1981   | Patriots Point Development Authority (PPDA) becomes a co-licensee (License Amendment 9) and the ship was bareboat chartered for public display at the Patriots Point Naval and Maritime Museum, Mt. Pleasant, SC from 1981 through 1994.                                                                 |
| July 17, 1991     | The National Park Service designated the ship as a National Historic Landmark.                                                                                                                                                                                                                           |
| June 29, 1994     | License Amendment 12 removed PPDA as co-licensee. After drydocking, MARAD places the ship in protective storage at the James River Reserve Fleet, Ft. Eustis, VA.                                                                                                                                        |
| December 11, 2006 | Post Shutdown Decommissioning Activities Report, Revision 0 was submitted but withdrawn on January 27, 2007.                                                                                                                                                                                             |
| January 31, 2007  | License Amendment 13 was issued. It included six administrative changes. The most significant change is following 30 day notification to NRC, the ship can be located at any appropriate domestic location with a MARAD approved Port Operating Plan.                                                    |
| May 8, 2008       | NSS was moved to Pier 13 Canton Marine Terminal at 4601 Newgate Ave., Baltimore, MD.                                                                                                                                                                                                                     |
| October 3, 2008   | MARAD submits to NRC its Environmental Assessment and Finding of No Significant Impact regarding NSS Decommissioning.                                                                                                                                                                                    |
| December 11, 2008 | Post Shutdown Decommissioning Activities Report, Revision 1 submitted.                                                                                                                                                                                                                                   |
| May 2017          | Consolidated Appropriations Act for FY 2017 (Public Law 115-31) provides \$24 million to fund SAFSTOR activities and start decommissioning.                                                                                                                                                              |
| March 2018        | Consolidated Appropriations Act for FY 2018 (Public Law 115-141) provides \$107 million. This amount is in addition to the \$24 million provided by the Consolidated Appropriations Act for FY 2017. The sum equals the \$131 million estimate to complete decommissioning and terminate the NSS license |

| <b>Date</b>    | <b>Event Description</b>                                                                                            |
|----------------|---------------------------------------------------------------------------------------------------------------------|
| April 23, 2018 | Amendment 15 allows dismantlement and disposal of the facility.                                                     |
| June 12, 2018  | Amendment 16 revises Technical Specifications to allow creating D-deck Containment Vessel (CV) door.                |
| April 22, 2019 | MARAD publishes its Supplemental Environmental Assessment and Finding of No Significant Impact regarding NSS DECON. |

### **1.7 Confirmation of Information (RAI Response)**

In Reference [1-9], NSS confirmed the following information as requested by NRC:

- The radiation safety officer position has been and will be maintained until License Termination. Throughout the remediation process, the RSO routinely evaluated work activities, contamination levels, and worker exposures to ensure ALARA was maintained. The RSO will continue to perform such activities as required until the license is terminated.
- An administrative limit of 15 mrem/y was established to ensure the actual residual radioactivity will be significantly less than 25 millirem per year (mrem/y). The administrative limit includes *as low as reasonably achievable* (ALARA) considerations.
- No elevations of residual radioactivity will exceed the 15 mrem/y derived concentration guideline limit (DCGLw) concentrations.
- All sediment (sludge) and water containing residual radioactivity have been removed.
- Processes are in place that are more restrictive than in the License Termination Plan (e.g., processes or procedures are established for decontamination personnel to attempt to remediate any area causing instruments to have readings in excess of 1,000 cpm).
- Removable activity will be reduced to less than 10 percent of the total activity present consistent with assumptions associated with developing the DCGLs.

MARAD confirms the accuracy of the information above and that these actions will ensure that actual residual radioactivity remaining at license termination will coincide with a much lower hypothetical dose to an average member of the critical group than 25 mrem/y and will demonstrate the residual radioactivity in the N.S. *SAVANNAH* at license termination is ALARA.

### **1.8 References**

- 1-1 *Updated Final Safety Analysis Report*, STS-004-002, Revision 13, July 20, 2023
- 1-2 STS-100, *Post Shutdown Decommissioning Activities Report*, Revision 1, December 11, 2008
- 1-3 *Programmatic Agreement among the U.S. Department of Transportation, Maritime Administration, the U.S. Nuclear Regulatory Commission, the Advisory Council on Historic Preservation, and the Maryland State Historic Preservation Officer for the Decommissioning and Disposition of the Nuclear Ship Savannah*, Baltimore, Maryland dated March 17, 2023.
- 1-4 Regulatory Guide 1.179, *Standard Format and Contents for License Termination Plans for Nuclear Power Reactors*, Rev. 2, July 2019
- 1-5 NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, Rev. 2, April 2018



- 1-6 NUREG-1757, Volume 2, Consolidated Decommissioning Guidance - Characterization, Survey, and Determination of Radiological Criteria, Rev. 1, September 2006
- 1-7 Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated October 3, 2008, - *Submittal of Finding of No Significant Impact and Environmental Assessment* (ML082810182)
- 1-8 CR-137, *Supplemental Environmental Assessment and Finding of No Significant Impact*, April 2019
- 1-9 Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated December 19, 2024, *License Amendment Request No. LAR 2023-01, Confirmation of Information*

## 2 SITE CHARACTERIZATION

### 2.1 Introduction

In accordance with the underlying intent of 10 CFR 50.82(a)(9)(ii)(A), the guidance of *Regulatory Guide 1.179, Standard Format and Content for License Termination Plans for Nuclear Power Reactors* [Reference 2-1] and the guidance in NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, [Reference 2-2], this chapter provides a summary of MARAD's site-specific characterization activities performed over the period from CY 2003 through CY 2020. The chapter also includes a summary description of the *Historical Site Assessment* (HSA) [Reference 2-3].

The purpose of site characterization is to ensure that the Final Status Surveys (FSSs) will be conducted in all areas where contamination existed, remains, or has the potential to exist or remain. With respect to NSS, the results of the characterization surveys, including the HSA, demonstrate that it is unlikely that significant quantities of residual radioactivity have gone undetected. As described in later chapters, remediation and FSS efforts will address any currently undetected residual radioactivity.

References 2-1 and 2-2 describe the content required for this chapter. Summarizing from these references, the LTP should include the following items, which are not meant to be all-inclusive:

- The LTP should describe historic events (including dates, types of occurrences, and locations inside and outside the facility), such as radiological spills, onsite disposals, or other radiological accidents or incidents, that resulted or could have resulted in the contamination of structures, equipment, letdown areas, or soils and ground water beneath buildings and in outside areas (see 2.2);
- The LTP describes, in summary form, the original shutdown (see 2.1.1) and current radiological and non-radiological status of the site (see 2.1.2);
- The LTP describes the survey instruments and supporting quality assurance (QA) practices used in the site characterization program. The LTP should discuss how the licensee applied the data quality objectives discussed in NUREG-1575 during site characterization;
- The LTP identifies the background levels used during scoping or characterization surveys;
- The LTP site characterization is sufficiently detailed to allow the Nuclear Regulatory Commission (NRC) staff to determine the extent and range of radiological contamination of structures, systems (including sewer systems and waste management systems), floor drains, ventilation ducts, piping and embedded piping, rubble, ground water and surface water, components, residues, and environment, including maximum and average contamination levels and ambient exposure rate measurements of all relevant areas (structures, equipment, and soils) of the site (including contamination on and beneath paved parking lots) (see 2.1.4 for summary information); and,
- The LTP site characterization should contain sufficiently detailed data to support planning for all remaining decommissioning activities and the final status survey program.

MARAD's site characterization efforts have been iterative, beginning roughly in 2003 and continuing to present. From 2018 – 2020, MARAD completed detailed characterization surveys throughout the ship to support decommissioning and license termination planning and the acquisition of contract services to perform the related dismantlement, waste disposal, remediation and survey work. The 2018 characterization included radiological spaces outside the Reactor Compartment (RC) and Containment Vessel (CV). The 2019 characterization was inside the RC and CV only. These surveys are documented as reports CR-104 [Reference 2-4] and CR-109 [Reference 2-5].



Note to Reviewers: As provided in Reference 2-1, a licensee can submit its entire site characterization package separately at any time before submitting the LTP and reference it in the LTP, or the licensee can submit the site characterization as an integral part of the LTP. MARAD has summarized its site characterization efforts in its *Updated Final Safety Analysis Report* (UFSAR) [Reference 2-6] beginning with Revision 11. This chapter of the LTP contains an expanded discussion of the NSS site characterization activities. Reviewers should be aware that these expanded discussions are drawn from contemporary reports, often verbatim, with some dating back nearly twenty years. With minor exceptions, these discussions have not been edited to account for the passage of time. Furthermore, there are instances where parent reference documents, such as NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* [Reference 2-7] are quoted within the body of the text. These reference documents typically do not include language applicable to a ship, e.g., a floor should be a deck; a wall should be a bulkhead; and a ceiling should be an overhead in most cases. For some survey areas and units, these words may be used in reference to complex internal ship structure. The LTP may include footnotes or other explanatory material where the parent reference appears confusing. Such explanations may also be found in subsequent chapters.

### 2.1.1 Operations and Final Shutdown Summary

The commercial operation of the NSS ended in July 1970. In November 1970, NSS made a final round trip voyage from Galveston, TX to New Orleans, LA for drydocking. Upon the ship's return to Galveston, the reactor was shutdown, for what later proved to be the final time. This was a normal controlled shutdown in accordance with operating procedures and was not the result of any accident condition.

Over the course of 1971, the reactor was defueled and prepared for long-term layup. At the time MARAD expected that NSS would, at some later date, be refueled and returned to service. As described in References [2-3] and [2-6], the spent fuel was transferred to the Atomic Energy Commission (AEC) in 1972 for reprocessing. By early 1973, it was evident that the expected return to service would not occur. MARAD then discontinued the maintenance activities that would have permitted the reactor to be refueled. Decades later, when the decommissioning rulemaking required a declaration of permanent cessation of operations, MARAD determined that the completion of defueling activities on December 3, 1971, would serve that purpose.

### 2.1.2 Current Site Radiological and Non-Radiological Conditions

After completing the 2018 – 2020 characterization surveys, the following radiologically controlled areas (RCAs) were remediated and are no longer RCAs:

- Port Stabilizer Room
- Starboard Stabilizer Room
- Port Charging Pump Room
- Starboard Charging Pump Room
- Forward Control which includes on C-Deck the Cold Water Chemistry Lab (port) and Radiation Monitoring Room (starboard) plus on D-deck the Gas Adsorption Equipment Room (port) and Radiation Sampling Room (starboard).
- Health Physics Laboratory
- Hot Chemistry Laboratory
- D Deck Nuclear Electronics Workshop and Storeroom (NEWS)



- Bulk Stores (including Special Stores #1)

### 2.1.3 Chronology of Decommissioning Planning and Characterization

In its December 2008 revised *Post Shutdown Decommissioning Activities Report* (PSDAR) [Reference 2-8], MARAD provides a summary description of the planning activities associated with decommissioning and license termination. Other documents on the NS-1 docket provide additional context and detail such as the MARAD annual reports for CY 2002 – 2007 and the records of public meetings between MARAD and NRC in 2003 and 2004. To an extent, MARAD benefitted from detailed investigations and surveys performed in 1998-1999 by the Army Corps of Engineers to support decommissioning planning for their nuclear power barge STURGIS, a plant of similar characteristics and history. At the outset, MARAD believed that it would be necessary to dispose of the NSS Reactor Pressure Vessel (RPV) at the commercial Low Level Radioactive Waste (LLRW) repository at Barnwell, SC, on 1) the basis that the RPV was not expected to meet the waste acceptance criteria for the commercial LLRW repository at Clive, UT,<sup>6</sup> and 2) MARAD was uncertain if the Department of Energy (DOE) would accept the NSS waste at one of its facilities. Because Barnwell would not accept out-of-compact waste after 2008, and because it was unlikely that the RPV could be removed before that date, it appeared that decommissioning would be geographically limited to Mid-Atlantic Compact states.<sup>7</sup> This was perceived to be too limiting from a competitive acquisition perspective, resulting in a need for more detailed and discrete information. The progression of characterization efforts, particularly regarding the disposition of the RPV, is more apparent within this context. Eventually, the competitive pressures relaxed when it was shown that the RPV could meet the Clive waste acceptance criteria. Those pressures were essentially eliminated in 2009 when the additional commercial LLRW repository was opened in Andrews, TX.<sup>8</sup> In 2019, MARAD also received a determination from the DOE that NSS waste was of AEC origin and eligible for disposal at certain of their sites; however, in consultation with DOE, MARAD determined to pursue a commercial alternative for waste disposal.

In 2003, MARAD awarded a decommissioning planning contract to WPI, Inc., operating from offices in Richmond, VA. WPI's initial efforts are described in Section 2.4.1 of the PSDAR [Reference 2-8] and included the 2004 RPV activation analysis described in Section 2.3.1 of this chapter. This activation analysis is documented as report CR-142 [Reference 2-9] and was the technical basis for the conclusion that the RPV would not meet the Clive waste acceptance criteria.

MARAD awarded a follow-on contract to WPI in late 2004 to perform the characterization scoping surveys described in Section 2.3.2 of this chapter. This effort was performed in the first half of CY 2005. It extended throughout the ship and is documented as report CR-038 [Reference 2-10]. The effort included radiological and environmental sampling and involved the first entries into the CV since 1975. Although the overall effort met the pre-survey expectations, one significant finding did not support the 2004 RPV activation analysis. This led directly to the destructive sampling of the RPV and surrounding Neutron Shield Tank described in Section 2.3.3 of this chapter. The activities were performed in the latter half of CY 2005 and are documented as report CR-056 [Reference 2-11] dated January 2006.

---

<sup>6</sup> Based largely on commercial decommissioning experience up to that time, and later supported by the 2004 activation analysis described in this chapter.

<sup>7</sup> The Mid-Atlantic Compact, consisting of the states of South Carolina, New Jersey, and Connecticut. For NSS waste to be disposed at Barnwell after July 2008, decommissioning would have to take place in one of those three states. Connecticut was not considered a viable option for a variety of reasons, and New Jersey would not permit NSS waste to be included in its allowed site volume. This apparently restricted decommissioning to South Carolina, which had only one known suitable site available (i.e., Barnwell).

<sup>8</sup> With two LLRW sites available, and no restriction on the location where decommissioning activities could be performed, there was adequate competition for services under the Federal Acquisition Regulations.



The above activities, together with a draft Environmental Assessment, supported MARAD decommissioning planning up to the submittal of PSDAR Rev. 0 in December 2006. As described in the PSDAR, Rev. 1 [Reference 2-8], that document was withdrawn soon after submittal. The decommissioning project itself was rescope, with a near-term focus on returning NSS to protective storage, albeit with significant administrative and technical upgrades to meet contemporary SAFSTOR criteria. Although the full scope of the SAFSTOR effort was ultimately not funded, MARAD was able to complete the research and investigations necessary to prepare and complete the HSA. The HSA was revised in 2023. MARAD completed an Environmental Assessment (EA) and Finding of No Significant Impact (FONSI) in 2008 and submitted these to NRC for its information and use on October 3, 2008 [Reference 2-12]. Following the submittal of the PSDAR, Rev. 1 [Reference 2-8], planning to support the SAFSTOR technical upgrades continued into 2009; however, as mentioned earlier, funding to implement these upgrades was not appropriated, and the upgrades were not carried out. The administrative efforts were completed. The uncompleted SAFSTOR technical program included a MARSSIM-based detailed characterization campaign.

Decommissioning funds were appropriated in two tranches, one in FY 2017 for \$24M, and the other in FY 2018 for \$107M. With resources available, MARAD tasked its integrated support contractor to implement the characterization plan. This campaign was divided into two separate efforts; the first was performed in August-September 2018 and involved areas of the ship outside of the RC and CV. This effort is described in Section 2.3.4 of this chapter and is documented in report CR-104 [Reference 2-4]. The second effort took place after asbestos insulation was removed from components in the CV. This effort was conducted in 2019-2020, is described in Section 2.3.5 of this chapter, and is documented in report CR-109 [Reference 2-5].

Two other characterization efforts are described in this chapter. In 2019, a MARSSIM-based survey was conducted on the fully exposed exterior surfaces of the hull, while the ship was on drydock in Philadelphia, PA. This effort is described in Section 2.3.6 of this chapter and is documented in report CR-143 [Reference 2-13]. Finally, in 2021, the exterior lead shielding on the Neutron Shield Tank (also known as the Primary Shield Tank) was sampled and analyzed to support the release of the material. This effort is described in Section 2.3.7 of this chapter and is documented in report CR-144 [Reference 2-14].

In addition to the above-described characterization efforts, the site's operational Radiation Protection Program provided valuable historical data and continues to provide input regarding site radiological conditions. Measurements and samples beyond the scope of the operational survey program have been conducted in areas recognized as needing additional information to assess the type, magnitude, and extent of contamination. These measurements and samples have been considered in decommissioning planning.

#### **2.1.4 Other Considerations Regarding Site Characteristics and Characterization**

The NSS site possesses a number of unique or unusual features and characteristics that distinguish it from typical land-based facilities. These are described in Section 5.2 of Chapter 5 of the LTP. Some of these features and characteristics have direct bearing on the decommissioning planning and the past characterization efforts described in this chapter. Among these are the following:

- The site (i.e., the ship) contains no soil;
- The site contains no surface or ground water;
- The site contains no embedded pipe, no rubble, no buried or surface paved parking lot;
- Topside deck drains gravity drained overboard;
- Welded hull blanks prevented any auxiliary or secondary system from discharging overboard after operations ceased, and,
- The NSS "sewer systems" operated as follows (see also Chapter 9 of the UFSAR):



- Both sampling sinks and the decontamination shower drain in the Cold Water Chemistry Lab (C deck Port) gravity drain to Contaminated Water Tank Starboard TD-6;
- The decontamination shower at frame 125 gravity drained overboard. The hull opening was welded closed in 1976;
- There are no deck drains other than the "shower drain" in the cold chemistry laboratory;
- Sinks and showers gravity drained overboard. The hull opening was welded closed in 1976. These are not contaminated systems; and,
- Toilets drained to the sewage tank in the engine room where it was pumped overboard. The hull opening was welded closed in 1976. This is not a contaminated system.

The overall objectives of the NSS characterization program were:

- To identify potential, likely, or known sources of radioactive material and radioactive contamination based on existing or derived information;
- To identify spaces in the ship that need further remediation as opposed to those posing no threat to human health;
- To provide an assessment of the likelihood of contaminant migration;
- To provide information useful for scoping and characterization surveys; and,
- To establish appropriate survey units and provide initial classification of these survey units as impacted or non-impacted by radioactivity.

Note that there were no significant radiological events or activities reported in the HSA or during the museum period where the "passenger and stateroom" shower, sink or sewer systems could have become contaminated.

Characterization efforts for the NSS decommissioning project were an iterative process spanning all aspects of the remediation activities. The information developed during the characterization program represents a radiological and hazardous material assessment based on the knowledge and data available at the end of 2019. This information was sufficient to satisfy the objectives listed above. Additional measurements and samples may be obtained during the remediation process to continue to ensure adequacy of area classifications and effectiveness of the FSSs to show compliance with the established Derived Concentration Guideline Levels (DCGLs), in accordance with the guidelines of MARSSIM.

The site characterization incorporates the results of investigations and surveys conducted to quantify the extent and nature of contamination at the NSS. In addition, the results of site characterization surveys and analyses have been and continue to be used to identify areas of the site that will require remediation, as well as to plan remediation methodologies, develop waste classification and volumes, and estimate disposal costs.

The information obtained from the characterization provides guidance for decontamination and remediation planning. Materials which were shown to be contaminated - such as sludges, liquids, residues and system components - at concentrations greater than the unrestricted release criteria have been and will continue to be removed and properly packaged for shipment and disposal. Extensive characterization and monitoring have been performed. Measurements and samples were taken in each accessible area, along with the historical information, to provide a clear picture of the residual radioactive materials and its vertical and lateral extent at the ship.

(RAI Response) There are no inaccessible areas on the NSS and we have completed characterization.



## 2.2 *Historical Site Assessment*

### 2.2.1 Introduction

The HSA for the NSS was completed in 2008 by AREVA Federal Services. The report documenting the HSA is CR-003 [Reference 2-3]. The process for conducting the HSA was established in accordance with MARSSIM guidelines. Assessment activities included reviews of records, inspections of the ship, evaluation of existing characterization-type data, and personal interviews with former crewmembers. Many of these interviews were conducted during a reunion of the former crew held in May 2008.

The HSA focused on historical events and routine operational processes that resulted in contamination of the plant systems and rooms within the Radiologically Controlled Area (RCA). The HSA, as part of the initial characterization program, was conducted to support the objectives detailed in Section 2.1.

### 2.2.2 Methodology

The HSA was designed to evaluate input from two separate sources - plant records and personnel interviews. The review of plant records included review of the following:

- Routine radioactive effluent release reports;
- Non-routine reports submitted to the NRC under provisions of the technical specifications, 10 CFR 20, or 10 CFR 50;
- Plant incident reports;
- Corrective action reports; and,
- Findings documented in accordance with other assessment processes such as the Decommissioning Quality Assurance Plan (DQAP) and oversight activities.<sup>9</sup>

The information obtained through this process forms the input data for the records that are maintained on site to satisfy the requirements of 10 CFR 50.75(g)(1). The objective of the document reviews was to identify events that caused the contamination of systems, buildings (i.e., ship compartments and structures), external surfaces, subsurface areas, or waterways, via atmospheric releases, liquid releases, or release of solid radioactive material. For each event, available supporting documentation regarding event description, facility and system design, radiological surveys and analysis, remediation efforts, and post remediation surveys was collected and reviewed.

Assessment activities included:

- Reviews of documents related to the ship;
- Inspections of various areas of the ship;
- Evaluation of existing data on radioactive, hazardous, and toxic contaminants; and,
- Personal interviews with former crew members.

In addition to the review of plant records, telephone interviews with individuals involved in nuclear operations at the NSS were conducted. Personnel interviewed included selected present and former employees and contractors involved in operations, maintenance, and radiation protection activities at the ship. Additional interviews were conducted during the crew reunion that took place during the week of

---

<sup>9</sup> An NRC approved quality assurance plan was not required until 1983 - many years after the NSS received a Possession-only License in 1976.

May 19, 2008. Many former crewmembers participated and several of them were interviewed, covering the same topics as discussed in the telephone interviews.

### 2.2.3 Results

Information reviewed during the HSA identified several events that involved atmospheric releases, unplanned liquid releases, facility contamination and release of radioactive material. The following list describes the major events in each of these categories and the site areas impacted by the events.

Representative documented spills of radioactivity include:

- A 1962 incident at the sampling station where a Tygon tube failed and sprayed the operator with contaminated water with activity of  $3.5\text{E-}04 \mu\text{Ci/mL}$ ;
- A case in 1962 where a desurger ruptured in the charge pump room, spraying an engineer with contaminated water with activity of  $2.3\text{E-}06 \mu\text{Ci/mL}$ ;
- A case in 1962 where air samples in passenger areas showed  $5.5\text{E-}10 \mu\text{Ci/cm}^3$ , above background levels which were typically in the range of  $1.0\text{E-}11$  to  $1.0\text{E-}12 \mu\text{Ci/cm}^3$ ;
- A 1966 primary coolant leak in the containment vessel that necessitated extensive decontamination;
- A 1966 radioactive spill of a few drops of contaminated water on the linoleum deck in Hot Chemistry Laboratory;
- A 1968 primary system leak from a pressure relief system isolation valve;
- A 1969 primary system leak from a control rod drive buffer seal;
- Another 1969 primary system leak in vent piping from a primary coolant pump that released 3500 gallons inside the containment vessel;
- A case in 1969 where contamination was found in the engine room on the steps leading to one of the buffer seal charge pump rooms during maintenance on one of the charge pumps; and,
- An instance in 1971 where low-level contamination of  $20\text{-}60 \text{ pCi/100cm}^2$  was detected on the Promenade Deck in an area where casks had been transferred.

## 2.3 Characterization Activities

### 2.3.1 Activation Analysis in 2004

An activation analysis program was completed in 2004 and documented in CR-142 [Reference 2-9].

(RAI Response) The purpose of 2004 activation analysis was to determine the waste classification of the RPV.

The objective of that assessment was the analytical determination of nuclide activation levels in the NSS RPV, reactor internals and neutron shield tank (NST) for the purpose of waste classification. That effort involved a dual approach – manual calculations using a simplified reactor model for isotopic irradiation/decay, and a detailed irradiation analysis using the ORIGEN-ARP 2.00 computer code. Oak Ridge National Laboratory developed the code for the NRC and DOE to satisfy a need for an "easy-to-use" standardized method of isotope activation and depletion/decay analysis for radioactive material.

The principal isotopes contributing to activity levels include Fe-55, Co-60, Ni-63, Nb-94, C-14, and Ni-59. Other activation products present at shutdown (1970) either have half-lives less than a year and have now decayed to insignificant Curie levels or are present in insignificant quantities resulting in negligible contributions to the current Curie inventory. As shown in Table 4 of CR-142, insignificant quantities of Nb-94 and C-14 are less than 0.001 Ci and less than 0.1 Ci for Fe-55, Co-60, Ni-59, and Ni-63. The



decay time used for this evaluation was 37 years, which assumed that the RPV, reactor internals, and neutron shield tank would be packaged and shipped in November 2007. This assumption provided additional conservatism for assessing the packaging and shipment of the RPV and reactor internals when they were removed in 2022.

Activity levels were determined analytically and then averaged over the waste volume in the RPV, reactor internals and NST to obtain Curie concentrations for each nuclide in accordance with calculation techniques acceptable to Barnwell and in accordance with 10 CFR Part 61. The averaged Curie concentration levels of each nuclide were compared with Barnwell's waste acceptance criteria and presented in Table 2-1.

**Table 2-1 Barnwell Waste Acceptance Criteria Classification of the RPV and Reactor Internals**

| Radio-nuclide                        | NSS Total Curies (November 2007) in RPV and internals (Curies) | NSS Concentration in RPV and internals (Curies/m <sup>3</sup> ) | Barnwell Waste Acceptance Criteria     |                | NSS Concentration Relative to the Waste Acceptance Classification Limit |
|--------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------|----------------|-------------------------------------------------------------------------|
|                                      |                                                                |                                                                 | Concentration (Curies/m <sup>3</sup> ) | Classification |                                                                         |
| Fe-55                                | 17.8                                                           | 1.39                                                            | < 700                                  | A              | 0.002                                                                   |
| Co-60                                | 1108                                                           | 86.74                                                           | < 700                                  | A              | 0.124                                                                   |
| Ni-59                                | 30.6                                                           | 2.40                                                            | < 22                                   | A              | 0.109                                                                   |
| C-14 in metal                        | 7.32                                                           | 0.57                                                            | < 8                                    | A              | 0.072                                                                   |
| Nb-94                                | 0.100                                                          | 0.0078                                                          | < 0.02                                 | A              | 0.391                                                                   |
| Sum of the Fractions – Class A Waste |                                                                |                                                                 |                                        |                | 0.698                                                                   |
| Ni-63 in metal                       | 2902                                                           | 227.2                                                           | ≤ 700                                  | B              | 0.324                                                                   |

### 2.3.2 WPI Characterization in 2005

This program involved extensive radiological surveys and sampling as described in the WPI detailed report, CR-038, *Radiological and Non-Radiological Spaces Characterization Survey Report* [Reference 2-10]. The NSS Characterization Project was intended to provide 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. MARAD used the information obtained from this project to develop appropriate decommissioning strategies and to estimate associated costs.

(RAI Response) The intent of the WPI 2005 characterization program was to provide a basis for which the government could estimate the cost of performing the decommissioning. A new comprehensive decommissioning characterization plan, *STS-198 Characterization Plan 2018* [Reference 2-15], was written and issued to supplement and close data gaps in the 2005 characterization data. This 2018 plan was the basis for the 2018 and 2019 characterization efforts.

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 was conducted from March 20 to April 25, 2005. As this characterization activity aged, MARAD determined that it effectively devolved into a scoping characterization that, at best, would provide insight for developing a new characterization performed much closer to actual decommissioning.

Included were 1,423 smears, 26 paint samples, 14 metal samples, six core bores in the concrete secondary containment, 10 crud samples from the primary system, four water samples from the primary side of the steam generators, one water sample from the essentially empty Neutron Shield Tank (NST), and 11 air samples.

In-situ gamma spectroscopy was also performed in 16 locations using the Berkeley Nucleonics SAM 935® portable surveillance and measurement system, which uses a 3 inch by 3 inch NaI (TI) detector to provide isotopic identification.

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  $\pm 20\%$  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. The daily source count was entered on the Instrument Source Check Log for each instrument and verified to be within this  $\pm 20\%$  range.

Table 2-2 presents the portable instrumentation used for the project.



Table 2-2 2005 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       |

The non-radiological areas were clear of detectable radiological contamination. The non-radiological areas evaluated are summarized in Table 2-3.

**Table 2-3 2005 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 foot – 0 inch Flat                               | 5                         | Background         | All < background    |
| Hold Deck (i.e., Horseshoe Tank Top)                | 6                         | 38 $\mu$ R/hour*   | All < background    |
| Cargo Hold Number 4 (aft)                           | 5                         | 250 $\mu$ R/hour** | All < background    |
| Machinery Casing, boat to C Deck                    | 4                         | Background         | All < background    |
| Machinery Space and Control Center                  | 8                         | Background         | All < background    |
| Hold Number 5, M.S. & D.A. Equip Rm and Workshop Rm | 2                         | Background         | All < background    |

\*Hold Deck (i.e., Horseshoe Tank Top) had a pipe running under the deck plate in the passageway that read 38  $\mu$ R/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. (Note that piping in the Tank Top area was removed in 2019. The piping removed included suction and discharge piping for the Buffer Seal Charging Pumps as well as piping of the Equipment Drain and Waste Collection system.)

\*\*Hold Number 4, "D" Deck Starboard, had readings on the aft bulkhead up to 250  $\mu$ R/hour. This appears to be shine from the Cold Water Chemistry Lab (Radiation Monitoring Room).



Table 2-4 provides a summary of radiological conditions found during the evaluation of radiological areas excluding containment. Note that both Hold Deck (i.e., Horseshoe Tank Top) and Cargo Hold Number 4 (aft) were subsequently designated as Radiological Areas. The values listed are maximums.

**Table 2-4 2005 Radiological Area Summary**

| <b>Deck/Compartments</b>                                                                      | <b>Dose Rate Found</b> | <b>Contamination Found<br/>(dpm/100cm<sup>2</sup>)</b> |
|-----------------------------------------------------------------------------------------------|------------------------|--------------------------------------------------------|
| Hot Chemistry Lab, D Deck port side of the Control Center room                                | Background             | < 1000                                                 |
| Port Forward Stabilizer Room, upper level, 14 foot – 0 inch Flat                              | 8 $\mu$ R/hour         | All < background                                       |
| Port Forward Stabilizer Room, lower level                                                     | 150 $\mu$ 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, C Deck                                                              | 50 $\mu$ R/hour        | All < background                                       |
| Gas Adsorption Equip Room (enter through Cold Water Chemistry Lab, C Deck), lower level       | 2000 $\mu$ R/hour      | Max 3904                                               |
| Hold #4, D Deck, starboard                                                                    | 250 $\mu$ R/hour       | All < background                                       |
| Charge Pump Rooms, port and starboard                                                         | 180 $\mu$ R/hour       | All < background                                       |
| Health Physics Lab, A Deck                                                                    | 5 $\mu$ R/hour         | Max 1221                                               |
| Hold Deck, aft of containment, port-to-starboard crossover passage (i.e., Horseshoe Tank Top) | 25 $\mu$ R/hour        | All < background                                       |
| Hold Deck, outside containment, port and starboard passages (i.e., Horseshoe Tank Top)        | 38 $\mu$ R/hour        | All < background                                       |

Table 2-5 provides a summary of radiological conditions found during the evaluation of Reactor Compartment areas outside of the Containment Vessel. The values listed are maximums.

**Table 2-5      2005 Reactor Compartment Radiological Summary**

| <b>Deck/Compartments</b>                           | <b>Dose Rate Found</b> | <b>Contamination Found<br/>(dpm/100cm<sup>2</sup>)</b> |
|----------------------------------------------------|------------------------|--------------------------------------------------------|
| 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 Deck and D Deck | 3–5 µR/hour            | All < background                                       |
| Lower level of Secondary Containment               | 221 mR/hour            | All < background                                       |

Reactor Compartment Lower Level, 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; and,
- Port side general area was 60–80 µR/hour.

No radiological contamination was found.



Table 2-6 provides a summary of radiological conditions found during the evaluation of CV. The values listed are maximums.

**Table 2-6 2005 CV Radiological Summary**

| Deck/Compartments                                           | Dose Rate Found  | Contamination Found (dpm/100cm <sup>2</sup> ) |
|-------------------------------------------------------------|------------------|-----------------------------------------------|
| CV, upper hatch closed                                      | 15 $\mu$ R/hour  | All < background                              |
| CV, upper hatch open                                        | 400 $\mu$ R/hour | All < background                              |
| CV, 1 <sup>st</sup> level                                   | 500 $\mu$ R/hour | 1200                                          |
| CV, inside shield tank upper ring                           | 7 mR/hour        | All < background                              |
| CV, 2 <sup>nd</sup> level                                   | 3 mR/hour        | All < background                              |
| CV, 3 <sup>rd</sup> level                                   | 10 mR/hour       | < 1000                                        |
| CV, 3 <sup>rd</sup> level, area over U-tube steam generator | 35 mR/hour       | < 1000                                        |
| CV, 4 <sup>th</sup> level                                   | 3 mR/hour        | All < background                              |

### 2.3.3 RPV, Reactor Internals and NST Sampling in 2005

In 2005, a project was conducted on the NSS to determine the Curie content and isotopic inventory of the RPV, Reactor Internals, and NST by extracting metal samples at selected locations in the RPV and internals, and subsequent radiochemical analysis. The objective of this project was to refine the 2004 activation analysis performed by WPI and obtain a more accurate set of nuclide activation measurements for waste classification of the RPV for disposal purposes. These measurements are based on current RPV and internals conditions as observed from actual metal sampling in the reactor internals. The results of the activity are documented in WPI report number CR-056 [Reference 2-11].

(RAI Response) The purpose of 2005 sampling and analysis activities was to determine the waste classification of the RPV.

Using a heavy metal boring system, a 4 inch access hole was drilled through the external lead shield and the outer and inner annuli of the NST, and the thermal insulation layer adjacent to the RPV shell. The 4 inch bore was sleeved with PVC pipe. A 1.0625 inch hole was bored in the center through the carbon steel RPV shell, the 0.5 inch stainless steel cladding on the RPV shell inner surface, and through the outer thermal shield. A 0.5 inch hole was drilled through the middle thermal shield.

All metal samples were taken in the form of chips by extending a drill bit with an extension shaft, operating inside of a sleeve, through the metal to be sampled. The sleeve forced the chips up the drill bit flute from which samples were obtained. A new drill bit and sleeve was used for each sample to eliminate cross contamination. Each sample was packaged separately and marked to preserve a chain of custody.

A total of eight metal samples, one insulation sample, and two liquid samples from the secondary steam generator loops were collected, bagged, packaged for transportation and shipped to GEL Laboratories, LLC (GEL), a QA certified laboratory in Charleston, SC. A 10 CFR Part 61 analysis of seven metal samples was performed. The lead shield and thermal insulation were analyzed by gamma scan only.

Table 2-7 below presents the results of total RPV nuclide activation levels based on actual radiochemistry data from the samples and analysis using the ORIGEN code for the Part 61 analyses, respectively. The concentration of each radionuclide was averaged over the entire volume of metal in the RPV and

internals. As shown, all nuclides are within the Waste Classification Class A limit both individually per isotope and when combined using the sum of the fractions for Class A Waste, which is 0.89. These results satisfy the WAC criteria and averaging methodology for burial at Chem-Nuclear Systems (now EnergySolutions - Barnwell, SC) and Envirocare (now EnergySolutions) of Utah (Clive, UT).

**Table 2-7 Summary of the RPV and Internals Activities**

| Nuclide  | Metal Sample Analysis |                       | ORIGEN  |                       | WAC Class A Limit / Ratio* |
|----------|-----------------------|-----------------------|---------|-----------------------|----------------------------|
|          | Curies                | Curies/m <sup>3</sup> | Curies  | Curies/m <sup>3</sup> | Curies/m <sup>3</sup>      |
| Ni-59*** | 4.1                   | 0.3                   | 3.9     | 0.3                   | 22 / 0.014                 |
| Nb-94*** | < MDA**               | --                    | <0.0001 | --                    | --                         |
| C-14***  | <0.01                 | --                    | <0.0001 | --                    | --                         |
| Ni-63*** | 385                   | 30.1                  | 356     | 27.9                  | 35 / 0.86                  |
| Co-60    | 62                    | 4.9                   | 80      | 6.3                   | 700 / 0.007                |
| Fe-55    | 1.1                   | 0.09                  | 0.9     | 0.07                  | 700 / 1.3E-4               |

\*Ratio of Curie concentration from metal sample analysis to Class A limit

\*\* Minimum detectable Activity Level

\*\*\* in activated metal

#### 2.3.4 Characterization Activities in 2018

Radiation Safety and Control Services Inc. (RSCS) performed an NSS radiological characterization in specific areas outside of the reactor compartment and containment vessel in August and September 2018. The results of the characterization effort are documented in CR-104 [Reference 2-4]. The intention of this work was not to repeat previous characterization efforts, but to fill in the gaps and expand the characterization data in certain areas. The areas surveyed are presented in Table 2-8.



Table 2-8 2018 Areas Surveyed

| Survey Unit | Description                                            | Location (Deck) |
|-------------|--------------------------------------------------------|-----------------|
| 103A1       | Port Stabilizer Room                                   | Hold            |
| 104A1       | Port Charging Pump Room                                | Hold            |
| 105A1       | Starboard Charging Pump Room                           | Hold            |
| 106A1       | Cold Water Chemistry Lab/ Radiation Monitoring Room    | C               |
| 107A1       | Gas Absorption Equipment Room/ Radiation Sampling Room | D               |
| 108A1       | Health Physics Lab                                     | A               |
| 109A1       | Hot Chemistry Lab                                      | D               |
| 201A1       | State Room B1                                          | B               |
| 202A1       | Horseshoe area                                         | Hold            |
| 203A1       | Hold Deck (below deck plates)                          | Hold            |
| 308A1       | NEWS Room bulk inventory                               | System          |
| 111A1       | CRDM Pump Room                                         | B               |
| 301A1       | Navigation Bridge Deck: exterior surfaces and deck     | Navigation      |
| 302A1       | Boat Deck – exterior surfaces and deck                 | Boat            |
| 303A1       | Starboard Stabilizer Room                              | Hold            |
| 304A1       | B Deck Fan Room                                        | B               |
| 305A1       | Engine Room Machinery Space                            | D               |
| 306A1       | Cargo Hold No.4 C Deck (Starboard)                     | C               |
| 307A1       | Cargo Hold No.4 D Deck (Starboard)                     | D               |
| 309A1       | Cold Chemistry Lab                                     | D               |
| 401B1       | Background (A3 + Barber & Beauty Shop)                 | A               |
| 105D1       | Buffer Seal (System SL) Booster Pumps & Charge Pumps   | System          |
| 113D1       | Radioactive Waste and Dilution System (WD)             | System          |
| 119D1       | Radiation Monitoring System (RM)                       | System          |
| 119D2       | Installed Check Source locations                       | System          |

The primary focus of radiological characterization was a MARSSIM based approach using scans, static measurements, smears and dose rate measurements in twenty identified survey units. In addition, several systems/items were also included in this characterization program. CAD drawings of the survey units were created specifically for documentation – including floors, walls, and ceilings. Seventeen static/smear locations were designated in each survey unit using Visual Sample Plan (VSP) software. A total of ten tritium samples were part of this characterization and survey units with the highest potential

for tritium were selected for these samples. The MARSSIM survey class included specific instructions for collection of measurements and data logging, figures with locations, and documentation for recording survey activities/results. These surveys were designed to collect the specified radiological samples and analysis for these areas (scan, static, smear, dose rate, sample).

For the survey design, the Co-60, H-3, and Am-241 screening values, taken from NUREG/CR-5512, Vol. 3, Table 5.19 [Reference 2-16], were used as investigation levels. The investigation levels for beta and gamma scans were 500 cpm and 5,000 cpm respectively.

A characterization survey package was created for each survey unit, which included specific instructions for collection of measurements and data logging, figures with locations and documentation for recording survey activities/results.

Radiological surveys were performed with the following instrumentation:

- Thermo RadEye SX with Ludlum Model 43-89 detector (alpha/beta directs and beta scans);
- Thermo RadEye SX with Ludlum Model 44-10 (gamma scans);
- Ludlum Model 3 with Ludlum Model 44-9 (beta scans);
- Bicon MicroRem (dose rate); and,
- Ludlum Model 19 (dose rate).

Instruments were properly calibrated, and beta efficiencies were determined with Tc-99, alpha efficiencies with Th-230 and gamma calibrations with Cs-137. Operational checks were performed each day prior to use. With a 3-minute count time and 1-minute background, direct measurement minimum detectable concentrations were in the range of 10 to 39 dpm/100cm<sup>2</sup> alpha and 98 to 338 dpm/100cm<sup>2</sup> beta. Measurements were collected with the detector approximately 0.5 inches from the surface.

In Situ Object Counting System (ISOCS) measurements were performed with a 2x2 inch stabilized and ISOCS characterized sodium iodide detector with a lead collimator that was portable for access to the various locations within the ship. The ISOCS sensitivity varied by count time, the object being counted, and the distance from the object.

Smears were counted at the RSCS laboratory on a Tennelec gas proportional counting system. The minimum detectable activity for alpha smear measurements was approximately 16 dpm/100cm<sup>2</sup> and approximately 43 dpm/100cm<sup>2</sup> for beta smears. In accordance with the DQAP and the Radiation Protection Program (RPP), GEL analyzed tritium smears (method GL-RAD-A-002) and also counted 48 smears for quality assurance by gas proportional counting (method GL-RAD-A-001).

The radiological data generated was intended only to provide guidance for future decontamination and remediation activities for these areas. Use of properly calibrated instruments with operational checks and duplicate measurements as part of the survey process provided data quality indicators. The data quality was acceptable with no deviations from measurement protocols and reasonable agreement with duplicate measurements.



The following was performed during this characterization program:

- 396 alpha/beta direct measurements;
- 412 alpha/beta removable measurements;
- 10 tritium measurements;
- 403 dose rate measurements;
- Beta scans;
- Gamma scans; and,
- 69 ISOCs measurements.

Table 2-9 provides the maximum results for each type of survey conducted.

**Table 2-9      2018 Maximum Results by Measurement Type**

| <b>Measurement</b> | <b>Criteria</b>                | <b>Maximum</b>                   | <b>Location<br/>(Survey Unit)</b>              | <b>Description</b>                           |
|--------------------|--------------------------------|----------------------------------|------------------------------------------------|----------------------------------------------|
| Beta Scan          | 500 cpm                        | 30,000 cpm                       | 105D1 (Buffer Seal System)                     | Valve SL-57V (internal contamination)        |
| Gamma Scan         | 5,000 cpm                      | 73,166,400 cpm                   | 105D1 (Buffer Seal System)                     | buffer seal coolers (internal contamination) |
| Alpha Static       | 27 dpm / 100cm <sup>2</sup>    | 264 dpm / 100cm <sup>2</sup>     | 306A1 (Cargo Deck 4 C Deck Starboard)          | deck                                         |
| Beta Static        | 7,100 dpm / 100cm <sup>2</sup> | 722,172 dpm / 100cm <sup>2</sup> | 105D1 (Buffer Seal System)                     | booster pump (internal contamination)        |
| Alpha Removable    | 27 dpm / 100cm <sup>2</sup>    | 14 dpm / 100cm <sup>2</sup>      | 109A1 (Hot Chemistry Lab)                      | box                                          |
| Beta Removable     | 7,100 dpm / 100cm <sup>2</sup> | 7,576 dpm / 100cm <sup>2</sup>   | 105D1 (Buffer Seal System)                     | booster pump                                 |
| Tritium (H-3)      | 1.2E8 dpm / 100cm <sup>2</sup> | 6,638 dpm / 100cm <sup>2</sup>   | 107A1 (Gas Absorption/Radiation Sampling Room) | sample sink                                  |
| Dose Rate          | None (information only)        | 400 µR / h                       | 119D2 (Sources)                                | steering gear sources                        |

Tables 2-10 and 2-11 summarize the results by survey unit. Not Applicable is indicated by N/A.

Table 2-10 NSS 2018 Characterization Summary Table A

| Survey Unit | Beta Scan Maximum CPM | Alpha Static >27 DPM/100cm <sup>2</sup> | Alpha Static Maximum DPM/100cm <sup>2</sup> | Beta Static >7,100 DPM/100cm <sup>2</sup> | Beta Static Maximum DPM/100cm <sup>2</sup> | Alpha Removable >27 DPM/100cm <sup>2</sup> | Alpha Removable Maximum DPM/100cm <sup>2</sup> |
|-------------|-----------------------|-----------------------------------------|---------------------------------------------|-------------------------------------------|--------------------------------------------|--------------------------------------------|------------------------------------------------|
| 103A1       | 8,389                 | 0                                       | 20                                          | 1                                         | 72,811                                     | 0                                          | 6                                              |
| 104A1       | 772                   | 0                                       | 15                                          | 0                                         | 3,502                                      | 0                                          | 6                                              |
| 105A1       | 527                   | 0                                       | 15                                          | 0                                         | 847                                        | 0                                          | 3                                              |
| 106A1       | 979                   | 0                                       | 17                                          | 0                                         | 898                                        | 0                                          | 3                                              |
| 107A1       | 3,703                 | 0                                       | 11                                          | 2                                         | 49,441                                     | 0                                          | 6                                              |
| 108A1       | 1,100                 | 0                                       | 18                                          | 0                                         | 560                                        | 0                                          | 3                                              |
| 109A1       | 1,543                 | 0                                       | 4                                           | 0                                         | 2,247                                      | 0                                          | 14                                             |
| 111A1       | 356                   | 1                                       | 57                                          | 0                                         | 558                                        | 0                                          | 10                                             |
| 201A1       | 8,093                 | 0                                       | 18                                          | 0                                         | 2,900                                      | 0                                          | 3                                              |
| 202A1       | 289                   | 0                                       | 6                                           | 0                                         | 657                                        | 0                                          | 3                                              |
| 203A1       | 319                   | 0                                       | 9                                           | 0                                         | 1,475                                      | 0                                          | 3                                              |
| 301A1       | 238                   | 1                                       | 41                                          | 0                                         | 627                                        | 0                                          | 6                                              |
| 302A1       | 2,413                 | 0                                       | 3                                           | 0                                         | 47                                         | 0                                          | 1                                              |
| 303A1       | 645                   | 0                                       | 3                                           | 0                                         | 449                                        | 0                                          | 13                                             |
| 304A1       | 803                   | 0                                       | 18                                          | 0                                         | 373                                        | 0                                          | 4                                              |
| 305A1       | 742                   | 0                                       | 11                                          | 0                                         | 880                                        | 0                                          | 3                                              |
| 306A1       | 532                   | 13                                      | 264                                         | 0                                         | 359                                        | 0                                          | 3                                              |
| 307A1       | 11,036                | 0                                       | 6                                           | 0                                         | 1,099                                      | 0                                          | 3                                              |
| 309A1       | 805                   | 0                                       | 23                                          | 0                                         | 1,727                                      | 0                                          | 3                                              |
| 401B1       | 587                   | 4                                       | 76                                          | 0                                         | 3,213                                      | 0                                          | 3                                              |



Table 2-10 NSS 2018 Characterization Summary Table A (continued)

| Survey Unit | Beta Scan Maximum CPM | Alpha Static >27 DPM/100cm <sup>2</sup> | Alpha Static Maximum DPM/100cm <sup>2</sup> | Beta Static >7,100 DPM/100cm <sup>2</sup> | Beta Static Maximum DPM/100cm <sup>2</sup> | Alpha Removable >27 DPM/100cm <sup>2</sup> | Alpha Removable Maximum DPM/100cm <sup>2</sup> |
|-------------|-----------------------|-----------------------------------------|---------------------------------------------|-------------------------------------------|--------------------------------------------|--------------------------------------------|------------------------------------------------|
| 105D1       | 30,000                | 0                                       | 17                                          | 9                                         | 722,172                                    | 0                                          | 3                                              |
| 113D1       | 30                    | N/A                                     | N/A                                         | 0                                         | 0                                          | 0                                          | 3                                              |
| 119D2       | N/A                   | N/A                                     | N/A                                         | N/A                                       | N/A                                        | 0                                          | 3                                              |
| 308A1       | N/A                   | N/A                                     | N/A                                         | N/A                                       | N/A                                        | N/A                                        | N/A                                            |

Table 2-11 NSS 2018 Characterization Summary Table B

| Survey Unit | Beta Removable >7,100 DPM/100cm <sup>2</sup> | Beta Removable Maximum DPM/100cm <sup>2</sup> | Dose Rate Maximum $\mu$ rem/h | Tritium Removable >1.6E8 DPM/100cm <sup>2</sup> | Tritium Removable Maximum DPM/100cm <sup>2</sup> |
|-------------|----------------------------------------------|-----------------------------------------------|-------------------------------|-------------------------------------------------|--------------------------------------------------|
| 103A1       | 0                                            | 453                                           | 9                             | -                                               | -                                                |
| 104A1       | 0                                            | 481                                           | 12                            | 0                                               | 3,352                                            |
| 105A1       | 0                                            | 69                                            | 3                             | 0                                               | 41                                               |
| 106A1       | 0                                            | 16                                            | 7                             | 0                                               | 16                                               |
| 107A1       | 0                                            | 4,022                                         | 120                           | 0                                               | 6,638                                            |
| 108A1       | 0                                            | 14                                            | 3                             | 0                                               | 63                                               |
| 109A1       | 0                                            | 1,667                                         | 2                             | 0                                               | 855                                              |
| 111A1       | 0                                            | 23                                            | 3                             | -                                               | -                                                |
| 201A1       | 0                                            | 14                                            | 3                             | -                                               | -                                                |
| 202A1       | 0                                            | 27                                            | 4                             | -                                               | -                                                |
| 203A1       | 0                                            | 27                                            | 3                             | -                                               | -                                                |

Table 2-11 NSS 2018 Characterization Summary Table B (continued)

| Survey Unit | Beta Removable >7,100 DPM/100cm <sup>2</sup> | Beta Removable Maximum DPM/100cm <sup>2</sup> | Dose Rate Maximum $\mu$ rem/h | Tritium Removable >1.6E8 DPM/100cm <sup>2</sup> | Tritium Removable Maximum DPM/100cm <sup>2</sup> |
|-------------|----------------------------------------------|-----------------------------------------------|-------------------------------|-------------------------------------------------|--------------------------------------------------|
| 301A1       | 0                                            | 13                                            | 4                             | -                                               | -                                                |
| 302A1       | 0                                            | 4                                             | 3                             | -                                               | -                                                |
| 303A1       | 0                                            | 20                                            | 2                             | -                                               | -                                                |
| 304A1       | 0                                            | 66                                            | 2                             | 0                                               | 17                                               |
| 305A1       | 0                                            | 20                                            | 3                             | -                                               | -                                                |
| 306A1       | 0                                            | 23                                            | 2                             | -                                               | -                                                |
| 307A1       | 0                                            | 27                                            | 4                             | -                                               | -                                                |
| 309A1       | 0                                            | 16                                            | 1.5                           | 0                                               | 2                                                |
| 401B1       | 0                                            | 27                                            | 2                             | -                                               | -                                                |
| 105D1       | 1                                            | 7,576                                         | 10                            | N/A                                             | N/A                                              |
| 113D1       | 0                                            | 34                                            | 1.5                           | N/A                                             | N/A                                              |
| 119D2       | 0                                            | 65                                            | 400                           | N/A                                             | N/A                                              |
| 308A1       | N/A                                          | N/A                                           | N/A                           | N/A                                             | N/A                                              |



### 2.3.5 Characterization Activities in 2019

A detailed profile of radiological and non-radiological contaminants on the ship in radiological spaces was performed in 2019, again by RSCS. The results of the characterization efforts are documented in CR-109 [Reference 2-5]. This scope of work was to perform a radiological and environmental hazard characterization for the RC and CV. The intention of this work was not to repeat previous characterization efforts, but to fill in the gaps and expand the characterization data in certain areas.

(RAI response) All system components in section 2.3.5 of the LTP are removed with exception of the secondary side only portions of the Steam Generators, the NST outer shell and the Pressurizer shell with no internals.

Radiological surveys were performed with the following instrumentation:

- Ludlum Telepole;
- Thermo RadEye SX with Ludlum Model 43-93 detector (alpha/beta directs and beta scans);
- Thermo RadEye SX with Ludlum Model 44-10 (gamma scans);
- Ludlum Model 3 with Ludlum Model 44-9 (beta scans);
- Bicron MicroRem (dose rate);
- Ludlum Model 19 (dose rate);
- AMP-100 dose rate probe;
- Ludlum 3030E with a 43-10-1 probe above a fixed position smear counter; and,
- NaIs and OSPREY ISOCS Characterized.

Instruments were properly calibrated, and beta efficiencies were determined with Tc-99, alpha efficiencies with Th-230 and gamma calibrations with Cs-137. Source check responses were established for each instrument with plus and minus two standard deviation values determined. Operational checks were performed each day prior to use. Control charts for background and daily source checks were established for the counting instruments such as the RadEye with 43-83 alpha beta probe and the Ludlum 3030 with the 43-10-1 gross alpha/beta probe.

For the survey design, the Co-60, H-3, and Am-241 screening values, taken from NUREG/CR-5512, Vol. 3, Table 5.19 [Reference 2-16], were used as investigation levels.

Equation 2-1 was used to calculate the Minimum Detectable Activity (MDA):

$$MDA (dpm) = \frac{3 + 3.29 \sqrt{R_b t_s (1 + \frac{t_s}{t_b})}}{eff * t_s} \quad \text{Equation 2-1}$$

Where:

- $R_b$  = background count rate (c/m)
- $t_s$  = sample count time (min)
- $t_b$  = background count time (min)
- $eff$  = counting efficiency in counts per disintegration (c/d)

Baseline radiation and contamination surveys were performed in the Reactor Compartment and Containment Vessel between April 5 and April 30, 2019. The surveys were conducted to evaluate area

---

**License Termination Plan – (STS-004-003)**

---

conditions for end state and decommissioning planning. MARSSIM scans were not performed since component removals or remediations during decommissioning were deemed likely to change the locations of surface contamination.

The surveys consisted of:

- General Area, contact, and 30 cm dose rates (not background corrected);
- 100cm<sup>2</sup> removable contamination smears and gross wipes/smears;
- Biased scans with alpha-beta or beta-gamma detectors; and,
- Fixed position counts with alpha-beta detectors.

The quantity of smear samples and measurements for the baseline surveys are summarized in Table 2-12. In addition to the 273 100cm<sup>2</sup> smears documented on the surveys, several dozen large area smears were obtained to get sufficient general area surface contamination activity for a reliable radionuclide mix to be generated.

**Table 2-12      2019 Baseline Survey Measurement Summary (Quantity Collected)**

| <b>Location</b>           | <b>100cm<sup>2</sup><br/>Smear<br/>Count</b> | <b>Fixed<br/>Position<br/>Scans</b> | <b>Surface<br/>Scans</b> | <b>GA Dose<br/>Rate</b> | <b>Contact/30<br/>cm</b> |
|---------------------------|----------------------------------------------|-------------------------------------|--------------------------|-------------------------|--------------------------|
| CV Level 1                | 30                                           | 6                                   | 14                       | 12                      | 6                        |
| CV Level 2                | 30                                           | 5                                   | 12                       | 14                      | 11                       |
| CV Level 3                | 30                                           | 4                                   | 12                       | 12                      | 9                        |
| CV Level 4                | 26                                           | 5                                   | 16                       | 14                      | 4                        |
| RC Upper Level A          | 14                                           | 3                                   | 12                       | 8                       | 1                        |
| RC Upper Level B          | 27                                           | 7                                   | 20                       | 15                      | 2                        |
| RC Mid-Level C & D        | 54                                           | 1                                   | 32                       | 16                      | 2                        |
| RC Lower Level<br>Forward | 42                                           | 6                                   | 30                       | 17                      | 17                       |
| RC Lower Level Aft        | 20                                           | 1                                   | 12                       | 10                      | 6                        |
| <b>Total</b>              | <b>273</b>                                   | <b>38</b>                           | <b>160</b>               | <b>118</b>              | <b>58</b>                |

Scans and fixed position measurements are reported in corrected counts per minute (ccpm) with background levels in the areas ranging from 0 – 0.5 cpm alpha and 100 – 20,000 cpm beta. The highest alpha and beta backgrounds reported in each area in Table 2-12 were used along with Equation 1 to calculate the minimum detectable corrected counts per minute (MDCC) and MDAs for fixed position readings that used a 1-minute background (tb) and a 3-minute count time (ts). Comparison of the MDAs to the screening DCGLs in Table 2-13 demonstrates that adequate sensitivity was maintained even in the highest background locations with worst case MDAs of 49% of the Co-60 [7,100 dpm/100cm<sup>2</sup> DCGL] and 12% of the Cs-137 [28,000 dpm/100cm<sup>2</sup> DCGL].



**Table 2-13 Fixed Position Alpha ( $\alpha$ ) Beta ( $\beta$ ) Sensitivity in Highest  $\alpha$   $\beta$  Background per Survey Area**

| Location                   | Alpha Bkg cpm | Beta Bkg cpm | Alpha MDCC ccpm | Beta MDCC ccpm | Alpha MDA dpm | Beta MDA dpm | % Co-60 DCGL | % Cs-137 DCGL |
|----------------------------|---------------|--------------|-----------------|----------------|---------------|--------------|--------------|---------------|
| CV Level 1                 | 0.5           | 2000         | 4               | 171            | 9             | 1098         | 15%          | 4%            |
| CV Level 2                 | 0.5           | 15000        | 4               | 466            | 9             | 2997         | 42%          | 11%           |
| CV Level 3                 | 0.5           | 15000        | 4               | 466            | 9             | 2997         | 42%          | 11%           |
| CV Level 4                 | 0.5           | 20000        | 4               | 538            | 9             | 3459         | 49%          | 12%           |
| RC Lower Level AFT         | 0             | 350          | 1               | 72             | 3             | 463          | 7%           | 2%            |
| RC Lower Level FWD         | 0             | 1500         | 1               | 148            | 3             | 952          | 13%          | 3%            |
| RC Mid-Level C Deck        | 0             | 130          | 1               | 44             | 3             | 285          | 4%           | 1%            |
| RC Mid-Level D Deck Aft    | 0             | 130          | 1               | 44             | 3             | 285          | 4%           | 1%            |
| RC Mid-Level D Deck        | 0             | 130          | 1               | 44             | 3             | 285          | 4%           | 1%            |
| RC Upper Level B Deck      | 0             | 110          | 1               | 41             | 3             | 262          | 4%           | 1%            |
| RC Upper Level A Deck      | 0             | 110          | 1               | 41             | 3             | 262          | 4%           | 1%            |
| RC Upper Level A Deck      | 0             | 110          | 1               | 41             | 3             | 262          | 4%           | 1%            |
| RC Upper Level Ventilation | 0             | 100          | 1               | 39             | 3             | 251          | 4%           | 1%            |
| CV RC Systems              | 0.5           | 20000        | 4               | 538            | 9             | 3459         | 49%          | 12%           |

The system characterization was focused on obtaining representative samples of interior contaminants. This included smears as well as samples of any sludges, liquids, or other materials present. It also focused on obtaining interior beta and gamma dose rates to supplement dose to curie estimates of the source terms present. System access and sampling was performed in accordance with a detailed Work Order and daily Job Hazards Analysis briefs. Area surveys, system surveys, and sampling were performed using project-specific procedures for the instruments used and sampling performed.

On-site gamma spectroscopy measurements were performed with a 2x2 stabilized and characterized sodium iodide detector with a lead collimator that was also portable for access to the various locations within the ship. The geometry composer software was used to create a smear composite, paint chip sample, as well as liquid and sludge sample container geometries for on-site analysis.

### License Termination Plan – (STS-004-003)

In accordance with the DQAP and the RPP, GEL also analyzed baseline survey smears with positive activity for quality assurance by gas proportional counting (method GL-RAD-A-001) and tritium smears (method GL-RAD-A-002). System smear sample composites were also analyzed by gamma spectroscopy at the same laboratory. These results were reviewed and five of the smear composites were selected for hard-to-detect analysis to provide C-14, Ni-63, Sr-90 and Tc-99 results. These Radionuclides of Concern (ROCs) were obtained during characterization planning. The bolded and italicized ID cells in Table 2-14 were selected for hard-to-detect analysis.

Results of characterization surveys on external surfaces of system components and decks show that there is very little removable and total activity. The results of internal system component surveys only established removable levels and not total activity or whether radioactivity has penetrated the material.

The required MDA for gamma spectrometry was set at 25 pCi/filter for Cs-137. The analysis method was by DOE HASL 300, 4.5.2.3/Ga-01-R.

**Table 2-14 Off-site Laboratory Smear Composite Gamma Spectroscopy Results**

| Sample ID                 | Location                                       | Co-60<br>pCi | Ag-108m<br>pCi | Cs-137<br>pCi | Co/Cs<br>Ratio |
|---------------------------|------------------------------------------------|--------------|----------------|---------------|----------------|
| RCCV-RS-006               | Smears from PRT PR-T1 Effluent Condensing Tank | 6.02E+02     |                |               |                |
| <b><i>RCCV-RS-010</i></b> | Smears from Steam generator                    | 3.58E+04     |                | 1.39E+02      | 2.58E+02       |
| RCCV-RS-002               | Smears from PD-T1 Lab Waste Tank               | 7.67E+03     | 1.79E+01       | 3.68E+01      | 2.08E+02       |
| <b><i>RCCV-RS-007</i></b> | Smears from Pressurizer                        | 4.26E+04     |                | 3.39E+02      | 1.26E+02       |
| <b><i>RCCV-RS-001</i></b> | Smears from IX piping                          | 8.21E+04     | 2.52E+02       | 9.09E+02      | 9.03E+01       |
| RCCV-RS-003               | Smears from PD-T2                              | 1.05E+03     | 1.73E+01       | 2.33E+01      | 4.51E+01       |
| RCCV-RS-004               | Smears from PD-T3                              | 2.40E+03     |                | 2.27E+02      | 1.06E+01       |
| RCCV-RS-011               | Smears from SLT-1 Buffer Seal Surge Tank       | 1.79E+03     | 1.07E+01       | 6.57E+02      | 2.72E+00       |
| <b><i>RCCV-RS-005</i></b> | Smears from PD-T4                              | 3.96E+03     | 3.94E+01       | 3.05E+03      | 1.30E+00       |
| RCCV-RS-009               | Smears from Emergency Cooling Heat Exchanger   | 4.06E+02     | 1.45E+02       | 7.72E+02      | 5.26E-01       |
| RCCV-RS-008               | Smears from SC-E1 pipe Shutdown Circ. sys.     | 1.95E+02     | 4.27E+01       | 8.31E+02      | 2.35E-01       |
| <b><i>RCCV-RS-012</i></b> | Smears from Ventilation                        | 2.15E+02     | 1.65E+01       | 9.81E+03      | 2.19E-02       |

**Note:** The bolded and italicized Sample ID cells in Table 2-14 were selected for hard-to-detect analysis.

Table 2-15 presents the off-site laboratory results for the steam generator composite with the hard-to-detect radionuclides. The required MDA for H-3 analysis was 150 pCi/filter. The analysis method was by EPA 906.0 Modified. The required MDA for C-14 analysis was 10 pCi/filter. The analysis method was by EPA EERF C-01 Modified. The required MDA for Ni-63 analysis was 20 pCi/filter. The analysis method was by DOE RESL Ni-1, Modified. The required MDA for Tc-99 analysis was



**License Termination Plan – (STS-004-003)**

10 pCi/filter. The analysis method was by DOE EML HASL-300, Tc-02-RC Modified. The required MDA for Sr-90 analysis was 2 pCi/filter. The analysis method was by EPA 905.0 Modified /DOE RP501 Rev. 1 Modified.

The composite activities in Tables 2-15 through Table 2-19 were compared to the 90th percentile building screening values from NUREG/CR-5512, Volume 3, Table 5.19 [Reference 2-16]. There is no value for Ag-108m in the screening table; therefore, the value for Ag-110m was used as a substitute for the calculations.

**Table 2-15      Steam Generator Composite Smear Results Compared to Screening DCGLs**

| <b>Nuclide</b> | <b>Total<br/>Composite<br/>pCi</b> | <b>Total<br/>Composite<br/>DPM</b> | <b>Screening<br/>DCGL<br/>DPM/100cm<sup>2</sup></b> | <b>Activity/<br/>Screening<br/>DCGL<br/>Fraction</b> | <b>Normalized<br/>Fraction</b> |
|----------------|------------------------------------|------------------------------------|-----------------------------------------------------|------------------------------------------------------|--------------------------------|
| C-14           | 3.50E+02                           | 7.77E+02                           | 3.70E+06                                            | 2.10E-04                                             | 3.97E-06                       |
| Co-60          | 3.58E+04                           | 7.95E+04                           | 7.10E+03                                            | 1.12E+01                                             | 2.12E-01                       |
| Ni-63          | 3.38E+07                           | 7.50E+07                           | 1.80E+06                                            | 4.17E+01                                             | 7.88E-01                       |
| Sr-90          | <MDA                               | <MDA                               | 8.70E+03                                            | 0.00E+00                                             | 0.00E+00                       |
| Tc-99          | 7.90E+01                           | 1.75E+02                           | 1.30E+06                                            | 1.35E-04                                             | 2.55E-06                       |
| Ag-108m        | <MDA                               | <MDA                               | 1.00E+04                                            | 0.00E+00                                             | 0.00E+00                       |
| Cs-137         | 1.39E+02                           | 3.09E+02                           | 2.80E+04                                            | 1.10E-02                                             | 2.08E-04                       |
| <b>Total</b>   |                                    |                                    |                                                     | <b>5.29E+01</b>                                      | <b>1.00E+00</b>                |

**License Termination Plan – (STS-004-003)**

Table 2-16 presents the off-site laboratory results for the Pressurizer composite with the hard-to-detect radionuclides.

**Table 2-16 Pressurizer Composite Smear Results Compared to Screening DCGLs**

| <b>Nuclide</b> | <b>Total Composite pCi</b> | <b>Total Composite DPM</b> | <b>Screening DCGL DPM/100cm<sup>2</sup></b> | <b>Activity/ Screening DCGL Fraction</b> | <b>Normalized Fraction</b> |
|----------------|----------------------------|----------------------------|---------------------------------------------|------------------------------------------|----------------------------|
| C-14           | 2.23E+03                   | 4.95E+03                   | 3.70E+06                                    | 1.34E-03                                 | 8.60E-05                   |
| Co-60          | 4.26E+04                   | 9.46E+04                   | 7.10E+03                                    | 1.33E+01                                 | 8.56E-01                   |
| Ni-63          | 1.79E+06                   | 3.97E+06                   | 1.80E+06                                    | 2.21E+00                                 | 1.42E-01                   |
| Sr-90          | 1.39E+00                   | 3.09E+00                   | 8.70E+03                                    | 3.55E-04                                 | 2.28E-05                   |
| Tc-99          | 2.74E+01                   | 6.08E+01                   | 1.30E+06                                    | 4.68E-05                                 | 3.01E-06                   |
| Ag-108m        | <MDA                       | <MDA                       | 1.00E+04                                    | 0.00E+00                                 | 0.00E+00                   |
| Cs-137         | 3.39E+02                   | 7.53E+02                   | 2.80E+04                                    | 2.69E-02                                 | 1.73E-03                   |
| <b>Total</b>   |                            |                            |                                             | <b>1.56E+01</b>                          | <b>1.00E+00</b>            |

Table 2-17 presents the off-site laboratory results for the Containment Drain Tank (PD-T4) composite with the hard-to-detect radionuclides.

**Table 2-17 Containment Drain Tank Composite Smear Results Compared to Screening DCGLs**

| <b>Nuclide</b> | <b>Total Composite pCi</b> | <b>Total Composite DPM</b> | <b>Screening DCGL DPM/100cm<sup>2</sup></b> | <b>Activity/ Screening DCGL Fraction</b> | <b>Normalized Fraction</b> |
|----------------|----------------------------|----------------------------|---------------------------------------------|------------------------------------------|----------------------------|
| C-14           | 5.10E+01                   | 1.13E+02                   | 3.70E+06                                    | 3.06E-05                                 | 1.77E-05                   |
| Co-60          | 3.96E+03                   | 8.79E+03                   | 7.10E+03                                    | 1.24E+00                                 | 7.16E-01                   |
| Ni-63          | 1.95E+05                   | 4.33E+05                   | 1.80E+06                                    | 2.41E-01                                 | 1.39E-01                   |
| Sr-90          | <MDA                       | <MDA                       | 8.70E+03                                    | 0.00E+00                                 | 0.00E+00                   |
| Tc-99          | 1.42E+01                   | 3.15E+01                   | 1.30E+06                                    | 2.42E-05                                 | 1.40E-05                   |
| Ag-108m        | 3.94E+01                   | 8.75E+01                   | 1.00E+04                                    | 8.75E-03                                 | 5.06E-03                   |
| Cs-137         | 3.05E+03                   | 6.77E+03                   | 2.80E+04                                    | 2.42E-01                                 | 1.40E-01                   |
| <b>Total</b>   |                            |                            |                                             | <b>1.73E+00</b>                          | <b>1.00E+00</b>            |

Table 2-18 presents the off-site laboratory results for the RC Exhaust Ventilation composite with the hard-to-detect radionuclides.



**Table 2-18 RC Exhaust Ventilation Composite Smear Results Compared to Screening DCGLs**

| Nuclide      | Total Composite pCi | Total Composite DPM | Screening DCGL DPM/100cm <sup>2</sup> | Activity/ Screening DCGL Fraction | Normalized Fraction |
|--------------|---------------------|---------------------|---------------------------------------|-----------------------------------|---------------------|
| C-14         | 6.43E+02            | 1.43E+03            | 3.70E+06                              | 3.86E-04                          | 4.47E-04            |
| Co-60        | 2.15E+02            | 4.77E+02            | 7.10E+03                              | 6.72E-02                          | 7.79E-02            |
| Ni-63        | 1.20E+04            | 2.66E+04            | 1.80E+06                              | 1.48E-02                          | 1.72E-02            |
| Sr-90        | <MDA                | <MDA                | 8.70E+03                              | 0.00E+00                          | 0.00E+00            |
| Tc-99        | <MDA                | <MDA                | 1.30E+06                              | 0.00E+00                          | 0.00E+00            |
| Ag-108m      | 1.14E+01            | 2.53E+01            | 1.00E+04                              | 2.53E-03                          | 2.93E-03            |
| Cs-137       | 9.81E+03            | 2.18E+04            | 2.80E+04                              | 7.78E-01                          | 9.02E-01            |
| <b>Total</b> |                     |                     |                                       | <b>8.63E-01</b>                   | <b>1.00E+00</b>     |

Table 2-19 presents the off-site laboratory results for the Primary Purification RC IX piping composite with the hard-to-detect radionuclides.

**Table 2-19 Primary Loop RC IX Piping Composite Smear Results Compared to Screening DCGLs**

| Nuclide      | Total Composite pCi | Total Composite DPM | Screening DCGL DPM/100cm <sup>2</sup> | Activity/ Screening DCGL Fraction | Normalized Fraction |
|--------------|---------------------|---------------------|---------------------------------------|-----------------------------------|---------------------|
| C-14         | 1.48E+04            | 3.29E+04            | 3.70E+06                              | 8.88E-03                          | 1.03E-02            |
| Co-60        | 8.21E+04            | 1.82E+05            | 7.10E+03                              | 2.57E+01                          | 2.98E+01            |
| Ni-63        | 5.24E+06            | 1.16E+07            | 1.80E+06                              | 6.46E+00                          | 7.49E+00            |
| Sr-90        | 1.59E+00            | 3.53E+00            | 8.70E+03                              | 4.06E-04                          | 4.70E-04            |
| Tc-99        | 1.67E+02            | 3.71E+02            | 1.30E+06                              | 2.85E-04                          | 3.31E-04            |
| Ag-108m      | 2.52E+02            | 5.59E+02            | 1.00E+04                              | 5.59E-02                          | 6.48E-02            |
| Cs-137       | 9.09E+02            | 2.02E+03            | 2.80E+04                              | 7.21E-02                          | 8.35E-02            |
| <b>Total</b> |                     |                     |                                       | <b>8.63E-01</b>                   | <b>1.00E+00</b>     |

The results of the RPV, Internals and NST Sampling in 2005 were also re-evaluated in 2019. The 2005 activated metal sample results were decayed to 2019. The decayed activity concentrations were converted from  $\mu\text{Ci/g}$  to  $\mu\text{Ci/cc}$  by multiplying by the average density of steel at 8 g/cc to determine the waste classification in accordance with 10 CFR Part 61.55. Table 2-20 presents the total activity concentrations and classification of the activated components.

**Table 2-20 Component Activity and Classification Summary**

| Component                        | Total<br>$\mu\text{Ci/cc}$ | Class |
|----------------------------------|----------------------------|-------|
| NST Outer Diameter (OD)          | 2.71E-02                   | A     |
| NST Inner Diameter (ID)          | 2.38E-02                   | A     |
| RPV OD                           | 2.82E-02                   | A     |
| RPV ID                           | 5.23E-01                   | A     |
| Outer Thermal Shield (OTS) ID/OD | 1.96E+01                   | A     |
| Middle Thermal Shield (MTS) OD   | 7.58E+01                   | B     |
| MTS ID                           | 1.40E+02                   | B     |
| <b>Total</b>                     | <b>2.36E+02</b>            |       |

(RAI Response) The results of a sampling and analysis campaign of the Reactor Pressure Vessel and Neutron Shield Tank in 2005, documented in CR-056 [Reference 2-11], shows no positive activation activity in the Neutron Shield Tank outer wall. An additional sampling campaign was conducted in 2005 and documented in CR-038 [Reference 2-10], in which 14 metal samples were taken from structural components 1) in close proximity to, 2) outside of the reactor pressure vessel (RPV) and 3) in direct line-of-sight of the core mid-plane. None of these metal samples showed activity above background. Six secondary containment concrete core bores were also collected. Four metal samples and two concrete cores along with steel plugs were sent to GEL labs for confirmatory analysis. The results of these samples showed no positive gamma emitting radionuclides in any metal samples, with the exception of naturally occurring K-40 being positively identified in one sample. No Tritium was detected in the concrete cores and only naturally-occurring gamma emitting radionuclides in the concrete.

(RAI Response) In 2018, the CV Portal was created to provide horizontal access to the CV. Creating the portal required the removing the layers of the CV shell: the concrete biological shielding and the laminated redwood and steel collision mat. One wood, one concrete and two metal samples were collected and sent for gamma spec and Hard-To-Detect (HTD) radionuclide analysis. The results of these samples showed no positive gamma emitting radionuclides in any metal samples or the wood sample, no positive HTD radionuclides in any sample and only naturally-occurring gamma emitting radionuclides in the concrete.

(RAI Response and actions completed) Given that no activation has been identified in any of the samples noted above, no activation of the secondary side portions of the Steam Generators and Pressurizer shell was expected, and none was discovered. In response to this request, MARAD has developed a work package to draw metallurgical samples, and has assigned the development of the survey plan and evaluation to an independent contractor. The evaluation will be provided to NRC when complete. [In response to this request, MARAD collected metallurgical samples and completed an evaluation CR-176, *Metallurgical Samples Evaluation* [Reference 2-17]. It was submitted to NRC on December 19, 2024 and confirms that the list of Radionuclides of Concern in the License Termination Plan is correct.]

(RAI Response) No additional characterization data was identified that affects radionuclides of concern, insignificant contributors, and/or surrogate ratios.



### 2.3.6 Survey of Exterior Hull in 2019

A MARSSIM-based radiological survey was performed by RSCS on the NSS exterior hull in September and October of 2019 while the ship was on drydock in Philadelphia, PA. The results of this survey are documented in CR-143 [Reference 2-13]. This survey was performed while the ship was on drydock because this was the only time that the exterior hull would be readily accessible to perform these surveys. This survey was performed following the methodology of a FSS, as described in the decommissioning activities guided by MARSSIM.

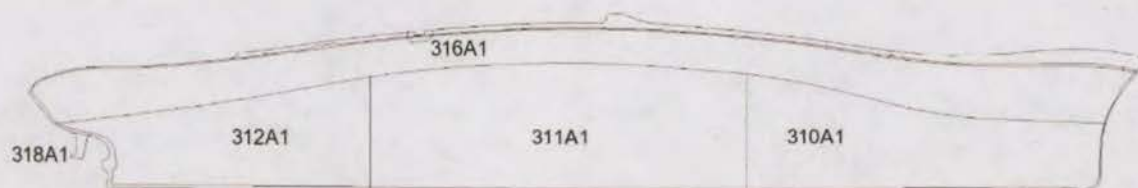
As part of the drydock maintenance activities, the underwater portion of the hull was stripped of paint. These surveys were performed after paint stripping (on the bare hull metal) to document the radiological conditions of the hull structural materials directly where available.

The survey design was a MARSSIM based approach using scans, static measurements, smears, and dose rate measurements in nine identified survey units. *Visual Sample Plan (VSP)* [Reference 2-18] software was used to create maps and to randomly select sample locations within each survey unit.

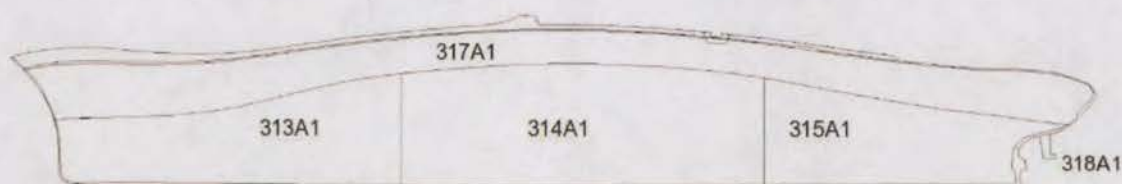
The hull was designated as a MARSSIM Class 3 area. The exterior hull of the ship contained a total of nine (9) survey units. Table 2-21 presents the nine survey units; Figure 2-1 depicts the starboard side and Figure 2-2 the port side.

**Table 2-21      Hull Survey Units**

| <b>FSS Unit Number</b> | <b>MARSSIM Survey Unit Class</b> | <b>Description of Hull Area Surveyed</b> |
|------------------------|----------------------------------|------------------------------------------|
| FSS-310A1              | 3                                | Starboard Fore                           |
| FSS-311A1              | 3                                | Starboard Mid                            |
| FSS-312A1              | 3                                | Starboard Aft                            |
| FSS-313A1              | 3                                | Port Fore                                |
| FSS-314A1              | 3                                | Port Mid                                 |
| FSS-315A1              | 3                                | Port Aft                                 |
| FSS-316A1              | 3                                | Starboard Above Boot Stripe              |
| FSS-317A1              | 3                                | Port Above Boot Stripe                   |
| FSS-318A1              | 3                                | Rudder                                   |



**Figure 2-1 NSS Starboard Survey Units**



**Figure 2-2 NSS Port Survey Units**

The screening DCGL for Co-60 (most restrictive) of 7,100 dpm /100cm<sup>2</sup> for beta (NUREG 1757, Vol 2, MARSSIM, App H, Table H.1) [Reference 2-19] was used for design of these surveys. It should be noted that this value is less than the Co-60 DCGL presented in Chapter 6. Alpha emitting radionuclides were not included in the screening DCGLs based upon the results of the recent characterization of the CV/RC showing no significant alpha were present; therefore, the planned approach did not include the scanning or static measurements for alpha on the hull.

These surveys were designed to collect the specified radiological samples and analysis for these areas (scan, static, smear, dose rate) as laid out in MARSSIM. For Class 3 survey areas, surface scan surveys have judgmental coverage, and given the degree of difficulty to access the survey areas, scan surveys are planned to be performed in the vicinity of the static locations.

The following measurements were performed during this MARSSIM Type Survey:

- 180 beta direct measurements;
- 180 beta removable measurements;
- 180 gamma dose rate measurements; and,
- Beta scan surveys.

Smears were counted at the RSCS laboratory on a low background gas proportional counting system.

Radiological surveys were performed with the following instrumentation:

- Thermo RadEye SX with Ludlum Model 43-89 dual-phosphor scintillation detector (beta scans);
- Thermo RadEye SX with 43-93 dual-phosphor scintillation detector (direct static beta measurements and beta scans); and,
- Bicron MicroRem (dose rate measurements).

The surveys were performed with calibrated instrumentation following the requirements of STS-005-008, *Radiological Instrumentation and Survey Documentation*. Swipes were stored in a safe condition



#### **License Termination Plan – (STS-004-003)**

---

following STS-005-019, *Chain of Custody of Samples*. All survey instruments were properly calibrated, and beta efficiencies were conservatively determined with Tc-99 and gamma efficiencies with Cs-137. Instruments were operationally checked daily.

A MARSSIM survey package was created for each survey unit, which included specific instructions for collection of measurements and data logging, figures with locations, and documentation for recording survey activities/results.

A summary of the survey results is provided in Tables 2-21 and 2-22.

**License Termination Plan – (STS-004-003)**

**Table 2-22 Descriptive Statistics, Beta Static Measurement Data, Background Corrected**

| Beta – $\beta$<br>Statistic        | Survey Unit (FSS) |         |         |         |         |         |         |         |         |
|------------------------------------|-------------------|---------|---------|---------|---------|---------|---------|---------|---------|
|                                    | 310A1             | 311A1   | 312A1   | 313A1   | 314A1   | 315A1   | 316A1   | 317A1   | 318A1   |
| <b>Number of Measurements</b>      | 20                | 20      | 20      | 20      | 20      | 20      | 20      | 20      | 20      |
| <b>Arithmetic Mean</b>             | -402.60           | 3.89    | -22.83  | -26.96  | -280.22 | -351.96 | -146.74 | -90.65  | 30.00   |
| <b>Standard Deviation (sample)</b> | 151.50            | 341.28  | 265.74  | 201.24  | 133.41  | 104.37  | 94.07   | 106.45  | 80.74   |
| <b>Standard Error of the Mean</b>  | 33.88             | 78.29   | 59.42   | 45.00   | 29.83   | 23.34   | 21.03   | 23.80   | 18.05   |
| <b>Coefficient of Variation</b>    | -0.38             | 87.73   | -11.64  | -7.47   | -0.48   | -0.30   | -0.64   | -1.17   | 2.69    |
| <b>Maximum</b>                     | -143.48           | 847.83  | 460.87  | 365.22  | 21.74   | -156.52 | -13.04  | 100.00  | 182.61  |
| <b>Median</b>                      | -432.61           | -139.13 | -143.48 | -19.57  | -297.83 | -323.91 | -134.78 | -86.96  | 34.78   |
| <b>Minimum</b>                     | -665.22           | -460.87 | -291.30 | -452.17 | -439.13 | -560.87 | -343.48 | -321.74 | -121.74 |
| <b>Range</b>                       | 521.74            | 1308.70 | 752.17  | 817.39  | 460.87  | 404.35  | 330.43  | 421.74  | 304.35  |
| <b>UCL95 (median)</b>              | 66.40             | 153.45  | 116.46  | 88.19   | 58.47   | 45.74   | 41.23   | 46.65   | 35.38   |
| <b>LCL95 (median)</b>              | 2.12              | 4.91    | 3.73    | 2.82    | 1.87    | 1.46    | 1.32    | 1.49    | 1.13    |



Table 2-23 NSS Hull MARSSIM Survey Summary

| Survey Unit | Beta Scan Average CPM | Beta Static >7,100 DPM / 100cm <sup>2</sup> | Beta Static Maximum DPM / 100cm <sup>2</sup> | Beta Removable >7,100 DPM / 100cm <sup>2</sup> | Beta Removable Maximum DPM / 100cm <sup>2</sup> | Net Dose Rate Maximum $\mu$ rem/h |
|-------------|-----------------------|---------------------------------------------|----------------------------------------------|------------------------------------------------|-------------------------------------------------|-----------------------------------|
| FSS-310A1   | -34.20                | 0                                           | -143.48                                      | 0                                              | 11.41                                           | 2                                 |
| FSS-311A1   | 27.00                 | 0                                           | 847.43                                       | 0                                              | 14.97                                           | 5                                 |
| FSS-312A1   | 19.80                 | 0                                           | 460.87                                       | 0                                              | 11.41                                           | 2                                 |
| FSS-313A1   | 12.42                 | 0                                           | 365.22                                       | 0                                              | 14.97                                           | 2                                 |
| FSS-314A1   | 7.80                  | 0                                           | 21.74                                        | 0                                              | 11.41                                           | 3                                 |
| FSS-315A1   | -3.18                 | 0                                           | -156.52                                      | 0                                              | 14.97                                           | 3                                 |
| FSS-316A1   | 1.06                  | 0                                           | 26.09                                        | 0                                              | 11.41                                           | 1                                 |
| FSS-317A1   | 5.70                  | 0                                           | 100.00                                       | 0                                              | 14.97                                           | 1                                 |
| FSS-318A1   | 10.20                 | 0                                           | 182.60                                       | 0                                              | 14.97                                           | 1                                 |

The MARSSIM survey of the exterior hull demonstrates that:

- No unexpected results or trends are evident in the data;
- The sampling and survey results demonstrate that residual radioactivity in the survey areas are indistinguishable from background levels;
- The data quality meets the necessary requirements and is deemed to be acceptable for its intended purpose;
- The amount of data collected from each survey unit is adequate to provide the required statistical confidence needed to decide that the DCGLs are met; and,
- All measurements were below the screening DCGL.

### 2.3.7 Sampling NST lead (Pb) in 2021

In October 2021, preparations were made for removal and release of the NST lead shielding. Lead samples were collected by drilling six ¼ inch diameter holes into the lead shielding at approximately 60 degree intervals. These holes were drilled below the shield tank cooling coils in the region of the highest neutron flux. Figure 2-3 shows the active core region by the black rectangle in the center of the figure. Two samples were collected at each location, an inner and outer sample. The purpose of the sampling was to verify whether any neutron activation occurred in the lead. In accordance with the DQAP and the RPP, samples were sent to GEL for gamma spectrometry and analysis of Hard-to-Detect radionuclides. Only one sample had a positive result at 0.15 pCi/g Cs-137. This result was attributed to cross contamination. The laboratory results are described in CR-144 [Reference 2-14].

(RAI Response) The purpose of the NST lead sampling in 2021 was to verify whether any neutron activation occurred in the lead to support the potential release of the material.

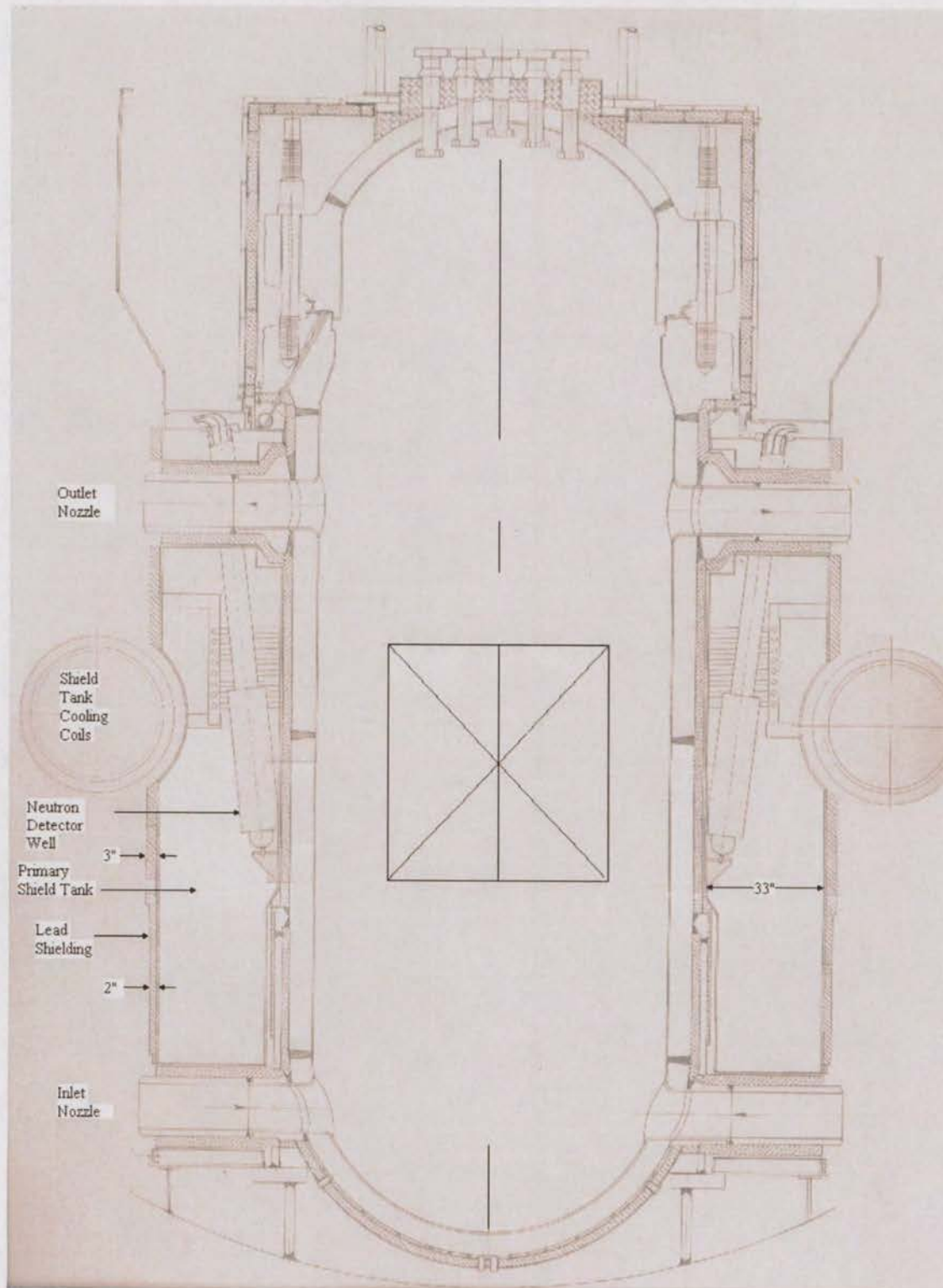


Figure 2-3 Neutron Shield Tank



### 2.3.8 Engine Room Survey in 2022

In November 2021, MARAD determined that a more detailed in-depth survey of the secondary systems contained in the engine room would be prudent to support license termination planning, especially with respect to the shipbreaking end state condition. The effort included removal of asbestos-containing insulation materials as a prerequisite activity. With the ACM removed, a survey package was developed and executed in 2022.

The survey package identified eighteen (18) survey points of the internal surfaces of the Engine Room steam, condensate, and feedwater system components for measurements. For all but one survey point, either two (2) or four (4) locations for measurements were specified; for survey point, number eighteen (18), eight (8) locations for measurements were specified. The technicians were required to collect a three (3) minute Total Surface Activity (TSA) measurement at the survey location with a Ludlum model 43-93 detector, collect a 100 cm<sup>2</sup> smear at the TSA location and perform a beta scan survey of 100% of the accessible system internals. The technicians were also required to collect a three (3) minute local area instrument background (beta and alpha) with the model 43-93 detector at or in the general area of the survey location. The Minimum Detectable Concentrations (MDCs) ranged from 311 to 377 dpm/100 cm<sup>2</sup>. Six smears were sent offsite for gamma isotopic analysis. Only one smear had positive Co-60 activity of 23 dpm/filter. This smear was from the Main Steam Moisture Separator. Based upon this analysis, the Main Steam system has been classified as Impacted.

## 2.4 Initial Classifications

The initial classifications were obtained from the preliminary classifications presented in the HSA. Those preliminary classifications were based upon the screening values for residual surface radioactivity for building surfaces presented in NUREG-1757, Volume 2, Table H-1. During development of the LTP, MARAD completed reviews of 1) radiological survey data (routine and non-routine) over the ship's operating history since 2008 and 2) the 2018 and 2019 characterization survey results compiled for the decommissioning.

### 2.4.1 Systems

During development of the LTP, an extensive review of systems was conducted by MARAD to determine those systems that contain radioactive materials or in which radioactive material was detected at some time during the operating history of the plant. Table 2-24 provides a listing of plant systems and their status relative to the potential for radioactivity. The assessment considers the internal portions of the systems. Systems that might be assessed as non-impacted and are located in contaminated areas may themselves be externally contaminated and may be considered for remediation or disposal as radioactive waste.

As described in Section 3.1.1 of this LTP, several components of the nuclear power plant are planned for retention, subject to confirmation before license termination. See Sections 3.1.1, and 5.9.2 through 5.9.5 for additional information.

**Table 2-24 Initial Classification of Systems**

| <b>Survey Unit</b> | <b>System Name</b>                                                                                                                                                                            | <b>Status</b> |
|--------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|
| SYS-101            | Reactor Space Ventilation System (RSV)                                                                                                                                                        | Impacted      |
| SYS-102            | Emergency Cooling System (DK)                                                                                                                                                                 | Impacted      |
| SYS-103            | Soluble Poison Shutdown System (SP)                                                                                                                                                           | Impacted      |
| SYS-104            | Primary Loop Purification System (PP)                                                                                                                                                         | Impacted      |
| SYS-105            | Buffer Seal System (SL)                                                                                                                                                                       | Impacted      |
| SYS-106            | Hydrogen Addition System (HA)                                                                                                                                                                 | Impacted      |
| SYS-107            | Primary Relief System (PR)                                                                                                                                                                    | Impacted      |
| SYS-108            | Primary Sampling System (SA)                                                                                                                                                                  | Impacted      |
| SYS-109            | Intermediate Cooling System (CW)                                                                                                                                                              | Impacted      |
| SYS-110            | Containment Cooling System (CC)                                                                                                                                                               | Impacted      |
| SYS-111            | Shutdown Circulation (SC)                                                                                                                                                                     | Impacted      |
| SYS-112            | Primary Pressurizer System (PE) including retained portions of the pressurizer                                                                                                                | Impacted      |
| SYS-113            | Radioactive Waste and Dilution System (WD)                                                                                                                                                    | Impacted      |
| SYS-114            | Equipment Drain and Waste Collection System (PD)<br>The remaining components are the Fresh Water Shield Tank, PD-T6 Contaminated Water Tank Port, and PD-T5 Contaminated Water Tank Starboard | Impacted      |
| SYS-115            | Gaseous Waste Collection and Disposal System (WL)                                                                                                                                             | Impacted      |
| SYS-116            | Main Steam System including retained portions of the Steam Generators                                                                                                                         | Impacted      |
| SYS-117            | Neutron Shield Tank and Fuel Transfer Tank (retained walls)                                                                                                                                   | Impacted      |
| SYS-401            | Ships Ventilation System                                                                                                                                                                      | Non-impacted  |
| SYS-402            | Service Water System                                                                                                                                                                          | Non-impacted  |
| SYS-403            | Potable Water System                                                                                                                                                                          | Non-impacted  |
| SYS-404            | Service Air System                                                                                                                                                                            | Non-impacted  |
| SYS-405            | Lubrication Oil System                                                                                                                                                                        | Non-impacted  |
| SYS-406            | Auxiliary Steam System                                                                                                                                                                        | Non-impacted  |
| SYS-407            | Main Condensate and Feedwater System                                                                                                                                                          | Non-impacted  |



## 2.4.2 Structures

Classification is the process by which an area or survey unit is described according to its radiological characteristics. The significance of classification is that this process determines the FSS survey design and the procedures used to develop this design. In classifying areas, those that have no reasonable potential for residual contamination are classified as non-impacted areas. These areas have no radiological impact from site operations and are typically identified early in decommissioning. Areas with some potential for residual contamination are classified as impacted areas. Impacted areas are further divided into one of three classifications as defined by MARSSIM:

- Class 1 areas: Areas that have, or had prior to remediation, a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radiological surveys) above the DCGL. Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions, 2) locations where leaks or unplanned releases are known to have occurred, 3) waste storage sites, and 4) areas with contaminants in discrete solid pieces of material with high specific activity. Note that areas containing contamination in excess of the DCGL prior to remediation would generally be classified as Class 1 areas unless ample evidence exists to show that a lower classification is justified;
- Class 2 areas: These areas have, or had prior to remediation, a potential for radioactive contamination or known contamination, but are not expected to exceed the DCGL. To justify changing the classification from Class 1 to Class 2, there should be measurement data that provides a high degree of confidence that no individual measurement would exceed the DCGL<sub>w</sub>. Other justifications for reclassifying an area as Class 2 may be appropriate based on sites-specific considerations. Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive materials were present in an unsealed form (e.g., process facilities), 2) potentially contaminated transport routes, 3) areas downwind from stack release points, 4) upper bulkheads and overheads of some buildings or rooms subjected to airborne radioactivity, 5) areas where low concentrations of radioactive materials were handled, and 6) areas on the perimeter of former contamination control areas; and,
- Class 3 areas: Any impacted areas that are not expected to contain any residual radioactivity or are expected to contain levels of residual radioactivity at a small fraction of the DCGL, based on site operating history and previous radiological surveys. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a non-impacted classification.

Class 1 areas have the greatest potential for contamination and therefore receive the highest degree of survey effort for the final status survey, followed by Class 2 areas, and then by Class 3 areas. Non-impacted areas do not require any level of survey coverage because they have no potential for residual contamination. As a survey progresses, reevaluation of classifications may be necessary based on newly acquired survey data. The FSS plan includes a process by which measurements that approach pre-defined action levels (fractions of the DCGLs) are investigated to see if reclassification of an area(s) is necessary.

The initial classifications were obtained from the preliminary classifications presented in the HSA. Those preliminary classifications were based upon the screening values for residual surface radioactivity for building surfaces presented in NUREG-1757, Volume 2, Table H-1. During development of the LTP, MARAD completed reviews of 1) radiological survey data (routine and non-routine) over the ship's operating history since 2008 and 2) the 2018 and 2019 characterization survey results compiled for the decommissioning. The 2018 and 2019 radiological characterization survey data in particular represents a substantial volume of information.

### License Termination Plan – (STS-004-003)

---

The survey results will be notated in the FSS packages with the survey unit number shown in Table 2-25. The preliminary survey unit numbers assigned in the 2018 characterization effort will not be used (i.e., the numbers in Tables 2-10 and 2-11).

Based upon the nature and extent of contamination detected and the areas to be surveyed, some of the survey unit decks and bulkheads below 2 meters high will be treated as either a Class 1 or Class 2 survey unit. Depending on the area, the bulkhead above 2 meters and the overhead will be treated as either a Class 2 or Class 3 survey unit.

(RAI Response) The information provided in Table 2-8 was based on area designations shown in the STS-198 *Characterization Plan 2018* [Reference 2-15]. A characterization survey outside of the CV and RC was planned and executed in 2018 and documented in CR-104 [Reference 2-4]. Since 2018, some of the areas have been consolidated and others have been renamed to more familiar descriptions. For instance, the NEWS Room bulk inventory is now identified as the Electronic Work Shop and Bulk Stores Rooms in LTP Table 2-25 as STR-312. The Hold Deck is located directly below the Horseshoe area and was separated from each other for the characterization effort. They will be surveyed as one unit during the FSS as STR-208. The CRDM pump room is located on the B Deck and is identified as the Hydraulic Equipment Room in STR-310. One structural survey unit in the RC was not included in Table 2-25. It is designated as STR-211 Reactor Compartment – Mid-Level 14ft Flat. One structure in the CV was not included in Table 2-25. It is designated as STR-111 Cupola Inner Wall. The updated LTP Table 2-25 is presented on the next page. Underlined text indicates the added text; there are no deletions.



**License Termination Plan – (STS-004-003)**

**Table 2-25 Initial Classification of Structures or Rooms**

| <b>Survey Unit #</b> | <b>Survey Unit Description</b>                                                                          | <b>Deck or Elevation</b> | <b>Initial Classification</b> |
|----------------------|---------------------------------------------------------------------------------------------------------|--------------------------|-------------------------------|
| STR-101              | Containment Vessel (CV) – 1st Level (Tanktop)                                                           | 5'                       | 1                             |
| STR-102              | Containment Vessel (CV) – 2nd Level (Flat)                                                              | 14'                      | 1                             |
| STR-103              | Containment Vessel (CV) – 3rd Level (D Deck)                                                            | 23'                      | 1                             |
| STR-104              | Containment Vessel (CV) – 4th Level (C Deck)                                                            | 32'                      | 1                             |
| STR-105              | Reactor Compartment – Lower Level                                                                       | 5' – 23'                 | 1                             |
| STR-106              | Port Stabilizer Room and Port Booster Pump Room                                                         | Hold                     | 1                             |
| STR-107              | Port Charging Pump Room                                                                                 | Hold                     | 1                             |
| STR-108              | Starboard Charging Pump Room                                                                            | Hold                     | 1                             |
| STR-109              | Auxiliary Access Trunk, C-Deck the Cold Water Chemistry Lab (Port) and Radiation Monitoring Room (Stbd) | A - C                    | 1                             |
| STR-110              | Gas Absorption Equipment Room/ Radiation Sampling Room                                                  | D                        | 1                             |
| STR-111              | Cupola Inner Wall                                                                                       | A - B                    | 1                             |
| STR-201              | Reactor Compartment – Mid Level D Deck                                                                  | 23'                      | 2                             |
| STR-202              | Reactor Compartment – Mid Level C Deck                                                                  | 32'                      | 2                             |
| STR-203              | Reactor Compartment – Upper Level B Deck                                                                | 41'                      | 2                             |
| STR-204              | Reactor Compartment – Upper Level A Deck                                                                | 50'                      | 2                             |
| STR-205              | Starboard Stabilizer Room                                                                               | Hold                     | 2                             |
| STR-206              | Engine Room Machinery Space                                                                             | Hold – Boat Deck         | 2                             |
| STR-207              | Health Physics Lab                                                                                      | A                        | 2                             |
| STR-208              | Horseshoe area <u>and Hold Deck</u>                                                                     | Hold                     | 2                             |
| STR-209              | Hot Chemistry Lab                                                                                       | D                        | 2                             |
| STR-210              | Hold No. 4                                                                                              | Tanktop - D              | 2                             |
| STR-211              | Reactor Compartment – Mid-Level 14ft Flat                                                               | 14'                      | 2                             |

**License Termination Plan – (STS-004-003)**

**Table 2-25 Initial Classification of Structures or Rooms (continued)**

| <b>Survey Unit #</b> | <b>Survey Area Description</b>                                                                                                                                                                                                                                                       | <b>Deck or Elevation</b> | <b>Initial Classification</b> |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|-------------------------------|
| STR-301              | Navigation Bridge Deck: interior surfaces Pilot House, Gyro. Room, Emergency Generator Room, Fan Rooms, Battery Rooms, Chart and Radio Rooms, Stairwells (ladders) down to Boat Deck                                                                                                 | Navigation Bridge        | 3                             |
| STR-302              | Navigation Bridge Deck: exterior surfaces, top of the house and radar mast                                                                                                                                                                                                           | Navigation Bridge        | 3                             |
| STR-303              | Boat Deck: interior surfaces Officers P/S Rooms, Officers Lounge, Fan Room, Passageways, Capt.'s Stateroom and Day Room, Chief Eng.'s Stateroom and Day Room, Stairwells (ladders) going down to Promenade Deck                                                                      | Boat                     | 3                             |
| STR-304              | Boat Deck: exterior surfaces                                                                                                                                                                                                                                                         | Boat                     | 3                             |
| STR-305              | Promenade Deck: interior surfaces of Main Lounge, Veranda, Pantry, Novelty Shop, Men's Room, Powder Room, Card Room, Writing/Library Room, Projection Booth, Stairwells (ladders) going down to A Deck                                                                               | Promenade                | 3                             |
| STR-306              | Promenade Deck: exterior surfaces                                                                                                                                                                                                                                                    | Promenade                | 3                             |
| STR-307              | A Deck: interior surfaces of Passengers Staterooms, Crew Spaces, Barber Shop, Hospital Spaces, Main Lobby, Pantry, Fan Rooms, Hydrogen Room, Passageways, Stairwell (ladders) going down to B Deck (See footnote at end of table.)                                                   | A                        | 3                             |
| STR-308              | A Deck Forward exterior surfaces forward of Frame 99 including Mast Houses, Masts, Deck Machinery and Cargo Gear.                                                                                                                                                                    | A                        | 3                             |
| STR-309              | A Deck Aft exterior surfaces aft of Frame 168: including Docking Bridge, Masts, Deck Machinery and Cargo Gear.                                                                                                                                                                       | A                        | 3                             |
| STR-310              | B Deck: interior surfaces of Crew Staterooms, Main Galley, Dining Room, Crew's Mess, Officers Mess, Officers Pantry, Crew Lounges, Crew's Pantry, Scullery, <u>Hydraulic Equipment Room</u> , Passageways, Stairwells (ladders) going down to C Deck (See footnote at end of table.) | B                        | 3                             |



**License Termination Plan – (STS-004-003)**

**Table 2-25 Initial Classification of Structures or Rooms (continued)**

| <b>Survey Unit #</b>        | <b>Survey Area Description</b>                                                                                                                                                                                                                                                                                                                                                                                                                                     | <b>Deck or Elevation</b> | <b>Initial Classification</b> |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|-------------------------------|
| STR-311                     | C Deck: interior surfaces of Main Laundry, Soiled Linen Room, Clean Linen Room, Food Freezers and Refrigerators, Butcher Shop, Crew Staterooms and Bathrooms, Respiratory Equipment Rooms, Viewing Gallery Area, Garbage Room, Nuclear Battery Room, Mechanical Space, Stewards Stores, Engine Room Stores, CO2 Room, Music Entertainment Equipment Room, Electric Work Shop, Carpenter Shop, Passageways (all), Stairwells (ladders) down to D Deck <sup>10</sup> | C                        | 3                             |
| STR-312                     | D Deck: Electronics Work Shop, Bulk Stores Rooms, Special Store Rooms #1, 2, and 3, Food Freezers and Refrigerators, Machinery Space Equipment Room, Workshop Room, Engineering Stores Room, Spare Parts Storeroom, Passageways (all) (See footnote 10)                                                                                                                                                                                                            | D                        | 3                             |
| STR-313                     | Refrigerator rooms - Vegetables and Dairy (Port and Starboard), Passageways and Stairwells (ladders) going down to Horseshoe area and up to D-deck                                                                                                                                                                                                                                                                                                                 | 14 foot flat             | 3                             |
| STR-314                     | Dry Stores (port) and Steward (starboard) outboard of horseshoe area                                                                                                                                                                                                                                                                                                                                                                                               | Tanktop                  | 3                             |
| STR-315                     | Cargo Hold No. 3                                                                                                                                                                                                                                                                                                                                                                                                                                                   | C Deck                   | 3                             |
| STR-316                     | Cargo Hold No. 4                                                                                                                                                                                                                                                                                                                                                                                                                                                   | C Deck                   | 3                             |
| STR-317                     | Elevators and Elevator Shafts                                                                                                                                                                                                                                                                                                                                                                                                                                      | All Decks                | 3                             |
| FSS-310A1 through FSS-318A1 | Exterior surfaces of the Hull                                                                                                                                                                                                                                                                                                                                                                                                                                      | All                      | 3                             |
| STR-401                     | Port, Starboard, Fore Peak, and Aft Ballast Tanks                                                                                                                                                                                                                                                                                                                                                                                                                  |                          | Non-impacted                  |
| STR-402                     | Shaft Alley and Shaft Alley Recess                                                                                                                                                                                                                                                                                                                                                                                                                                 |                          | Non-impacted                  |
| STR-403                     | Cargo Holds 1 and 2                                                                                                                                                                                                                                                                                                                                                                                                                                                | All levels               | Non-impacted                  |
| STR-404                     | Cargo Holds 5 through 7 (See footnote at end of table.)                                                                                                                                                                                                                                                                                                                                                                                                            | All levels               | Non-impacted                  |
| STR-405                     | Chain Locker and Windless Equipment Room                                                                                                                                                                                                                                                                                                                                                                                                                           | All levels               | Non-impacted                  |
| STR-406                     | Steering Gear Room, Paint Locker, Bos'n Storerooms                                                                                                                                                                                                                                                                                                                                                                                                                 | All levels               | Non-impacted                  |

<sup>10</sup> These spaces have been converted to other uses since the Possession-only License - such as meeting rooms, office space, records storage, etc.

## 2.5 References

- 2-1 Regulatory Guide 1.179, *Standard Format and Contents for License Termination Plans for Nuclear Power Reactors*, Rev. 2, July 2019
- 2-2 NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, Rev. 2, April 2018
- 2-3 CR-003, *Historical Site Assessment*, Revision 1, August 2023
- 2-4 CR-104, *Radiological Characterization (Outside of Reactor Compartment and Containment Vessel)*, Revision 1, March 2019
- 2-5 CR-109, *Radiological Characterization - Reactor Compartment and Containment Vessel*, Revision 1, February 2020
- 2-6 *Updated Final Safety Analysis Report*, STS-004-002, Revision 13, July 20, 2023
- 2-7 NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*, Revision 1, August 2000
- 2-8 STS-100, *Post Shutdown Decommissioning Activities Report*, Revision 1, December 11, 2008
- 2-9 CR-142, *Reactor Vessel, Internals and Neutron Shield Tank Characterization and Classification Assessment*, April 3, 2004
- 2-10 CR-038, *Radiological and Non-Radiological Spaces Characterization Survey Report*, Revision 1, February 2, 2006
- 2-11 CR-056, *Reactor Pressure Vessel Drilling, Sampling and Radiochemical Analysis Project Report*, Revision 1, January 31, 2006
- 2-12 Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated October 3, 2008, - *Submittal of Finding of No Significant Impact and Environmental Assessment* (ML082810182)
- 2-13 CR-143, *MARSSIM Survey of the Exterior Hull*, December 2020
- 2-14 CR-144, *Primary Shield Water Tank Lead Sample Results*, April 2022
- 2-15 STS-198, *Characterization Plan 2018*, Revision 0, May 1, 2018
- 2-16 NUREG/CR-5512, Vol. 3, *Residual Radioactive Contamination from Decommissioning – Parameter Analysis*, October 1999
- 2-17 CR-176, *Metallurgical Samples Evaluation*, July 2024
- 2-18 *Visual Sample Plan*, Pacific Northwest National Lab, USDOE
- 2-19 NUREG-1757, Vol 2, Rev 2, *Consolidated Decommissioning Guidance, Characterization, Survey, and Determination of Radiological Criteria*, July 2022



### 3 IDENTIFICATION of REMAINING SITE DISMANTLEMENT ACTIVITIES

#### 3.1 Introduction

In accordance with the underlying intent of 10 CFR 50.82(a)(9)(ii)(B), the guidance of *Regulatory Guide 1.179, Standard Format and Content for License Termination Plans for Nuclear Power Reactors* [Reference 3-1] and the guidance in NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, [Reference 3-2], the purpose of this chapter is to provide a summary of remaining site dismantlement, decontamination activities, and related decommissioning activities at the time the LTP is submitted.

The information includes those areas and equipment that need further remediation and an assessment of the potential radiological conditions that may be encountered. Estimates of the occupational radiation dose and the quantity of radioactive material to be released to unrestricted areas during the completion of the scheduled tasks are provided. The projected volumes of radioactive waste that will be generated are also included. These activities will be undertaken pursuant to the current 10 CFR Part 50 license, are consistent with the *Post Shutdown Decommissioning Activities Report* (PSDAR) [Reference 3-3] and do not depend upon LTP approval to proceed.

Reference 3-2 further requires identification of any decommissioning tasks that require coordination with other Federal or State regulatory agencies and an explanation of how that coordination will occur. It also requires a list of the remaining activities that do not involve unreviewed safety questions or changes in a facility's technical specifications.

##### 3.1.1 Dismantlement Scope and Planned Final Ship Configuration

The scope of dismantlement described in the PSDAR is based on several fundamental assumptions, which are supported by the initial characterization efforts described in Chapter 2. Among the assumptions are:

- a) The ship itself is not dismantled as part of DECON;
- b) Existing accesses are utilized to support dismantlement of systems and components;<sup>11</sup> and,
- c) Major structures will not be dismantled.

These assumptions are based, in part, on National Historic Preservation Act (NHPA) requirements and satisfactory Final Status Surveys (FSSs). Among the initial structures planned to be retained are the Containment Vessel (CV) and its foundation, and the Secondary Shield described in Chapter 5 of the *Updated Final Safety Analysis Report* (UFSAR) [Reference 3-4]. Primary ship structures will be decontaminated and remediated to the extent necessary to meet the license termination criteria.

These include the decks and bulkheads which form the boundaries of radiologically controlled areas,

---

<sup>11</sup> In practice, two additional accesses were created and support dismantlement activities. These are the CV horizontal portal installed in 2018, and the roughly 6' x 8' opening between Cargo Hold 4 and the RCLL installed in 2021. The CV portal was intended primarily for personnel access and egress but has also been used for material handling. The reverse is true for the CH 4 – RCLL access. Both accesses will remain in place after LT.



and the contaminated liquid storage tanks<sup>12</sup> that are integral to the ship's double bottom hull structure.

Major dismantlement was focused on the removal and disposal of systems and components as described in Section 3.3 of the PSDAR. Characterization efforts, after submittal of the PSDAR, refined the plan outlined in the PSDAR and supported detailed dismantlement planning. The initial scope of dismantlement involved systems and components described in the UFSAR [Reference 3-4]. The initial scope included the following: a) Reactor Plant Auxiliary Systems described in Chapter 9, b) the Primary Coolant Systems and Components described in Chapter 7, and c) the Reactor Compartment cooling and exhaust systems described in Chapter 3. Components of the reactor core described in Chapter 6 that are within the Reactor Pressure Vessel were removed with the RPV itself.<sup>13</sup> The Power Conversion Systems described in Chapter 8 are excluded from the scope of dismantlement. Temporary systems, such as the contaminated liquid transfer and collection system (see 3.1.2), will be dismantled when no longer required. They will be disposed as Low Level Radioactive Waste (LLRW).

After the 2019-2020 characterization was complete, MARAD modified the dismantlement scope and specified the secondary side elements of the port and starboard steam generators for retention. The primary coolant tubes and tube sheets in the heat exchangers were removed, packaged, and disposed in 2022. The heat exchanger shells were decontaminated and remediated as required to meet the license termination criteria.

Towards the end of CY 2021, a major change in the industrial approach towards removal of the RPV was accepted by MARAD. In this approach, the common outer circumferential wall of the Neutron Shield Tank (NST) / Fuel Transfer Tank (FTT), including the exterior lead shielding surrounding the NST, was designated for retention. Two diametrically opposed access openings were created in the NST a) to permit cutting operations to free the RPV from its supports and b) to disconnect the inner and outer walls of the NST/FTT. The RPV, with the inner NST/FTT circumferential wall attached, was lifted clear of the remaining tank structure in November 2022. The change in approach was accepted after activation analyses and surveys of the exterior wall and lead shielding was performed, as described in Section 2.3.7. The primary purpose for the change was to significantly improve occupational safety by eliminating the hand-removal of the lead shielding. Subject to confirmation during FSS, MARAD expects the structure to meet the license termination criteria, and to be retained in-situ.

Finally, another change was made during CY 2022 related to the Pressurizer. Initially, the Pressurizer was to be removed intact as a heavy lift. Retaining the NST/FTT outer wall created clearance problems within the CV, such that intact removal of the Pressurizer was no longer considered practical. Instead, a large access was cut into one side of it, so that its internals could be removed. Initial decontamination using laser ablation significantly reduced interior contamination. Further remediation was performed by grinding the inner stainless-steel cladding. The lower hemispherical section of the Pressurizer containing heater penetrations could not be decontaminated

---

<sup>12</sup> This includes the Fresh Water Shield Tank (FWST). The FWST - a component of the Clean Ballast System and not the Equipment Drain and Waste System - was used to store primary coolant when the plant was mothballed in 1975-76. Consequently, the FWST contained contaminated liquid, and is subject to remediation and survey.

<sup>13</sup> In practice, because the RPV Head was removed and shipped as a component, the internal Belleville Spring and Upper Flow Baffle were removed and shipped separately because they protruded above the RPV flange. The flange surface was mated to a new combined lifting and cover plate; therefore, the two internals were removed as interferences.



and was disposed as LLRW. If decontamination and remediation efforts are confirmed during FSS, the remaining portions of the Pressurizer shell will be retained in-situ.

At the end of the project, the final configuration of the ship's former RCAs is expected to be as follows:

- All RCAs (including LLRW storerooms, the material handling area in Cargo Hold 4, and controlled areas in Cargo Hold 3) will be de-posted and removed from radiological controls as part of the License Termination process. The end-state configuration of these spaces will be unrestricted release from radiological controls.
- The CV and Secondary Shielding will be intact and retained in-situ. The CV Cupola Head and Shield Ring will be reinstalled. Access (gratings, platforms and ladders) and lighting within the CV will be restored.
- The Reactor Compartment Hatch will be closed, and its rigging system will be removed and stowed in Cargo Hold 1. Once complete, the hatch will be inoperative without the use of an exterior crane.
- The DHVAC system described in Chapter 3 of Reference 3-4 will be decontaminated to the extent necessary and retained in operating condition.

(RAI Response) LTP Section 3.1.1 discusses, in part, the distinction between structures and components, and specifically includes two contaminated waste tanks (PD-T5 and PD-T6) which are part of the PD system, as structures, because they are integral to the ship's double bottom hull structure. These contribute as structures in the dose model. LTP footnote 12 adds the Fresh Water Shield Tank (FWST), also an integral double bottom tank, as part of a system. Similar to these, the Soluble Poison Tank is integral to ship structure even though it is classified as a system component. During operations, the Reactor Space Void Tank contained saltwater ballast. It is not a Reactor Auxiliary System component, but it has been impacted by in-leakage of stored primary coolant from the FWST. The sixth system tank is the surge tank of the Intermediate Cooling Water system. These six tanks are described above in Table 8-1. The retained steam generators, pressurizer shell, and neutron shield tank are all system components. The Containment Vessel is considered a structure.

(RAI Response) The DCGLs provided in Chapter 6 of the LTP apply equally to structures and components (also systems and portions of systems) since the dose model used to develop the DCGLs simply applies a conservative value to the time spent working with material containing residual radioactivity and considers the combination of all exposure pathways and selects the lowest DCGL (highest dose) from each of the pathways and radionuclides of concern (ROCs). Therefore, the distinction between structure or components will have no impact on the selection or application of the DCGLs for final status surveys.

### 3.1.2 Completed Dismantlement Activities

Major dismantlement activities were completed in the first half of CY 2023. Previously completed dismantlement activities have been summarized in each calendar year annual report since dismantlement was authorized by License Amendment 15 in 2018. During the project's first phase, reactor auxiliary systems and components in RCAs outside the reactor compartment were

dismantled. The resultant LLRW was stored onboard the ship in areas designated for the purpose. That waste was designated as legacy waste for disposal during Phase II. It was disposed of in 2022.

Dismantlement activities during Phase II of the DECON-LT project focused on the three major spaces within the Reactor Compartment.<sup>14</sup> Minor component, small bore piping, electrical cabling, ventilation ductwork, and interference removals began in September 2021. Also, during 2021, a contaminated liquid transfer system, including a storage bladder, was installed and tested. During 2022, major component removals were completed, including the CRDM tower, port and starboard Steam Generator tubes and tube sheets, the RPV Head, two RPV internal components, and the RPV itself. During 2023, the lower section of the Pressurizer was removed and shipped as LLRW. During 2022 and 2023, reactor auxiliary system components, contaminated liquids and mixed waste were disposed.

During dismantlement and decontamination operations, MARAD concluded that there was potential preservation value to retaining the aft Reactor Coolant System (RCS) piping, and deferred shipping of this waste material until sampling and analysis was completed with a view towards decontamination of the pipe segments to levels below the DCGLs. The aft RCS piping segments were moved to a temporary RMA created in Cargo Hold 3 pending evaluation. Metallurgical samples were shipped in the third quarter of 2023. At the time of LTP submittal, MARAD has not yet decided the fate of the pipe segments. If disposed, these segments will be among the last LLRW shipments.

All dismantlement was essentially complete at the time of LTP submittal.

### 3.1.3 Coordination of Activities and Unreviewed Safety Questions

There are no remaining decommissioning activities which require specific coordination with other Federal or State agencies. MARAD has coordinated prior completed activities with such agencies, including the transit of the RPV through the Howard Street Tunnel beneath Baltimore City. MARAD maintains contacts with Federal, State, and local Baltimore City agencies as a matter of routine. Periodic updates will be provided as the project progresses to license termination.

Decommissioning activities at NSS will continue to be conducted in accordance with the requirements of 10 CFR 50.82(a)(6) and (a)(7). At the time of LTP submittal, the remaining activities do not involve any unreviewed safety questions or changes in the Technical Specifications. If an activity requires prior NRC approval under 10 CFR 50.59, or a change to the technical specifications or license, a License Amendment Request will be made to the NRC for review and approval before implementing the activity in question.

### 3.1.4 Proposed Methods to Prevent Recontamination

The methods to prevent recontamination (i.e., isolation and control) are described in Section 5.4.4.

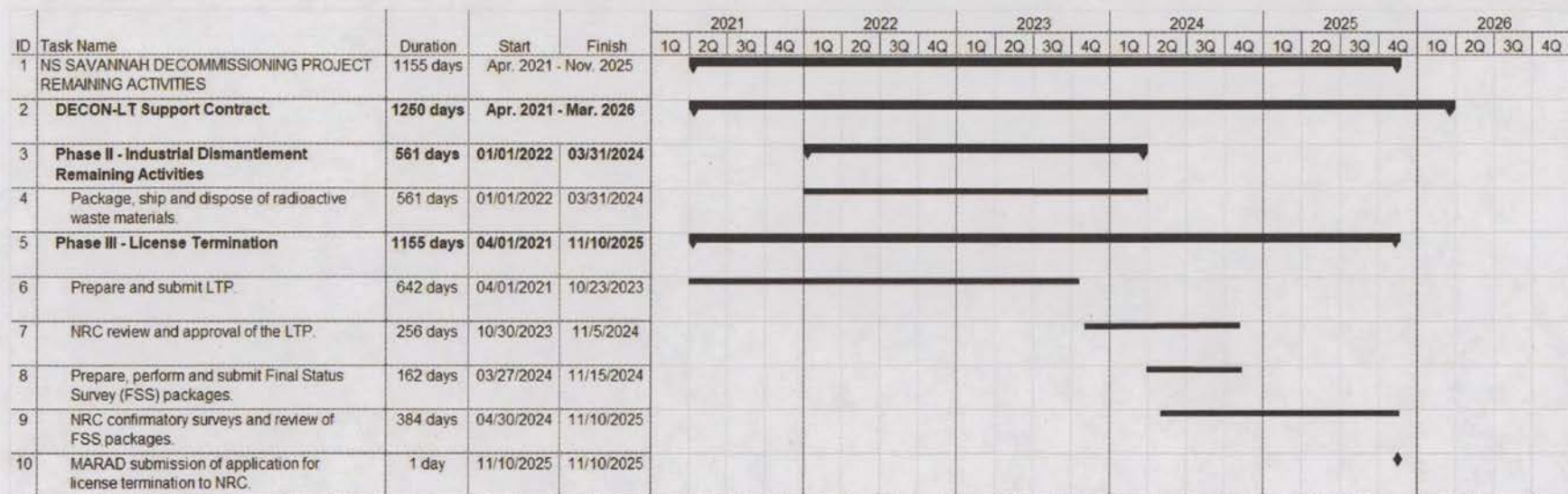
Figure 3-1 presents the current schedule for completing the remaining License Termination activities.

---

<sup>14</sup> The three spaces are the Containment Vessel, and the Reactor Compartment Upper and Lower Levels that surround the CV.



### License Termination Plan – (STS-004-003)



**Figure 3-1 Remaining License Termination Activities**

### **3.2 Remaining Activities**

At the time of LTP submittal, all dismantlement was essentially complete. Shipment of LLRW will continue until complete.

Decontamination and remediation of structures will be ongoing and will include those structures listed in Section 3.1.1. These activities will continue, as required, during the FSS period. As described in Section 3.1.1, certain structures (NST/FTT outer wall and lead shielding, Pressurizer shell; CV shell; and CV upper hemisphere secondary shielding) are planned for retention subject to confirmation that they meet the license termination criteria. If these structures fail to meet the criteria of the approved LTP, they will be dismantled and shipped as LLRW. This would require a period of remobilization by MARAD's decommissioning contractor; consequently, no changes to the current RCA boundaries for personnel entry and exit, monitoring stations, dosimetry issue and material handling arrangements will be made until the status of the retained structures and components is confirmed by NRC. If required, a revision to the LTP will be submitted by MARAD.

### **3.3 Waste Projections**

Table 3-1 provides a summary of remaining waste quantities. Table 3-2 provides a summary of the waste shipments through August 31, 2023. MARAD decided not to process waste onsite or to attempt to segregate waste streams. The total volume of low-level radioactive waste for disposal was originally estimated at 22,844 cubic feet. The solid waste was and future solid waste will be shipped to the licensed EnergySolutions radioactive waste disposal facility (ES) in Clive, Utah. Liquid waste and future liquid waste will be shipped to ES, Erwin, TN.

**Table 3-1 Projected Remaining Waste Quantities as of September 30, 2023**

| <b>Waste Type</b>                           | <b>Waste Class</b> | <b>Waste Volume (ft<sup>3</sup>)</b> |
|---------------------------------------------|--------------------|--------------------------------------|
| LLRW – metal 2 IMs standard size components | A                  | 2025                                 |
| Chromate/Lead Trash (bags)                  | Mixed              | 260                                  |
| Dry Active Waste / Metal (bags)             | A                  | 25                                   |
| 5 Drums 250 gallons of water                | Mixed              | 34                                   |
| Radium 226 Sources (steering gear)          | A                  | 1.00                                 |
| 1 Drum 4 gallons of oil                     | Mixed              | 0.53                                 |
| <b>Totals</b>                               |                    | <b>2345.53</b>                       |



**License Termination Plan – (STS-004-003)**

**Table 3-2 Summary of Waste Disposed from Ship through September 30, 2023**

| <b>Container</b>           | <b>Unit Quantity</b> | <b>Liquid Content</b> | <b>Solid Content</b>                            | <b>Total Volume</b>             | <b>Generated</b> | <b>Hazard Classification</b> |
|----------------------------|----------------------|-----------------------|-------------------------------------------------|---------------------------------|------------------|------------------------------|
| Intermodal                 | 24                   |                       | Dry Active Waste / Metal                        | 16200 ft <sup>3</sup>           | Phase II         | Radioactive                  |
| Intermodal                 | 5                    |                       | Dry Active Waste / Metal                        | 3375 ft <sup>3</sup>            | Phase I          | Radioactive                  |
| Intermodal                 | 3                    |                       | Lead (Pb)                                       | 21200 lbs.                      | Phase I/II       | Recycle                      |
| Intermodal                 | 2                    |                       | Water/Chromate /Lead (Pb)                       | 184 ft <sup>3</sup>             | Phase II         | Mixed                        |
| B-12                       | 2                    |                       | Lead (Pb)                                       | 90 ft <sup>3</sup>              | Phase II         | Mixed                        |
| Sealand                    | 1                    |                       | Reactor Internals                               | 312 ft <sup>3</sup>             | Phase II         | Radioactive                  |
| Reactor Head               | 1                    |                       | Reactor Head                                    | 168 ft <sup>3</sup>             | Phase II         | Radioactive                  |
| Reactor Pressure Vessel    | 1                    |                       | RPV                                             | 2424 ft <sup>3</sup>            | Phase II         | Radioactive                  |
| Control Rod Drive Tower    | 1                    |                       | Metal                                           | 1600 ft <sup>3</sup>            | Phase II         | Radioactive                  |
| Tanker                     | 4                    | Water                 |                                                 | 18124 gal.                      | Phase II         | Radioactive                  |
| Control Rod Drive Oil Drum | 2                    | Oil                   | Personal Protective Equipment / Lead (Pb) fines | 70 gal. and 280 ft <sup>3</sup> | Phase II         | EPA Code D007 and D008       |

(RAI response) The disposal facility used for liquid waste associated with the NSS decommissioning was an EnergySolutions LLC facility located in Erwin, Tennessee called Erwin ResinSolutions. The address of the facility is given below:

151 T.C. Runnion Road  
Erwin, Tennessee 37650

(RAI response) The disposal facility used for solid waste associated with the NSS decommissioning was an EnergySolutions LLC facility located in Clive, Utah called the Clive Disposal Site (Bulk Waste Facility). The address of the facility is given below:

Interstate 80, Exit 49  
Clive, Utah 84029

(RAI response) No decommissioning activities described in the LTP generated low level Class B, Class C or Greater-Than-Class C (GTCC) waste.

## License Termination Plan – (STS-004-003)

(RAI response) However, during a routine radiation survey in July 2008, radium sources associated with the ship's steering gear were discovered. In June 2024, the sources were shipped as greater than Class A waste. They were not part of the nuclear power plant and might be found on other conventional ships of the NSS's era. This waste was not related to decommissioning.

### 3.4 Occupational Exposure

Table 3-3 provides the actual project dose as of September 30, 2023 and the dose estimate to complete the remaining activities. In April 2022, the total radiation exposure to complete decommissioning activities was estimated to be approximately 2.258 person-rem.

**Table 3-3 Radiation Exposure - Project Total and Estimate to Complete Remaining Activities**

| Activity                                            | Exposure (person-rem) |
|-----------------------------------------------------|-----------------------|
| Project Dose as of September 30, 2023 (approximate) | 2.168                 |
| Decontamination of rooms/areas                      | 0.010                 |
| <b>Total</b>                                        | <b>2.178</b>          |

No quantity of radioactive material will be released to unrestricted areas during the completion of the scheduled remaining tasks.

### 3.5 Major Project Milestones

Table 3-3 presents the general project milestones. MARAD recognizes that circumstances can change during decommissioning. If necessary, MARAD will provide an updated schedule to the NRC.

**Table 3-4 General Project Milestones**

| Date                                                              | Milestone                                                 |
|-------------------------------------------------------------------|-----------------------------------------------------------|
| 4 <sup>th</sup> Quarter 2023                                      | Submit LTP to NRC for review                              |
| 4 <sup>th</sup> Quarter 2023 Through 1 <sup>st</sup> Quarter 2024 | Package, ship, and dispose of radioactive waste materials |
| 1 <sup>st</sup> through 4 <sup>th</sup> Quarter 2024              | Submit Final Status Surveys                               |
| 2 <sup>nd</sup> Quarter 2024 through 4 <sup>th</sup> Quarter 2025 | NRC Confirmatory Surveys                                  |
| 4 <sup>th</sup> Quarter 2024                                      | NRC approval of LTP                                       |
| 4 <sup>th</sup> Quarter 2025                                      | License terminated                                        |

### 3.6 References

- 3-1 Regulatory Guide 1.179, *Standard Format and Contents for License Termination Plans for Nuclear Power Reactors*, Rev. 2, July 2019
- 3-2 NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, Rev. 2, April 2018
- 3-3 STS-100, *Post Shutdown Decommissioning Activities Report*, Revision 1, December 11, 2008



3-4 *Updated Final Safety Analysis Report*, STS-004-002, Revision 13, July 20, 2023

## 4 REMEDIATION PLANS

In accordance with the underlying intent of 10 CFR 50.82(a)(9)(ii)(C), the guidance of Regulatory Guide 1.179, *Standard Format and Content for License Termination Plans for Nuclear Power Reactors* [Reference 4-1] and the guidance in NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, [Reference 4-2], this chapter describes plans for site remediation and discusses how residual radioactivity on the site will meet the As Low As Reasonably Achievable (ALARA) criterion for unrestricted release.

References 4-1 and 4-2 describe the content required for this chapter. Summarizing from these references, the License Termination Plan (LTP) should include the following items, which are not meant to be all-inclusive:

- The LTP discusses in detail how facility and site areas will be remediated to meet the NRC criteria for license termination in Subpart E of 10 CFR Part 20, including the proposed residual radioactivity levels [Derived Concentration Guideline Levels] (DCGLs). Discussions should focus on any unique techniques or procedures used to evaluate whether the DCGLs have been met including the following:
  - Summarize the techniques that will be used to remediate building structures and components (e.g., scabbling, hydrolazing, grit blasting, etc.).
  - Summarize the equipment that will be decontaminated and how the decontamination will be accomplished.
  - Summarize the radiation protection methods and control procedures that will be employed including a summary of the procedures already authorized under the existing license and any changes in the radiological controls to be implemented to control radiological contamination associated with the remaining decommissioning and remediation activities.
  - Commit to conduct decommissioning activities in accordance with approved written procedures.
  - Include a detailed description of the techniques that will be employed to remove or remediate surface and subsurface soils, groundwater, and surface water and sediments.
  - Describe plans, if any, for onsite disposal of decommissioning waste.
- The LTP includes a schedule that demonstrates how and in what time frames the licensee will complete the interrelated decommissioning activities. 10 CFR 50.82(a)(3) requires completion of decommissioning within 60 years. If the completion of decommissioning is delayed for more than 60 years, the LTP, must include a justification for the delay in accordance with 10 CFR 50.82(a)(3).

As described in sections 2.1.4 and 5.2 of this LTP, the NSS site contains no surface or subsurface soils, groundwater, or surface water features, consequently, there is no detailed description in the LTP of any techniques that would normally be employed to remove or remediate them.

There are no plans for onsite disposal of decommissioning waste.

Generically, an environmental remediation plan is a summary of planned remedies that will be used to achieve cleanup goals found on a property during a site characterization. To achieve license termination, 10 CFR 50.82(a)(9)(ii)(C) requires the LTP provide the "plans for site remediation." NRC focuses these plans to include the provisions to meet the criteria from Subpart E of 10 CFR 20 before the site may be



released for unrestricted use. The two radiological criteria for unrestricted use specified in 10 CFR 20.1402 [Reference 4-3] are:

- 1) The Total Effective Dose Equivalent (TEDE) from residual radioactivity that is distinguishable from background radiation must not be greater than 25 mrem/year to the AMCG; and,
- 2) Residual radioactivity levels must be ALARA.

Please note that as footnoted in Chapter 1 and described in Section 6.2 of this LTP, the TEDE selected for NSS is 15 mrem/year. Wherever a paragraph cites the 25 mrem/year standard, reviewers should interpret this to mean the NSS administrative limit of 15 mrem/year and includes *as low as reasonably achievable* (ALARA) considerations. For the purposes of the LTP, the Remediation Plan is a list of techniques, methods and technologies that will be used to meet 1) and 2) above. The effectiveness of these techniques will be confirmed by implementing the Final Status Survey (FSS) Plan described in Chapter 5.

Decontamination and dismantlement activities are conducted in accordance with NSS administrative programs and procedures. These programs and procedures are frequently assessed for technical content and compliance. Revisions have been, and will continue to be made, to these programs and procedures to accommodate the changing work environment inherent to reactor decommissioning. The revisions will continue to be documented, processed, and approved in accordance with the existing NSS License, Technical Specifications, and Administrative Procedures. Consistent with Regulatory Guide 1.179 [Reference 4-2], details regarding changes to the Radiation Protection Program (RPP) to address remediation and decommissioning activities are not provided in this LTP. Changes to the RPP will be provided in either 1) Annual Reports as required by the Technical Specifications or 2) in periodic updates to the UFSAR or LTP.

This chapter describes two key items:

- The methods that may be used to remediate contaminated systems, components, and structure surfaces; and,
- The methods to demonstrate compliance with the ALARA criterion in 10 CFR 20.1402 per the guidance in NUREG-1757 [Reference 4-6].

As described in Chapter 6, MARAD has adopted a dose scenario, with associated parameters and assumptions, based on a 15 mrem/year release limit. Also note that Chapter 3 describes in detail the remaining site remediation and dismantlement activities and the order in which they will occur for each structure, system and/or component. It also notes that MARAD recognizes circumstances can change during decommissioning. The current schedule for completing the remaining License Termination Activities is shown in Chapter 3, Figure 3-1. MARAD expects to complete decommissioning and request termination of its license well before the 60-year period prescribed by 10 CFR 50.82(a)(3). For reference, the NSS deadline is December 3, 2031.

Section 4.3 provides a summary of the radiation protection methods and control procedures that will be employed to address the impact of dismantlement and remediation activities.

#### **4.1 Remediation Actions and ALARA Evaluations**

When dismantlement and decontamination actions are completed, residual radioactivity may remain on the ship surfaces at concentrations that correspond to the NSS dose criterion of 15 mrem/year. The remaining residual radioactivity must also satisfy the ALARA criterion, which requires an evaluation as to whether it is feasible to further reduce residual radioactivity to levels below those necessary to meet the dose criterion (i.e., to levels that are ALARA). See Section 4.4 of this chapter for a discussion of ALARA.



## 4.2 Remediation Actions

Remediation actions are performed throughout the decommissioning process and are based on the results of radiological surveys. For example, a survey may be performed in an area where prior to a large component removal, no survey was possible and the collected survey data indicates that remediation is required. When decommissioning activities in a survey unit are complete, characterization surveys are conducted when additional information is needed for the proper planning of the survey unit's FSS. A turnover survey will be performed in preparation for FSS activities when a review of previous survey data for the survey unit cannot confirm a) there is sufficient data to perform FSS design and b) an FSS in the survey unit is likely to meet release criteria. If the characterization survey or turnover survey determines that additional remediation is necessary, then the completed remediation activities will be followed by a Remedial Action Support Survey to verify that a survey unit is likely to meet release criteria following the performance of an FSS.

These remediation techniques, methods, and technologies are standard to the commercial nuclear industry. They represent the current best practice methods and use a consistent approach intended to facilitate the most cost-effective balance between hazardous waste removal and decontamination cleaning. All remediation actions described may not necessarily be required but are listed as possible actions that may be taken during the decommissioning of the NSS. The appropriate remediation technique(s), method(s) and/or technologies that will be employed are dependent on the physical composition and configuration of the contaminated media requiring remediation. At the NSS, the principal media that will be subjected to remediation are structural surfaces. Characterization survey results and historical survey data indicate that generally there is minimal contamination identified to date.

### 4.2.1 Pressure Washing

Pressure washing uses a nozzle of intermediate water pressure to direct a jet of pressurized water that removes superficial materials from the suspect surface. A header may be used to minimize overspray. A wet vacuum system is used to suction the potentially contaminated water into containers for filtration or processing.

### 4.2.2 Needle Guns

A method of scabbling is accomplished using needle guns. The needle gun is a pneumatic air-operated tool containing a series of tungsten-carbide or hardened steel rods enclosed in housing. The rods are connected to an air-driven piston to abrade and fracture the media surface. The media removal depth is a function of the residence time of the rods over the surface. Typically, one to two millimeters are removed per pass. Generated debris collection, transport, and dust control are accomplished in the same manner as other scabbling methods. Use of needle guns for removal and chipping of media is usually reserved for areas not accessible to normal scabbling operations. These include, but are not limited to, inside corners, cracks, joints, and crevices. Needle gunning techniques can also be applied to painted and oxidized surfaces.

### 4.2.3 High Pressure Water Blasting

Most contaminated piping will be removed and disposed of as radioactive waste. If radiological conditions inside the pipe are in excess of the release criteria and the system is to remain in place, then *in situ* remediation will be performed. One method that may be used to remediate the pipe interior surfaces is high pressure water blasting. A typical High-Pressure Liquid-Jetting System has a high-pressure water pump capable of producing a water pressure of 10,000 psi to 20,000 psi at an actual flow rate that ranges from 44 gallons per minute at 10,000 psi to 23 gallons per minute at 20,000 psi. A rotating jet-mole tip is used for 360-degree coverage of pipe interiors. The jet mole is attached to a lance and high-pressure hose. The lance is manually advanced through the interior of



the pipe. As the lance is advanced, the high-pressure water abrades the interior surface of the pipe to remove the corrosive layer, internal debris, and radiological contamination. The wastewater containing the removed contamination is then collected and stored for processing as liquid radiological waste.

(RAI Response) The aft loop of the Reactor Coolant System pipe segments and valves were disposed in early 2024 as noted in STS-224, *Annual Report for Calendar Year 2023* [Reference 4-4]. In all other respects, the end state at license termination will agree with the descriptions in LTP Sections 3.1, 3.1.1, and 3.1.2, with minor exceptions. Sections 3.1 and 3.1.1 of the LTP cross reference to the STS-100, *Post Shutdown Decommissioning Activities Report*, Revision 1 [Reference 4-5]. The PSDAR lists systems slated for dismantlement in its Section 3.3. For clarity, Table 8-1, Summary of System End States at License Termination, provides a description of the end state configuration for the systems covered by the PSDAR, and Sections 3.1 and 3.1.1 of the LTP. The minor exceptions are described in the system status column where appropriate. There is no credible reuse scenario for the pipe in the preservation end state; the pipe would be disposed as scrap in the shipbreaking end state; and in the artificial reefing end state, the pipe is submerged and would be nearly impossible to access by divers based on its location deep within the engine room lower level. The tanks discussed in Table 8-1 will be surveyed.

(RAI Response) Regarding the sentence, "This system has been removed in its entirety," note that bulkhead penetrations and deck penetrations for some of these systems remain. These systems were cut as close to the bulkhead or deck as possible, leaving the minimum amount of piping on each side of the bulkhead or deck. In numerous instances, the bulkhead was fitted with a sleeve through which the pipe passed. All of these penetrations have been surveyed.

**Table 4-1      Summary of System End States at License Termination (RAI Response)**

| <b>ID</b> | <b>System Name</b>                    | <b>Status</b>                                                                                                        |
|-----------|---------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| CRD       | Control Rod Drive                     | This system has been removed in its entirety.                                                                        |
| PE        | Primary Pressurizing                  | This system has been removed in its entirety with the exception of the retained portions of the pressurizer.         |
| SL        | Buffer Seal                           | This system has been removed in its entirety.                                                                        |
| SC        | Shutdown Circulation                  | This system has been removed in its entirety.                                                                        |
| PR        | Primary Relief                        | This system has been removed in its entirety.                                                                        |
| WL        | Gaseous Waste Collection and Disposal | This system has been removed in its entirety.                                                                        |
| CC        | Containment Cooling                   | This system has been removed in its entirety. All that remains is the support structure for Containment Air Coolers. |

**License Termination Plan – (STS-004-003)**

**Table 4-1 Summary of System End States at License Termination (RAI Response) (continued)**

| ID  | System Name                          | Status                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-----|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PD  | Equipment Drain and Waste Collection | Piping for this system has been removed in its entirety. All that will remain are two tanks integral the ship's double bottom structure. These tanks are PD-T5 Contaminated Water Tank Starboard and PD-T6 Contaminated Water Tank Port.                                                                                                                                                                                                                                                                                                                                                                                 |
| PP  | Primary Loop Purification            | Piping for this system has been removed in its entirety.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| HA  | Hydrogen Addition                    | Piping for this system has been removed except as follows:<br><br>Two orphan lengths of HA piping will be grouted.<br><br>In the Hydrogen Addition Room, several ancillary devices will remain and include components such as a pressure gauge, tubing, miscellaneous pressure control or monitoring devices, etc.                                                                                                                                                                                                                                                                                                       |
| SP  | Soluble Poison                       | Piping for this system has been removed in its entirety. All that will remain is the Soluble Poison Tank which has been drained and will be surveyed.                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| DK  | Emergency Cooling                    | The DK system has been removed forward of the Engine Room (forward of Bulkhead 126). Heat exchangers and saltwater side of the system will remain intact and will be surveyed.                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| CW  | Intermediate Cooling Water           | Piping and components in the engine room will remain. These include the sea water heat exchangers and connecting piping, and the supply and return fresh (intermediate cooling) water connections to the system outside of the engine room. All other piping and components forward of the engine room have been removed except for the Intermediate Cooling Water Surge Tank located in the Reactor Compartment Upper Level, which has been drained and will be surveyed. Six short lengths of pipe that looped through the ceiling in the port horseshoe area are cut at each end and orphaned. They will be surveyed. |
| RSV | Reactor Space Ventilation            | This system has been removed in its entirety with the exception of ductwork penetrations through various spaces. These penetrations are accessible for survey.                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| WD  | Waste Dilution and Disposal          | This system has been removed in its entirety.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| SA  | Primary Sampling                     | This system has been removed in its entirety.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |



Table 4-1 Summary of System End States at License Termination (RAI Response) (continued)

| ID   | System Name                | Status                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| None | Clean (salt water) Ballast | LTP Chapter 3.1.1 identifies the Fresh Water Shield Tank (FWST) as subject to FSS. Although this integral double bottom hull structure tank is not part of a Reactor Auxiliary System, it was used to store the primary coolant drained from the primary system in the mid-1970s. Similarly, the Reactor Space Void Tank, another integral double bottom hull structure tank which is surrounded by the FWST is not part of a Reactor Auxiliary System. It was impacted by a leak of the stored primary coolant from the FWST. The Void Tank is subject to FSS. |

#### 4.2.4 Laser Ablation

Laser Ablation is a process utilizing a very controlled Laser System, where pulses of light energy are used to dislodge surface contamination such as oxides and coatings from the surface of a substrate. Up to 90% of the dislodged material is instantly turned into vapor by the plasma of the laser. Vaporized residues are collected immediately after ablation by a strong point-source vacuum system that captures process residues. They pass through multi-stage filtering to be scrubbed free of particles and vapors, preventing hazardous airborne contaminants and minimizing clean-up. The particulates are deposited in a canister for disposal. The integral vacuum system can make a two-step process of cleaning and vacuuming in a single step. Waste reduction can be up to 98% of a typical sand blasting operation. The surface of the substrate after laser ablation leaves a clean uniform profile. This system has been used to decontaminate some of the inside surfaces of the Pressurizer.

#### 4.2.5 Chemical Strippers

Chemical stripping is a physical separation process where one or more components are removed from a surface. Chemical strippers may be used, as appropriate, for the removal of certain contaminants in small areas, after evaluation and approval from NSS management.

#### 4.2.6 Grinding

Grinding is a type of abrasive machining process which uses a grinding wheel as a cutting tool. Portable tools such as angle grinders are employed and use a rotating abrasive wheel to remove material from surfaces, cracks, or corners. The outcome is similar to needle gunning.

#### 4.2.7 Sponge and Abrasive Blasting

Sponge and abrasive blasting are similar techniques that use media or materials coated with abrasive compounds such as silica sands, garnet, aluminum oxide, and walnut hulls. Sponge blasting is less aggressive, incorporating a foam media that, upon impact and compression, absorbs contaminants. The medium is collected by vacuum and the contaminants are washed from the medium so the medium may be reused. Abrasive blasting is more aggressive than sponge blasting but less aggressive than scabbling. Both operations use intermediate air pressures. Sponge and abrasive blasting are intended for the removal of surface films and paints.

In addition to the above techniques, MARAD is considering a combination of chemical decontamination and ultrasonic cleaning for select sections of reactor coolant system piping, with an objective of preserving sections of the aft Reactor Coolant System piping.



### **4.3 Remediation Activities Impact on the Radiation Protection Program**

The RPP approved for decommissioning at the NSS is similar to the one that was implemented during its commercial operation. That program was scaled back after NSS was mothballed and the Possession-only License was issued. During the museum period, the state of South Carolina employed its own radiological protection processes and procedures on NSS. After NSS was returned to sole MARAD custody, MARAD employed the Army Corps of Engineers' STURGIS radiological monitoring and surveillance program on NSS. This lasted until 2005, when MARAD began developing renewed administrative programs and procedures in anticipation of decommissioning. Throughout this period of the Possession-only License and until License Amendment 15 was issued in 2018 to authorize dismantlement and disposal of waste, radiological activity was limited to performing only routine radiological activities such as surveys and confirmation of correct postings. No remediation was performed prior to Amendment 15 because the Technical Specifications allowed no activity that was likely to generate radiological waste.

The current approved RPP at NSS, developed after 2005 through to the present, complies with all federal and state regulatory requirements for the protection of occupational personnel from radiological hazards encountered or expected to be encountered during the decommissioning. In addition, the program ensures the protection of the public from radiological hazards and ensures occupational, effluent, and environmental dose from exposure to radioactive materials is and remains ALARA. To ensure that adequate and proper engineering controls and hazard mitigation techniques are employed, work control programs and procedural requirements allow radiation protection personnel to integrate radiation protection and radiological hazard mitigation measures directly into the work planning and scheduling process. Consequently, the necessary radiological controls are correctly implemented to accommodate each remediation technology as appropriate. Remedial action support survey design is described in Sections 5.3 and 5.4.

The spread of loose surface contamination is mitigated by the routine remediation of work areas by washing and wiping. Water washing with a detergent is effective in reducing low levels of loose surface contamination over large surface areas. Wiping with detergent-soaked or oil-impregnated media is an effective technique to reduce loose surface contamination on small items, overhead spaces and small hand tools. These activities are referred to as "good housekeeping." These same techniques are also effective in reducing low levels of surface contamination on structural surfaces.

More aggressive methods for intermediate levels of surface contamination may be appropriate, such as:

- Pressure washing;
- High-pressure water blasting;
- Grinding; and,
- Sponge and Abrasive Blasting.

Pipes, surfaces and drain lines can be cleaned and hot spots removed using these techniques and technologies. Small tools, hoses, and cables can also be pressure washed in a containment to reduce contamination levels.

The RPP implements radiological controls 1) to reduce personnel exposure to radiation and contamination and 2) to prevent the spread of contamination from established contaminated areas. Decommissioning does not present any new challenges to the RPP. There are no known unique safety issues associated with remediating any contaminated structures. Decommissioning planning allows radiation protection personnel to focus on each area of the site and plan each activity well before execution of the remediation technique. The decommissioning organization is staffed by contractors experienced in and capable of



applying these remediation techniques on contaminated systems, structures or components during decommissioning.

A comprehensive review of all radiation procedures was performed in 2020, after which numerous procedures were revised to make them consistent with current industry practice and with other NSS administrative procedures. These procedures were approved in accordance with the Technical Specifications, Decommissioning Quality Assurance Plan (DQAP), and NSS administrative processes.

#### 4.4 ALARA Evaluation

Guidance for conducting ALARA analyses is provided in NUREG-1757 Vol. 2 [Reference 4-6], which describes acceptable methods for determining when further reduction of residual radioactivity is required to concentrations below the levels necessary to satisfy the 25 mrem/yr. dose criterion.

In Chapter 6 of NUREG-1757, there is a section identified as "Predetermined Compliance Measure." The following paragraph is from this section.

*Under the predetermined compliance measure, the licensee would agree to meet the dose calculated for the preferred option or the radiological concentrations associated with this dose. This could be met by either establishing deterministic concentration limits for the site or agreeing to use a specified dose scenario with associated parameters and assumptions. If the licensee's final survey results meet the self-imposed concentration limits (or dose limit), the licensee has met the ALARA requirement.*

As described in Section 3.1.1 of Chapter 3, several components will remain in-situ at the end of dismantlement and will be retained - subject to satisfactory FSSs. These components are located within the Containment Vessel (CV) and include the secondary sides of both steam generator assemblies, the upper section of the pressurizer shell (internals removed and interior surfaces decontaminated), and the common exterior annular wall of the Neutron Shield Tank / Fuel Transfer Tank. The structure of the CV itself will also remain. MARAD is confident that these components and structures will meet the DCGLs proposed in Chapter 6. The steam generator shells had no detectable contamination during the 2019 characterization campaign. Initial internal characterization data for many of the systems remaining after decommissioning is completed was obtained in 2019. The results of those surveys showed that the internal surfaces of those systems have low loose surface contamination levels and total surface contamination levels below the DCGLs proposed in Chapter 6 of this LTP. All reasonable efforts will be made to locate and remove any loose contamination on external surfaces of the ship. Based upon the short operating history, long decay time, and unique design of the NSS, routine surveys of the ship indicate very low levels of contamination in the CV and Reactor Compartment.

The dose limit for FSSs and License Termination is specified in Chapter 6 of the LTP and is administratively equal to 15 mrem/year. The administrative limit includes *as low as reasonably achievable* (ALARA) considerations. Chapter 6 also presents the radiological concentrations associated with this dose. It is anticipated that the FSS of components and structures will show contamination levels well below the 15 mrem/year DCGLs. The goal of the FSS is to meet the self-imposed concentration limits. As described in Chapter 6, MARAD has adopted a dose scenario, with associated parameters and assumptions, based on a 15 mrem/year release limit.

When FSS is complete and the dose scenario is confirmed met, MARAD will have met the ALARA requirement, and no further analyses are required.



#### 4.4.1 ALARA Evaluation (RAI response)

10 CFR 20.1402 Radiological criteria for unrestricted use states:

A site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a TEDE to an average member of the critical group that does not exceed 25 mrem (0.25 mSv) per year, including that from groundwater sources of drinking water, and the residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA).

To ensure that the NSS meets these requirements, MARAD has established an administrative limit of less than or equal to 15 mrem (0.15 mSv) per year of residual radioactivity that is distinguishable from background radiation results in a TEDE to an average member of the critical group. This administrative limit includes *as low as reasonably achievable* (ALARA) considerations.

The initial decision to apply the 15 mrem/y criteria rather than the 25 mrem/y criteria stipulated in 10 CFR 20.1402 was to avoid a potential regulatory conflict following license termination. This potential conflict could occur for future ship-breaking or preservation activities for the NSS which are governed by EPA regulations which endorse an annual radiation exposure limit to the public of 15 mrem/y. MARAD made this decision after it awarded its fixed price decommissioning services contract, such that the contractor's fixed price was based remediating to 25 mrem/y. When MARAD decided to remediate to 15 mrem/y, the contractor did not require a contract value increase to meet this objective. Therefore, the cost of the decision was zero despite minor possible increases in waste disposal, transportation and labor. MARAD and its contractor believe those possible increases are too low to quantify since removal of surficial residual radioactivity is not controlled with enough precision to predict these costs. As such, the costs for remediation to levels even lower than 15 mrem/yr cannot be accurately predicted despite the fact that residual radioactivity levels on the NSS are well below the DCGLs associated with 15 mrem/y.

Because the cost for remediation to 15 mrem/y or below is known to be zero, the application of equations N-1 and N-2 is artificially skewed. Therefore, we have prepared an evaluation of the benefits and costs for remediation in accordance with NUREG 1757, Volume 2, Rev. 1, Appendix N. In this case, the monetary equivalent for future dose savings at 15 mrem/y is calculated as a benefit and the cost is considered zero as described above. In accordance with NUREG 1757, Volume 2, Rev. 1, Appendix N, if the benefit is greater than the cost then the action is considered ALARA and should be performed. In our case where the cost is zero, any positive benefit at 15 mrem/y would justify this lower dose limit.

This ALARA evaluation is based on a ship scrapping scenario. Our assumptions and estimates are based on MARAD's extensive experience in shipbreaking as discussed in Chapter 6.3.1 of the LTP. MARAD identified an exemplar shipbreaking project for this analysis. The project is the S.S. *CAPE JOHN*, completed in 2015 in Brownsville, TX. *CAPE JOHN* was a contemporary of NSS and is of the basic hull and machinery design from which NSS was derived. It's hull form and power requirements were similar enough to NSS that the differences can be accounted for. Table 4-1, Comparison of NSS to *CAPE JOHN*, summarizes these differences. The significant difference between the NSS and the *CAPE JOHN* is the machinery weight, which on NSS includes the weight of the nuclear power plant (3000 tons), including the Containment Vessel (CV) and Collision Boundary. With essentially all components removed from the CV, we estimate the remaining machinery is double that of the *CAPE JOHN* or 2000 tons. This value accounts for additional machinery weight of auxiliary systems associated with passenger operations (e.g., air conditioning), auxiliaries unique to the nuclear power plant (e.g., diesel generators, take-home motor), component



differences based on saturated main steam (e.g., moisture separators, larger turbines) and the weight of the retained nuclear components.

**Figure 4-1 Comparison of Cape John to NSS**

| <b>Long tons (2240 pounds per ton)</b> | <b>CAPE JOHN</b> | <b>SAVANNAH</b>                                          |
|----------------------------------------|------------------|----------------------------------------------------------|
| Lightship Weight                       | 8,640            | 12,334                                                   |
| Steel Weight                           | 5,210            | 5,300                                                    |
| Machinery Weight                       | 1,040            | 1980<br>[4,420 total machinery weight – (3000 + 2(250))] |
| Outfitting                             | 2,390            | 2,480                                                    |

CAPE JOHN was dismantled over seven months and required 16,313 man hours for on-board and ground cutting. For this evaluation, we estimated that approximately 11 workers would be required to scrap the NSS in a year. The DCGLs were derived with an exposure duration assumed to be 6 hours/day for 250 days or 1500 hours per year for the ship scraping worker.

If each of the 11 workers were exposed to residual radioactivity represented by DCGLs set at 25 mrem/y for the working year of 1500 hours, each worker would receive a dose of 25 mrem and would result in a collective dose of 275 p-mrem. If each of the workers were exposed, under the same conditions, at DCGLs equivalent to 15 mrem/y, each worker would receive a dose of 15 mrem and would result in a collective dose of 165 p-mrem. This is a collective dose savings of 100 p-mrem.

Therefore, under all exposure conditions, the individual and collective doses would be approximately three-fifths (3/5) of the doses if the DCGL was set to 15 mrem/y rather than at 25 mrem/y.

As described above, Equations N-1 and N-2 from NUREG 1757, Volume 2, Revision 2, Appendix N are used to determine the monetary benefit from MARAD's proposed action. In this analysis, the variables used in the calculation are shown in the table below (Table 4-2).

Figure 4-2 Results of Equations N-1 and N-2

| Parameter                     | Parameter Description                          | Parameter Value | Parameter units  |
|-------------------------------|------------------------------------------------|-----------------|------------------|
| Pd                            | Population density                             | 1               | p/m <sup>2</sup> |
| A                             | Area being evaluated                           | 10              | m <sup>2</sup>   |
| 0.025                         | Annual dose limit for NSS                      | 0.015           | rem/y            |
| F                             | Fraction of the residual radioactivity removed | 1               | fraction         |
| <i>Conc/DCGL<sub>w</sub></i>  | Ratio of conc to DCGL <sub>w</sub>             | 1               | fraction         |
| R                             | Monetary Discount Rate                         | 0.07            | y <sup>-1</sup>  |
| Λ                             | Decay Constant, Cs-137                         | 0.0231          | y <sup>-1</sup>  |
| N                             | Number of years                                | 1               | y                |
| PW(AD <sub>Collective</sub> ) | Present worth of future averted dose           | 0.1432          | p-rem            |
| V <sub>AD</sub>               | Value of averted dose                          | 5,200           | \$/p-rem         |
| B <sub>AD</sub>               | Benefit from averted dose for remediation      | \$745           | USD              |

The analysis shows that the benefit of reducing the dose limit from 25 to 15 mrem has a monetary benefit of \$745 in year 1 following license termination. If this analysis is performed for a period of 70 years (as presented in Chapter 6.14 of the LTP), the benefit would be well less than \$5200 using the same parameter values for all other parameters. This \$5200 benefit also ignores radioactive decay and is considered very small in comparison to most industrial activities including the decommissioning costs and ship breaking. Essentially, this low benefit value in comparison to the zero cost shows that using our lower dose limit meets the ALARA requirement from 10 CFR 20 Subpart E.

#### 4.5 Summary of Remediation Techniques, Procedure and Issues

NUREG-1700, *Standard Review Plan for License Termination Plan* [Reference 4-2] and its Appendix A list a number of acceptance criteria associated with remediation that "... focus on any unique techniques or procedures used to evaluate whether the DCGLs have been met ..."

MARAD has conducted remediation activities as described in Section 3.1. Thus far, MARAD has identified no unique techniques or procedures that will be used to evaluate whether the DCGLs have been met. MARAD has identified no unique safety issues and no remediation issues associated with remediating contaminated SSCs.

#### 4.6 References

- 4-1 Regulatory Guide 1.179, *Standard Format and Contents for License Termination Plans for Nuclear Power Reactors*, Rev. 2, July 2019
- 4-2 NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, Rev. 2, April 2018



**License Termination Plan – (STS-004-003)**

---

- 4-3 Code of Federal Regulations, Title 10, Part 20.1402, *Radiological Criteria for Unrestricted Use*.
- 4-4 STS-224, *Annual Report for Calendar Year 2023*, February 29, 2024
- 4-5 STS-100, *Post Shutdown Decommissioning Activities Report*, Revision 1, December 11, 2008
- 4-6 NUREG-1757, Volume 2, *Consolidated Decommissioning Guidance Characterization, Survey, and Determination of Radiological Criteria*, Rev. 1, September 2006

## 5 FINAL STATUS SURVEY PLAN

### 5.1 Introduction

In accordance with the underlying intent of 10 CFR 50.82(a)(9)(ii)(D), the guidance of *Regulatory Guide 1.179, Standard Format and Content for License Termination Plans for Nuclear Power Reactors* [Reference 5-1] and the guidance in NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, [Reference 5-2], this chapter describes the methods to be used in planning, designing, conducting, and evaluating Final Status Surveys (FSSs) at the NSS. These surveys will demonstrate that the dose from residual radioactivity is less than the maximum dose criterion for license termination for unrestricted use specified in 10 CFR 20.1402 [Reference 5-3]. As described in Chapter 6 and elsewhere in this LTP, MARAD has committed to a lower dose criterion of 15 mrem/year. The additional requirement of 10 CFR 20.1402 that all residual radioactivity at the site be reduced to levels that are As Low As Reasonably Achievable (ALARA) is addressed in Chapter 4.

References 5-1 and 5-2 describe the content required for this chapter. Summarizing from these references, the LTP should include the following items, which are not meant to be all-inclusive:

- Describe the methods proposed for surveying all equipment, systems and structures, as well as a method for ensuring that sufficient data are included for a meaningful statistical survey. Use diagrams, plot plans, and facility layout drawings to facilitate presentation.
- Describe the methods the licensee will use to establish background radiation levels. Discuss variances in background radiation that can be expected (e.g., between structures constructed of different materials), as outlined in draft NUREG-1501, "Background as a Residual Radioactivity Criterion for Decommissioning," issued August 1994 (Ref. 14).
- Describe the QA program to support both field survey work and laboratory analysis. Address the QA organization; training and qualification requirements; survey instructions and procedures, including water, air, and soil sampling procedures; document control; control of purchased items; inspections; control of survey equipment; handling, storage, and response [(i.e., operational)] checks; shipping of survey equipment and laboratory samples; disposition of nonconformance items; corrective action; QA records; and survey audits, including methods to be used for reviewing, analyzing, and auditing data.
- Describe the verification surveys and evaluations used to support the delineation of radiologically affected (contaminated) areas and unaffected (uncontaminated) areas.
- Identify the major radiological contaminants.
- Discuss methods used for addressing hard-to-detect radionuclides.
- Describe access control procedures to avoid recontamination of clean areas.
- Identify survey units having the same area classification.
- Describe scanning performed to locate small areas of elevated concentrations of residual radioactivity.
- Discuss levels established for investigating significantly elevated concentrations of residual radioactivity. Include survey instrument calibration and efficiency calculations.
- Describe the reference coordinate system established for the site areas.

The FSS Plan was developed using the guidance of NUREG-1575, *The Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)* [Reference 5-4]; and NUREG-1757; *Consolidated*



*Decommissioning Guidance - Characterization, Survey, and Determination of Radiological Criteria* [Reference 5-5]. The process described in this plan adheres to the guidance of MARSSIM for the design of FSS. MARSSIM allows for advanced survey technologies that can effectively scan 100% of the surface and record the results. MARAD does not expect to use any advanced survey technologies.

## 5.2 Scope

The FSS Plan encompasses the radiological assessment of all affected structures and systems for the purpose of quantifying the concentration of any residual activity that remains following all decontamination activities. Concentration limits have been established to represent the maximum dose rate criterion for unrestricted release specified in 10 CFR 20.1402 and are presented in Chapter 6 of the LTP.

The NSS site possesses unique features that both simplify, and perhaps complicate, the FSS process. The features and their characteristics, follow:

- The licensed site of the NSS is the boundary defined by the ship's hull (see Figures 1-1, 1-2 and 1-3). The hull is waterborne, and its former sea connections are fitted with welded steel blanks which prevent any auxiliary or secondary system from discharging overboard. So long as the primary hull structure, including the blanks, is intact, the site (i.e., the ship) is isolated from the marine and terrestrial environments.
- Being waterborne and isolated from the terrestrial environment, the site contains no soil and no ground water. Surveys of such features are not applicable to NSS. There is also no surface water feature such as may be present on a land-based site.
- Being isolated from the marine and terrestrial environments, the background radiation within the NSS site is lower than typical sites.
- The site is mobile, and thus is not permanently fixed to any particular location. The ship is periodically removed from any long-term berthing site for routine maintenance of the hull (e.g., drydocking or shipyard repairs such as occurred following museum service in 1994, after removal from layup in the MARAD James River Reserve Fleet during the period 2006-2008, and the temporary removal from the ship's current Baltimore layberth site for drydocking in 2019-2020). The future site of dispositioning activities (preservation, shipbreaking or artificial reefing) is unknown at the time of LTP submittal.
- The nature of the ship's construction means that the site contains no embedded pipe, as the term is commonly understood. Piping penetrations through structural steel bulkheads are typically less than one (1) inch in length, and can readily be surveyed, decontaminated, or removed. The longest lengths of piping penetrations are those which pass through the concrete secondary shielding. Here, the maximum length of pipe is about four (4) feet, and again, such piping is accessible from at least one side. Similarly, there will be no rubble backfill, structures remaining below grade, and no buried or surface paved parking lots, such as might be found at typical decommissioning sites.

The FSS Plan developed for NSS accounts for each of these characteristics and features.

### 5.2.1 Final Status Survey Organization

As described in the Section 2, Organization and Responsibilities of the *Decommissioning Quality Assurance Plan* (DQAP) [Reference 5-6], the SAVANNAH Technical Staff (STS) organizational unit is MARAD's licensee organization and is primarily made up of a combination of direct employees and contractors. The organization is structured on the basis that the objectives of the DQAP will be met by those who manage, perform and support the activities within the scope of this plan. Those who

perform work on quality related functions are directly responsible for meeting quality standards and reporting nonconformances or conditions adverse to quality. The requirements stipulated in the DQAP shall be imposed on all personnel and organizations, including contractors, who perform quality related decommissioning activities.

With submittal of the LTP, the function of FSS is an activity added to the scope of the DQAP. The major changes are adding an LTP Manager and an FSS Manager to the existing organization. The LTP Manager is responsible for overall FSS project coordination and direction as it relates to Phase 3 Decommissioning and License Termination. The FSS Manager is responsible for overall management and onsite implementation of the FSS Project. The existing STS organization supports FSS activities. As licensee, MARAD is responsible, with support from STS, for performing assessments of the implementation of the FSS program, including procedure adherence and conformance reviews of selected FSS reports. Figure 5-1 is the organizational chart of the FSS organization.

### **5.2.2 Final Status Survey Administrative Procedures**

Procedure STS-005-029, *Final Status Survey Program* [Reference 5-7] establishes the requirements for activities performed in support of FSSs. It includes a description of key FSS positions and their responsibilities. Other FSS administrative procedures include but are not limited to the following:

- STS-005-030, *Preparation of FSS Packages* [Reference 5-8]
- STS-005-031, *Calculation of the Number of Measurements* [Reference 5-9]
- STS-005-032, *Survey Unit Turnover and Control* [Reference 5-10]
- STS-005-033, *Final Status Survey Data Assessment* [Reference 5-11]
- STS-005-034, *Survey Unit Classification* [Reference 5-12]
- STS-005-035, *Preparation of Survey Unit Release Records* [Reference 5-13]
- STS-005-036, *Entrance Seal Log for Isolated Survey Units* [Reference 5-14]

### **5.3 Summary of the Final Status Survey Process**

The FSS provides data to demonstrate that all radiological parameters satisfy the established guideline values and conditions. The primary objectives of an FSS are to:

- Select/verify survey unit classification;
- Demonstrate that the potential dose from residual radioactivity is below the release criterion for each survey unit; and,
- Demonstrate that the potential dose from small areas of elevated activity is below the release criterion for each survey unit.



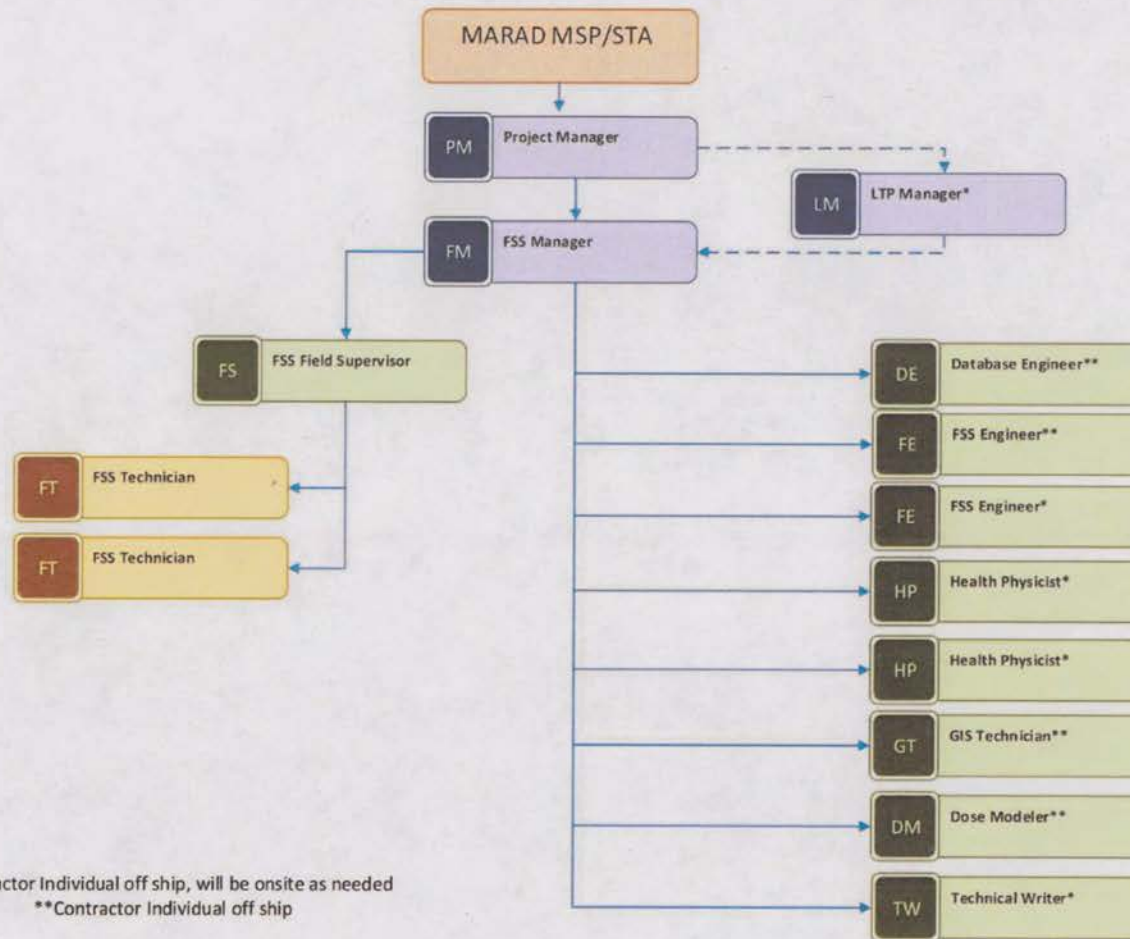


Figure 5-1 FSS Organization

The FSS process consists of four principal elements:

- Planning;
- Design;
- Implementation; and,
- Assessment.

The DQOs and Data Quality Assessment (DQA) processes are applied to these four principal elements. DQOs allow for systematic planning and are specifically designed to address problems that require a decision to be made and provide alternate actions, as is the case in FSS. The DQA process is an evaluation method used during the assessment phase of FSS to ensure the validity of survey results and demonstrate achievement of the sampling plan objectives (e.g., to demonstrate compliance with the release criteria in a survey unit).

Survey planning includes review of the Historical Site Assessment (HSA) and other pertinent characterization information to establish the radionuclides of concern and survey unit classifications. Survey units are fundamental elements for which FSSs are designed and executed. The classification of a survey unit determines how large it can be in terms of surface area. If any of the radionuclides of concern are present in background, the planning effort may include establishing appropriate reference areas and reference materials to be used to establish baseline concentrations for these radionuclides and their variability. A reference coordinate system may be used for documenting locations where measurements were made and to allow replication of survey efforts, if necessary.

Before the survey process can proceed to the design phase, concentration levels representing the maximum dose criterion of 10 CFR 20.1402 must be established. As described in Chapter 6, MARAD has committed to a lower dose criterion of 15 mrem/year. These concentrations are established for surface contamination. These surface contamination concentrations are used in the survey design process to establish the minimum sensitivities required for the survey instruments and techniques, and in some cases, the spacing of fixed measurements to be made within a survey unit. Surface concentrations that correspond to the maximum dose criterion are referred to as Derived Concentration Guideline Levels (DCGLs). A DCGL established for the average member of the critical group exposed to residual radioactivity in a survey unit is called a DCGL<sub>w</sub>.<sup>15</sup>

After the DCGL<sub>w</sub> is established, a survey design is developed that selects the appropriate survey instruments and techniques to provide adequate coverage of the unit through a combination of scans, fixed measurements, and sampling. This process ensures that data of sufficient quantity and quality are obtained to make decisions regarding the suitability of the survey design assumptions and whether the unit meets the release criterion. Approved procedures will direct this process to ensure consistent implementation and adherence to applicable requirements.

Survey implementation is the process of performing the survey plan for a given survey unit. This consists of scan measurements and fixed measurements. Data will be stored and controlled.

The DQA approach is applied to FSS results to ensure their validity and to demonstrate that the objectives of the FSS are met. Data assessment includes data Verification and Validation (V&V), review of survey design bases, and data analysis. For a given survey unit, the survey data are evaluated to determine if the

---

<sup>15</sup> The "W" in DCGL<sub>w</sub> stands for Wilcoxon Rank Sum test, which is the statistical test recommended in MARSSIM for demonstrating compliance when the contaminant is present in background. The Sign test recommended for demonstrating compliance when the contaminant is not present in background also uses the DCGL<sub>w</sub>.



residual activity levels in the unit meet the applicable release criterion and if any areas of elevated activity exist. In some cases, the data evaluation will show that all measurements made in a given survey unit were below the applicable DCGL<sub>w</sub>. If so, demonstrating compliance with the release criterion is a simple matter and requires little in the way of analysis. In other cases, residual radioactivity may exist where measurement results both above and below the DCGL<sub>w</sub> are observed. In these cases, statistical tests must be performed to determine if the survey unit meets the release criterion. The statistical tests that may be required to make decisions regarding the residual activity levels in a survey unit relative to the applicable DCGL<sub>w</sub> must be considered in the survey design to ensure that a sufficient number of measurements are collected.

MARSSIM specifies two (2) non-parametric statistical tests to be applied to FSS data to evaluate whether a set of measurements demonstrates compliance with the release criterion for a given survey unit. Those are the 1) Wilcoxon Rank Sum Test and 2) Sign Test. On NSS, FSS data will only be evaluated with the Sign Test because the radionuclide(s) of interest either does not exist in background or is not present in a concentration that is a relevant fraction of the DCGL<sub>w</sub>.

Quality assurance and quality control measures are employed throughout the FSS process to ensure that all decisions are made based on data of acceptable quality. Quality assurance and control measures are applied to ensure:

- The plan is correctly implemented as prescribed;
- DQOs are properly defined and derived;
- All data are collected by individuals with the proper training following approved procedures;
- All instruments are properly shipped, handled, stored, operationally checked and calibrated in accordance with approved procedures;
- All collected data are validated, recorded, and stored in accordance with approved procedures;
- All required documents are properly maintained;
- If necessary, corrective actions are prescribed and implemented; and,
- Effectiveness of corrective actions is reviewed, when appropriate.

These measures apply to any services provided in support of remedial action support surveys and FSSs.

Survey results will be converted to appropriate units (i.e., dpm/100cm<sup>2</sup>) and compared to investigation levels to determine appropriate follow-up action. Measurements exceeding investigation levels will be verified and investigated and, following confirmatory measurement(s), the affected area may be remediated and/or reclassified and a re-survey performed consistent with the guidance in MARSSIM and commensurate with the classification and extent of contamination.

Documentation of the FSS survey will transpire in two types of reports. An FSS Survey Unit Release Record will be prepared to provide a complete record of the "as left" radiological status of an individual survey unit, relative to the specified release criteria. An FSS Final Report, which is a written report submitted to the NRC, will be prepared to provide a summary of the survey results and the overall conclusions from multiple survey units. It will include the associated Release Records. These reports will demonstrate that the NSS meets the radiological criteria for unrestricted use. They are discussed in detail in Section 5.10. Reports will be compiled after FSS activities for all survey units for a given final report are completed. This approach should minimize the submittal of redundant historical assessment information and provide for a logical approach to perform reviews and independent verification.

## 5.4 Survey Planning

### 5.4.1 Data Quality Objectives

The DQO process is incorporated as an integral component of the data life cycle at the NSS. The DQO process is used in the planning phase for scoping, characterization, remediation, and FSS plan development using a graded approach. Survey plans that are complex or that have a higher level of risk associated with an incorrect decision (such as FSSs) would require significantly more effort than a survey plan used to obtain data relative to the extent and variability of a contaminant. This process, described in MARSSIM, is a series of planning steps found to be effective in establishing criteria for data quality and developing survey plans. DQOs allow for systematic planning and are specifically designed to address problems that require a decision to be made and provide alternate actions. Furthermore, the DQO process is flexible in that the level of effort associated with planning a survey is based on the complexity of the survey and nature of the hazards. Finally, the DQO process is iterative allowing the survey planning team to incorporate new knowledge and modify the output of previous steps to act as input to subsequent steps.

The DQO process consists of performing the following seven steps:

- State the Problem;
- Identify the Decision;
- Identify the Inputs to the Decision;
- Define the Boundaries of the Decision;
- Develop a Decision Rule;
- Specify Tolerable Limits on Decision Errors; and,
- Optimize the Design for Obtaining Data.

The actions taken to address these DQO process steps survey during the planning phase for an FSS for a particular survey area are addressed below.

#### State the Problem

The first step of the planning process consists of defining the problem. This step provides a clear description of the problem, identification of planning team members (especially the decision-makers), a conceptual model of the hazard to be investigated and the estimated resources. The problem associated with FSS is to determine whether an area meets the radiological release criterion of 10 CFR 20.1402 and the 15 mrem/year standard employed by EPA.

#### Identify the Decision

This step of the DQO process consists of developing a decision statement based on a principal study question (i.e., the stated problem) and determining alternative actions that may be taken based on the answer to the principal study question. Alternative actions identify those measures to resolve the problem. The decision statement combines the principal study question and alternative actions into an expression of choice among multiple actions. For FSS the principal study question is "Does residual radioactive contamination present in the survey unit exceed the release criteria?" The alternative actions may include no action, investigation, resurvey, remediation, and reclassification.



#### Identify Inputs to the Decision

The information required depends on the type of media under consideration and whether existing data are sufficient or new data are needed to make the decision. If the decision can be based on existing data, then the source(s) will be documented and evaluated to ensure reasonable confidence that the data are acceptable. If new data are needed, then the type of measurement (e.g., scan, direct measurement and sampling) will be determined.

Each of the following:

- Sampling methods;
- Sample quantity;
- Sample matrix;
- Type(s) of analyses; and,
- Analytic methods and measurement process performance criteria, including detection limits

are established to ensure adequate sensitivity relative to the action level and to minimize bias. Action levels provide the criterion for choosing among alternative actions (e.g., whether to take no action, perform confirmatory measurements or sampling). These action levels may be radioactivity concentration (dpm/100cm<sup>2</sup>) or measurement device response (count rate corrected for background, etc.).

#### Define the Boundaries of the Study

This step of the DQO process includes identification of the target population of interest, the spatial and temporal features of the population pertinent to the decision, time frame for collecting the data, practical constraints and the scale of decision making. In FSS, the target population is the set of direct measurements that constitute an area of interest (i.e., the survey unit). The medium of interest is specified during the planning process. The spatial boundaries include the entire area of interest including contamination depth, area dimensions, and natural boundaries, as needed. Temporal boundaries include those activities impacted by time-related events including weather conditions, seasons (i.e., more daylight available in the summer), operation of equipment under different environmental conditions, resource loading, and work schedule.

#### Develop a Decision Rule

This step of the DQO process develops the binary statement that defines a logical process for choosing among alternative actions. The decision rule is a clear statement using the "If...then..." format and includes action level conditions and the statistical parameter of interest (e.g., mean of data). Decision statements can become complex depending on the objectives of the survey and the radiological character of the affected area.

#### Specify Tolerable Limits on Decision Errors

This step of the DQO process incorporates hypothesis testing and probabilistic sampling distributions to control decision errors during data analysis. Hypothesis testing is a process based on the scientific method that compares a baseline condition to an alternate condition. The baseline condition is technically known as the null hypothesis. Hypothesis testing rests on the premise that the null hypothesis is true and that sufficient evidence must be provided for rejection. The primary consideration during FSS will be demonstrating compliance with the

release criteria. The following statement may be used as the null hypothesis at NSS: "The survey unit exceeds the release criteria."

Decision errors occur when the data set leads the decision-maker to make false rejections or false acceptances during hypothesis testing. The  $\alpha$  error (Type I error) is set at 0.05 (5%). The  $\beta$  error may be variable depending upon the objectives of the surveys. A nominal value of 0.05 (5%) has been established for the  $\beta$  error (Type II error). Another output of this step is assigning probability limits to points above and below the gray region where the consequences of decision errors are considered acceptable. The upper bound corresponds to the release criteria. The Lower Bound of the Gray Region (LBGR) is determined in this step of the DQO process. LBGR is influenced by a parameter known as the relative shift. The relative shift is set between (and including) 1 and 3. If the relative shift is not between (or including) 1 and 3, then the LBGR is adjusted. Graphing the probability that a survey unit does not meet the release criteria may be used during FSS. This graph, known as a power curve, may be performed retrospectively (i.e., after FSS) using actual measurement data. This retrospective power curve may be important when the null hypothesis is not rejected (i.e., the survey unit does not meet the release criteria) to demonstrate that the DQOs have been met.

#### Optimize the Design for Obtaining Data

The first six steps are the DQOs that develop the performance goals of the survey. This final step in the DQO process leads to the development of an adequate survey design.

#### 5.4.2 Survey Units

A survey area may consist of one or more survey units. A survey unit is a physical area consisting of structures or rooms of a specified size and shape which will be subject to an FSS. Compliance with the applicable criteria will be demonstrated for each survey unit.

Survey units are limited in size based on classification, exposure pathway modeling assumptions, and site-specific conditions. The surface area limits, used in establishing the initial set of survey units for the FSS Plan, are provided in Table 5-1 for rooms and structures. The area limits for structures refer to the deck area and not the total surface area, which would include the bulkheads and overhangs. This is consistent with the guidance of MARSSIM. The deck area limits given in Table 5-1 were also used to establish survey unit sizes for structures such as exterior surfaces. The limits given in Table 5-1 will also be used should the need arise to establish any new survey units beyond the initial set given in this plan.

As indicated in Table 5-1, associated areas of NSS that are classified as impacted have been divided into survey units to facilitate survey design. Each survey unit has been assigned an initial classification based on the site characterization process and the historical site assessment as described in Chapter 2 of the LTP.



Table 5-1 Survey Unit Surface Area Limits

| Survey Unit Classification            | Suggested Surface Area Limit                              |
|---------------------------------------|-----------------------------------------------------------|
| Class 1: Structures/Rooms (deck area) | $\leq 100 \text{ m}^2$                                    |
| Class 2: Structures/Rooms (deck area) | $100 \text{ m}^2 \leq \text{area} \leq 1,000 \text{ m}^2$ |
| Class 3: Structures/Rooms (deck area) | No Limit                                                  |
| Systems and Components                | No Limit                                                  |

A survey unit can have only one classification. Thus, situations may arise where it is necessary to create new survey units by subdividing areas within an existing unit. For example, residual radioactivity may be found within a Class 3 survey unit, or residual radioactivity in excess of the DCGL<sub>w</sub> may be found in a Class 2 unit. In such cases, it may be appropriate to define a new survey unit within the original unit that has a lower (more restrictive) classification. Alternately, the classification of the entire unit can be made more restrictive.

#### 5.4.3 Reference Coordinate Systems

On a ship, the location of any given point is defined by identifying its distance from one of three axes or reference points. Elevation is typically defined by the deck (floor) on which the point exists, or by its height above Baseline (BL). The BL is a horizontal line that follows the molded line of the keel and represents the “bottom” of the ship. Because some exterior and interior decks have an upward rise known as sheer, the height of a particular deck above BL may vary along the ship’s length.

The point will be defined by its distance from the Forward Perpendicular (FP). The FP is an arbitrary fixed vertical line that runs through the intersection of the ship’s bow with its design waterline. The ship’s transverse frames are numbered running aft, with the FP having no frame designation, but essentially being equal to Frame 0. Transverse bulkheads (walls) are typically aligned on frames.

Finally, the point is defined by its distance from the ship’s Centerline (CL). The CL is a vertical plane running the length of the ship. Distances are measured to port (left) or starboard (right). Ship compartments (rooms or spaces) may be numbered using an alpha-numeric designation to represent its location relative to the three axes (Deck, Frame, and Center). Compartments that are to port of center use an even number designation. Compartments that are to starboard of center use an odd number designation. Compartments which extend to both sides of the CL are said to be “on Center” and use the numeral “0” in their designation. However, on NSS, many compartments employ a simple noun-name designation.

The reference coordinate system for NSS survey units will include a benchmark, or origin point. This benchmark will be defined using the ship’s reference system and will typically be located at the lowest, forwardmost point of the survey unit that is closest to the CL. The coordinate system used for surveys will typically take the form of a triangular grid of intersecting, perpendicular lines; but other patterns (e.g., rectangular and polar) may be used as convenient, depending on the circumstances or shape of the survey unit. The system will serve as a convenience for documenting survey efforts and other information pertaining to a given survey unit. The coordinate system also provides a means to specify general locations for measurements performed for quality control or



verification purposes. The benchmark and survey pattern will be provided for each survey unit in the FSS packages.

Physical gridding of a survey unit will only be done in cases where it is beneficial and cost effective to do so. When physical gridding is used, benchmark locations will be designated by marking a spot by a suitable technique.

#### 5.4.4 Area Preparation: Isolation and Control

Before FSS activities can begin in an area, a transition must occur where planned decommissioning activities are completed, and the area is subsequently assessed to scope the required isolation and control measures. A walkdown will occur to establish if the area is ready for final survey activities and identify any work practice issues that must be addressed in survey planning and design. Determination of readiness for FSS will be based on a characterization survey, turnover survey and/or a Remedial Action Support Survey (RASS) indicating that the residual radioactive material is likely to comply with the FSS criteria.

The following criteria must be met for an area to be deemed ready for isolation and control:

- Known contaminated decommissioning activities in the area are complete and any additional decommissioning activities identified shall pose a very low risk to add contamination to an area, including removal, as necessary, of items (e.g., equipment mounts, bulkhead hangers, and exposed studs) that could interfere with final survey activities;
- All planned decommissioning activities in areas either adjacent to the survey unit to be isolated or that could otherwise affect it are controlled using isolation and control techniques, are complete or are deemed not to have any reasonable potential to spread radioactive material to the survey unit;
- All tools and equipment not needed for final survey activities are removed;
- Any equipment to be used for final survey activities is evaluated to ensure it does not pose the potential for introducing radioactive material into the survey unit; and,
- Where practical, transit paths to or through the survey unit, except those required to support final survey activities, are eliminated or re-routed.

Once the area meets the isolation and control criteria, isolation and control will be achieved through a combination of personnel training, physical barriers, postings, and site notices as appropriate, to prevent unauthorized access to an isolated survey unit.

Isolation and control measures will be implemented through approved plant procedures. An administrative process will be used to evaluate, approve (or deny), and document all activities conducted in these areas during and following FSSs.

(RAI Response) MARAD procedure STS-005-032, *Survey Unit Turnover and Control* [Reference 5-10] was revised to require the performance of periodic surveillances on completed survey units.

#### 5.4.5 Selection of DCGLs

Chapter 6 of this plan describes in detail the modeling performed to develop the radionuclide specific DCGLs for room, system, and equipment surfaces. For situations where gross activity measurement methods are used to demonstrate compliance with the license termination criteria, the radionuclide specific DCGLs will be used to establish gross activity DCGLs. These gross activity DCGLs will be established based on a representative radionuclide mix established for the entire ship. In cases where measurable activity still exists, scaling factors will be used to establish the activity contribution for



any hard-to-detect radionuclides that may be present. Scaling factors will be selected from available composite waste stream analyses or similar assays. Such analyses may be performed periodically and documented in support of waste characterization needs.

For cases of survey units for which there is no measurable activity distinguishable from background, a representative radionuclide mix may be selected based upon historical characterization information for the survey unit of interest or for units with similar history and physical characteristics (e.g., information from adjacent areas).

#### 5.4.5.1 Gross Activity DCGLs

For alpha or beta surface activity measurements, field measurements will typically consist of gross activity assessments rather than radionuclide-specific techniques. Gross activity DCGLs will be established, based on the representative radionuclide mix, as follows:

$$\text{Gross Activity DCGL} = \frac{1}{\frac{f_1}{\text{DCGL}_1} + \frac{f_2}{\text{DCGL}_2} + \dots + \frac{f_n}{\text{DCGL}_n}} \quad (\text{Equation 5-1})$$

Where:

$f_n$  = fraction of the total activity contributed by radionuclide  $n$

$n$  = the number of radionuclides

$\text{DCGL}_n$  = DCGL for the Radionuclide of Concern (ROC) - presented in Chapter 6

Gross activity DCGLs will be developed for gross beta measurements. No gross alpha activity measurements will be made.

In NUREG-1757, Vol 2, Section 3.3, the NRC staff considers radionuclides and exposure pathways that contribute no greater than 10 percent of the dose criteria to be insignificant contributors. Equation 5-1 will be applied to all radionuclides in which no single radionuclide can be screened out if greater than or equal to 5% of the mix and the sum of all screened radionuclides cannot exceed 10%. If Hard-To-Detect radionuclides are not screened out, they will be included by surrogate ratio DCGL as shown below.

#### 5.4.5.2 Surrogate Ratio DCGLs

It is acceptable industry practice to assay a Hard-To-Detect (HTD) radionuclide by using a surrogate relationship to an Easy-To-Detect (ETD) radionuclide. A common example would be to use a beta measurement to assay an alpha emitting radionuclide. Another example would be to relate a specific radionuclide, such as Cesium-137 or Co-60, to one or more radionuclides of similar characteristics. In such cases, to demonstrate compliance with the release criteria for the survey unit, the DCGL for the surrogate radionuclide or mix of radionuclides must be scaled to account for the fact that it is being used as an indicator for an additional radionuclide or mix of radionuclides. The result is referred to as the surrogate DCGL.

The following process will be applied to assess the need to use surrogate ratios for FSS:

- Determine whether HTD radionuclides (e.g., Ni-63, Sr-90, H-3) are likely to be present in the survey unit based on process knowledge, historical data or characterization;
- When HTD radionuclides are likely to be present, establish a relationship using a representative number of samples (typically six or more). The samples may come from another survey unit if the source of the contamination and expected concentrations are reasonably the same. These samples will be analyzed for ETD and HTD radionuclides using gross alpha, alpha spectroscopy, gross beta analysis or gamma spectroscopy techniques;



- Screen HTD radionuclides in which no single radionuclide can be screened out if greater than or equal to 5% of the mix and the sum of all screened radionuclides cannot exceed 10%; and,
- Radionuclides not screened out will require a surrogate DCGL. Surrogate relationships will be determined from the samples results by developing a surrogate relationship for each HTD radionuclide.

The surrogate DCGL is computed as:

$$DCGL_{surrogate} = DCGL_{ETD} \times \frac{DCGL_{HTD}}{(f_{HTD:ETD} \times DCGL_{ETD}) + DCGL_{HTD}} \quad (\text{Equation 5-2})$$

Where:

$DCGL_{ETD}$  = the DCGL for the easy-to-detect radionuclide

$DCGL_{HTD}$  = the DCGL for the hard-to-detect radionuclide

$f_{HTD:ETD}$  = the activity ratio of the hard-to-detect radionuclide to the easy-to-detect radionuclide

#### 5.4.5.3 Elevated Measurement Comparison and Area Factors

The DCGL is established for the average residual contamination in a survey unit. Values of the  $DCGL_W$  may be scaled using area factors to obtain a DCGL that represents the same dose to an individual from residual contamination over a smaller area within a survey unit. Such a value is called  $DCGL_{EMC}$ , where the subscript EMC stands for Elevated Measurement Comparison. The  $DCGL_{EMC}$  is defined as the product of the applicable  $DCGL_W$  and a correction factor known as the area factor.

Area factors are only used on Class 1 land and building surveys in which the scanning Minimum Detectable Concentrations (MDC) is greater than the DCGL. Review of the scanning MDCs for the instruments to be used for the FSS are a small fraction of the DCGLs. Therefore, no area factors have been calculated and the  $DCGL_{EMC}$  will not be used.

(RAI response) All external surfaces above the  $DCGL_W$  have been or will be remediated to less than the  $DCGL_W$ . Any internal surface in a system above the  $DCGL_W$  will be remediated, or the component will be removed and properly disposed. Our investigation level is set at 75% of the  $DCGL_W$ , which is identified as the Operational  $DCGL_W$  in LTP Table 5-2. The Investigation Level for a Class 3 survey unit has been further reduced to 25% of the Operational  $DCGL_W$ . These Investigation Levels give us confidence that measurement locations greater than the  $DCGL_W$  will either be remediated or removed.

#### 5.4.5.4 Release Limits for Non-Structural Components and Systems

Non-structural components and systems will be surveyed to the DCGLs specified in Chapter 6 of this plan.

### 5.5 Final Status Survey Design Elements

The general approach prescribed by MARSSIM for FSSs requires that at least some minimum number of measurements or samples be taken within a survey unit, so that the non-parametric statistical tests used for data assessment can be applied with adequate confidence. Decisions regarding whether a given survey unit meets the applicable release criterion are made based on the results of these tests. Scanning measurements are used to check the design basis for the survey by evaluating if any small areas of elevated activity exist that would require reclassification, tighter grid spacing for the fixed measurements, or both. However, MARSSIM also recognizes that alternatives to this general approach for FSSs exist.



Specifically, MARSSIM states that if the equipment and methodology used for scanning are capable of providing data of the same quality as fixed measurements (e.g., detection limit, location of measurements, ability to record and document results), then scanning may be used in place of fixed measurements, provided that results are documented for at least the number of locations that would have been required had fixed measurements been used.

FSSs for the NSS rooms and areas will be designed, following MARSSIM guidance, using combinations of fixed measurements, traditional scanning surveys, and other advanced survey methods, as appropriate, to evaluate survey units relative to their applicable release criteria.

Under MARSSIM, the level of survey effort required for a given survey unit is determined by the potential for contamination as indicated by its classification. Class 3 survey units receive judgmental scanning and randomly located measurements or samples. Class 2 survey units receive scanning over a portion of the survey unit based on the potential for contamination, combined with fixed measurements or sampling performed on a systematic grid. Class 1 survey units receive scanning over 100% of the survey unit combined with fixed measurements or sampling performed on a systematic grid. Depending on the sensitivity of the scanning method, the grid spacing may need to be adjusted to ensure that small areas of elevated activity are detected.

For combinations of fixed measurements and traditional scanning, MARSSIM methodology is to select a requisite number of measurement locations to satisfy the decision error rates for the non-parametric statistical test to be used for data evaluation and to account for sample losses or data anomalies. The purpose of scans is to confirm that the area was properly classified and to identify elevated areas in the event that contamination is not uniformly distributed and represented by the results of fixed measurements. Depending on the sensitivity of the scanning method used, the number of fixed measurement locations may need to be increased so the spacing between measurements is reduced. Details on selecting the number and location of fixed measurements are presented in subsequent subsections of this plan. The coverage requirements that will be applied for scans performed in support of FSSs for the NSS are:

- For Class 1 survey units, 100% of the accessible surface will be scanned;
- For Class 2 survey units, between 10% and 100% of the surface will be scanned in a combination of systematic and judgmental measurements for external surface area units and for deck and lower bulkheads of structures; and 10% to 50% of the surface will be covered for upper bulkheads and overheads;
- Scanning will be done on a judgmental basis for Class 3 survey units.

Though the emphasis of MARSSIM is on conducting FSSs through a combination of fixed measurements and scans, MARSSIM also allows for use of advanced survey technologies when these techniques meet the applicable requirements for data quality and quantity. Advanced technologies in this context refers to survey techniques where the instrument is capable of recording data as an area is surveyed and the measurement sensitivity is an acceptable fraction of the applicable DCGL<sub>w</sub>. Such methods are desirable for FSSs since they allow survey units to be assessed with a single measurement rather than separate fixed measurements and scans. Advanced survey techniques may be used alone or in combination with fixed measurements and scans to assess a survey unit.

MARSSIM states that MDCs should be as far below the DCGL<sub>w</sub>, as possible, with values less than 10% of the DCGL<sub>w</sub> being preferred and up to 50% of the DCGL<sub>w</sub> being acceptable. These same criteria will be used when deciding if advanced survey techniques can be used in place of fixed measurements and traditional scans for a given survey unit.



With respect to the survey methods and techniques discussed above, the survey design criteria that will be employed for FSSs surveys for the NSS site are summarized below. Note that "fixed measurements" is used interchangeably to refer to measurements or samples taken at specific locations.

- For Class 1 or Class 2 survey units, advanced survey technologies may be used exclusively only in survey units for which the above coverage requirements can be achieved and MDCs are no greater than 50% of the applicable DCGL<sub>w</sub>.
- For Class 1 or Class 2 survey units for which advanced technologies would have an acceptable MDC, but the above coverage requirements cannot be achieved, advanced technologies may be used over 100% of the accessible area with a combination of fixed measurements and traditional scans used over the remainder of the area.

For any survey units for which advanced survey techniques are impractical, fixed measurements and traditional scans will be used exclusively in accordance with this plan.

#### 5.5.1 Selecting the Number of Fixed Measurements and Locations

The MARSSIM methodology for evaluating whether a survey unit meets its applicable release criterion using fixed measurements plus scans is based on using non-parametric statistical tests for data assessment. Specifically, the methods of MARSSIM are based on two non-parametric tests: the Wilcoxon Rank Sum (WRS) test and the Sign test. Selection of the required minimum number of data points depends on which statistical test is going to be used to evaluate the data, and thus depends on what type of measurements are to be made (gross measurement, net measurement or radionuclide specific) and if the radionuclide(s) of interest appear(s) in background. On NSS, FSS data will only be evaluated with the Sign Test because the radionuclide(s) of interest either does not exist in background or is not present in a concentration that is a relevant fraction of the DCGL<sub>w</sub>.

##### 5.5.1.1 Establishing Acceptable Decision Error Rates

One input to the process of selecting the required number of data points for a given survey, which does not depend on the statistical test applied, is the selection of the acceptable decision error rates. Decision errors refer to making false decisions by either rejecting a null hypothesis when it is true (a Type I error) or accepting a null hypothesis when it is false (a Type II error). With respect to FSSs, the null hypothesis is that the survey unit of interest contains residual contamination in excess of the applicable release criterion. Thus, a Type I error refers to concluding that an area meets the release criteria when in fact the area does not meet the release criteria. The probability of making a Type I error is referred to as alpha ( $\alpha$ ). Likewise, a Type II error refers to concluding a unit does not meet the release criteria when it actually does meet the release criteria. The probability of making a Type II error is denoted beta ( $\beta$ ). Selecting values of  $\alpha$  or  $\beta$  that are too low will result in an excessive number of fixed measurements being required. Likewise, selecting a  $\beta$  value that is too large can result in excessive costs in that survey units that meet the release criterion could be subjected to superfluous remediation efforts. Under the current regulatory models, an  $\alpha$  value that is too large equates to greater risk to the public in that there is a greater chance of releasing a survey unit that does not meet the release criterion.

The decision error rates for FSSs designed for the NSS site will be set as follows:

- The  $\alpha$  value will always be set to 0.05 unless prior NRC approval is granted for using a less restrictive value; and,
- The  $\beta$  value is nominally set to 0.05 but may be changed without NRC approval if it is found that more fixed measurements than necessary are being made to demonstrate compliance with the release criterion.



#### 5.5.1.2 Determining the Relative Shift

Another input to the process of selecting the required number of measurements that is somewhat independent of the statistical test to be employed is the determination of what is called the relative shift. The relative shift is a parameter that quantifies the concentrations to be measured in a survey unit relative to the variability in these measurements. The relative shift is a function of the  $DCGL_w$ , a parameter called the "lower bound of the gray region" (LBGR) and the expected standard deviation of the measurements to be made in the survey unit ( $\sigma_s$ ). The  $\sigma_s$  values will be selected by:

- Using existing characterization or remediation support survey data; or,
- Making preliminary measurements.

Given that  $\sigma_s$  values should reflect a combination of the spatial variability in the concentration and the precision in the method of measurement, these values will be selected based on existing survey data only when the existing measurements were made using techniques equivalent to those to be used during the FSS.

The LBGR represents the concentration to which the survey unit must be cleaned (decontaminated) to have an acceptable probability of passing the statistical test. The difference between the  $DCGL_w$  and the LBGR, known as the shift, can be thought of as a measure of the resolution of the measurements that will be made in a survey unit. If the LBGR is near the  $DCGL_w$ , the shift will be small, and thus a strong potential for Type I errors will exist. Likewise, if the shift is large, the probability of Type II errors increases. The shift is denoted as  $\Delta$ .

The relative shift ( $\Delta/\sigma_s$ ) is computed as the quotient of the shift and the appropriate standard deviation values. If no reference area data are needed to evaluate the survey results, the expected standard deviation of the measurements ( $\sigma_s$ ) is used. When preliminary data are not obtained, it may be reasonable to assume a coefficient of variation on the order of 30%, based on experience.

To compute the relative shift, the appropriate sigma value and an initial LBGR are selected. Per MARSSIM, the initial value for the LBGR will be set to one-half of the  $DCGL_w$ . If the resulting relative shift is not between 1.0 and 3.0, the LBGR is adjusted until it is. If the relative shift is too low, the LBGR is decreased; if the relative shift is too high, the LBGR is increased.

#### 5.5.1.3 Selecting the Required Number of Measurements for the Sign Test

The minimum number of fixed measurements required for the Sign test is computed by the following equation:

$$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{4(\text{Sign } p - 0.5)^2} \quad (\text{Equation 5-3})$$

Where:

- $N$  = the minimum number of measurements required
- $Z_{1-\alpha}$  = the percentile represented by the  $\alpha$  decision error
- $Z_{1-\beta}$  = the percentile represented by the  $\beta$  decision error
- $\text{Sign } p$  = the probability that a random measurement from the survey unit will be less than the  $DCGL_w$  when the survey unit median concentration is equal to the LBGR

In lieu of calculating the value of  $N$  by Equation 5-3, the value of  $N$  will be obtained from Table 5.5, "Values of  $N$  for Use with the Sign Test" in MARSSIM. On NSS, FSS data will only be evaluated

with the Sign Test because the radionuclide(s) of interest either does not exist in background or is not present in a concentration that is a relevant fraction of the DCGL<sub>w</sub>.

#### 5.5.1.4 Determining Measurement Locations

For Class 1 and Class 2 survey units, fixed measurements will be performed over a systematic measurement pattern consisting of a grid having either a triangular or a square pitch. The pitch (grid spacing) will be determined based on the number of measurements required and whether the desired grid is triangular or square. Given that a triangular grid in general is more efficient than a square grid for detecting small areas of elevated activity, triangular grids should be employed for FSSs involving fixed measurements in Class 1 and Class 2 survey units when practical.

Systematic grids will not be used for surveys involving fixed measurements for Class 3 units. Instead, fixed measurement locations will be selected at random throughout the survey unit area by generating pairs of random numbers between zero and one. One pair of random numbers will be generated for each fixed measurement to be made. The random number pairs, representing (x,y) coordinates, will be multiplied by the maximum length and width dimensions of the survey unit to yield the location for each fixed measurement. For odd-shaped survey units, a rectangular area encompassing the survey unit will be used to establish the maximum length and width. A new pair of random numbers will be generated if any of them give locations that are not actually within the survey unit boundaries. New pairs of numbers will also be generated in cases where a measurement cannot be made at a specific location because of an obstruction, inaccessibility, etc.

The spacing to be used in setting up the systematic grid used to establish fixed measurement locations for Class 1 and Class 2 areas will be computed as

$$L = \sqrt{\frac{A}{0.866N}} \quad \text{for a triangular grid, or} \quad (\text{Equation 5-4})$$

$$L = \sqrt{\frac{A}{N}} \quad \text{for a square grid} \quad (\text{Equation 5-5})$$

Where:

$L$  = *grid spacing (dimension is square root of the area)*

$A$  = *the total area of the survey unit*

$N$  = *the desired number of measurements*

The value of N should include additional measurements required to ensure against losses or unusable data.

Once the grid spacing is established, a random starting point will be established for the survey pattern using the same method as described above for selecting random locations for Class 3 units. Starting from this randomly selected location, a row of points will then be established parallel to one of the survey unit axes at intervals of L. Additional rows will then be added parallel to the first row. For a triangular grid, additional rows will be added at a spacing of 0.866L from the first row, with points on alternate rows spaced mid-way between the points from the previous row. For a square grid, points and rows will be spaced at intervals of L. Section 5.5.2.5 of MARSSIM describes the process to be used for selecting fixed measurement locations and provides examples of how to establish both a systematic grid and random measurement locations.



Measurement locations may also be determined with *Visual Sample Plan (VSP)*. Pacific Northwest National Laboratory created VSP. VSP is a software tool that supports the development of a defensible sampling plan based on statistical sampling theory and the statistical analysis of sample results to support confident decision making. VSP couples the site, building, room and sample location visualization capabilities with optimal sampling design and statistical analysis strategies.

### 5.5.2 Judgmental Assessments

For those Class 2 and Class 3 survey units for which 100% of the area is not surveyed, it is important to consider performing judgmental assessments to augment any regimented measurements made in accordance with the above guidance. Such assessments may consist of biased measurements performed in locations based on site knowledge and professional judgment. Judgmental assessments serve to provide added assurance that residual contamination on the ship has been adequately located and characterized. The basis for judgmental assessments will be documented in the survey package for each survey unit.

### 5.5.3 Data Investigations

#### 5.5.3.1 Investigation Levels

An important aspect of the FSS is the selection and implementation of investigation levels. Investigation levels are levels of radioactivity used to indicate when additional investigations may be necessary. Investigation levels also serve as a quality control check to determine when a measurement process begins to deviate from expected norms. For example, a measurement that exceeds an investigation level may indicate a failing instrument or an improper measurement. However, in general, investigation levels are used to confirm that survey units have been properly classified.

When an investigation level is exceeded, the first step is to confirm that the initial measurement result exceeds the particular investigation level. Depending on the results of the investigation actions, the survey unit may subsequently require reclassification, remediation, and/or resurvey. Investigation levels are established for each class of survey unit. The investigation levels (criteria), to be employed for the FSS effort, are given in Table 5-2 (revised per RAI Response).

**Table 5-2 Investigation Levels (RAI Response)**

| <b>Survey Unit Classification</b> | <b>For fixed measurements, perform investigation if:</b> | <b>For scan measurements, perform investigation if:</b> |
|-----------------------------------|----------------------------------------------------------|---------------------------------------------------------|
| Class 1                           | > Operational DCGL <sub>w</sub> .                        | > Operational DCGL <sub>w</sub>                         |
| Class 2                           | > Operational DCGL <sub>w</sub>                          | > Operational DCGL <sub>w</sub>                         |
| Class 3                           | > 0.25 × Operational DCGL <sub>w</sub>                   | >0.25 x Operational DCGL <sub>w</sub>                   |
| Systems and Components            | > Operational DCGL <sub>w</sub>                          | > Operational DCGL <sub>w</sub>                         |

(RAI Response) For Class 1 survey units, measurements above the DCGL<sub>w</sub> are not necessarily unexpected. Measurements in Class 1 survey units that exceed the DCGL<sub>w</sub> will be investigated.

In Class 2 or Class 3 areas, neither measurements above the DCGL<sub>w</sub> nor areas of elevated activity are expected. Thus, any fixed measurements or sampling results that exceed the DCGL<sub>w</sub> in these areas will be investigated. In the case of Class 3 areas, where any residual radioactivity would be



unexpected, fixed measurement or sample results that are greater than  $0.25 \times \text{DCGL}_w$  will be investigated.

In cases where an advanced survey method is used instead of fixed measurements, the investigation levels given in Table 5-1 for fixed measurements will be applied.

#### 5.5.3.2 Investigations

Locations where initial measurements give results that exceed an applicable investigation level will be identified for confirmatory measurements. If it is confirmed that residual activity exists in excess of the investigation level, additional measurements will be made to determine the extent of the area of elevated activity and to provide reasonable assurance that other areas of elevated activity do not exist. Potential sources of the elevated activity will be postulated and evaluated against the original classification of the survey unit and its associated characterization data. The possibility of the source of the elevated activity having affected other adjacent or nearby survey units will also be evaluated. Documentation will be compiled containing the results from the investigation surveys and showing any areas where residual activity was confirmed to be in excess of the investigation level. If residual activity in excess of the applicable investigation level is confirmed, the documentation will also address the potential source(s) of the activity and the impact this has on the original classification assigned to the survey unit. A decision will then be made regarding re-classification of the unit in whole or in part.

#### 5.5.3.3 Remediation (RAI Response)

If during the performance of an FSS, any areas of residual activity are found to be in excess of the  $\text{DCGL}_w$ , those areas will be remediated with the goal to reduce the activity to less than or equal to the  $\text{DCGL}_w$ . Remediation actions are discussed in Section 4 and documented as described in Section 5.10.

#### 5.5.3.4 Re-classification

If survey results from a Class 2 unit indicate residual activity in excess of the  $\text{DCGL}_w$ , all or part of the survey unit will be re-classified as Class 1. The decision to either re-classify the entire survey unit or sub-divide it, will depend on the areal extent of the activity found to exceed the  $\text{DCGL}_w$ . If a survey unit is sub-divided, the portion of the unit containing the elevated activity will be assigned the more restrictive classification, while the remainder of the unit will retain its original classification.

If survey results for a Class 3 survey unit indicate unexpected residual activity, all or part of the unit containing the activity will be re-classified. Since Class 3 survey units tend to be physically large, it is not anticipated that an entire unit would require re-classification in the event unexpected residual activity is found. However, if the unit is small enough, it is possible an entire Class 3 unit could be re-classified.

If residual activity is found in a Class 3 survey unit at levels equal to 50% of the  $\text{DCGL}_w$ , the affected portion of the unit will be re-classified as Class 2. In the unlikely event that residual activity is found in excess of the  $\text{DCGL}_w$ , the affected area will be re-classified as Class 1.

Re-classification of areas from a less to a more restrictive classification may be done without prior NRC approval; however, re-classification to a less restrictive classification would require prior NRC approval. MARAD does not expect to make less restrictive reclassifications after submittal of the LTP.

#### 5.5.3.5 Re-survey

If a survey unit is re-classified (in whole or in part), or if remediation is performed within a unit, then the areas affected are subject to re-survey. Any re-surveys will be designed and performed as



specified in this plan based on the appropriate classification of the survey unit. That is, if a survey unit is re-classified or a new survey unit is created, the survey design will be based on the new classification.

If a survey unit is sub-divided, the survey design for the remaining area of the original survey unit may or may not be affected depending on the remaining surface area of the unit and its classification. If the original survey unit was Class 3, then the only impact on the survey design (in the case of fixed measurements or sampling) is to perform additional measurements at randomly selected locations until the required total number of measurements is met. If the original survey unit was Class 2, the spacing of the measurement locations may need to be adjusted depending on the remaining surface area of the survey unit relative to its original area. If there is a large change in the surface area, then a new survey design will be necessary to accommodate the required number of measurements in the smaller area. If there is not a large change in area, then the impact on the grid spacing is minimal (with respect to areal coverage), and additional measurement locations need only be selected at random to obtain the required number of measurements. Thus, for the purpose of FSSs at the NSS, a change in the surface area of a Class 2 survey unit that changes the grid spacing by 25% or less will not require fixed measurements or sampling to be repeated using a tighter spacing. If the change in surface area is such that the grid spacing is changed by more than 25%, a new survey design will be required. Assessments against the 25% criterion, if applicable, will be an element of the investigation process and documented in the FSS report for the affected survey unit.

If remediation is required in only a small area of a Class 1 survey unit, any replacement measurements required will be made within the remediated area at systematically selected locations following verification that the remediation activities did not affect the remainder of the unit. Re-survey will be required in any area of a survey unit affected by subsequent remediation activities.

### ***5.6 Survey Protocol for Non-structural Systems and Components***

The guidance provided in MARSSIM for conducting FSSs does not include guidance for conducting FSSs for non-structural system or components. Non-structural systems and components refer to anything not attached to or not an integral part of a building or structure.

Surface activity assessments for non-structural systems and components can be made by making measurements at traps, tanks, open piping and other appropriate access points where activity levels should be representative of those on the interior surfaces. Assessments may also be made via in-situ gamma-spectroscopy or pipe crawlers, provided adequate instrument efficiencies and detection limits can be achieved. Detection limits for surface activity assessments should be at least 50% of the release limits. If necessary, scaling factors may be applied to establish gross activity levels via radionuclide-specific measurements or other assessments, as appropriate. MARAD expects limited use of in-situ gamma-spectroscopy or pipe crawlers.

Evaluations as to whether 1) material should be considered as a structure or a component will be made and 2) comparisons with the dose modeling scenarios used to develop the DCGLs that govern release of structures. Examples of parts of structures that are considered in the development of DCGLs include decks, bulkheads, overheads, doors/hatches, windows/portholes, sinks, hoods, lighting fixtures, built-in laboratory benches, and built-in furniture. Examples of non-structural systems and components include pumps, motors, heat exchangers, and piping between components.

### ***5.7 Survey Implementation and Data Collection***

The requirements and objectives outlined in the LTP and the DQAP [Reference 5-6] will be incorporated into approved procedures. Procedures will govern the survey design process, survey performance and data assessment (decision making). The FSS design will be carried out in accordance with the approved



procedures and the DQAP, resulting in the generation of raw data. The product of the survey design process is a survey package, which addresses various elements of the survey, including, but not limited to:

- Maps of the survey area showing the survey unit(s) and measurement/sample locations, as appropriate;
- Applicable DCGLs;
- Instrumentation to be used;
- Types and quantities of measurements to be made or collected;
- Investigation criteria;
- QA/QC requirements (e.g., replicate measurements);
- Applicable health and safety procedures; and,
- Applicable operating procedures.

#### 5.7.1 Survey Methods

The survey methods to be employed in the FSSs will consist of combinations of scanning, fixed measurements, advanced technologies, sampling, and other methods as needed to meet the survey objectives. Additional methods may be used if such become available between the time this plan is adopted and final survey activities are completed. However, any new technologies must still meet the applicable requirements of this plan. Note that in some cases, the same instrument may be used for more than one type of survey.

##### 5.7.1.1 Scanning

Scanning is the process by which the operator uses portable radiation detection instruments to detect the presence of radionuclides on a specific surface (i.e., bulkhead, deck, equipment). The term scanning survey is used to describe the process of moving portable radiation detectors across a surface with the intent of locating residual radioactivity. Investigation levels for scanning surveys are determined during survey planning to identify areas of elevated activity. Scanning surveys are performed to locate contamination anomalies indicating residual gross activity that may require further investigation or action. These investigation levels may be based on the DCGL<sub>w</sub>.

No matter what survey approach is selected (combination of instrumentation and techniques), one of the most important elements of a survey is *a priori* scanning to confirm that the unit is properly classified and to identify any areas where residual activity levels are elevated relative to the DCGL<sub>w</sub>. The purpose of scanning is to detect areas of residual activity that may not be detected by other measurement methods. Thus, scanning should always be performed prior to any fixed measurements or sample collections in a survey unit. If the scanning indicates that the unit or some area within the unit has been improperly classified, then the survey design process must be evaluated to either assess the effect of re-classification on the survey unit as a whole (if the whole unit requires re-classification) or a new design must be established for the new unit(s) (in the case of sub-division). A new survey design will require a re-evaluation of the survey strategy to decide if it can meet the requirements of the revised survey design. If not, the survey strategy must be revised based on the available instrumentation and methods.

Table 5-3 gives the areal coverage requirements when scanning is used with fixed measurements.



**Table 5-3 Traditional Scanning Coverage Requirements**

| Survey Unit Classification | Required Scanning Coverage Fraction                                                         |
|----------------------------|---------------------------------------------------------------------------------------------|
| Class 1                    | 100%                                                                                        |
| Class 2                    | Decks, or lower bulkheads of rooms: 10% to 100%<br>Upper bulkheads or overheads: 10% to 50% |
| Class 3                    | Judgmental                                                                                  |
| Systems and Components     | Judgmental                                                                                  |

#### 5.7.1.2 Fixed Measurements

Fixed measurements are taken by placing the instrument at the appropriate distance above the surface, taking a discrete measurement for a pre-determined time interval, and recording the reading. Fixed measurements may be collected at random locations in a survey unit or may be collected at systematic locations and supplement scanning surveys for the identification of small areas of elevated activity. Fixed measurements may also be collected at locations identified by scanning surveys as part of an investigation to determine the source of the elevated instrument response. Professional judgment may also be used to identify locations for fixed measurements to further define the areal extent of contamination. Locations for fixed measurements specified by a given survey design will be established as discussed in Section 5.5.

#### 5.7.1.3 Advanced Technologies (RAI Response)

The advanced technologies in Section 5.7.1.3 focused on the use of the surface contamination monitor. Due to technical difficulties with this equipment, MARAD will not be using this equipment for Final Status Surveys (FSS). One advanced technology, not found in NRC guidance, is the use of in-situ gamma spectrometry or commonly called the ISOCS. This technology will be used under certain circumstances for FSS.

In the context of this Plan, advanced technologies refer to survey instruments or methods that do not use conventional hand-held detectors connected to ratemeters or scalars. The ISOCS has been widely used for final status surveys at recent nuclear power plant decommissionings, primarily for subsurface concrete evaluations. MARAD is planning on using the ISOCS for measurements on the steam drums and potentially on portions of the CV, RC or other areas where ISOCS measurements can save time and cost rather than using conventional survey equipment. The count times will be long enough to ensure that the MDCs for any count will fall in the MARSSIM recommended range of 10 to 50 percent of the DCGLs. A technical document, CR-167 [Reference 5-15], evaluates the sensitivity of the ISOCS for use on the steam drums and structural surfaces that shows that the ISOCS has sufficient sensitivity to be used for Final Status Surveys of surfaces and components.

The operation of the ISOCS system is described by SAVANNAH Technical Staff (STS) procedure OI-CANBERRA ISOC-01, *Operation of Canberra in Situ Object Counting Systems* [Reference 5-16]. That procedure specifies that quality control checks be performed prior to collecting measurements and following the completion of work at the end of the day. The results of these checks are recorded in the Final Status Survey Package paperwork.

The individuals using the ISOCS system are provided by MARAD's joint venture decommissioning integrated services provider, Nuclear Ship Support Services, LLC (NSSSJV). NSSSJV competes for these individuals within the wider domestic active decommissioning market. Given the large



number of such projects ongoing, readily qualified personnel are in short supply; not just for ISOCS operation, but for many FSS activities. To address this shortfall, NSSSJV sourced FSS technicians from the population of highly trained Radiation Protection Technicians (RPTs) that service operating plants. To prepare these individuals to perform FSSs, a specialized three-day training course for Final Status Survey technicians, identified as the FSS Academy, was developed and deployed by NSSSJV partner Radiation Safety and Control Services, Inc. (RSCS) in early 2024. The three instructors for this course were health physicists certified by the American Board of Health Physics (ABHP), and each have over thirty years of professional health physics experience including ISOCS modeling. The three instructors are Subject Matter Experts. The two day classroom portion was designed for managers, supervisors and technicians. It discussed an overview of MARSSIM, the NSS LTP and implementation of Final Status Survey packages. .

On the third day, Final Status Survey technicians received specialized training on the use of instrumentation, including the ISOCS. The technicians were taught how to perform a quality control check as well as how to collect a measurement. The technicians only perform these two tasks. The collected spectrum, along with a picture of the measurement surface and the distance from the detector to the measurement surface are sent to a qualified subject matter expert to generate the efficiency model in the Geometry Composer software and perform the analysis. Academy RPT participants are required to pass a written exam and practical factors demonstration before qualifying as FSS Technicians.

Duplicate ISOCS measurements would only be performed when the entire data set in a survey unit was from ISOCS measurements. Currently, the ISOCS is being used to investigate or verify radioactivity concentrations causing an elevated gross activity measurement. There are no current plans to perform an entire ISOCS based survey in a survey unit. If that becomes the case, then a duplicate measurement will be prescribed in the Final Status Survey Package per STS-005-030, *Preparation of FSS Packages* [Reference 5-8]. If the ISOCS measurement results are grossly different than the fixed measurements, the Health Physicist performing the comparison would adjust the model parameters to reach better agreement or to reassess or re-perform the fixed measurements and/or scans as part of the data assessment process.

The depth profile analysis is a common technique that is applied to volumetric residual radioactivity in concrete for land-based nuclear power plants. For the NSS, residual radioactivity is limited to metal surfaces and is not distributed to depths within the metal surface to an extent where modeling differences would be manifested.

#### 5.7.1.4 Samples

Sampling is the process of collecting a portion of a medium as a representation of the locally remaining medium. The collected portion of the medium is then analyzed to determine the radionuclide concentration. Examples of materials that may be sampled include trap sediments and lagging. Samples will be collected during characterization surveys. No samples are anticipated during FSSs.

If water or sludge is encountered in a system during FSS, sample results will be compared the Effluent Concentrations (ECs) listed in Table 2, Column 2 of Appendix B to 10CFR20. If the sample results are greater than the ECs, the medium will be remediated or removed.

All collected samples will be controlled under the chain of custody protocols. Samples will be sent to off-site laboratories that 1) participate in inter- and intra-laboratory comparisons, 2) use NIST traceable sources, 3) have a corrective action program and 4) have an internal audit program.

(RAI Response) At license termination, no reactor plant related water or sediment will remain on the ship.



## **5.7.2 Survey Instrumentation**

### **5.7.2.1 Instrument Selection**

The selection and proper use of appropriate instruments for both fixed measurements and scanning is one of the most important factors in assuring that a survey accurately determines the radiological status of a survey unit and meets the survey objectives. The particular capabilities of a radiation detector establish its potential for being used in conducting a specific type of survey. For certain radionuclides or radionuclide mixtures, both alpha and beta radiation may have to be measured. In addition to assessing average radiological conditions, the survey objectives must address identifying small areas of elevated activity.

The radiation detectors to be used for final survey activities at the NSS can be divided into three general classes:

- Gas-filled detectors;
- Scintillation detectors; and,
- Solid-state detectors.

Gas-filled detectors include ionization chambers, proportional counters (both gas-flow and pressurized) and Geiger-Mueller (GM) detectors. Scintillation detectors include plastic scintillators, zinc-sulfide (ZnS) detectors, and sodium-iodide (NaI) detectors. Solid-state detectors include both n-type and p-type intrinsic germanium detectors.

Instruments must be stable and reliable under the environmental and physical conditions where they will be used, and their physical characteristics (size and weight) should be compatible with the intended application. The instrument must be able to detect the type of radiation of interest, and, depending on the application, the measurement system should be capable of measuring levels that are less than the  $DCGL_W$ . However, in some cases instruments used for scanning may have detection limits that are greater than the  $DCGL_W$ . This is allowed by MARSSIM and is acceptable as long as the grid spacing (for Class 1 survey units) and investigation levels used are in accordance with this plan.

Instrument detection limits are typically quantified in terms of their minimum detectable concentration (MDC). The MDC is the concentration that a given instrument and measurement technique can be expected to detect 95% of the time under actual conditions of use.

In general, instruments used for measurements to demonstrate that the average concentration in a survey unit is less than the  $DCGL_W$  should have an MDC that is no greater than 50% of the  $DCGL_W$ . However, though it is not anticipated, there may be special circumstances where the best available technology cannot meet this goal. In such a case, measurements will be made at the best MDC that can be achieved.

### **5.7.2.2 Calibration and Maintenance**

All instrumentation used for measurements to demonstrate compliance with the radiological criterion for license termination at the NSS will be calibrated and maintained under approved procedures and the DQAP or vendor QA plan that satisfies the requirement of the DQAP. Instruments will be calibrated for normal use under typical field conditions. Calibration standards will be traceable to the National Institute of Standards and Technology. If external vendors are used for instrument calibration or maintenance, these services must be approved and conducted under the DQAP. Calibration records will be maintained as required by approved procedures and the DQAP.

Instruments used to measure gross beta surface activity will be calibrated to Tc-99 or Co-60 to bound the beta energies for the beta-emitting radionuclides that will be encountered during final survey activities. Based upon the characterization data in CR-109 [Reference 5-17], measurements for alpha activity will not be needed. If additional characterization activities are performed and alpha measurements are needed, Pu-239 or Th-230 will likely be used to calibrate instruments used to assess alpha surface activity or the alpha surface activity will be scaled to an Easy-to-Detect radionuclide.

Instrument efficiencies may require modifications to account for surface conditions or paint coverings. Such modifications, if necessary, will be established using the information in Section 5 of NUREG-1507 [Reference 5-18] and pertinent site characterization data.

#### 5.7.2.3 Operational Checks

Instrumentation will be checked for proper operation in accordance with approved procedures. If the instrument operational check does not fall within the established range, the instrument will be removed from use until the reason for the deviation can be resolved and acceptable operation is again demonstrated. If the instrument fails a post-survey source check, all data collected during that time period with the instrument will be carefully reviewed and possibly adjusted or discarded, depending on the cause of the failure.

(RAI Response) Performance of operational checks is specified in the Final Status Survey Packages per STS-005-030, *Preparation of FSS Packages* [Reference 5-8]. A special form for documenting operational checks is included in the survey packages. Operational checks are required on a daily basis and are conducted prior to performing the survey. Additional operational checks are performed during the shift and at the end of the day for the full duration of the survey.

#### 5.7.2.4 MDC calculations

Before any measurements are performed, the instruments and techniques to be used must be shown to have sufficient detection capability relative to the applicable DCGLs. The detection capability of a given instrument and measurement technique is quantified by its MDC.

##### 5.7.2.4.1 MDCs for Static Measurements

Per NUREG-1507, MDCs for static measurements in which the background and sample count times are equal are computed as:

$$MDC_{static} = \frac{3 + 4.65\sqrt{B}}{Kt} \quad \text{(Equation 5-6)}$$

Where:

**3 and 4.65** = constants as described in NUREG-1507

**B** = background counts during the measurement time interval (t)

**t** = counting time

**K** = a proportionality constant that relates the detector response to the activity level in the sample being measured

The proportionality constant K typically encompasses the detector efficiency, self-absorption factors and probe area corrections, as required. The dimensions of the counting interval "t" are consistent with those for the MDC and the proportionality constant K. Thus, "t" would be in minutes to compute an MDC in dpm/100cm<sup>2</sup>.



Calculation of the MDC in which the background and measurement count times are not equal are computed as:

$$\text{MDC}_{\text{static}} = \frac{3 + 3.29 \sqrt{R_b t_s (1 + \frac{t_s}{t_b})}}{\text{eff} * t_s * (\frac{A}{100})} \quad (\text{Equation 5-7})$$

Where:

- $R_b$  = background count rate (c/m)
- $t_s$  = sample count time (min)
- $t_b$  = background count time (min)
- $\text{eff}$  = counting efficiency (c/d) = source efficiency ( $\epsilon_s$ ) x instrument efficiency ( $\epsilon_i$ )
- $A$  = physical area of detector (cm<sup>2</sup>)

#### 5.7.2.4.2 MDCs for Beta-Gamma Scan Surveys for Structure Surfaces

As recommended in NUREG-1507, MDCs for surface scans for structure surfaces for beta and gamma emitters will be computed as:

$$\text{MDC}_{\text{scan}} = \frac{1.38 \sqrt{B_t * (\frac{60}{t})}}{\sqrt{p} * \text{eff} * (\frac{A}{100})} \quad (\text{Equation 5-8})$$

Where:

- 1.38 = sensitivity index,
- $B$  = number of background counts in time interval  $t$
- $p$  = surveyor efficiency = 0.5
- $\text{eff}$  = counting efficiency (c/d) = source efficiency ( $\epsilon_s$ ) x instrument efficiency ( $\epsilon_i$ )
- $A$  = physical area of the detector (cm<sup>2</sup>)
- $t$  = time interval of the observation while the probe passes over the source

The value of 1.38 used for the sensitivity index corresponds to a 95% confidence level for detection of a concentration at the scanning MDC with a false positive rate of 60%. The factor of 100 corrects for probe areas that are not 100cm<sup>2</sup>. In the case of a scan measurement, the counting interval is the time the probe is over the source of radioactivity. This time depends on scan speed, the size of the source, and the fraction of the detector's sensitive area that passes over the source; with the latter depending on the direction of probe travel. The efficiency term in Equations 5-7 and 5-8 may be adjusted to account for effects such as self-absorption, as appropriate.

(RAI Response) MARAD reviewed MARSSIM and determined that a sensitivity index (d') factor of 1.38 is appropriate for our use. This is a conservative administrative decision and the training we conducted with the FSS technicians included field scanning using simulation technology which stressed that the scanning should be reversed and slowed for areas where an elevated response is perceived. MARAD's use of 1.38 for the sensitivity index is consistent with our FSS training. In addition, use of 1.38 has been an industry standard in nuclear power plant License Termination Plans such as Humboldt Bay, Zion, LaCrosse, Fort Calhoun, Yankee Rowe, Connecticut Yankee, and Maine Yankee (i.e., it is a precedent) and is used as the

performance goal in an example calculation of the minimum detectable count rate in MARSSIM

5.7.2.5 Typical Instrumentation and MDCs

(RAI Response) The revised Table 5-4 provides nominal data for the types of field instrumentation anticipated for use in the final survey efforts for the NSS.



Table 5-4 Available Instruments and Associated MDCs (RAI Response)

| Instrument                                                      | Application                                              | Nominal Background | Nominal MDC (fixed measurement)                                                         | Nominal Scan MDC                    |
|-----------------------------------------------------------------|----------------------------------------------------------|--------------------|-----------------------------------------------------------------------------------------|-------------------------------------|
| ZnS scintillator Ludlum Model 43-93 (100cm <sup>2</sup> )       | beta-gamma scans or fixed measurements                   | 150 cpm            | 394 dpm/100cm <sup>2</sup> Note 1                                                       | 1603 dpm/100cm <sup>2</sup> Note 2  |
| Gas Flow Proportional Ludlum Model 43-37 (584 cm <sup>2</sup> ) | beta-gamma scans                                         | 350 cpm            | N/A                                                                                     | 452 dpm/100 cm <sup>2</sup> Note 3  |
| 2" x 2" NaI detector connected to Osprey MCA                    | in-situ gamma spectroscopy                               | N/A                | Co-60 2.20E3 dpm/100 cm <sup>2</sup><br>Cs-137 2.15E3 dpm/100 cm <sup>2</sup><br>Note 4 | N/A                                 |
| Cesium Iodide (CsI) scintillator Ludlum Model 44-159-1          | gamma scans or fixed measurements inside pipes and ducts | 100 cpm            | 1310 dpm/100 cm <sup>2</sup> Note 5                                                     | 3630 dpm/100 cm <sup>2</sup> Note 6 |

## General notes:

Efficiencies of the Ludlum 43-93 and 43-37 detectors have been determined with 2 large area NIST certified Tc-99 and Cs-137 calibration sources. Efficiencies of the ISOCS detector are determined with Geometry Composer software. Efficiencies of the Ludlum 44-159-1 detector have been determined by MicroShield® and empirical testing.

(RAI Response) Note 1: Detector in contact with surface, scalar setting equal to 1-minute count time for both background and measurement, total weighted efficiency equal to 0.152 c/d.

(RAI Response) Note 2: Detector at 0.75 inches from the surface, circular hot spot area equal to 100 cm<sup>2</sup>, scan speed equal to 1 detector width per second (9.14 cm/s), total weighted efficiency equal to 0.104 c/d.

(RAI Response) Note 3: Detector at 0.75 inches from the surface, circular hot spot area equal to 100 cm<sup>2</sup>, scan speed equal to 1 detector width per second (15.9 cm/s), total weighted efficiency equal to 0.127 c/d.

(RAI Response) Note 4: Source to detector distance equal to 1 meter, detector with 90-degree collimator, circular plane geometry, source thickness equal to 2 mm, count time equal to 1000 seconds.

(RAI Response) Note 5: The Field of View (FOV) and source length is equal to 1 foot, detector in contact with bottom of pipe or duct, scalar setting equal to 1-minute count time for both background and measurement, total weighted efficiency equal to 0.0377 c/d for a 1.5 inch diameter pipe.

(RAI Response) Note 6: The Field of View (FOV) and source length is equal to 1 foot, detector in contact with bottom of pipe or duct, scan speed equal to 0.25 m/s, total weighted efficiency equal to 0.0377 c/d for a 1.5 inch diameter pipe.

(RAI Response) The static and scan MDCs in the updated Table 5-4 were calculated with the total weighted efficiencies as documented in CR-164, *Calculation of Weighted Efficiencies and MDCs of Ludlum Detectors for Final Status Surveys on the NS SAVANNAH* [Reference 5-19]. The efficiencies used to calculate the MDCs in Table 5-4 are based upon the total efficiency, not with the source and instrument efficiencies. MARSSIM states that the use of a total efficiency derived from measurements made on certified  $4\pi$  activity traceable sources "...is not a problem, provided that the calibration source exhibits characteristics similar to the surface contamination (i.e., radiation energy, backscatter effects, source geometry, self-absorption)." Those four parameters were evaluated in CR-164 with the conclusion that the calibration sources exhibit characteristics similar to the surface contamination on the ship. Table 5-4 has been revised to list the MDC for the ISOCS system in dpm/100 cm<sup>2</sup>. The ISOCS system is a 2" x 2" NaI detector connected to an Osprey MCA with a 90-degree collimator. The evaluation of the ISOCS for use in Final Status Surveys has been documented in CR-167, *Use of In-Situ Gamma Spectroscopy for Final Status Survey (FSS) at the NS SAVANNAH* [Reference 5-15].

(RAI Response) A pipe crawler, per se, will not be used for Final Status Surveys. The detector chosen for internal pipe and duct measurements for FSS is a Ludlum 44-159-1, which is a 0.7 inch diameter Cesium Iodide (CsI) scintillator. The MDCs listed in Table 5-4 were taken from CR-165, *Efficiency and MDC of Ludlum Pipe Detectors for Final Status Survey (FSS) on the NS SAVANNAH* [Reference 5-20].

(RAI Response) Sodium Iodide (NaI) detectors are used for scanning during Remedial Action Support Surveys (RASS) to identify elevated locations in a survey unit. The only NaI detector used in FSS is the ISOCS.



### 5.7.3 Survey Considerations for Structures and Equipment

The condition of surfaces following decontamination activities can affect the choice of survey instruments and techniques. Surface irregularities may also cause difficulty in rolling or maneuvering detector systems on wheels. In such cases, depending on the survey instrumentation used and the radiations of interest, evaluations of instrument efficiencies may be required to assess the need for corrections for variables such as source-to-detector distance or surface condition. Surface efficiency corrections, if necessary, may be established using the information given in Section 5 of NUREG-1507 or, if practical, via fixed measurements. If any corrections to measurement efficiencies are required, the impact of these corrections on instrument MDCs will be assessed to ensure that measurements can still be performed with the required sensitivity relative to the applicable DCGLs.

Expansion joints, stress cracks, deck/bulkhead interfaces and penetrations into decks and bulkheads for piping, conduit, anchor bolts, etc., are potential sites for accumulation of contamination and pathways for migration into bilges and hollow bulkhead spaces. External surfaces and drainage points are also important survey locations.

### 5.8 Survey Data Assessment

Prior to evaluating the data collected from a survey unit against the release criterion, the data are first confirmed to have been acquired in accordance with all applicable procedures and QA/QC requirements. Any discrepancies between the data quality or the data collection process and the applicable requirements are resolved and documented prior to proceeding with data analysis. Data assessment will be performed by trained personnel using approved procedures.

The first step in the data assessment process is to convert all survey results to DCGL units. Next, the individual measurements and sample concentrations will be compared to DCGL levels for evidence of small areas of elevated activity or results that are outliers relative to the rest of the measurements. Graphical analyses of survey data that depict the spatial correlation of the measurements are especially useful for such assessments and will be used to the extent practical. The results may indicate that additional data or additional remediation and resurvey may be necessary. If this is not the case, the survey results will then be evaluated using direct comparisons or statistical methods, as appropriate, to determine if they exceed the release criterion. If the release criterion has been exceeded or if results indicate the need for additional data points, appropriate further actions will then be determined.

Interpreting the results from a survey is most straightforward when all measurements are higher or lower than the  $DCGL_w$ . In such cases, the decision that a survey unit meets or exceeds the release criterion requires little in terms of data analysis. However, formal statistical tests provide a valuable tool when a survey unit's measurements are neither clearly above nor entirely below the  $DCGL_w$ .

The first step in evaluating the data for a given survey unit is to draw simple comparisons between the measurement results and the release criterion. The result of these comparisons will be one of three conclusions: 1) the unit meets the release criterion; 2) the unit does not meet the release criterion; or 3) no conclusion can be drawn from simple comparisons and thus one of the non-parametric statistical tests must be applied.

The initial data evaluation will be as described in Table 5-5.

**Table 5-5 Initial Evaluation of Survey Results (Background Reference Area Not Used)**

| <b>Evaluation Result</b>                                                                                                        | <b>Conclusion</b>                               |
|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| All measured concentrations less than the DCGL <sub>w</sub>                                                                     | Survey unit meets the release criterion         |
| Average concentration exceeds the DCGL <sub>w</sub>                                                                             | Survey unit does not meet the release criterion |
| Individual measurement result(s) exceeds the DCGL <sub>w</sub> and the average concentration is less than the DCGL <sub>w</sub> | Conduct the Sign test                           |

Note that given the site contains no soil, laboratory analysis is not anticipated. Similarly, split sampling is not anticipated given that it is typically associated with evaluating soil.

### 5.8.1 Sign Test

Radionuclide specific measurements for which the radionuclide(s) of interest either does not exist in background or is not present in a concentration that is a relevant fraction of the DCGL<sub>w</sub> will be evaluated using the Sign test. In addition, the Sign test may be used to evaluate gross activity measurements from survey units containing multiple materials.

The Sign test is applied as described in the following steps:

1. (RAI Response) For each survey unit measurement, subtract the gross activity measurement from the DCGL<sub>w</sub> and record the differences.
2. Discard any difference that is exactly zero and reduce the total number of measurements (N) by the number of zero differences.
3. Count the number of positive differences. This value is the test statistic S+.
4. Compare the number of positive differences (S+) to the critical values from Table I.3 of the MARSSIM for the appropriate values of N (total measurements) and α (decision error rate). (A positive difference corresponds to a measurement below the DCGL<sub>w</sub> and contributes evidence that the survey unit meets the release criterion.)

If S+ is greater than the critical value in MARSSIM Table I.3, then the null hypothesis is rejected, and the survey unit meets the release criteria.

(RAI Response) MARAD is ignoring ambient background and is not subtracting ambient background from each gross activity measurement prior to performing the Sign Test. MARAD determined this is a conservative decision because the measurement is biased to a higher value. The revised Section 5.8.1 is as stated in the above three paragraphs.

### 5.8.2 Unity Rule

When radionuclide specific measurements are made in survey units having multiple radionuclides, compliance with the radiological release criterion will be assessed through use of the unity rule, also known as the sum of fractions. The unity rule, represented in the expression below, is satisfied when radionuclide mixtures yield a combined fractional concentration limit that is less than or equal to one, i.e.:

$$\frac{C1}{DCGL1} + \frac{C2}{DCGL2} + \dots + \frac{Cn}{DCGLn} \leq 1 \quad \text{(Equation 5-9)}$$



Where:

$C_n$  = Concentration of radionuclide  $n$

$DCGL_n$  = DCGL for radionuclide  $n$

### 5.8.3 Data Assessment Conclusions

The result of the data assessment is the decision to reject or not to reject the null hypothesis. A rejection of the null hypothesis leads to the decision that the survey unit meets the release criterion. If the data assessment concludes that the null hypothesis cannot be rejected, this may be due to one of two things: 1) the average residual concentration in the survey unit exceeds the  $DCGL_w$ ; or 2) the analysis did not have adequate statistical power. "Power" in this context refers to the probability that the null hypothesis is rejected when it is indeed false. A retrospective power analysis can be used if a survey unit is found not to meet the release criterion to determine if this is indeed due to excess residual activity or if it is due to an inadequate sample size.

Retrospective power analyses, if necessary, will be performed following the methods of MARSSIM Section I.9 for the Sign test. If the analysis finds that an inadequate number of measurements were collected to support the data assessment for a given survey unit, additional measurements may be collected, and the analysis will be repeated. Increasing the number of measurements acquired within a given survey unit increases the probability of rejecting the null hypothesis when it is indeed false. Likewise, if the analysis with the additional measurements still concludes that the residual concentration in the survey unit exceeds the  $DCGL_w$ , then the unit must be remediated and resurveyed.

## 5.9 Notes on Structure and System Surveys

As described in Chapter 3, a number of structures and components have been left in-situ and are expected to be retained subject to confirmation through FSS. This section describes FSS considerations for these structures and components, which includes the ship's hull itself.

### 5.9.1 Exterior Hull Survey

As described in detail in Chapter 2, a MARSSIM based survey of the exterior hull while the ship was on drydock was performed in 2019 [Reference 5-21].

The MARSSIM survey of the exterior hull demonstrates that:

- No unexpected results or trends are evident in the data;
- The sampling and survey results demonstrate that residual radioactivity in the survey areas are indistinguishable from background levels;
- The data quality meets the necessary requirements and is deemed to be acceptable for its intended purpose;
- The amount of data collected from each survey unit is adequate to provide the required statistical confidence needed to decide that the DCGLs are met; and,
- All measurements were well below the Co-60 building surface screening level in NUREG-1757.

MARAD proposes that these surveys are acceptable for FSS and therefore, the null hypothesis that residual radioactivity in the survey units exists in concentrations above the applicable DCGLs should be rejected for the survey units of the hull.

An FSS report will be prepared and submitted for these hull surveys.



### **5.9.2 Neutron Shield Tank / Fuel Transfer Tank**

The primary (neutron) shield tank surrounds the reactor vessel up to the hot legs. It is approximately 185 inches in outside diameter and 17 feet, 8 inches high. When filled, the shield tank formed a 33-inch-thick water annulus that provided the required neutron shielding to prevent excessive neutron activation of material inside the containment vessel and to reduce the neutron doses outside the secondary shield. Peripheral lead shielding, varying in thickness from 1 to 4 inches of lead, is placed on the outside of the primary shield tank.

The fuel transfer tank is similar in dimensions to the primary shield tank. It surrounds the reactor vessel head above the hot legs and is normally empty. It has no lead shielding. During refueling operations before the reactor vessel head is lifted, the fuel transfer tank (also called the upper shield tank in the 1968 refueling log) is filled with water to 36 inches above the lower reactor vessel flange to reduce dose during refueling when the head is removed from the vessel.

Portions of the outer shells of these tanks have been decontaminated and will be left in place. A MARSSIM based survey will be designed and implemented for both tanks. Based upon the current decommissioning schedule, performance of these surveys will be completed prior to approval of the LTP. MARAD proposes that these surveys are acceptable for FSS, and therefore, the null hypothesis that residual radioactivity in these tank shells exists in concentrations above the applicable DCGLs should be rejected. The NRC will be notified prior to performance of the surveys.

### **5.9.3 Steam Generators**

The heat exchanger tube sheet and U-tubes were removed from both steam generators. The interior of each SG/Heat Exchanger shell has been decontaminated. They will be reassembled after license termination and left in place. Prior to being reassembled, the interior surface of both steam generator shells will be surveyed. A MARSSIM based survey will be designed and implemented. Based upon the current decommissioning schedule, performance of these surveys will be completed prior to approval of the LTP. MARAD proposes that these surveys are acceptable for FSS, and therefore, the null hypothesis that residual radioactivity in the SG/Heat Exchanger shells exists in concentrations above the applicable DCGLs should be rejected. The NRC will be notified prior to performance of the surveys.

### **5.9.4 Pressurizer**

The interior of the upper section of the Pressurizer has been decontaminated to allow leaving it in place on completion of the decommissioning. The lower section containing the heater sleeves and other penetrations will be disposed as Low Level Radioactive Waste (LLRW). The remaining interior surface of the Pressurizer will be surveyed. A MARSSIM based survey will be designed and implemented. Based upon the current decommissioning schedule, performance of this survey will be completed prior to approval of the LTP. MARAD proposes that these surveys are acceptable for FSS, and therefore, the null hypothesis that residual radioactivity in the Pressurizer exists in concentrations above the applicable DCGLs should be rejected. The NRC will be notified prior to performance of the survey.

### **5.9.5 Double Bottom Tanks**

Per current plans, the Fresh Water Shield Tank, PD-T5, and PD-T6 will be decontaminated to allow leaving each tank in place on completion of the decommissioning. The interior surfaces of these tanks will be surveyed. A MARSSIM based survey will be designed and implemented. Based upon the current decommissioning schedule, performance of these surveys will be completed prior to approval of the LTP. MARAD proposes that these surveys are acceptable for FSS, and therefore, the



null hypothesis that residual radioactivity in the tanks exists in concentrations above the applicable DCGLs should be rejected. The NRC will be notified prior to performance of the surveys.

#### **5.10 Final Status Survey Release Records and Reports**

The documentation describing the FSS for a given survey unit will include:

- A physical description of the survey unit;
- A summary of any characterization data associated with the survey unit including any required investigations, re-classifications or subdivisions;
- The classification history of the unit;
- A description of remediation activities (if any) performed during FSS;
- Results and discussion of any ALARA evaluations, if performed;
- A discussion of the survey design (combination of scans and fixed measurements used; number of measurements; grid spacing; etc.);
- Tabular and graphical depictions of survey results including quality control results;
- Discussions of data assessments; and,
- A statement that the survey unit meets the applicable release criteria.

As noted in Section 5.3, FSS results will be documented and made available to the NRC for multiple survey areas rather than for individual survey units. Reports will be compiled after FSS activities for all the survey units within a given area are completed. These reports will be prepared and submitted per NSS administrative procedures.

When a survey unit fails, the FSS report will include the following:

- A description of any changes in initial survey unit assumptions relative to the extent of residual radioactivity;
- A summary of the investigation conducted to ascertain the reason for the failure;
- A summary of the effect that the failure has on the conclusion that the facility is ready for final radiological surveys; and,
- A summary of the effect of the failure has on other survey unit information.

(RAI Response) MARAD understands that only FSSRs which ultimately demonstrate meeting the release criteria will be submitted to the NRC. If a survey unit fails, the cause will be evaluated, and corrections will be performed. This may also include additional remediation and resurveying. These actions are defined in MARAD procedure STS-005-033, *Final Status Survey Data Assessment*. After all actions have been taken and completion of a successful FSS, the Final Status Survey Release Record will include a discussion of the failure, any follow-up actions and the results of the survey data and data analysis from the successful survey.

#### **5.11 Quality Assurance and Quality Control Measures**

MARAD implements a comprehensive DQAP [Reference 5-6] to assure conformance with established NRC requirements and accepted industry standards. All activities, including FSS activities, performed at the NSS are required to meet the requirements of the DQAP. The participants in the DQAP ensure that the FSS activities are performed in a safe and effective manner.

The DQAP makes no distinction between performing FSS activities and performing any other activities in the scope of the DQAP. All activities in the scope of the DQAP are performed in accordance with the DQAP. The function of FSS is an activity in the scope of the DQAP.

Quality control (QC) and quality assurance (QA) measures are integrated into all decommissioning activities, including implementation of the FSS. All FSS activities essential to data quality will be implemented and performed under approved procedures. Effective implementation of administrative controls will be verified through self-assessments, monitoring and audit activities, with corrective actions being prescribed, implemented and verified in the event any deficiencies are identified. These measures apply to the related services provided by off-site vendors. Note that self-assessments are performed by individuals with direct responsibilities in the area they assess. Audits and monitoring are performed by individuals with no direct responsibilities in the area they are auditing or monitoring.

QA/QC activities for the FSS effort will serve to ensure that surveys are performed by trained individuals using approved written procedures and properly calibrated instruments that are sensitive to the suspected contaminant. In addition, QC measures will be taken to obtain quantitative information to demonstrate that measurement results have the required precision and are sufficiently free of errors to accurately represent the site being investigated. QC checks will be performed as prescribed by the implementing procedures for field measurements. For field measurements, replicate measurements in each survey unit will be made for randomly chosen location(s) of the original measurements by either a different technician or by a different instrument.



### 5.12 References

- 5-1 Regulatory Guide 1.179, *Standard Format and Contents for License Termination Plans for Nuclear Power Reactors*, Rev. 2, July 2019
- 5-2 NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, Rev. 2, April 2018
- 5-3 Code of Federal Regulations, Title 10, Part 20.1402, *Radiological Criteria for Unrestricted Use*
- 5-4 NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)*, Revision 1, August 2000
- 5-5 NUREG-1757, Volume 2, *Consolidated Decommissioning Guidance - Characterization, Survey, and Determination of Radiological Criteria*, Rev. 1, September 2006
- 5-6 STS-003-001, *Decommissioning Quality Assurance Plan*, Revision 3
- 5-7 STS-005-029, *Final Status Survey Program*
- 5-8 STS-005-030, *Preparation of FSS Packages*
- 5-9 STS-005-031, *Calculation of the Number of Measurements*
- 5-10 STS-005-032, *Survey Unit Turnover and Control*
- 5-11 STS-005-033, *Final Status Survey Data Assessment*
- 5-12 STS-005-034, *Survey Unit Classification*
- 5-13 STS-005-035, *Preparation of Survey Unit Release Records*
- 5-14 STS-005-036, *Entrance Seal Log for Isolated Survey Units*
- 5-15 CR-167, TSD 24-022, *Use of In-Situ Gamma Spectroscopy for Final Status Survey (FSS) at the N.S. SAVANNAH*, April 30, 2024
- 5-16 OI-CANBERRA ISOC-01, *Operation of Canberra in Situ Object Counting Systems*
- 5-17 CR-109, *Radiological Characterization - Reactor Compartment and Containment Vessel*, Revision 1, February 2020
- 5-18 NUREG-1507, *Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions*, Revision 1, August 2020
- 5-19 CR-164, *Calculation of Weighted Efficiencies and MDCs of Ludlum Detectors for Final Status Surveys on the NS SAVANNAH*, June 2024
- 5-20 CR-165, *Efficiency and MDC of Ludlum Pipe Detectors for Final Status Survey (FSS) on the NS SAVANNAH*, April 2024
- 5-19 CR-143, *MARSSIM Survey of the Exterior Hull*, December 2020

## 6 COMPLIANCE with the RADIOLOGICAL CRITERIA for LICENSE TERMINATION

### 6.1 Introduction

In accordance with the underlying intent of 10 CFR 50.82(a)(9)(ii)(E), the guidance of *Regulatory Guide 1.179, Standard Format and Content for License Termination Plans for Nuclear Power Reactors* [Reference 6-1] and the guidance in NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, [Reference 6-2], this chapter describes the methods by which MARAD will demonstrate compliance with the radiological criteria for license termination with unrestricted release of the site.

References 6-1 and 6-2 describe the content required for this chapter. Summarizing from these references, the LTP must clearly present the radiological criteria proposed for license termination. If a licensee requests unrestricted release of the site in accordance with Subpart E of 10 CFR Part 20, then the LTP should demonstrate that the dose from residual radioactivity that is distinguishable from background radiation does not exceed 25 millirem (mrem) (0.25 millisievert (mSv)) per year to an average member of the critical group from all appropriate pathways over a 1,000-year period, including the methods and assumptions used to demonstrate compliance. The LTP should also demonstrate that residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA).

With respect to the long-term dose period from residual radioactivity, Section 4.2.2 of NUREG-1496, Vol 1 (*Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for License Termination of NRC-Licensed Nuclear Facilities* [Reference 6-3]) states that the 1,000-year period applies to soils and assumes a 70-year lifespan period for buildings. Section 5.2 of the LTP describes the features and characteristics of the NSS site in some detail and emphasizes how the NSS differs from typical land-based sites. NSS neither contains soil, nor is situated in soils. Post license termination and pre-disposition, NSS is more akin to a building than a land site, therefore, MARAD considers the 70-year period to be more appropriate for NSS. MARAD addresses the potential longevity of NSS after license termination in Section 6.14 of this chapter.

This chapter considers and describes three post license termination end-state scenarios for NSS; preservation, shipbreaking, and artificial reefing. The worst-case scenario from a dose perspective is immediate shipbreaking. The dose to workers and the public in the preservation end state is minimal. Furthermore, the preservation end-state benefits from continued radiological decay over time, with the result that the dose to workers from deferred shipbreaking (i.e., shipbreaking that occurs after preservation uses end) is less than that in the immediate shipbreaking end-state. Artificial reefing, as described later in the chapter, is a less-likely but plausible scenario that requires significant environmental remediation in its own right (see Section 6.3 description of artificial reefing) and would in all likelihood require the removal of any remaining reactor-generated residual radioactivity. Section 6.3.1 of this chapter provides details of MARAD's ship disposal programs to provide context to reviewers for these post license termination activities.

As described throughout the LTP, the NSS is not dismantled as part of the MARAD DECON-LT project. The ship, as the boundary element of the licensed site and nuclear facility contained therein, will remain intact after license termination, with certain structural elements and components containing residual radioactivity retained in-situ and released (see Chapter 3 for a description of structures and components expected to remain in place). Materials that exceed the license termination criteria will be removed. No waste will be disposed of onsite. For these reasons, only surface contamination Derived Concentration Guideline Levels (DCGLs) have been calculated.



Based on the potential end-state conditions described in Section 6.3, calculations have been performed to estimate potential doses to workers and members of the public from materials with potential residual surface contamination that remain on the NSS following license termination. This chapter of the LTP presents the evaluations of the impact of these remaining radioactive materials on workers and members of the public. There are eleven (11) radionuclides that have been evaluated against many scenarios including the ship in a Preservation status and activities during the Shipbreaking status. The Shipbreaking evaluation includes seven (7) handling and processing scrap steel scenarios and five (5) groundwater leachate scenarios as shown in NUREG-1640<sup>16</sup> [Reference 6-4]. The scenarios bound both domestic and possible international disposition of the scrap steel. The maximum dose rate coefficient from all evaluated scenarios for each radionuclide was chosen to calculate the surface contamination limit or DCGL for use in the Final Status Surveys (FSSs) of the ship.

## **6.2 Proposed Radiological Criteria for License Termination**

MARAD intends to request unrestricted release of the NSS site in accordance with the radiological criteria for unrestricted release specified in Title 10, Section 20.1402, of the Code of Federal Regulations (10 CFR 20.1402). The criteria are:

- Dose Criterion: The residual radioactivity that is distinguishable from background radiation results in a Total Effective Dose Equivalent (TEDE) to an average member of the critical group that does not exceed 25 mrem/year, including that from groundwater sources of drinking water; and,
- ALARA Criterion: The residual radioactivity has been reduced to levels that are As Low As Reasonably Achievable (ALARA).

Chapter 4, Sections 4.1 and 4.4 of the LTP describe the methods and results for demonstrating compliance with the ALARA Criterion. This Chapter describes the methods for demonstrating compliance with the Dose Criterion. As noted in Chapters 1 and 4, MARAD has adopted a TEDE of 15 mrem/year rather than the prescribed 25 mrem/year. Two factors influenced this decision. The first, and of lesser importance, is to demonstrate ALARA compliance by use of the predetermined compliance measure, as described in Chapter 4. The second, and of greater importance, is the recognition by MARAD that after the license is terminated, the disposition methods for the remaining site, i.e., the ship, are all subject to U.S. Environmental Protection Agency (EPA) regulation and enforcement (see sections 6.3 and 6.3.1 of this chapter). By selecting the 15 mrem/year standard employed by EPA, MARAD hopes to avoid jurisdictional conflict after NRC terminates the NS-1 license.

Also, regarding the dose criterion, please note that as described throughout the LTP, the NSS is not a land-based site and is isolated from the terrestrial environment. Consequently, the site cannot be a groundwater source of drinking water, and thus that portion of the dose criterion is not applicable to NSS.

## **6.3 Potential End State Conditions**

Once the NRC license is terminated, and NSS is released without restrictions, MARAD will be free to dispose of the ship. As described elsewhere in this LTP, NSS is a federally owned NHL. Its disposition is thus an integral part of the overarching undertaking being considered by MARAD and NRC under the NHPA. The disposition process that MARAD will employ is detailed in the 2023 Programmatic Agreement (PA), to which both MARAD and NRC are signatories. The disposition, regardless of its

---

<sup>16</sup> Use of NUREG-1640 is consistent with guidance in NUREG 1757, Vol 2, Rev. 1 Appendix I pages I-27 and I-28 See 5.0 Scenarios Evaluated for full discussion.



outcome, is itself a controlled process executed under MARAD control, with regulatory oversight by the EPA through enforcement of the Toxic Substances Control Act (TSCA) because of the presence of polychlorinated biphenyls (PCBs) in regulated quantities dispersed throughout the ship.

The PA disposition process is based on the existing statutory methods available to MARAD. These include 1) physical destruction and recycling of the ship through shipbreaking; 2) beneficial reuse by sinking the vessel in shallow water to form, or act as part of an existing, artificial reef; and 3) preservation for public use. Each of these methods is evaluated in this chapter. For the purposes of the evaluation, the methods are defined as follows:

#### Shipbreaking

The Occupational Safety and Health Administration (OSHA) defines shipbreaking<sup>17</sup> as: “... *the process of dismantling an obsolete vessel's structure for scrapping or disposal. Conducted at a pier, drydock or dismantling slip, it includes a wide range of activities, from removing all gear and equipment to cutting down and recycling the ship's infrastructure.*” Shipbreaking is a complex and hazardous activity, with workers exposed to hazardous materials (lead (Pb), asbestos, PCBs, and others), hazardous working conditions, and hazardous work activities. OSHA standards at 29 CFR 1915 are intended to protect workers from the industry-specific nature of these hazards. In addition, OSHA maintains a National Emphasis Program<sup>18</sup> to reduce and eliminate workplace hazards in shipbreaking operations. This program was renewed following a 2015 Memorandum of Understanding among OSHA, EPA, the US Navy and MARAD to coordinate and share information on domestic ship recycling activities. Both OSHA and EPA have prepared guidelines for use by shipbreaking facilities that address key aspects of 1) environmental compliance and 2) protection of worker safety and health. MARAD was a member of the interagency working group that helped develop the guideline documents. In short, shipbreaking is a domestic industry that has substantial, continuing federal oversight and enforcement.

#### Reefing

The National Oceanographic and Atmospheric Administration (NOAA) is responsible for developing and maintaining the long-term National Artificial Reef Plan, as provided in the National Fishing Enhancement Act (Act) of 1984 (33 U.S.C. § 2101 et seq.). NOAA first published the plan in 1985. The plan was comprehensively revised and republished in February 2007. The plan defines the term “artificial reef” as “. . . a structure which is constructed or placed in waters covered under this title for the purpose of enhancing fishery resources and commercial and recreational fishing opportunities.” The term “waters” covered under this chapter is defined as “. . . the navigable waters of the United States and the waters superjacent to the outer continental shelf as defined in Section 2 of the Outer Continental Shelf Lands Act . . . to the extent such waters exist in or are adjacent to any State.” Based on the best scientific information available, artificial reefs in waters covered under the Act “... shall be sited and constructed, and subsequently monitored and managed in a manner which will:

- 1) enhance fishery resources to the maximum extent practicable;
- 2) facilitate access and use by US recreational and commercial fishermen;

---

<sup>17</sup> See OSHA “Shipbreaking Safety Fact Sheet”

<sup>18</sup> See OSHA CPL 03-00-020 dated March 7, 2016.



- 3) minimize conflicts among competing uses of waters covered under this title and the resources in such waters;
- 4) minimize environmental risks and risks to personal health and property; and
- 5) be consistent with generally accepted principles of international law and shall not create any unreasonable obstruction to navigation.”

Although not a focus of the 1985 reef plan, sport diving has developed substantially in the past few decades and now rivals the impact of recreational fishing. The 2007 amended reef plan added sport diver enhancement and access to the design considerations for artificial reefs. Similarly, the use of reefs as mitigative strategies against the loss or degradation of marine habitats and aquatic resources has been added to the 2007 plan.

Artificial reefing programs are generally administered by states. The Army Corps of Engineers has permit authority for the construction and placement of an artificial reef under Section 404 of the Clean Water Act (CWA) (33 U.S.C. §1344), and Section 103 of the Marine Protection, Research and Sanctuaries Act (MPRSA) (33 U.S.C. §1413). In each case, the EPA provides guidance on the application of the statutes.

Obsolete ships may be employed in the creation or expansion of an artificial reef. When this is the case, the ship is normally prepared in accordance with the joint MARAD-EPA *National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs* [Reference 6-5] which includes radioactive materials in its list of “other materials of environmental concern” that should be removed when preparing a ship for reefing. As a matter of policy, MARAD does not make ships constructed prior to 1985 available for the artificial reef program, based on the presumed presence of PCBs in ships constructed before that date.

#### Preservation

Preservation is any prospective non-transportation use of the ship that involves unrestricted public access (e.g., museum, conference center, entertainment venue, educational facility, etc.). The ship may be operated by MARAD directly, but it is more likely that it would be conveyed to a third party for preservation use. Preservation scenarios are not indefinite and may at some future date result in shipbreaking. It is generally accepted that conveyance of a vessel for preservation is a distribution in commerce for the purposes of TSCA compliance. In the case of NSS, therefore, any preservation scenario either requires the federal government to retain title to the vessel, or to maintain a reversionary interest in it. This is consistent with MARAD’s existing authorities for conveyance of NSS for preservation purposes and is outlined in the PA. The action ensures that TSCA compliance is guaranteed by a federal agency, and that MARAD, acting in its capacity as an agent for federal ship disposal (see 6.3.1 below), will undertake any future shipbreaking activity.

#### 6.3.1 MARAD Ship Disposal Program

MARAD is the disposal agent for surplus federally owned merchant-type vessels of 1,500 gross tons<sup>19</sup> or more, as provided in the Federal Property and Administrative Services Act of 1949 (40 U.S.C. § 548). Since 2001, MARAD’s Office of Ship Disposal Programs is responsible for the disposition of MARAD-owned obsolete vessels and for other qualifying federally owned vessels transferred to MARAD for disposal. Prior to 2001, ships were disposed via brokers to both domestic and international shipbreaking

---

<sup>19</sup> Gross tonnage is a measure of volume (one ton equals 100 cubic feet) used for a variety of regulatory purposes. NSS measures 15,590 gross tons



facilities. Except for four (4) vessels sold to an English firm in a 2003 pilot project, the export of MARAD obsolete ships for scrapping physically ended in 1994. The primary method employed by MARAD to dispose of obsolete ships is shipbreaking, either through competitive sales, or fee for service contracts. The choice of method is heavily dependent on external market factors, such as the price of scrap steel. The proceeds of ship sales are deposited in MARAD's Vessel Operations Revolving Fund (VORF),<sup>20</sup> consequently the program is expected to maximize the proceeds derived from its activities. To ensure consistency in its approach, the program makes little distinction between competitive sales and fee for service contracts from a technical standpoint and uses a Federal Acquisition Regulation (FAR) Best Value approach to making awards.

MARAD works closely with EPA, OSHA, and the U.S. Navy (USN) to monitor domestic ship recycling facilities. MARAD pre-qualifies recycling facilities to ensure that such facilities meet environmental and occupational safety and health standards. Only qualified facilities may bid for MARAD-sponsored ship recycling opportunities, whether by competitive sales or fee for service contracts. Ship Disposal Program staff act as Contracting Officer's Representatives to monitor the performance of work, and MARAD Office of Environmental Compliance staff periodically inspect and monitor contractor facilities and performance.

A similar technical approach is taken to disposal via artificial reefing, except that MARAD is not responsible for the costs for vessel preparation and sinking. Over the twenty-year period from FY 2001 to FY 2020, MARAD has disposed 231 ships.<sup>21</sup> Only four (4) of these ships have been reefed, and the most recent such project was in 2010. Similarly, only one (1) vessel has been donated (preservation) in that timeframe. The Navy's deep-ocean live-fire sinking exercises, known as SINKEX, are another low-frequency method of ship disposal. Any vessel proposed for SINKEX must be prepared to the same standards as those for artificial reefing. Candidate vessels are chosen by the USN and have exclusively been drawn from former naval auxiliaries and demilitarized former combatant vessels. Since 2001, no merchant vessels have been employed in a SINKEX and only two (2) vessels have been disposed in this manner by MARAD, both in FY 2005.

As described above, future shipbreaking of NSS, whether immediately following LT, or at some deferred date after a period of preservation use, will be performed by MARAD<sup>22</sup> in accordance with its established processes and procedures for vessel disposal. This activity will be a controlled industrial process with independent regulatory oversight by EPA and OSHA. Similar processes would be involved in the less likely but plausible event that NSS is reefed. Disposition for preservation will be considered in its own right under the PA and may deviate from the current MARAD donation process. Regardless of the methods employed, preservation will also be a controlled process that involves EPA from the standpoint of TSCA compliance and will require a continued federal interest in the ship.

#### 6.3.1.1 Foreign Shipbreaking of MARAD Vessels

MARAD's current ship disposal program was established after passage of the Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001, Pub. L. No. 106-398, Appendix, § 3502, 114 Stat. 1654

---

<sup>20</sup> The VORF account has three subaccounts which support MARAD operations (50%), maritime education and training (25%), and maritime heritage projects (25%, of which approximately ¾ are transferred to the National Park Service to award and administer National Maritime Heritage Grants). The distribution is specified by the National Maritime Heritage Act of 1994, as amended.

<sup>21</sup> Source – MARAD Office of Ship Disposal Programs Annual Report for FY 2020, January 2021.

<sup>22</sup> MARAD acknowledges that over a seventy-year or greater timeframe, there may be reorganizations that affect MARAD. MARAD presumes that any such reorganization will not eliminate the need for federal ship disposal, and that the extent federal obligations for ship disposal will be considered in such a reorganization.



(2000). Among its provisions was authorization of pilot projects for foreign disposal. Given the lack of domestic shipbreaking capacity at the time, foreign disposal was viewed as a likely necessary action to remove the growing backlog of ships awaiting disposal (at the time, the backlog was over 150 ships). MARAD's efforts to export obsolete ships for disposal were unsuccessful. In its June 2004 progress report to Congress, MARAD concluded that foreign disposal was not practicable, and, because the underlying conditions have not changed, it has not attempted foreign disposal since that time. The conclusion from that report is repeated below.

*Based upon years of futile attempts to export ships for recycling and MARAD's experience with the pilot project to send ships to AbleUK, MARAD has concluded that foreign vessel disposal is commercially impractical under current U.S. law and regulation. The central barrier to the export of MARAD vessels is the Toxic Substances Control Act (TSCA) and the prohibition on export of polychlorinated biphenyls (PCBs), 15 U.S.C. §2605(e). As demonstrated by the current litigation surrounding the AbleUK contract, only an exemption established by a full rulemaking process would enable vessels to be disposed overseas. The length of time required to pursue such a rulemaking (likely a year or more), the uncertainty of receiving an exemption, and the restrictive nature of the exemption -- valid for only one year and limited to a specific export contract (such as ships going to the AbleUK facility), make overseas recycling untenable given the existing statutory constraints.*

### 6.3.2 Ship Conditions at License Termination

The preservation end state is defined above as "any prospective use of the ship that involves unrestricted public access (museum, conference center, entertainment venue or educational facility)." Although the future configuration of the ship is dependent on satisfactory final status and confirmatory surveys, it is useful to contemplate the practical considerations of what structures containing residual radioactivity are likely to be present at license termination and how those structures might actually contribute to the use of the ship in the preservation scenario. The preservation scenario is considered herein because the structures and components are removed in the shipbreaking scenario, and they will most likely be removed if the ship is reefed.

Decades of environmental monitoring and reporting clearly show that exposure inside NSS and outside of former RCAs is indistinguishable from background. MARAD expects that this condition will be confirmed as part of license termination. Therefore, it is reasonable to project that the only likely source for individual exposure in the preservation end state will be from residual structures inside the former RCAs. License Amendment 8 was issued in 1976 and established the Possession-only License. In its Safety Evaluation, the Office of Nuclear Reactor Regulation discussed the condition of the ship in a manner that supports both the historical record and MARAD's expectations. The Safety Evaluation Report for License Amendment 8 stated in part "... the survey results demonstrate that all areas of the ship, external to the containment vessel, have surface contamination levels that are significantly less than the areas acceptable for release to unrestricted access (RG 1.86). Also, only six (6) areas of the ship external to the containment vessel showed any direct radiation above background (0.02mr/hr)." The six (6) areas listed were the Hot Chemistry Lab, Port and Starboard Charge Pump Rooms, Port Stabilizer Room, Lower Secondary Room, and Forward Control Room.<sup>23</sup> These six spaces along with the Health Physics Lab, the Reactor Compartment Upper Level, Containment Vessel and Starboard Stabilizer Room,

---

<sup>23</sup> Since 2006, the Lower Secondary Room has been referred to as the Reactor Compartment Lower Level (RCLL). The Forward Control Room which includes on C-Deck the Cold Water Chemistry Lab (port) and Radiation Monitoring Room (starboard) plus on D-deck the Gas Adsorption Equipment Room (port) and Radiation Sampling Room (starboard) is colloquially referred to as the Cold Water Chemistry Lab (CCL).



were designated as RCAs prior to post dismantlement surveys. Note that the Starboard Stabilizer Room was designated because a cross flooding duct connected it to the Port Stabilizer Room, in which contaminated systems and equipment were located. The Health Physics Lab became an RCA when the 1981 museum-era Technical Specifications came into effect. Those Technical Specifications contained a very restrictive definition of RCA which was intended to prevent inadvertent public access to radioactive material<sup>24</sup> by posting and securing spaces that might not otherwise have been controlled. The Health Physics Lab is an example of such a space; it had been used as a MARAD office space prior to the ship's transfer to the PPDA museum. Radioactive material inside the lab was confined to a sink drain. The lab is located inside the hospital complex, which was on the PPDA public self-guided tour route. License Amendment 14 removed this restrictive definition in favor of the definitions contained in 10 CFR 20. Surveys after the drain piping was removed during decommissioning confirmed the space was no longer an RCA.

Outside of the Reactor Compartment itself, the several former RCAs are positioned in such a way that they are unlikely to contribute to the preservation condition in anything other than an incidental manner. The components, equipment, and systems contained in these spaces have been dismantled as of the date of LTP submittal. Any remaining contamination is located on the steel structure of the compartments and is subject to further remediation before FSS. This would be the source for any residual radioactivity below the DCGLs at license termination. Among these spaces, only the Stabilizer Rooms offer any interest from an interpretive standpoint.<sup>25</sup> These spaces are inconvenient to access and would be unlikely to be part of any self-guided tour of the ship. "Behind the scenes" guided tours might be conducted but would be unlikely to involve more than a few minutes of exposure on any such event. Other spaces, such as the Port and Starboard Charge Pump Rooms, would be accessed periodically for inspection and survey, including entry into the double bottom tanks below the pump rooms.<sup>26</sup>

This leaves the Reactor Compartment, including the Containment Vessel, as the most likely source of exposure. Not coincidentally, these are the spaces which hold the greatest interest and which will be occupied for the longest amount of time in any given year. They will also contain the bulk of residual reactor-generated detectable radioactivity, in the form of retained structures. At the time of LTP submittal, MARAD expects that the retained structures and components will include the upper section of the pressurizer shell, the common exterior annular wall of the Fuel Transfer Tank and Neutron Shield Tank (including its exterior lead shielding), and the secondary side of both Steam Generator assemblies. Gratings and ladders inside the CV are required by MARAD's integrated services contract to be free-released or replaced. The final decisions on retained structures and components were not made at the time of LTP submittal. Using the 2018 CV Portal as a means of access, MARAD envisions that guided and self-guided tours of the CV will feature in the preservation end-state scenario. This is the basis for the representative "Tour Guide on Ship" dose model described in Section 6.9.1.

#### **6.4 Radionuclides for Evaluation**

As described in Chapter 2 of the LTP, a significant effort was undertaken in 2019 to perform a radiological and environmental hazard characterization for the RC and CV. It is documented in CR-109

---

<sup>24</sup> License Amendment 9 introduced TS 3.4, Radiological Criteria for Radiation Control Areas. Amendment 9 is sometimes referred to as the "museum ship" amendment and was designed to allow for unrestricted visitation by the public. TS 3.3 defined a radiation control area as "an area of the ship with radiation levels from reactor generated radioactive materials in excess of 0.25mR/hr above natural background as measured at one meter from any surface, and/or surface contamination in excess of the limits prescribed in Table I of NRC Reg. Guide 1.86."

<sup>25</sup> These spaces contain the operating machinery for the ship's gyrofin stabilizers.

<sup>26</sup> Note that double bottom tank entry is infrequent and is normally performed during a drydocking availability.



---

**License Termination Plan – (STS-004-003)**

---

[Reference 6-6]. The surveys and sampling consisted of area baseline surveys of the RC and CV areas and survey and sampling of component interior surfaces.

Primary systems and waste treatment systems were sampled extensively. In accordance with the Decommissioning Quality Assurance Plan and the Radiation Protection Program, composite smears from twelve (12) locations were sent to GEL Laboratories, LLC in South Carolina for gamma spectrometry. Five (5) of those composite smear samples were also analyzed for HTD radionuclides. In addition, a sludge sample was also sent for HTD analysis. Table 6-1 presents the samples sent for HTD radionuclides.

**Table 6-1      Samples for Hard to Detect Analyses**

| <b>Sample ID</b> | <b>Location of Sample</b>                    |
|------------------|----------------------------------------------|
| RCCV-RS-001      | Smears from Ion Exchange piping              |
| RCCV-RS-005      | Smears from Containment Drain Tank PD-T4     |
| RCCV-RS-007      | Smears from Pressurizer                      |
| RCCV-RS-010      | Smears from Steam generator                  |
| RCCV-RS-012      | Smears from Ventilation System               |
| RCLL-RM-001A     | Sludge sample from Makeup Storage Tank PD-T2 |

The initial suite of radionuclides is presented in Table 6-2.

**Table 6-2      Initial Suite of Radionuclides**

| <b>Nuclide</b> | <b>T 1/2<br/>(years)</b> |
|----------------|--------------------------|
| C-14           | 5.73E+03                 |
| Co-60          | 5.27E+00                 |
| Ni-63          | 1.00E+02                 |
| Sr-90          | 2.86E+01                 |
| Tc-99          | 2.13E+05                 |
| Cs-137         | 3.02E+01                 |
| H-3            | 1.23E+01                 |
| Fe-55          | 2.70E+00                 |

The results of the laboratory analyses of the samples presented in Table 6-1 are presented in Table 6-3.

**Table 6-3 Offsite Laboratory Results of Sample Analyses**

| <b>Nuclide</b> | <b>SG smear composite (pCi)</b> | <b>PZR smear composite (pCi)</b> | <b>PD-T4 smear composite (pCi)</b> | <b>RC Exhaust Vent smear composite (pCi)</b> | <b>RC IX Piping smear composite (pCi)</b> | <b>Makeup Storage Tank Sludge (pCi/g)</b> |
|----------------|---------------------------------|----------------------------------|------------------------------------|----------------------------------------------|-------------------------------------------|-------------------------------------------|
| C-14           | 3.50E+02                        | 2.23E+03                         | 5.10E+01                           | 6.43E+02                                     | 1.48E+04                                  | 8.60E+03                                  |
| Co-60          | 3.58E+04                        | 4.26E+04                         | 3.96E+03                           | 2.15E+02                                     | 8.21E+04                                  | 2.35E+05                                  |
| Ni-63          | 3.38E+07                        | 1.79E+06                         | 1.95E+05                           | 1.20E+04                                     | 5.24E+06                                  | 7.70E+06                                  |
| Sr-90          | <MDA                            | 1.39E+00                         | <MDA                               | <MDA                                         | 1.59E+00                                  | 6.61E+01                                  |
| Tc-99          | 7.90E+01                        | 2.74E+01                         | 1.42E+01                           | <MDA                                         | 1.67E+02                                  | 6.23E+01                                  |
| Ag-108m        | <MDA                            | <MDA                             | 3.94E+01                           | 1.14E+01                                     | 2.52E+02                                  | 6.91E+02                                  |
| Cs-137         | 1.39E+02                        | 3.39E+02                         | 3.05E+03                           | 9.81E+03                                     | 9.09E+02                                  | 6.97E+04                                  |
| H-3            | NA                              | NA                               | NA                                 | NA                                           | NA                                        | 1.56E+04                                  |
| Fe-55          | NA                              | NA                               | NA                                 | NA                                           | NA                                        | 6.56E+04                                  |
| Am-241         | NA                              | NA                               | NA                                 | NA                                           | NA                                        | 4.69E+00                                  |
| Pu-239/240     | NA                              | NA                               | NA                                 | NA                                           | NA                                        | 3.89E+00                                  |
| <b>Totals</b>  | <b>3.38E+07</b>                 | <b>1.84E+06</b>                  | <b>2.02E+05</b>                    | <b>2.27E+04</b>                              | <b>5.34E+06</b>                           | <b>8.10E+06</b>                           |

Note: NA = not analyzed

The fraction of the total activity in each sample for each radionuclide was calculated.

(RAI Response) Table 6-3, *Offsite Laboratory Results of Sample Analyses* was developed as a result of the 2019 characterization data, which positively identified some additional radionuclides and is the complete list of residual radionuclides considered for DCGLs. LTP Table 6-2, *Initial Suite of Radionuclides* originated from STS-198, *Characterization Plan 2018* [Reference 6-7], Table 7-1, Radionuclides of Concern as the starting point.

(RAI Response) MARAD considered and used the radionuclide lists in 10 CFR 61.55, *Licensing Requirements for Land Disposal of Radioactive Waste* to generate shipping manifests for activated and contaminated components and for development of ROCs. The 2005 analysis of RPV samples included all the 10 CFR 61.55 Waste Classification Table 1 and Table 2 radionuclides.

(RAI Response) Table 6-3 includes all of the radionuclides listed in Table 6-2. Because Table 6-3 forms the basis for the DCGLs, and is more inclusive than Table 6-2, there was no deselection of radionuclides, and, therefore, there is no justification for not including radionuclides present in the remaining components and surfaces of the ship.



For radionuclide results that were less than the MDA, the fraction of the total activity for that radionuclide was assigned a value of zero (0). The fraction of total activity for each sample is presented in Table 6-4.

**Table 6-4      Radionuclide Fractions of the Sample Analyses**

| <b>Nuclide</b> | <b>SG<br/>composite<br/>fractions</b> | <b>PZR<br/>composite<br/>fractions</b> | <b>PD-T4<br/>composite<br/>fractions</b> | <b>RC exhaust<br/>vent<br/>composite<br/>fractions</b> | <b>RC IX<br/>piping<br/>composite<br/>fractions</b> | <b>Makeup<br/>Storage<br/>Tank<br/>Sludge<br/>fractions</b> |
|----------------|---------------------------------------|----------------------------------------|------------------------------------------|--------------------------------------------------------|-----------------------------------------------------|-------------------------------------------------------------|
| C-14           | 1.03E-05                              | 1.22E-03                               | 2.52E-04                                 | 2.84E-02                                               | 2.77E-03                                            | 1.06E-03                                                    |
| Co-60          | 1.06E-03                              | 2.32E-02                               | 1.96E-02                                 | 9.48E-03                                               | 1.54E-02                                            | 2.90E-02                                                    |
| Ni-63          | 9.99E-01                              | 9.75E-01                               | 9.65E-01                                 | 5.29E-01                                               | 9.82E-01                                            | 9.51E-01                                                    |
| Sr-90          | 0.00E+00                              | 7.57E-07                               | 0.00E+00                                 | 0.00E+00                                               | 2.98E-07                                            | 8.17E-06                                                    |
| Tc-99          | 2.33E-06                              | 1.49E-05                               | 7.03E-05                                 | 0.00E+00                                               | 3.13E-05                                            | 7.70E-06                                                    |
| Ag-108m        | 0.00E+00                              | 0.00E+00                               | 1.95E-04                                 | 5.03E-04                                               | 4.72E-05                                            | 8.54E-05                                                    |
| Cs-137         | 4.11E-06                              | 1.85E-04                               | 1.51E-02                                 | 4.33E-01                                               | 1.70E-04                                            | 8.61E-03                                                    |
| H-3            | -                                     | -                                      | -                                        | -                                                      | -                                                   | 1.93E-03                                                    |
| Fe-55          | -                                     | -                                      | -                                        | -                                                      | -                                                   | 8.10E-03                                                    |
| Am-241         | -                                     | -                                      | -                                        | -                                                      | -                                                   | 5.79E-07                                                    |
| Pu-239/240     | -                                     | -                                      | -                                        | -                                                      | -                                                   | 4.81E-07                                                    |
| <b>Totals</b>  | <b>1.00E+00</b>                       | <b>1.00E+00</b>                        | <b>1.00E+00</b>                          | <b>1.00E+00</b>                                        | <b>1.00E+00</b>                                     | <b>1.00E+00</b>                                             |

The radionuclide fractions in Table 6-4 were summed and then normalized to obtain the radionuclide distribution and for calculation of the Radionuclides of Concern.

Table 6-5 presents the results of the calculations.

**Table 6-5      Radionuclide Sum of Fractions and Normalized Sum of Fractions**

| <b>Nuclide</b> | <b>Sum of Fractions</b> | <b>Normalized Sum of Fractions</b> |
|----------------|-------------------------|------------------------------------|
| C-14           | 3.37E-02                | 5.61E-03                           |
| Co-60          | 9.78E-02                | 1.63E-02                           |
| Ni-63          | 5.40E+00                | 9.00E-01                           |
| Sr-90          | 9.22E-06                | 1.54E-06                           |
| Tc-99          | 1.27E-04                | 2.11E-05                           |
| Ag-108m        | 8.30E-04                | 1.38E-04                           |
| Cs-137         | 4.57E-01                | 7.61E-02                           |
| H-3            | 1.93E-03                | 3.21E-04                           |
| Fe-55          | 8.10E-03                | 1.35E-03                           |
| Am-241         | 5.79E-07                | 9.66E-08                           |
| Pu-239/240     | 4.81E-07                | 8.01E-08                           |
| Totals         | 6.00E+00                | 1.00E+00                           |

### **6.5 Documents for Guiding Calculations**

Two primary documents were reviewed to provide perspective on calculating doses and generation of DCGLs. They are IAEA Safety Report Series No. 44 [Reference 6-8] which provides calculations and concentrations of radionuclides for exemption and clearance that are valid for all types of solid material containing radionuclides of artificial or natural origin except foodstuffs and drinking water. The second document is NUREG-1640 [Reference 6-4] which provides calculations of both mass-based and surficial dose rate conversion factors for scrap steel, aluminum, copper and concrete.

Both documents use a multiple scenario approach which include a foundry worker, landfill worker, residents living near a landfill using contaminated groundwater and being exposed to re-purposed products. The IAEA report presents a set of realistic parameters and low probability parameters. The realistic parameters were used to calculate a 10  $\mu$ Sv/y (1 mrem/y) activity concentrations and the low probability parameters were used to calculate a 1 mSv/y (100 mrem/y) activity concentrations. The lowest concentration from either calculation was then rounded to the nearest power of 10 and listed as the release value. The report describes only one (1) scenario for the foundry worker. There is no scenario for the scrap pile worker. In addition, the analyses were deterministic, meaning only single values were used for the parameters.

In contrast, the NUREG report has six (6) foundry/steel mill scenarios and a scrap yard worker scenario. Almost all parameters have distributions which allows for a probabilistic analysis. The scenarios were



established based upon site visits to scrap yards and foundries, making the calculations realistic as compared to the IAEA report.

Based upon this review, NUREG-1640 was a much more robust evaluation and directly applicable to the shipbreaking scenario of the NSS.

## **6.6 Exposure Scenarios Evaluated**

As described in Section 6.1 of this chapter, the worst-case scenario from a dose perspective is the immediate scrapping of NSS following license termination. NUREG-1640 evaluated 37 steel scrap scenarios that included handling, processing, transportation, product use, landfill disposal, groundwater leachate, and atmospheric release. Those evaluations are based on some of the steps that would most likely be involved in processing scrap steel. A review of the radionuclides present on the NSS against the list of critical groups for steel in Table 3.22 in NUREG-1640, shows that the critical groups are from the seven (7) handling and processing scenarios or from the five (5) groundwater leachate scenarios. These 12 scenarios are directly applicable to the Shipbreaking of the NSS. Table 6-6 presents the potentially exposed individuals in each phase (i.e., the critical group). Those individuals listed as significant, are those who are full time employees at the task, or their tasks require handling or manipulating potentially contaminated components. Calculations of potential doses were performed for significant individuals in the timeframe immediately following license termination. In the less likely but plausible event that NSS is reefed after license termination, the immediate shipbreaking scenario is considered a bounding scenario given the likely need, as described in Section 6.3, to remove at least some of the structures and components containing residual radioactivity as part of the ship preparations for reefing. Section 6.11 evaluates the potential exposure to recreational divers in the reefing scenario if the structures and components are not removed. Finally, Table 6-6 also includes the potentially exposed individuals in the preservation scenario, with the understanding that their potential exposures are not evaluated against NUREG-1640 (see Section 6.8 regarding the significant individual in the preservation scenario).

The use of NUREG-1640 is consistent with the plain language of Appendix I of NUREG 1757, Vol. 2, Rev. 1. Appendix I has the following purpose:

*This appendix consists of the technical guidance for the use of the site-specific dose modeling, applicable to Decommissioning Groups 4–9.*

The NSS is in Decommissioning Group 4. Section I.3.3.3.6 Offsite Scenarios provides the following guidance on developing scenarios:

*Licensees can use generic analyses to screen the importance of offsite uses with such sources as NUREG-1640, "Radiological Assessments for Clearance of Materials from Nuclear Facilities." (NRC 2003) Pg I-27*

On page I-28, NUREG-1757 [Reference 6-9] provides an even broader array of guidance for developing scenarios:

*Licensees may be able to use information from NUREG/CR-5512, NUREG-1640, and NUREG-1717, as well as other licensees' analyses to screen their potential scenarios with quantitative methods.*

Developing scenarios using NUREG-1640 is consistent with NRC guidance contained in NUREG-1757. It is understood that NRC reviewers will evaluate the appropriateness of the scenarios during their review of the LTP.

**Table 6-6 Scenarios Evaluated for Calculation of Surface Contamination DCGLs**

| <b>Ship Status</b>     | <b>Description</b>                                                                        | <b>Exposed Individual</b> | <b>Significance</b>                    |
|------------------------|-------------------------------------------------------------------------------------------|---------------------------|----------------------------------------|
| Preservation           | Office Worker/Tour Guide                                                                  | Adult worker              | Significant – full time employee       |
| Preservation           | Housekeeping                                                                              | Adult worker              | Insignificant – part time employee     |
| Preservation           | Minor repairs/maintenance                                                                 | Adult worker              | Insignificant – part time employee     |
| Preservation           | Tours and meetings on ship                                                                | Members of the Public     | Insignificant – few hours per year     |
| Pre-Shipbreaking       | Housekeeping                                                                              | Adult worker              | Insignificant – part time employee     |
| Pre-Shipbreaking       | Minor repairs/maintenance                                                                 | Adult worker              | Insignificant – part time employee     |
| Shipbreaking           | Remediation of hazardous materials on ship                                                | Adult worker              | Significant – full time employee       |
| Shipbreaking           | Component removal/metal cutting on ship                                                   | Adult worker              | Significant – full time employee       |
| Shipbreaking           | 7 steel handling and processing scenarios defined in NUREG-1640                           | Adult worker              | Significant – full time employee       |
| Dismantlement complete | Groundwater infiltrated by leachate from landfills or storage piles defined in NUREG-1640 | Members of the Public     | Significant – potential daily exposure |

### **6.7 Dose Rate Equations for Remediation and Component Removal Workers**

The Remediation worker prepares the ship for the Component Removal worker. The Remediation worker removes fuels, oils, PCBs, asbestos, and combustible materials. Following the removal of combustible materials, asbestos and PCBs, the paint or preservative coatings must be stripped from surfaces to be cut. The Component Removal workers make the cuts on pipes and components of suitable size for removal from the ship.

The following equations are based upon those presented in NUREG-1640. They have been modified to obtain dose rates, convert gm to cm<sup>2</sup> and for varying contamination levels for the Remediation and Component Removal worker scenarios.

The surface area factor,  $f_{sa}$ , is used in the ingestion and inhalation calculations. It is the inverse of the mass to surface area (g/cm<sup>2</sup>). The values used in these calculations were derived from several sources such as NUREG-1640, ANSI N13.12-2013 [Reference 6-4] and steel pipe schedule charts. Values for Schedule 40 steel pipes in pounds per foot (lb/ft) were converted to g/cm<sup>2</sup>. Schedule 40 pipe has a thinner



wall thickness than a Schedule 80 pipe and is, therefore, conservative. The mass to surface area factors for 2 inch to 12 inch diameter pipes were calculated with a range of 2.9 to 7.8 g/cm<sup>2</sup>. This range spans the 4.53 to 5.34 g/cm<sup>2</sup> values in Appendix A of NUREG-1640 for converting mass-based values to surficial values for steel. Due to the large range of pipe diameters on the ship, mass to surface area factors for the 2 inch to 12 inch diameter pipes was appropriate for use in the calculations. Therefore, the surface area factor in the calculations was allowed to vary between 0.1 and 0.35 cm<sup>2</sup>/g.

The contamination factor,  $f_{cf}$ , is used in the external exposure calculations. It accounts for varying contamination levels in pipes and components encountered during their work activities. For these calculations, the contamination levels on the pipes and components were assumed to be uniform; therefore, the contamination factor has been conservatively set to 1.

The dilution factor,  $f_d$ , is used in the inhalation calculations. It accounts for respirator use. The Remediation worker is expected to handle and remove hazardous materials and will wear a full face, negative pressure respirator with a protection factor of 50. The dilution factor for the Remediation worker is 0.02. The Component Removal worker is not expected to wear a respirator; therefore, the dilution factor for the Component Removal worker is 1.

Equation 6-1, derived from Equation 3.9 in NUREG-1640, was used to calculate the dose rate from ingestion:

$$D_{ig} = F_{ig} I_g f_{sa} t_e e^{-\lambda_i t_s} \quad \text{Equation 6-1}$$

Where:

- $D_{ig}$  = the dose rate from ingestion per unit surface activity concentration on the material for radionuclide  $i$   $[(\mu\text{Sv/y})/(\text{Bq}/\text{cm}^2)]$
- $F_{ig}$  = the committed dose equivalent coefficient from FGR-11 for ingestion of radionuclide  $i$   $[\mu\text{Sv}/\text{Bq}]$
- $I_g$  = the ingestion rate  $[\text{g}/\text{h}]$
- $f_{sa}$  = the surface area factor  $[\text{cm}^2/\text{g}]$
- $t_e$  = the duration of internal exposure  $[\text{h}/\text{y}]$
- $\lambda_i$  = the radioactive decay constant  $[1/\text{y}]$
- $t_s$  = the interval from time scrap is cleared until scenario begins  $[\text{y}]$

Equation 6-2, derived from Equation 3.8 in NUREG-1640, was used to calculate the dose rate from inhalation:

$$D_{ih} = F_{ih} R_h f_{sa} f_d t_e \chi_d e^{-\lambda_i t_s} \quad \text{Equation 6-2}$$

Where:

- $D_{ih}$  = the dose rate from inhalation per unit surface activity concentration on the material for radionuclide  $i$   $[(\mu\text{Sv/y})/(\text{Bq}/\text{cm}^2)]$
- $F_{ih}$  = the committed dose equivalent coefficient from FGR-11 for inhalation of radionuclide  $i$   $[\mu\text{Sv}/\text{Bq}]$
- $R_h$  = the inhalation rate  $[\text{m}^3/\text{h}]$
- $f_{sa}$  = the surface area factor  $[\text{cm}^2/\text{g}]$

|             |   |                                                                   |
|-------------|---|-------------------------------------------------------------------|
| $f_d$       | = | the dilution factor used for wearing respirators [-]              |
| $t_e$       | = | the duration of internal exposure [h/y]                           |
| $\chi_a$    | = | the effective dust concentration in the air [g/m <sup>3</sup> ]   |
| $\lambda_i$ | = | the radioactive decay constant [1/y]                              |
| $t_s$       | = | the interval from time scrap is cleared until scenario begins [y] |

Equation 6-3, derived from Equation 3.6 in NUREG-1640, was used to calculate the dose rate from external exposure:

$$E_{ext}^i = e_{ext}^i t_e f_{cf} U_x e^{-\lambda_i t_s} \quad \text{Equation 6-3}$$

Where:

|             |   |                                                                                                                                                                           |
|-------------|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $E_{ext}^i$ | = | the dose rate from external exposure per unit surface activity concentration on the material for radionuclide $i$ [( $\mu$ Sv/y)/(Bq/cm <sup>2</sup> )]                   |
| $e_{ext}^i$ | = | the effective dose equivalent rate per unit surface activity concentration on the material, for radionuclide $i$ generated by MicroShield [(mSv/h)/(Bq/cm <sup>2</sup> )] |
| $t_e$       | = | the exposure time [h/y]                                                                                                                                                   |
| $f_{cf}$    | = | the contamination factor [-]                                                                                                                                              |
| $U_x$       | = | the uncertainty factor, which accounts for the variation of dose rate with position [-]                                                                                   |
| $\lambda_i$ | = | the radioactive decay constant [1/y]                                                                                                                                      |
| $t_s$       | = | the interval from time scrap is cleared until scenario begins [y]                                                                                                         |

## 6.8 Tools Used for Calculations and Analyses

The calculated surface contamination values in the Remediation worker and Component Removal worker scenarios were developed using a computerized risk analysis modeling tool, "ModelRisk 4.0", developed by Vose software. This analysis tool is a 3rd party add-on to Microsoft's Excel spreadsheet program. This tool allows for a variety of analysis and distribution propagations including:

- Monte Carlo Simulations of the sampling and propagation of a variety of distributions,
- Correlations of parameter values from data sets,
- Creation of empirical or pre-defined distributions from data sets,

An unlimited number of parameters contained within a standard spreadsheet calculation can be identified as distributions (either pre-defined or empirical) with this tool. Once the parameters have been appropriately defined and selected, and once the calculation framework (i.e., formulas) has been completed, the simulation can be performed. The number of iterations selected for executing the simulations in this analysis was set to 10,000 iterations. The 95<sup>th</sup> percentile was selected for the assessments of the Remediation and Component Removal workers. This provides the precision and confidence levels for good approximations to the theoretical distribution of potential doses.

RESRAD-BUILD code, Version 3.5 was used to calculate the dose rate coefficients for the Tour Guide on Ship scenario. Uncertainty analyses were run with the built-in distribution parameters for breathing



rate, ingestion rate and resuspension rates allowed to vary. The 95th percentile value for each radionuclide was chosen for the calculations.

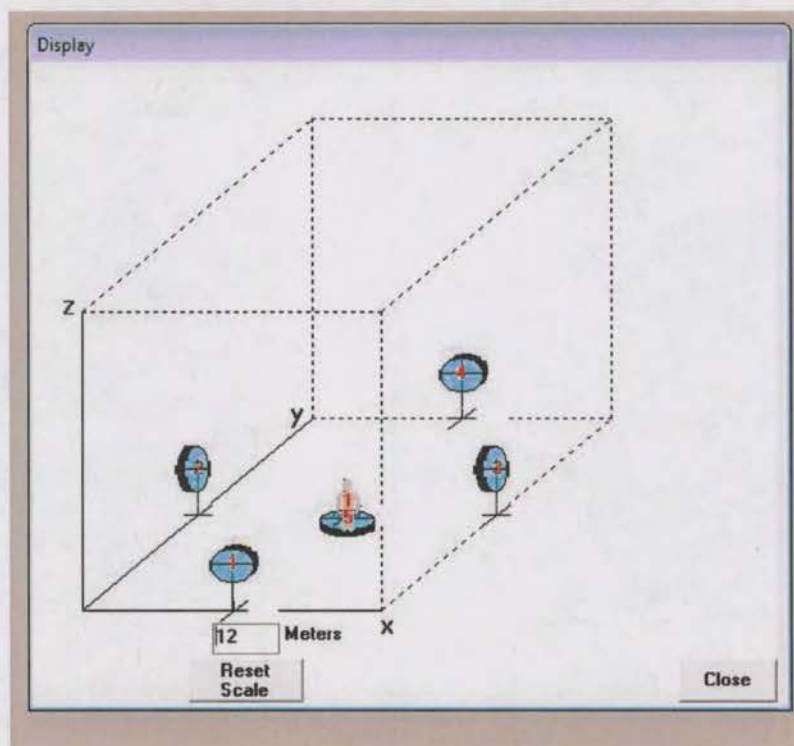
For the steel scrap scenarios in NUREG-1640, the effective dose equivalent rate coefficients have been calculated by Monte Carlo simulations. For parameters that are uncertain or variable, Monte Carlo sampling methods were used to pick the particular set of values in a given calculation, called a realization. In the NUREG-1640 analyses, the estimation of each dose, radionuclide concentration, or other intermediate parameter involved between 5,800 and 10,000 realizations. The 95<sup>th</sup> percentile was used for assessments of the Scrap Yard and Foundry workers and members of the public from groundwater leachate.

### **6.9 *Inputs to the Scenario Calculations***

As previously stated, the components being evaluated here are those that do not exceed the FSS release limits. These components will remain installed even though they may have measurable levels of radioactivity that are less than the DCGLs. The impact of these radioactive components on workers and members of the public is evaluated in the following sections.

#### **6.9.1 Tour Guide on Ship**

In this scenario, the tour guide is assumed to spend 8-hours per workday for 250 days per year in the CV and RC. The RESRAD-BUILD Version 3.5 model assumes the room size to be approximately equal to the size of the CV: 12 meters wide by 12 meters long. Five large area circular sources with a radius of 5 meters each were generated. One source is on each bulkhead at the midpoint, and one is on the deck in the middle. The Tour Guide is assumed to be standing on the source on the deck. The dose point for the calculations is 1 meter above the deck. Figure 6-1 is the RESRAD-BUILD depiction of the relationship between the sources and receptor (i.e., Tour Guide).



**Figure 6-1 Receptor and Sources for RESRAD-BUILD Model**

The initial runs were deterministic with default values for all parameters except the indoor fraction, which was set to 0.23. These initial runs were performed to get an estimate as to the general magnitude of the results. Uncertainty analyses were then run with the built-in distribution parameters for breathing rate, ingestion rate and resuspension rates allowed to vary. The 95<sup>th</sup> percentile value for each radionuclide was chosen for the calculations. The results with the uncertainty analyses were compared against the results of the other scenarios and showed that the Tour Guide dose rate coefficients were orders of magnitude lower than the other scenarios. Further modifications to the input parameters could not be justified. Parameters for Tour Guide on Ship Calculations are presented in Table 6-7.



Table 6-7 Parameters for Tour Guide on Ship Calculations

| Parameter            | Units              | Value  | Notes                                                                                        |
|----------------------|--------------------|--------|----------------------------------------------------------------------------------------------|
| Indoor Fraction      | unitless           | 0.23   | Equal to 2000 h/y / 8760 h/y                                                                 |
| Sources and strength | dpm/m <sup>2</sup> | 1      | Each source is a 5m radius disk on 4 bulkheads and the deck. Receptor is on the deck source. |
| Breathing Rate       | m <sup>3</sup> /d  | Varies | Triangular. min = 12, mode = 33.6 and max = 44                                               |
| Ingestion Rate       | m <sup>2</sup> /h  | Varies | Loguniform. min = 0.000028, max = 0.00029                                                    |
| Resuspension Rate    | 1/s                | Varies | Loguniform. min = 2.8E-10, max = 0.000014                                                    |
| Remaining parameters |                    |        | Default values                                                                               |

The RESRAD-BUILD reports are attachments to CR-139, TSD No. 21-089, Rev. 0, *Calculations to Support NS SAVANNAH Surface Contamination DCGLs* [Reference 6-10].

## 6.9.2 Remediation Worker on Ship

### External Exposure

After license termination, the first step in the shipbreaking process is to remove any hazardous materials from the ship. The individual performing this task is identified as a "Remediation worker." The Remediation worker on Ship scenario assumes that the greatest external exposure occurs during removal of asbestos and other hazardous materials from components and pipes.

A cylinder surface – external dose point model in MicroShield® Version 8.03 was developed for the source of exposure. The length of the pipe was 10 feet with the dose rate at 1 foot from the pipe was calculated to simulate the location of the worker. Three pipe diameters were modeled: 2," 4" and 12" diameter pipes. The source activity concentration was 1 Bq/cm<sup>2</sup> for each of the radionuclides. The thickness of a Schedule 40 pipe was used as the shield. Schedule 40 pipe has a thinner wall thickness than a Schedule 80 pipe and is, therefore, conservative. Cobalt-60, Ag-108m and Cs-137 are the only gamma emitters in the list of radionuclides on the ship. The largest effective dose coefficient is from the 12" diameter pipe and was used in the calculations. The Effective Dose Equivalent Rate, Anterior/Posterior Geometry with build-up was used to calculate the worker dose. The worker could be cutting a pipe with another pipe nearby; therefore, the Effective Dose Equivalent rate was multiplied by two (2) for conservatism.

Equation 6-3 was used to calculate the dose rate from external exposure per unit surface activity concentration in (μSv/y)/(Bq/cm<sup>2</sup>). Table 6-8 presents the values used in the calculations.

**Table 6-8      Parameters for Remediation Worker on Ship External Dose Calculations**

| Parameter                                                 | Symbol      | Units                         | Value | Notes                                                                                                                              |
|-----------------------------------------------------------|-------------|-------------------------------|-------|------------------------------------------------------------------------------------------------------------------------------------|
| Exposure time                                             | $t_e$       | h/y                           | 1500  | Assumed 6 h/d for 250 days. 6 h/d equals the maximum daily exposure duration for the Scrap Yard worker in Table B.8 of NUREG-1640. |
| Contamination factor                                      | $f_{cf}$    | -                             | 1     | Assumes uniform contamination levels                                                                                               |
| Uncertainty factor                                        | $U_x$       | -                             | 1     | Assumed no uncertainty                                                                                                             |
| Interval from time scrap is cleared until scenario begins | $t_s$       | y                             | 0     | Assumed no decay                                                                                                                   |
| Lambda                                                    | $\lambda_i$ | 1/y                           |       | From NRC Toolbox version 3.0.0                                                                                                     |
| Effective Dose Equivalent Rate Coefficient                | $e_{ext}$   | (mSv/h)/(Bq/cm <sup>2</sup> ) |       | Effective dose equivalent rate, Anterior/Posterior Geometry with build-up from MicroShield                                         |

The MicroShield® computer code reports are attachments to CR-139, TSD No. 21-089, Rev. 0, *Calculations to Support NS SAVANNAH Surface Contamination DCGLs* [Reference 6-10].



Ingestion

The rate of secondary ingestion is a highly uncertain parameter. A minimum value of the ingestion rate is zero. This corresponds to the ingestion by workers practicing good industrial hygiene. Company policies that prohibit eating or smoking in the workplace, along with wearing gloves, would minimize hand-to-mouth transfer.

For this parameter, the values presented in NUREG-1640 Appendix B, Table B.8 were used. The ingestion rate is a uniform distribution with a min at 0.0 and a max at 0.02 g/h.

The values for the committed dose equivalent coefficients for ingestion were taken from Federal Guidance Report No. 11 (FGR-11) [Reference 6-11].

Equation 6-1 was used to calculate the dose rate from ingestion per unit surface activity concentration in  $(\mu\text{Sv/y})/(\text{Bq/cm}^2)$ . Table 6-9 presents the values used in the calculations.

**Table 6-9 Parameters for Remediation Worker on Ship Ingestion Dose Calculations**

| Parameter                                                 | Symbol      | Units                  | Value    | Notes                                                                                                                              |
|-----------------------------------------------------------|-------------|------------------------|----------|------------------------------------------------------------------------------------------------------------------------------------|
| Inadvertent (Secondary) ingestion rate                    | $I_g$       | g/h                    | variable | NUREG-1640 App B, Table B.8. Uniform distribution with a min at 0.0 and a max at 0.02 g/h.                                         |
| Exposure duration                                         | $t_e$       | h/y                    | 1500     | Assumed 6 h/d for 250 days. 6 h/d equals the maximum daily exposure duration for the Scrap Yard worker in Table B.8 of NUREG-1640. |
| Surface area factor                                       | $f_{SA}$    | $\text{cm}^2/\text{g}$ | variable | ModelRisk Pert distribution with max at 0.35, min at 0.1 and mode at 0.2 based on mass/length data for Schedule 40 pipe.           |
| Interval from time scrap is cleared until scenario begins | $t_s$       | y                      | 0        | Assumed no decay.                                                                                                                  |
| Lambda                                                    | $\lambda_i$ | 1/y                    |          | From NRC Toolbox version 3.0.0.                                                                                                    |
| Committed Dose Equivalent Coefficient                     | $F_{ig}$    | $\mu\text{Sv/Bq}$      |          | Most conservative Dose Conversion Factors (DCFs) from FGR-11.                                                                      |

Inhalation

Inhalation rates vary with physical activity. For this parameter, the values presented in NUREG-1640 Appendix B, Table B.8 were used. The inhalation rate is a triangular distribution with mode at 1.2, min at 0.6 and max at 1.8 m<sup>3</sup>/h.

Airborne dust concentrations vary with ventilation rates and work activities. For this parameter, the values presented in NUREG-1640 Appendix B, Table B.8 were used. The airborne mass loading of material is a lognormal distribution with the mean at 2.433, the standard deviation at 1.27 and a max at 5 mg/m<sup>3</sup>.

The values for the committed dose equivalent coefficients for inhalation were taken from FGR-11.

Equation 6-2 was used to calculate the dose rate from inhalation per unit surface activity concentration in (μSv/y)/(Bq/cm<sup>2</sup>). Table 6-10 presents the values used in the calculations.

**Table 6-10 Parameters for Remediation Worker on Ship Inhalation Dose Calculations**

| Parameter                                                 | Symbol          | Units              | Value    | Notes                                                                                                                                             |
|-----------------------------------------------------------|-----------------|--------------------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Inhalation rate                                           | R <sub>h</sub>  | m <sup>3</sup> /h  | variable | NUREG-1640 App B, Table B.8. Triangular distribution with mode at 1.2, min at 0.6 and a max at 1.8 m <sup>3</sup> /h.                             |
| Exposure duration                                         | t <sub>c</sub>  | h/y                | 1500     | Assumed 6 h/d for 250 days. 6 h/d equals the maximum daily exposure duration for the Scrap Yard worker in Table B.8 of NUREG-1640.                |
| Dilution factor                                           | f <sub>d</sub>  | -                  | 0.02     | Assumed workers are wearing respirators with a PF = 50.                                                                                           |
| Surface area factor                                       | f <sub>SA</sub> | cm <sup>2</sup> /g | variable | ModelRisk Pert distribution with max at 0.35, min at 0.1 and mode at 0.2 based on mass/length data for Schedule 40 pipe.                          |
| Air Concentration                                         | X <sub>d</sub>  | g/m <sup>3</sup>   | variable | NUREG-1640 App B, Table B.8. Lognormal distribution with mode at 2.433, standard deviation of 1.27, min at 0.0 and a max at 5 mg/m <sup>3</sup> . |
| Interval from time scrap is cleared until scenario begins | t <sub>s</sub>  | y                  | 0        | Assumed no decay.                                                                                                                                 |
| Lambda                                                    | λ <sub>i</sub>  | 1/y                |          | From NRC Toolbox version 3.0.0.                                                                                                                   |
| Committed Dose Equivalent Coefficient                     | F <sub>ih</sub> | μSv/Bq             |          | Most conservative DCF from FGR-11.                                                                                                                |



## 6.9.3 Component Removal Worker on Ship

External Exposure

After the ship has been remediated, the next step in shipbreaking is to remove piping and components and start breaking the ship up for scrap. The individual performing this task is identified as the "Component Removal worker." The component removal worker on ship scenario assumes that the greatest external exposure occurs during removal of components and pipes.

The same source, used for the Remediation worker on Ship, was used to calculate the external exposures to the Component Removal worker on Ship.

Equation 6-3 was used to calculate the dose rate from external exposure per unit surface activity concentration in  $(\mu\text{Sv/y})/(\text{Bq/cm}^2)$ . Table 6-11 presents the values used in the calculations.

**Table 6-11 Parameters for Component Removal Worker on Ship External Dose Calculations**

| Parameter                                                 | Symbol      | Units                             | Value | Notes                                                                                                                              |
|-----------------------------------------------------------|-------------|-----------------------------------|-------|------------------------------------------------------------------------------------------------------------------------------------|
| Exposure time                                             | $t_e$       | h/y                               | 1500  | Assumed 6 h/d for 250 days. 6 h/d equals the maximum daily exposure duration for the Scrap Yard worker in Table B.8 of NUREG-1640. |
| Contamination factor                                      | $f_{cf}$    | -                                 | 1     | Assumes uniform contamination levels.                                                                                              |
| Uncertainty factor                                        | $U_x$       | -                                 | 1     | Assumed no uncertainty.                                                                                                            |
| Interval from time scrap is cleared until scenario begins | $t_s$       | y                                 | 0     | Assumed no decay.                                                                                                                  |
| Lambda                                                    | $\lambda_i$ | 1/y                               |       | From NRC Toolbox version 3.0.0.                                                                                                    |
| Effective Dose Equivalent Rate Coefficient                | $e_{ext}$   | $(\text{mSv/h})/(\text{Bq/cm}^2)$ |       | Effective dose equivalent rate, Anterior/Posterior Geometry with build-up from MicroShield.                                        |

Ingestion

The same values for secondary ingestion rates used for the Remediation worker on Ship are used for the Component Removal worker on Ship.

The same values for the effective dose coefficients for ingestion, used for the Remediation worker on Ship, are used for the Component Removal worker on Ship.

Equation 6-1 was used to calculate the dose rate from ingestion per unit surface activity concentration in  $(\mu\text{Sv/y})/(\text{Bq}/\text{cm}^2)$ . Table 6-12 presents the values used in the calculations.

**Table 6-12 Parameters for Component Removal Worker on Ship Ingestion Dose Calculations**

| Parameter                                                 | Symbol      | Units                    | Value    | Notes                                                                                                                              |
|-----------------------------------------------------------|-------------|--------------------------|----------|------------------------------------------------------------------------------------------------------------------------------------|
| Inadvertent (Secondary) ingestion rate                    | $I_g$       | g/h                      | variable | NUREG-1640 App B, Table B.8. Uniform distribution with a min at 0.0 and a max at 0.02 g/h.                                         |
| Exposure duration                                         | $t_e$       | h/y                      | 1500     | Assumed 6 h/d for 250 days. 6 h/d equals the maximum daily exposure duration for the Scrap Yard worker in Table B.8 of NUREG-1640. |
| Surface area factor                                       | $f_{SA}$    | $\text{cm}^2/\text{g}$   | variable | ModelRisk Pert distribution with max at 0.35, min at 0.1 and mode at 0.2 based mass/length data for Schedule 40 pipe.              |
| Interval from time scrap is cleared until scenario begins | $t_s$       | y                        | 0        | Assumed no decay.                                                                                                                  |
| Lambda                                                    | $\lambda_i$ | 1/y                      |          | From NRC Toolbox version 3.0.0.                                                                                                    |
| Committed Dose Equivalent Coefficient                     | $F_{ig}$    | $\mu\text{Sv}/\text{Bq}$ |          | Most conservative DCF from FGR-11.                                                                                                 |



Inhalation

The same values for the inhalation rate used for the Remediation worker on Ship are used for the Component Removal worker on Ship.

The same airborne dust concentrations used for the Remediation worker on Ship are used for the Component Removal worker on Ship.

The same values for the effective dose coefficients for inhalation used for the Remediation worker on Ship are used for the Component Removal worker on Ship.

Equation 6-2 was used to calculate the dose rate from inhalation per unit surface activity concentration in  $(\mu\text{Sv/y})/(\text{Bq}/\text{cm}^2)$ . Table 6-13 presents the values used in the calculations.

**Table 6-13 Parameters for Component Removal Worker on Ship Inhalation Dose Calculations**

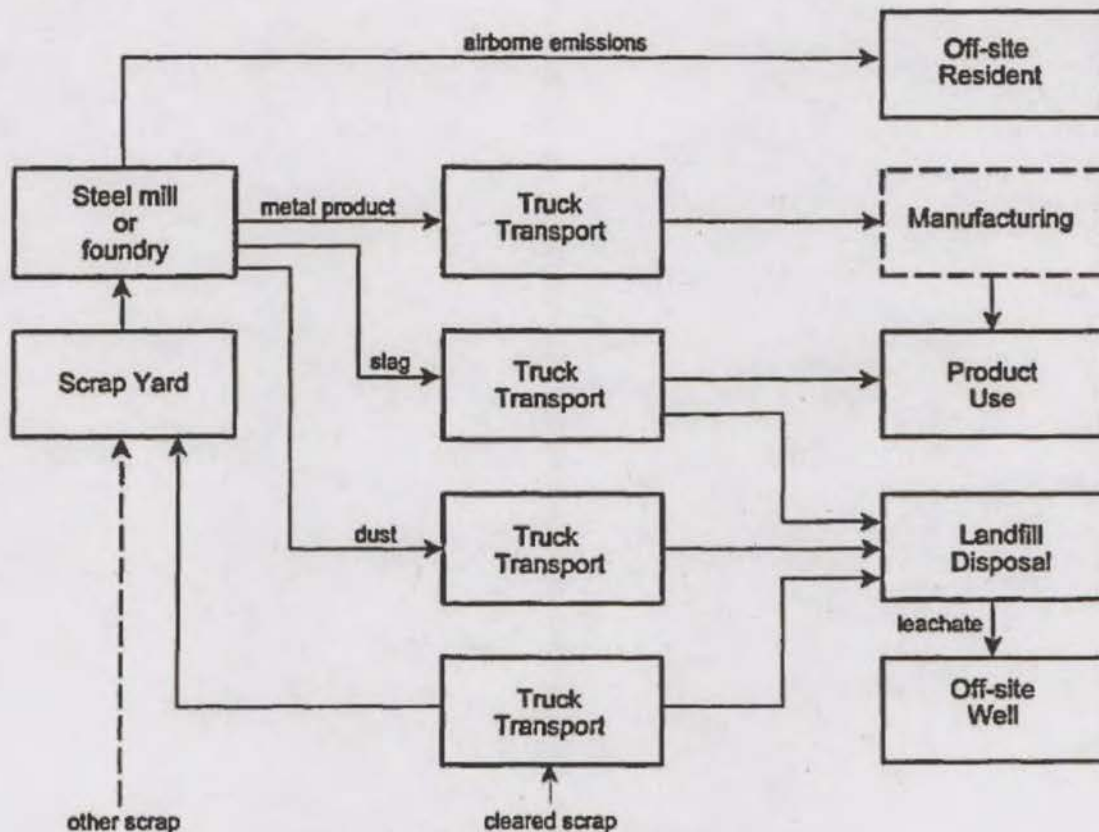
| Parameter                                                 | Symbol      | Units                    | Value    | Notes                                                                                                                                                 |
|-----------------------------------------------------------|-------------|--------------------------|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Inhalation rate                                           | $R_h$       | $\text{m}^3/\text{h}$    | variable | NUREG-1640 App B, Table B.8. Triangular distribution with mode at 1.2, min at 0.6 and max at $1.8 \text{ m}^3/\text{h}$ .                             |
| Exposure duration                                         | $t_e$       | $\text{h}/\text{y}$      | 1500     | Assumed 6 h/d for 250 days. 6 h/d equals the maximum daily exposure duration for the Scrap Yard worker in Table B.8 of NUREG-1640.                    |
| Dilution factor                                           | $f_d$       | -                        | 1        | Assumed workers are not wearing respirators.                                                                                                          |
| Surface area factor                                       | $f_{SA}$    | $\text{cm}^2/\text{g}$   | variable | ModelRisk Pert distribution with max at 0.35, min at 0.1 and mode at 0.2 based on mass/length data for Schedule 40 pipe.                              |
| Air Concentration                                         | $X_d$       | $\text{g}/\text{m}^3$    | variable | NUREG-1640 App B, Table B.8. Lognormal distribution with mode at 2.433, standard deviation of 1.27, min at 0.0 and max at $5 \text{ mg}/\text{m}^3$ . |
| Interval from time scrap is cleared until scenario begins | $t_s$       | y                        | 0        | Assumed no decay.                                                                                                                                     |
| Lambda                                                    | $\lambda_i$ | $1/\text{y}$             |          | From NRC Toolbox version 3.0.0.                                                                                                                       |
| Committed Dose Equivalent Coefficient                     | $F_{ih}$    | $\mu\text{Sv}/\text{Bq}$ |          | Most conservative DCF from FGR-11.                                                                                                                    |

#### 6.9.4 Scrap Steel Scenarios in NUREG-1640

The following paragraph has been taken directly from NUREG-1640.

*Assessments have been performed of the potential radiation doses to individuals from the recycling or disposal of iron and steel scrap that could be cleared from nuclear facilities. The assessment addresses 37 scenarios that depict exposures resulting from the handling and processing of cleared scrap and the products of melting and refining this scrap at steel mills and foundries, emission of airborne effluents from these facilities, transportation of scrap and furnace products, the use of these products, the landfill disposal of cleared scrap and furnace by-products, and the infiltration of well water by leachate from landfills and storage piles containing cleared scrap or furnace by-products. The analysis utilizes data on ferrous metal recycling, as currently practiced in the United States, and on contemporary U.S. work practices and living habits.*

Figure 3-1 from NUREG-1640 presents a schematic diagram of the flow of steel scrap, as characterized in the analysis. The analysis starts with the scrap steel released from the nuclear facility.



**Figure 3.1 Flow of steel scrap**

As previously noted, NUREG-1757 Volume 2 Section I.3.3.3.6 states:

*Licensees can use generic analyses to screen the importance of offsite uses with such sources as NUREG-1640, "Radiological Assessments for Clearance of Materials from Nuclear Facilities." (NRC 2003).*



In the Forward to NUREG-1640 Volume 1 states:

*The large variety of scenarios analyzed in this report may be realistically applied to certain situations in licensing requests. In other cases, the models and scenarios may be adapted to specifically fit the situation at hand. Such applications are facilitated by the explicit presentation of the exposure scenarios, calculational models, modeling parameters, and mathematical formulations in this report.*

After the Component Removal worker has completed breaking up the ship, the steel from the NSS will likely be processed in the scrap yard. Following processing, the scrap steel would be sent to a foundry/steel mill where it is mixed with non-radiologically impacted steel and processed. Activities in the steel mill include handling and processing the steel, slag and electric arc furnace (EAF) dust. Airborne emissions from the foundry also occur. Waste products from the foundry will eventually be placed into landfills where leachate from landfills could infiltrate nearby downgradient wells used as sources of drinking water. These exposure scenarios have been evaluated in NUREG-1640.

A review of the scrap yard and steel mill scenarios in Volume 1 of NUREG-1640 and the supporting model parameters in Appendix B of Volume 2 of NUREG-1640 was performed. Specific key parameters reviewed included:

#### Hours exposed

The daily duration of external and internal exposure for the scrap yard worker was assigned a range of 4 to 6 hours, assuming a uniform distribution, based on information obtained during visits to two scrap yards. This individual is assumed to work 250 days per year.

The daily duration of external and internal exposure for the slag worker was assigned a range of 2 to 6 hours, assuming a uniform distribution. This individual is assumed to perform other duties while being away from the slag pile. This individual is also assumed to work 250 days per year.

#### Inhalation Rates

NUREG-1640 states that the inhalation rates in the 1975 ICRP 23 [Reference 6-12] and 1997 EPA Exposure Factors Handbook [Reference 6-13] were reviewed to determine a reasonable range for the analysis. The 1997 EPA Handbook cites a number of studies performed under a variety of conditions. The study, which agrees best with the ICRP model, lists a mean adult inhalation rate of 1.2 m<sup>3</sup>/hr for light activities. Based on these data, this parameter was assigned a triangular distribution, with a mode of 1.2 m<sup>3</sup>/hr and a range of 0.6 to 1.8 m<sup>3</sup>/hr.

#### Ingestion Rates

The 1997 EPA Handbook cites an adult soil ingestion rate from gardening of 20 mg/hr. NUREG-1640 states this appears to be a reasonable estimate of the maximum hourly rate, averaged over one year of exposure in a work-related scenario, and is the value adopted for the exposure of the "reasonably maximally exposed individual" in the scrap metal assessments. A minimum value of the ingestion rate is zero. This corresponds to the ingestion of workers practicing good industrial hygiene. This parameter was assigned a uniform distribution of 0 to 0.02 g/hr.

#### External Exposure Modeling

NUREG-1640 states: Scrap piles observed by members of the project team during visits to scrap metal dealers vary widely in size and shape. A hemispherical pile was adopted for the analysis. Such a pile has rotational symmetry; thus, a scrap pile worker would receive the same dose regardless of his angular orientation with respect to the pile. Furthermore, a hemispherical pile is



completely specified by only one dimension-e.g., the volume. Consequently, a hemisphere is the simplest and, therefore, the most generic shape.

NUREG-1640, Appendix C states: Bulk densities of ferrous scrap range from 16 to 22 lb/cu ft prior to compaction. Twenty pounds per cubic foot (0.32 g/cc) was adopted as the bulk density for the analysis.

The source of external exposure for a scrap yard worker is a 3,500 ton (3,175 t) pile of steel scrap, at an average distance of 2 meters from the worker. A 3,500 ton pile at a density of 20 lb/cu ft equates to a volume of 350,000 cu feet. This is equivalent to a hemisphere with a diameter at the base of approximately 100 feet. This model is reasonable and appropriate.

The exposed individual in the slag handling scenario is a worker at a steel mill who transfers slag using a front-end loader. The slag is spread over a large, flat area - the vehicle is either on top or at the edge of the pile. A vehicle shielding factor is applied which accounts for the shielding afforded by the loader. Based on interviews with equipment manufacturers and landfill operators, a geometric model was developed to characterize the effective shielding for operators of this type of large equipment. Based on calculated transmission factors, this parameter is assigned a triangular distribution with a range of 0.3 to 0.7 and a mode of 0.5. Informal calculations were performed using MicroShield and found the vehicle shielding factor range and mode to be appropriate.

The uncertainty factor is applied and is used to account for different locations of the worker with respect to the slag. If the worker is on top of the slag, they are exposed to an effectively infinite slab of slag, which conforms to the exposure conditions modeled in FGR 12 [Reference 6-14], so uncertainty factor equals 1. When the worker is loading slag from the edge of the large, flat pile, they are exposed to one-half of an infinite slab, so the uncertainty factor equals 0.5. The uncertainty factor is assigned a uniform distribution of 0.5 to 1.

(RAI response) The external exposure scenario for the scrapyard worker was not modeled in MicroShield. MARAD relied on the data provided in NUREG-1640.

(RAI response) MARAD did not perform a sensitivity analysis for any of the exposure scenarios. Physical parameter values whether fixed or given a distribution for the Scrap Yard/Foundry Worker and Leachate are presented in NUREG-1640, Vol. 2, Appendices A through E. Physical parameter values for the Component Removal Worker are presented in LTP Table 6-11 through Table 6-13.

(RAI response) The technical justification for the mass of the hemisphere used for the external exposure modeling for the Scrapyard Worker scenario was presented in NUREG-1640. MARAD estimates approximately 1,000 tons of scrap steel with measurable contamination, but below the 15 mrem/y DCGLW, would go to a scrap yard. Based on the light ship weight presented in Table 1-1 of the LTP, steel containing residual radioactivity could be mixed with up to approximately ten times that mass of clean steel from the ship.

(RAI response) The mass and density of the pile or piles of NSS steel that will be generated at the scrap yard is unknown. The density of the pile will go up or down depending upon the size of the pieces in the pile. These unknowns could result in either underestimating, overestimating or be equal to the effective dose equivalent conversion factors in NUREG-1640 but are well within conservative margins to ensure compliance with dose limits and minimize risk. MARAD relied on the data provided in NUREG-1640.

#### Airborne Concentration

NUREG-1640 states: the airborne concentration of dust that is the source of inhalation exposure for the scrap pile worker was modeled based on data collected by the U.S. Occupational Safety &



Health Administration (OSHA) at the site of the World Trade Center in New York. After eliminating non-detect results and results greater than the OSHA 10 mg/m<sup>3</sup> limit, a random sample of 250 concentrations was used to calculate the average concentration. This parameter was assigned a custom distribution with a minimum of 0.962 mg/m<sup>3</sup>, maximum of 1.378 mg/m<sup>3</sup> and a mode of 1.170 to fit the data.

The parameters used for the airborne concentration for handling and processing the slag and EAF dust shown in Appendix B was a lognormal distribution with a range of 1.27 to 5.0 mg/m<sup>3</sup> with the mode at 2.433 mg/m<sup>3</sup>.

A 2016 study of dust exposure in a steel plant in Malaysia [Reference 6-15] was reviewed. Respirable particulate matter (PM<sub>2.5</sub>, PM<sub>10</sub>) and total particulate matter concentrations were evaluated. The mean concentration of the PM<sub>2.5</sub> dust ranged from 0.02 to 0.5 mg/m<sup>3</sup>. The mean concentration of the PM<sub>10</sub> dust ranged from 0.08 to 1.58 mg/m<sup>3</sup> which is bounded by the assumed distribution applied in this analysis.

#### Effective Dose Equivalent Conversion Factors

There are 7 exposure scenarios evaluated for the scrap yard and steel mill/foundry in NUREG-1640. The Effective Dose Equivalent (EDE) rate from all pathways for the 7 scenarios was evaluated to determine the most conservative dose rate coefficients. The 95<sup>th</sup> percentile dose rate coefficient was taken from Appendix F, Tables F1.1, F1.5, F1.9, F1.13, F1.14, F1.18 and F1.22. Table 6-14 presents the results of the evaluation.

There are 5 exposure scenarios evaluated for the leachate into groundwater in NUREG-1640. The EDE rate from all pathways for the 5 scenarios was evaluated to determine the most conservative dose rate coefficients. The 95<sup>th</sup> percentile dose rate coefficient was taken from Appendix F, Tables F1.62, F1.63, F1.64, F1.65 and F1.66. Table 6-15 presents the results of the evaluation.

#### 6.9.5 "ModelRisk 4.0" (RAI Response)

"ModelRisk 4.0", developed by Vose software, is a 3rd party add-on to Microsoft's Excel spreadsheet program. This tool allows for a variety of analysis and distribution propagations including:

- Monte Carlo Simulations of the sampling and propagation of a variety of distributions;
- Correlations of parameter values from data sets; and,
- Creation of empirical or pre-defined distributions from data sets.

With this tool, an unlimited number of parameters contained within a standard spreadsheet calculation can be identified as distributions (either pre-defined or empirical). Once the parameters are appropriately defined and selected, and, once the calculational formulas are completed, the simulation may be performed. In the execution of a simulation, the user inputs the number of iterations to be run which can be as low as 100 with no upper limit. Of course, as the number of iterations increase, the execution time to complete also increases. During the execution process, each probabilistic parameter is selected as a distribution and sampled during the simulation and the results of all calculations recorded for each simulation until all iterations are completed. Once the simulation is complete, the user can display the results in a variety of tabular or graphical formats. The analysis performed here provides the inputs and outputs of various simulations using some of these options.

ModelRisk contains over 1200 functions with the ability to apply up to 136 probability distributions 34 time-series models and 14 correlation models. As such, ModelRisk does not explicitly use input

files nor does it create an output file. However, ModelRisk can produce an output results report that can show the statistics associated with the identified probabilistic input parameters as well as the results of the statistics and percentile tables of the output parameters.

For Excel instances without ModelRisk installed, spreadsheet cells where probabilistic simulation parameters are defined are shown as #NAME? within the spreadsheet cell. Therefore, we assume that if we provide this file, it will be of no value. As an alternative, we have enclosed the ModelRisk simulation report for your review which shows input and output variables with various statistical parameters (see Attachment 1, ModelRisk Summary Report). We have also summarized the information contained in this report into the tables below to facilitate review.

The DCGL dose factors were required to be re-run to create the input and output reports. In all cases, the input parameters from the following LTP tables were used along with the applicable equations and engineering units using 10,000 simulations:

- Table 6-8: Parameters for Remediation Worker on Ship External Dose Calculations
- Table 6-9: Parameters for Remediation Worker on Ship Ingestion Dose Calculations
- Table 6-10: Parameters for Remediation Worker on Ship Inhalation Dose Calculations
- Table 6-11: Parameters for Component Removal Worker on Ship External Dose Calculations
- Table 6-12: Parameters for Component Removal Worker on Ship Ingestion Dose Calculations
- Table 6-13: Parameters for Component Removal Worker on Ship Inhalation Dose Calculations

Table 6-14 below provides the non-radionuclide dependent probabilistic parameters post simulation showing the summary statistics (mean, minimum, maximum and standard deviation) for the inhalation and ingestion pathways and for each worker. As noted in this table, for the same variable, slightly different values are shown as this is a result of the simulation sampling for the range of values and type of distribution applied to each variable.



**Table 6-14 Non-Radionuclide Input Parameter Distribution Summary for Both Worker Scenarios (RAI Response)**

| Scenario Factor                         | Variable Name                          | Mean     | Minimum  | Maximum  | St. dev. |
|-----------------------------------------|----------------------------------------|----------|----------|----------|----------|
| Ingestion for Component Removal Worker  | Inadvertent (Secondary) ingestion rate | 9.95E-03 | 1.48E-06 | 2.00E-02 | 5.78E-03 |
|                                         | Surface area factor                    | 2.08E-01 | 1.02E-01 | 3.40E-01 | 4.71E-02 |
| Inhalation for Component Removal Worker | Air Concentration                      | 2.27E-03 | 2.14E-04 | 5.00E-03 | 9.68E-04 |
|                                         | Inhalation rate                        | 1.20E+00 | 6.05E-01 | 1.79E+00 | 2.44E-01 |
|                                         | Surface area factor                    | 2.08E-01 | 1.02E-01 | 3.43E-01 | 4.71E-02 |
| Ingestion for Remediation Worker        | Inadvertent (Secondary) ingestion rate | 9.99E-03 | 6.92E-07 | 2.00E-02 | 5.81E-03 |
|                                         | Surface area factor                    | 2.09E-01 | 1.02E-01 | 3.39E-01 | 4.73E-02 |
| Inhalation for Remediation Worker       | Air Concentration                      | 2.27E-03 | 2.93E-04 | 5.00E-03 | 9.72E-04 |
|                                         | Inhalation rate                        | 1.20E+00 | 6.15E-01 | 1.80E+00 | 2.45E-01 |
|                                         | Surface area factor                    | 2.08E-01 | 1.02E-01 | 3.43E-01 | 4.71E-02 |

Table 6-15 and Table 6-16 below provide the output parameters of the following dose factors each in uSv/y per Bq/cm<sup>2</sup>: External, Ingestion, Inhalation and Total for each worker in separate tables and for each radionuclide.

**Table 6-15 Component Removal Worker Output Parameters (RAI Response)**

| Parameter                                                | Radionuclide | Mean     | Minimum  | Maximum  | St. dev. |
|----------------------------------------------------------|--------------|----------|----------|----------|----------|
| External Dose Factor<br>for Component<br>Removal Worker  | Ag-108m      | 1.33E+01 | 1.33E+01 | 1.33E+01 | 2.15E-12 |
|                                                          | Am-241       | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
|                                                          | C-14         | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
|                                                          | Co-60        | 1.83E+01 | 1.83E+01 | 1.83E+01 | 3.24E-12 |
|                                                          | Cs-137       | 4.59E+00 | 4.59E+00 | 4.59E+00 | 3.44E-13 |
|                                                          | Fe-55        | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
|                                                          | H-3          | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
|                                                          | Ni-63        | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
|                                                          | Pu-239/240   | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
|                                                          | Sr-90        | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
|                                                          | Tc-99        | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Ingestion Dose Factor<br>for Component<br>Removal Worker | Ag-108m      | 6.40E-03 | 5.79E-07 | 2.00E-02 | 4.10E-03 |
|                                                          | Am-241       | 3.06E+00 | 2.76E-04 | 9.53E+00 | 1.96E+00 |
|                                                          | C-14         | 1.75E-03 | 1.58E-07 | 5.46E-03 | 1.12E-03 |
|                                                          | Co-60        | 2.26E-02 | 2.04E-06 | 7.05E-02 | 1.45E-02 |
|                                                          | Cs-137       | 4.20E-02 | 3.79E-06 | 1.31E-01 | 2.69E-02 |
|                                                          | Fe-55        | 5.10E-04 | 4.61E-08 | 1.59E-03 | 3.26E-04 |
|                                                          | H-3          | 5.38E-05 | 4.86E-09 | 1.68E-04 | 3.44E-05 |
|                                                          | Ni-63        | 4.85E-04 | 4.38E-08 | 1.51E-03 | 3.10E-04 |
|                                                          | Pu-239/240   | 2.97E+00 | 2.68E-04 | 9.26E+00 | 1.90E+00 |
|                                                          | Sr-90        | 1.20E-01 | 1.08E-05 | 3.73E-01 | 7.66E-02 |
|                                                          | Tc-99        | 1.23E-03 | 1.11E-07 | 3.83E-03 | 7.86E-04 |



Table 6-15, Component Removal Worker Output Parameters (continued)

| Parameter                                           | Radionuclide | Mean     | Minimum  | Maximum  | St. dev. |
|-----------------------------------------------------|--------------|----------|----------|----------|----------|
| Inhalation Dose Factor for Component Removal Worker | Ag-108m      | 6.52E-02 | 5.87E-03 | 2.81E-01 | 3.54E-02 |
|                                                     | Am-241       | 1.02E+02 | 9.19E+00 | 4.40E+02 | 5.54E+01 |
|                                                     | C-14         | 4.80E-04 | 4.32E-05 | 2.07E-03 | 2.60E-04 |
|                                                     | Co-60        | 5.03E-02 | 4.53E-03 | 2.17E-01 | 2.73E-02 |
|                                                     | Cs-137       | 7.34E-03 | 6.61E-04 | 3.16E-02 | 3.98E-03 |
|                                                     | Fe-55        | 6.18E-04 | 5.56E-05 | 2.66E-03 | 3.35E-04 |
|                                                     | H-3          | 1.47E-05 | 1.33E-06 | 6.34E-05 | 7.99E-06 |
|                                                     | Ni-63        | 1.45E-03 | 1.30E-04 | 6.23E-03 | 7.85E-04 |
|                                                     | Pu-239/240   | 9.87E+01 | 8.89E+00 | 4.25E+02 | 5.36E+01 |
|                                                     | Sr-90        | 2.99E-01 | 2.69E-02 | 1.29E+00 | 1.62E-01 |
|                                                     | Tc-99        | 1.91E-03 | 1.72E-04 | 8.24E-03 | 1.04E-03 |
|                                                     |              |          |          |          |          |
| Total Dose Factor for Component Removal Worker      | Ag-108m      | 1.33E+01 | 1.33E+01 | 1.35E+01 | 3.57E-02 |
|                                                     | Am-241       | 1.05E+02 | 1.15E+01 | 4.43E+02 | 5.55E+01 |
|                                                     | C-14         | 2.23E-03 | 1.37E-04 | 6.59E-03 | 1.16E-03 |
|                                                     | Co-60        | 1.84E+01 | 1.83E+01 | 1.86E+01 | 3.12E-02 |
|                                                     | Cs-137       | 4.64E+00 | 4.59E+00 | 4.73E+00 | 2.72E-02 |
|                                                     | Fe-55        | 1.13E-03 | 1.35E-04 | 3.40E-03 | 4.73E-04 |
|                                                     | H-3          | 6.85E-05 | 4.22E-06 | 2.02E-04 | 3.55E-05 |
|                                                     | Ni-63        | 1.93E-03 | 2.67E-04 | 6.77E-03 | 8.50E-04 |
|                                                     | Pu-239/240   | 1.02E+02 | 1.11E+01 | 4.28E+02 | 5.36E+01 |
|                                                     | Sr-90        | 4.18E-01 | 5.77E-02 | 1.42E+00 | 1.81E-01 |
|                                                     | Tc-99        | 3.14E-03 | 4.03E-04 | 9.74E-03 | 1.32E-03 |
|                                                     |              |          |          |          |          |

**License Termination Plan – (STS-004-003)**

**Table 6-16 Remediation Worker Output Parameters (RAI Response)**

| <b>Scenario Factor</b>                       | <b>Radionuclide</b> | <b>Mean</b> | <b>Minimum</b> | <b>Maximum</b> | <b>St. dev.</b> |
|----------------------------------------------|---------------------|-------------|----------------|----------------|-----------------|
| External Dose Factor for Remediation Worker  | Ag-108m             | 1.33E+01    | 1.33E+01       | 1.33E+01       | 2.15E-12        |
|                                              | Am-241              | 0.00E+00    | 0.00E+00       | 0.00E+00       | 0.00E+00        |
|                                              | C-14                | 0.00E+00    | 0.00E+00       | 0.00E+00       | 0.00E+00        |
|                                              | Co-60               | 1.83E+01    | 1.83E+01       | 1.83E+01       | 3.24E-12        |
|                                              | Cs-137              | 4.59E+00    | 4.59E+00       | 4.59E+00       | 3.44E-13        |
|                                              | Fe-55               | 0.00E+00    | 0.00E+00       | 0.00E+00       | 0.00E+00        |
|                                              | H-3                 | 0.00E+00    | 0.00E+00       | 0.00E+00       | 0.00E+00        |
|                                              | Ni-63               | 0.00E+00    | 0.00E+00       | 0.00E+00       | 0.00E+00        |
|                                              | Pu-239/240          | 0.00E+00    | 0.00E+00       | 0.00E+00       | 0.00E+00        |
|                                              | Sr-90               | 0.00E+00    | 0.00E+00       | 0.00E+00       | 0.00E+00        |
|                                              | Tc-99               | 0.00E+00    | 0.00E+00       | 0.00E+00       | 0.00E+00        |
|                                              | Tc-99               | 0.00E+00    | 0.00E+00       | 0.00E+00       | 0.00E+00        |
| Ingestion Dose Factor for Remediation Worker | Ag-108m             | 6.43E-03    | 3.79E-07       | 2.06E-02       | 4.09E-03        |
|                                              | Am-241              | 3.07E+00    | 1.81E-04       | 9.86E+00       | 1.95E+00        |
|                                              | C-14                | 1.76E-03    | 1.04E-07       | 5.65E-03       | 1.12E-03        |
|                                              | Co-60               | 2.27E-02    | 1.34E-06       | 7.30E-02       | 1.44E-02        |
|                                              | Cs-137              | 4.21E-02    | 2.48E-06       | 1.35E-01       | 2.68E-02        |
|                                              | Fe-55               | 5.12E-04    | 3.02E-08       | 1.64E-03       | 3.25E-04        |
|                                              | H-3                 | 5.40E-05    | 3.18E-09       | 1.73E-04       | 3.43E-05        |
|                                              | Ni-63               | 4.87E-04    | 2.87E-08       | 1.56E-03       | 3.10E-04        |
|                                              | Pu-239/240          | 2.98E+00    | 1.76E-04       | 9.58E+00       | 1.90E+00        |
|                                              | Sr-90               | 1.20E-01    | 7.08E-06       | 3.86E-01       | 7.64E-02        |
|                                              | Tc-99               | 1.23E-03    | 7.26E-08       | 3.96E-03       | 7.84E-04        |
|                                              | Tc-99               | 1.23E-03    | 7.26E-08       | 3.96E-03       | 7.84E-04        |



Table 6-16, Remediation Worker Output Parameters (continued)

| Scenario Factor                               | Radionuclide | Mean     | Minimum  | Maximum  | St. dev. |
|-----------------------------------------------|--------------|----------|----------|----------|----------|
| Inhalation Dose Factor for Remediation Worker | Ag-108m      | 1.31E-03 | 9.40E-05 | 5.29E-03 | 7.17E-04 |
|                                               | Am-241       | 2.05E+00 | 1.47E-01 | 8.28E+00 | 1.12E+00 |
|                                               | C-14         | 9.62E-06 | 6.92E-07 | 3.89E-05 | 5.28E-06 |
|                                               | Co-60        | 1.01E-03 | 7.25E-05 | 4.08E-03 | 5.53E-04 |
|                                               | Cs-137       | 1.47E-04 | 1.06E-05 | 5.96E-04 | 8.07E-05 |
|                                               | Fe-55        | 1.24E-05 | 8.91E-07 | 5.01E-05 | 6.79E-06 |
|                                               | H-3          | 2.95E-07 | 2.12E-08 | 1.19E-06 | 1.62E-07 |
|                                               | Ni-63        | 2.90E-05 | 2.09E-06 | 1.17E-04 | 1.59E-05 |
|                                               | Pu-239/240   | 1.98E+00 | 1.42E-01 | 8.01E+00 | 1.09E+00 |
|                                               | Sr-90        | 5.99E-03 | 4.31E-04 | 2.42E-02 | 3.28E-03 |
|                                               | Tc-99        | 3.84E-05 | 2.76E-06 | 1.55E-04 | 2.10E-05 |
|                                               |              |          |          |          |          |
| Total Dose Factor for Remediation Worker      | Ag-108m      | 1.33E+01 | 1.33E+01 | 1.33E+01 | 4.15E-03 |
|                                               | Am-241       | 5.12E+00 | 4.42E-01 | 1.51E+01 | 2.25E+00 |
|                                               | C-14         | 1.77E-03 | 4.77E-06 | 5.67E-03 | 1.12E-03 |
|                                               | Co-60        | 1.83E+01 | 1.83E+01 | 1.84E+01 | 1.45E-02 |
|                                               | Cs-137       | 4.63E+00 | 4.59E+00 | 4.72E+00 | 2.68E-02 |
|                                               | Fe-55        | 5.24E-04 | 5.26E-06 | 1.66E-03 | 3.25E-04 |
|                                               | H-3          | 5.43E-05 | 1.46E-07 | 1.74E-04 | 3.43E-05 |
|                                               | Ni-63        | 5.16E-04 | 1.18E-05 | 1.60E-03 | 3.10E-04 |
|                                               | Pu-239/240   | 4.96E+00 | 4.28E-01 | 1.46E+01 | 2.19E+00 |
|                                               | Sr-90        | 1.26E-01 | 2.44E-03 | 3.93E-01 | 7.65E-02 |
|                                               | Tc-99        | 1.27E-03 | 1.60E-05 | 4.01E-03 | 7.84E-04 |
|                                               |              |          |          |          |          |

The final dose factors selected in the LTP represent the 95<sup>th</sup> percentile of each Total Dose factor. Table 6-17 provides the percentile values ranging from 1% to 99% for three key radionuclides and for each worker type. The full ModelRisk report provides detail on each radionuclide. Only the values for key radionuclides are provided here but additional values for other radionuclides are available. The values shown in this table represent the dose factors in uSv/y per Bq/cm<sup>2</sup>. As noted in this data set, the values for Co-60 and Cs-137 are tightly grouped through the percentile range whereas the Ni-63 values span over 2 orders of magnitude. This characteristic is caused by the dominance of the external dose factors for Co-60 and Cs-137 which were deterministic. In the case

**License Termination Plan – (STS-004-003)**

of Ni-63, no contribution is present for external dose, so the variance is based solely on the probabilistic parameters from inhalation and ingestion pathways.

**Table 6-17 Percentile Distributions of Total Dose factor for Each Worker Scenario and for Key Radionuclides (RAI Response)**

| Percentile<br>s | Co-60 Total<br>Dose<br>Factor<br>Comp.<br>Rem. | Co-60 Total<br>Dose<br>Factor<br>Rem.<br>Worker | Cs-137<br>Total Dose<br>Factor<br>Comp.<br>Rem. | Cs-137<br>Total Dose<br>Factor<br>Rem.<br>Worker | Ni-63 Total<br>Dose<br>Factor<br>Comp.<br>Rem. | Ni-63 Total<br>Dose<br>Factor<br>Rem.<br>Worker |
|-----------------|------------------------------------------------|-------------------------------------------------|-------------------------------------------------|--------------------------------------------------|------------------------------------------------|-------------------------------------------------|
| 1%              | 1.8333E+01                                     | 1.8313E+01                                      | 4.5932E+00                                      | 4.5880E+00                                       | 5.7226E-04                                     | 3.4383E-05                                      |
| 3%              | 1.8339E+01                                     | 1.8314E+01                                      | 4.5959E+00                                      | 4.5895E+00                                       | 7.2230E-04                                     | 5.4410E-05                                      |
| 5%              | 1.8343E+01                                     | 1.8315E+01                                      | 4.5981E+00                                      | 4.5910E+00                                       | 8.2150E-04                                     | 7.4366E-05                                      |
| 8%              | 1.8347E+01                                     | 1.8316E+01                                      | 4.6005E+00                                      | 4.5933E+00                                       | 9.2946E-04                                     | 9.8863E-05                                      |
| 10%             | 1.8350E+01                                     | 1.8317E+01                                      | 4.6022E+00                                      | 4.5947E+00                                       | 9.8672E-04                                     | 1.1731E-04                                      |
| 15%             | 1.8355E+01                                     | 1.8319E+01                                      | 4.6062E+00                                      | 4.5988E+00                                       | 1.1192E-03                                     | 1.6329E-04                                      |
| 20%             | 1.8359E+01                                     | 1.8321E+01                                      | 4.6099E+00                                      | 4.6028E+00                                       | 1.2245E-03                                     | 2.0989E-04                                      |
| 25%             | 1.8362E+01                                     | 1.8324E+01                                      | 4.6136E+00                                      | 4.6068E+00                                       | 1.3165E-03                                     | 2.5716E-04                                      |
| 30%             | 1.8366E+01                                     | 1.8326E+01                                      | 4.6178E+00                                      | 4.6110E+00                                       | 1.4036E-03                                     | 3.0611E-04                                      |
| 35%             | 1.8369E+01                                     | 1.8328E+01                                      | 4.6216E+00                                      | 4.6150E+00                                       | 1.5004E-03                                     | 3.5027E-04                                      |
| 40%             | 1.8373E+01                                     | 1.8330E+01                                      | 4.6255E+00                                      | 4.6191E+00                                       | 1.5939E-03                                     | 3.9780E-04                                      |
| 45%             | 1.8377E+01                                     | 1.8332E+01                                      | 4.6294E+00                                      | 4.6231E+00                                       | 1.6873E-03                                     | 4.4430E-04                                      |
| 50%             | 1.8380E+01                                     | 1.8335E+01                                      | 4.6336E+00                                      | 4.6274E+00                                       | 1.7815E-03                                     | 4.9324E-04                                      |
| 55%             | 1.8384E+01                                     | 1.8337E+01                                      | 4.6379E+00                                      | 4.6315E+00                                       | 1.8817E-03                                     | 5.3955E-04                                      |
| 60%             | 1.8388E+01                                     | 1.8339E+01                                      | 4.6417E+00                                      | 4.6355E+00                                       | 1.9918E-03                                     | 5.8921E-04                                      |
| 65%             | 1.8392E+01                                     | 1.8341E+01                                      | 4.6459E+00                                      | 4.6396E+00                                       | 2.1000E-03                                     | 6.3550E-04                                      |
| 70%             | 1.8397E+01                                     | 1.8344E+01                                      | 4.6506E+00                                      | 4.6438E+00                                       | 2.2348E-03                                     | 6.8332E-04                                      |
| 75%             | 1.8402E+01                                     | 1.8346E+01                                      | 4.6554E+00                                      | 4.6482E+00                                       | 2.3851E-03                                     | 7.3411E-04                                      |
| 80%             | 1.8409E+01                                     | 1.8349E+01                                      | 4.6612E+00                                      | 4.6533E+00                                       | 2.5627E-03                                     | 7.9325E-04                                      |
| 85%             | 1.8416E+01                                     | 1.8352E+01                                      | 4.6674E+00                                      | 4.6591E+00                                       | 2.7831E-03                                     | 8.6166E-04                                      |
| 90%             | 1.8427E+01                                     | 1.8356E+01                                      | 4.6747E+00                                      | 4.6663E+00                                       | 3.0841E-03                                     | 9.4412E-04                                      |
| 92%             | 1.8433E+01                                     | 1.8358E+01                                      | 4.6785E+00                                      | 4.6701E+00                                       | 3.2427E-03                                     | 9.8697E-04                                      |
| 95%             | 1.8445E+01                                     | 1.8362E+01                                      | 4.6850E+00                                      | 4.6772E+00                                       | 3.5748E-03                                     | 1.0694E-03                                      |
| 97%             | 1.8456E+01                                     | 1.8365E+01                                      | 4.6916E+00                                      | 4.6833E+00                                       | 3.9124E-03                                     | 1.1394E-03                                      |
| 99%             | 1.8477E+01                                     | 1.8370E+01                                      | 4.7028E+00                                      | 4.6939E+00                                       | 4.5217E-03                                     | 1.2580E-03                                      |



### 6.10 Analysis and Results

Simulations were run for the Remediation and Component Removal worker scenarios. Each simulation set was run with 10,000 iterations. The total dose rate per unit surface activity concentration on the material for each radionuclide in  $(\mu\text{Sv/y})/(\text{Bq/cm}^2)$  was calculated. The value for the 95<sup>th</sup> percentile of the simulation results was chosen to calculate the surface contamination limits. The dose rate coefficients in  $(\mu\text{Sv/y})/(\text{Bq/cm}^2)$  were converted to  $(\text{mrem/y})/(\text{dpm/cm}^2)$  by dividing by 600 ( $10 \mu\text{Sv/mrem} \times 60 \text{ dpm/Bq}$ ).

The RESRAD-BUILD model for the Tour Guide on Ship scenario generates results in  $(\text{mrem/y})/(\text{dpm/m}^2)$ . The results include all three exposure pathways. The dose rate coefficients were converted to  $(\text{mrem/y})/(\text{dpm/cm}^2)$  by dividing by  $10,000 \text{ cm}^2/\text{m}^2$ .

The evaluation of the NUREG-1640 scrap yard/foundry worker scenarios is the most conservative scenario for 3 radionuclides. The NUREG-1640 evaluation of the leachate scenarios is the most conservative for 3 radionuclides. The maximum 95<sup>th</sup> percentile EDE for each radionuclide was converted to  $(\text{mrem/y})/(\text{dpm/cm}^2)$ .

The maximum value of the effective dose equivalent rate coefficients for all the scenarios for each radionuclide was used for calculating the surface contamination DCGL. Table 6-20, Scenario Results, presents the results of the scenario calculations, showing the dose conversion factors (DCF), the maximum DCF and the scenario with the maximum DCF for each radionuclide.

Table 6-18 95<sup>th</sup> Percentile EDE from All Pathways - Scrap Yard and Foundry Worker $(\mu\text{Sv/y})/(\text{Bq/cm}^2)$ 

| Nuclide    | Scrap Yard | Handling Slag | Transferring EAF dust | Baghouse Maintenance | Handling Metal Product | Processing EAF Dust | Processing Steel Slag | Maximum | Worker                |
|------------|------------|---------------|-----------------------|----------------------|------------------------|---------------------|-----------------------|---------|-----------------------|
| C-14       | 9.0E-04    | 0.0E+00       | 0.0E+00               | 0.0E+00              | 4.9E-04                | 0.0E+00             | 0.0E+00               | 9.0E-04 | Scrap Yard            |
| Co-60      | 3.8E+01    | 0.0E+00       | 1.8E-01               | 5.6E-03              | 7.9E-01                | 5.4E-02             | 0.0E+00               | 3.8E+01 | Scrap Yard            |
| Ni-63      | 3.5E-04    | 0.0E+00       | 5.8E-08               | 6.2E-10              | 2.9E-04                | 9.8E-07             | 0.0E+00               | 3.5E-04 | Scrap Yard            |
| Sr-90      | 2.0E-01    | 6.9E-02       | 5.1E-03               | 4.3E-05              | 0.0E+00                | 1.3E-03             | 8.7E-02               | 2.0E-01 | Scrap Yard            |
| Tc-99      | 1.2E-03    | 0.0E+00       | 1.9E-05               | 9.5E-08              | 7.8E-04                | 3.3E-08             | 0.0E+00               | 1.2E-03 | Scrap Yard            |
| Ag-108m    | 2.1E+01    | 0.0E+00       | 1.4E+00               | 4.5E-02              | 5.3E-01                | 3.9E-01             | 0.0E+00               | 2.1E+01 | Scrap Yard            |
| Cs-137     | 7.5E+00    | 7.9E-02       | 2.3E+00               | 9.2E-02              | 0.0E+00                | 9.6E-01             | 8.7E-02               | 7.5E+00 | Scrap Yard            |
| H-3        | 2.7E-05    | 0.0E+00       | 0.0E+00               | 0.0E+00              | 1.1E-06                | 0.0E+00             | 0.0E+00               | 2.7E-05 | Scrap Yard            |
| Fe-55      | 3.4E-04    | 5.9E-06       | 4.7E-06               | 2.1E-13              | 1.9E-04                | 7.9E-07             | 5.5E-06               | 3.4E-04 | Scrap Yard            |
| Am-241     | 2.2E+01    | 2.8E+01       | 2.2E+00               | 1.1E-04              | 0.0E+00                | 4.7E-01             | 2.9E+01               | 2.9E+01 | Processing Steel slag |
| Pu-239/240 | 2.1E+01    | 2.0E+01       | 1.6E+00               | 1.1E-06              | 0.0E+00                | 3.3E-01             | 2.0E+01               | 2.1E+01 | Scrap Yard            |



Table 6-19 95<sup>th</sup> Percentile EDE from All Pathways - Leachate ( $\mu\text{Sv/y}/(\text{Bq}/\text{cm}^2)$ )

| Nuclide        | Leachate -<br>Ind dust | Leachate -<br>Mun dust | Leachate -<br>Ind scrap | Leachate -<br>Mun scrap | Leachate -<br>steel slag | Maximum | Scenario              |
|----------------|------------------------|------------------------|-------------------------|-------------------------|--------------------------|---------|-----------------------|
| C-14           | 4.3E-07                | 7.3E-09                | 9.5E-03                 | 3.8E-03                 | 0.0E+00                  | 9.5E-03 | Leachate - Ind scrap  |
| Co-60          | 0.0E+00                | 0.0E+00                | 0.0E+00                 | 0.0E+00                 | 0.0E+00                  | 0.0E+00 |                       |
| Ni-63          | 0.0E+00                | 0.0E+00                | 0.0E+00                 | 0.0E+00                 | 0.0E+00                  | 0.0E+00 |                       |
| Sr-90          | 8.2E-09                | 1.1E-09                | 4.5E-08                 | 7.1E-08                 | 2.9E-02                  | 2.9E-02 | Leachate - steel slag |
| Tc-99          | 5.8E-03                | 2.6E-03                | 1.4E+00                 | 5.3E-01                 | 0.0E+00                  | 1.4E+00 | Leachate - Ind scrap  |
| Ag-108m        | 0.0E+00                | 0.0E+00                | 0.0E+00                 | 0.0E+00                 | 0.0E+00                  | 0.0E+00 |                       |
| Cs-137         | 0.0E+00                | 0.0E+00                | 0.0E+00                 | 0.0E+00                 | 0.0E+00                  | 0.0E+00 |                       |
| H-3            | 0.0E+00                | 0.0E+00                | 1.4E-02                 | 5.4E-03                 | 0.0E+00                  | 1.4E-02 | Leachate - Ind scrap  |
| Fe-55          | 0.0E+00                | 0.0E+00                | 0.0E+00                 | 0.0E+00                 | 1.5E-25                  | 1.5E-25 | Leachate - steel slag |
| Am-241         | 0.0E+00                | 0.0E+00                | 0.0E+00                 | 0.0E+00                 | 0.0E+00                  | 0.0E+00 |                       |
| Pu-<br>239/240 | 0.0E+00                | 0.0E+00                | 0.0E+00                 | 0.0E+00                 | 0.0E+00                  | 0.0E+00 |                       |

**License Termination Plan – (STS-004-003)**

**Table 6-20 Scenario Results (mrem/y)/(dpm/cm<sup>2</sup>)**

| <b>Radionuclide</b> | <b>Tour Guide</b> | <b>Comp Removal Worker</b> | <b>Remediation Worker</b> | <b>NUREG-1640 Scrap Yard/Foundry Worker</b> | <b>NUREG-1640 Leachate</b> | <b>Maximum</b> | <b>Scenario</b>                      |
|---------------------|-------------------|----------------------------|---------------------------|---------------------------------------------|----------------------------|----------------|--------------------------------------|
| Ag-108m             | 9.56E-09          | 2.23E-02                   | 2.21E-02                  | 3.50E-02                                    | 0.00E+00                   | 3.50E-02       | NUREG-1640 Scrap Yard/Foundry Worker |
| C-14                | 1.96E-09          | 7.08E-06                   | 6.29E-06                  | 1.50E-06                                    | 1.58E-05                   | 1.58E-05       | NUREG-1640 Leachate                  |
| Co-60               | 1.88E-09          | 3.07E-02                   | 3.06E-02                  | 6.33E-02                                    | 0.00E+00                   | 6.33E-02       | NUREG-1640 Scrap Yard/Foundry Worker |
| Cs-137              | 4.04E-09          | 7.81E-03                   | 7.80E-03                  | 1.25E-02                                    | 0.00E+00                   | 1.25E-02       | NUREG-1640 Scrap Yard/Foundry Worker |
| Ni-63               | 9.99E-11          | 5.93E-06                   | 1.79E-06                  | 5.83E-07                                    | 0.00E+00                   | 5.93E-06       | Comp Removal Worker                  |
| Sr-90               | 7.10E-09          | 1.26E-03                   | 4.39E-04                  | 3.33E-04                                    | 4.83E-05                   | 1.26E-03       | Comp Removal Worker                  |
| Tc-99               | 2.37E-09          | 9.13E-06                   | 4.46E-06                  | 2.00E-06                                    | 2.33E-03                   | 2.33E-03       | NUREG-1640 Leachate                  |
| H-3                 | 4.53E-12          | 2.17E-07                   | 1.93E-07                  | 4.50E-08                                    | 2.33E-05                   | 2.33E-05       | NUREG-1640 Leachate                  |
| Fe-55               | 8.21E-12          | 3.26E-06                   | 1.85E-06                  | 5.67E-07                                    | 2.50E-28                   | 3.26E-06       | Comp Removal Worker                  |
| Am-241              | 4.80E-07          | 3.58E-01                   | 1.52E-02                  | 4.83E-02                                    | 0.00E+00                   | 3.58E-01       | Comp Removal Worker                  |
| Pu-239/240          | 9.31E-07          | 3.46E-01                   | 1.47E-02                  | 3.50E-02                                    | 0.00E+00                   | 3.46E-01       | Comp Removal Worker                  |

The maximum effective dose equivalent rate coefficient was then converted to a 15 mrem/year DCGL limit by dividing 15 by the maximum dose rate coefficient and then multiplying by 100. The resulting values are presented in Table 6-21.



Table 6-21 Surface Contamination Limits (DCGLs)

| Radionuclide | Maximum<br>(mrem/y)/(dpm/cm <sup>2</sup> ) | 15 mrem/year limit<br>(dpm/100cm <sup>2</sup> ) |
|--------------|--------------------------------------------|-------------------------------------------------|
| Ag-108m      | 3.50E-02                                   | 4.29E+04                                        |
| C-14         | 1.58E-05                                   | 9.47E+07                                        |
| Co-60        | 6.33E-02                                   | 2.37E+04                                        |
| Cs-137       | 1.25E-02                                   | 1.20E+05                                        |
| Ni-63        | 5.93E-06                                   | 2.53E+08                                        |
| Sr-90        | 1.26E-03                                   | 1.19E+06                                        |
| Tc-99        | 2.33E-03                                   | 6.43E+05                                        |
| H-3          | 2.33E-05                                   | 6.43E+07                                        |
| Fe-55        | 3.26E-06                                   | 4.60E+08                                        |
| Am-241       | 3.58E-01                                   | 4.19E+03                                        |
| Pu-239/240   | 3.46E-01                                   | 4.34E+03                                        |

Levels of removable (non-fixed) contamination shall be reduced to the lowest levels that are reasonably possible. The recommended maximum removable contamination levels should be set at 10% of the total levels.

When multiple radionuclides are present in the waste stream, the Sum of the Fractions (SOF) must be solved. Equation 6-4 presents the formula used to calculate the Sum of Fractions.

$$SOF = \sum \frac{SAC_i}{DCGL_i} \quad \text{Equation 6-4}$$

Where:

*SOF* = Sum of the fractions for all radionuclides of concern

*SAC<sub>i</sub>* = Surface Activity Concentration of radionuclide *i*, dpm/100cm<sup>2</sup>

*DCGL<sub>i</sub>* = Derived Concentration Guideline Level of radionuclide *i*, dpm/100cm<sup>2</sup>

The SOF must be less than or equal to 1 for the material to meet the release criterion.

### 6.11 Reefing

Sections 6.1, 6.3 and 6.3.1 of this chapter describe artificial reefing in sufficient detail to explain why this disposition scenario is unlikely to be exercised, especially given current MARAD policy to restrict vessels built before 1985 from this method of disposal. As noted in section 6.3.1, fewer than two (2) percent of MARAD vessels have been disposed via artificial reefing and none since FY 2010. As part of the NHPA consultation, MARAD has requested public comment regarding disposition options for NSS. Reefing the ship represented a very small fraction of the responses, fewer than five percent, and no state has expressed interest to MARAD in obtaining NSS for reefing. Nevertheless, because reefing of any vessel based on its age is not restricted by statute, for the purposes of the LTP MARAD considers

artificial reefing to be a Less Likely but Plausible (LLBP) scenario<sup>27</sup> and has evaluated potential exposures to determine if the DCGLs presented in Table 6-21 are limiting.

All else being equal with respect to the normal preparations of a ship for reefing, there are two potential end-state conditions for NSS if it is reefed. The structures and components that contain residual radioactivity are either retained in-situ and result in potential exposures in the marine environment and aquatic habitat, or they are removed prior to sinking the ship. In the case where the materials containing residual radioactivity are removed, the immediate shipbreaking scenario governs that activity and is bounding. Therefore, this section evaluates exposures in the case where the materials remain in-situ.

#### 6.11.1 Diver on a Reefed Ship

For this evaluation, the most likely exposed individual is a diver. The only exposure mode is through external exposure to structures and components. The same model used for external exposure to the Remediation and Component workers was used for the divers with the 1-foot air gap changed to water. The resulting dose rates were again multiplied by 2 for conservatism. The exposure time was conservatively assumed to be 1000 hours in a year. The calculated dose rate coefficients and 15 mrem/year activity concentrations are presented in Table 6-22.

**Table 6-22      Reefing Diver Dose Rate Coefficients and DCGLs**

| <b>Radionuclide</b> | <b>(mrem/year)/<br/>(dpm/cm<sup>2</sup>)</b> | <b>15 mrem/year<br/>limit<br/>(dpm/100cm<sup>2</sup>)</b> |
|---------------------|----------------------------------------------|-----------------------------------------------------------|
| Ag-108m             | 2.19E-03                                     | 6.85E+05                                                  |
| Co-60               | 4.40E-03                                     | 3.41E+05                                                  |
| Cs-137              | 7.95E-04                                     | 1.89E+06                                                  |

These DCGLs are approximately 14 to 16 times greater than those for the shipbreaking scenarios. Therefore, the shipbreaking DCGLs are bounding.

#### 6.11.2 Consuming Fish from a Reefed Ship

A potential exposure pathway in the reefing scenario is through the consumption of contaminated seafood. Current nuclide bio-accumulation models require site specific measurements of the biomasses of various functional groups and key species. The undetermined location and biota composition of the reefing scenario make such modeling impossible. However, using conservative assumptions of the composition of residual nuclides at the time of reefing, it can be shown that concentrations of the residual nuclides in the environment would be less than the NRC unrestricted effluent release limits. By demonstrating concentrations lower than the unrestricted effluent release limits, it is also demonstrated that concentrations of the nuclides would not create deleterious environmental effects including bioaccumulation of nuclides in species eaten by humans. Ultimately this demonstrates that an exposure pathway via contaminated seafood is not of concern.

<sup>27</sup> NUREG-1757, Volume 2 Section I.3.3.3.6 states "Even if offsite use is not considered reasonably foreseeable, offsite scenarios may be less likely but plausible scenarios and should be analyzed as scenarios, to understand the robustness of the analysis."



The following conservative assumptions are required to make this demonstration:

- 1) The total residual man-made radioactive material is equal to 1 curie.
- 2) All contamination is located within the containment vessel (CV).
- 3) All contamination is located within 1mm or less of the exposed surface of the containment vessel's structural steel.
- 4) Structural steel deterioration is dependent on multiple factors. Two primary factors are water temperature and depth of the steel below the water surface.
  - a) Higher water temperatures are correlated with faster rates of corrosion. This scenario will assume that the vessel is reefed in US controlled tropical waters and thus subject to the higher rates of corrosion. Corrosion rates derived from measurements collected from the USS Arizona in Pearl Harbor, Hawaii will be used for this scenario [Reference 6-16].
  - b) Lower depth is associated with slower rates of corrosion. The reefing scenario will assume the highest point of the reefed vessel is 30 feet below sea level. Correspondingly, the reactor hatch will be at a depth of 56 feet and lowest portion of the reactor compartment at a depth of 110 feet. Corrosion rates for a depth of 56 feet, the highest portion of the containment vessel, will be used for these calculations.
  - c) The corrosion rate (C) of 0.0026 mm/yr will be used as calculated from the following formula,

$$C = i_{\text{corr}} * 0.0254 \text{ mm/yr}$$

$$i_{\text{corr}} = -0.051 (\text{WD}) + 2.96$$

*Where:  $i_{\text{corr}}$  is the corrosion rate in mpy (mils per yr)*

$$1 \text{ mil/yr} = 0.0254 \text{ mm/yr}$$

- 5) The volume of the containment vessel is estimated at 1.13E9 mL
- 6) A 100% exchange of water within the CV is achieved AT LEAST once every five years. This is perhaps the most conservative of assumptions. All openings on the Savannah would be opened or removed prior to reefing. In such a scenario water exchange in the CV would likely be multiple times daily.

Using the assumption of 1 Curie of residual material and the fractions of the total activity of the nuclides (From LTP Table 6-5), the total remaining microcuries of each nuclide can be calculated and are presented in Table 6-19.

Based on the assumption of 0.0026 mm per year deterioration of steel in seawater and the assumption of 1mm depth of contamination, the release rate each nuclide every five years can be calculated as follows:

$$0.0026 \text{ mm/year} * 5 \text{ years} = 0.013 \text{ mm}$$

$$0.013 \text{ mm of contaminated steel} / 1 \text{ mm of total contamination} = 1.3 \% \text{ of contaminated steel}$$

Based on this rate of deterioration, we can show the concentration of the nuclides after five years of sustained release with no water exchange. The method to calculate the concentration of the nuclides in the containment vessel water is shown below.

$$\text{Conc}_i = A_i/V*0.013$$

*Where:  $A_i$  = Nuclide activity in  $\mu\text{Ci}$*

$$V = CV \text{ volume} = 1.13\text{E}9 \text{ ml}$$

Those activity concentrations were then compared to the 10CFR20 Appendix B, Table 2, Column 2 Effluent Concentrations. The results of the calculations are shown in the last two columns of Table 6-23. Note that all water concentrations are less than the effluent release concentrations in Appendix B of 10CFR20.

The low levels of nuclide concentrations show that the potential is below a level considered deleterious to humans and the environment. Given these concentrations are based on an extremely low rate of water exchange, consuming seafood from the reefed vessel is an unlikely potential pathway of exposure to individuals.



Table 6-23 Concentrations of the Residual Nuclides in the Containment Volume

| Nuclide    | Fraction of Total Activity | Activity (Ci) | Activity ( $\mu$ Ci) | Concentration in CV water after 5 years ( $\mu$ Ci/ml)<br>Note these were calculated for $\text{Conc}_i = A_i/V \times 0.013$ | NRC unrestricted release limit ( $\mu$ Ci/ml) |
|------------|----------------------------|---------------|----------------------|-------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|
| C-14       | 5.61E-03                   | 5.61E-03      | 5.61E+03             | 6.44E-08                                                                                                                      | 3E-05                                         |
| Co-60      | 1.63E-02                   | 1.63E-02      | 1.63E+04             | 1.87E-07                                                                                                                      | 3E-06                                         |
| Ni-63      | 9.00E-01                   | 9.00E-01      | 9.00E+05             | 1.03E-05                                                                                                                      | 1E-04                                         |
| Sr-90      | 1.54E-06                   | 1.54E-06      | 1.54E+00             | 1.77E-11                                                                                                                      | 5E-07                                         |
| Tc-99      | 2.11E-05                   | 2.11E-05      | 2.11E+01             | 2.42E-10                                                                                                                      | 6E-05                                         |
| Ag-108m    | 1.38E-04                   | 1.38E-04      | 1.38E+02             | 1.58E-09                                                                                                                      | 9E-06                                         |
| Cs-137     | 7.61E-02                   | 7.61E-02      | 7.61E+04             | 8.73E-07                                                                                                                      | 1E-06                                         |
| H-3        | 3.21E-04                   | 3.21E-04      | 3.21E+02             | 3.68E-09                                                                                                                      | 1E-03                                         |
| Fe-55      | 1.35E-03                   | 1.35E-03      | 1.35E+03             | 1.55E-08                                                                                                                      | 1E-04                                         |
| Am-241     | 9.66E-08                   | 9.66E-08      | 9.66E-02             | 1.11E-12                                                                                                                      | 2E-08                                         |
| Pu-239/240 | 8.01E-08                   | 8.01E-08      | 8.01E-02             | 9.19E-13                                                                                                                      | 2E-08                                         |

## 6.12 Area Factors

An area factor is the magnitude by which the concentration within a small area of elevated activity can exceed DCGL while maintaining compliance with the release criterion. Area factors are only applicable to Class 1 survey units where the residual activity may be non-uniform. Also, area factors are only applicable to land areas and building surfaces. Based upon the characterization of the surfaces within the CV and RC, we do not expect the need to calculate or use area factors during the FSS.

## 6.13 Radionuclides of Concern and Insignificant Dose Contributors

NUREG-1757, Vol 2, Section 3.3 [Reference 6-8] states:

*NRC staff considers radionuclides and exposure pathways that contribute no greater than 10 percent of the dose criteria to be insignificant contributors. Because the dose criteria are performance criteria, this 10 percent limit for insignificant contributors is an aggregate limitation only. That is, the sum of the dose contributions from all radionuclides and pathways considered insignificant should be no greater than 10 percent of the dose criteria.*

After removal of the radionuclides considered as Insignificant Dose Contributors (IDC), the remaining radionuclides are designated as the Radionuclides of Concern (ROC). The IDCs are determined by calculation of the Relative Dose Fraction. The Relative Dose Fraction,  $RDF_{i,k}$ , for radionuclide  $i$  in each sample is calculated using the radionuclide fractions from Table 6-4, the applicable DCGLs from Table 6-17 and Equation 6-5.

$$RDF_{i,k} = \frac{fA_{i,k}}{DCGL_i} \left[ \frac{1}{\sum_i \frac{fA_{i,k}}{DCGL_i}} \right] \quad \text{Equation 6-5}$$

Where:

$RDF_{i,k}$  = Relative Dose Fraction for radionuclide  $i$  in the sample

$fA_{i,k}$  = Activity fraction of radionuclide  $i$  in the sample

$DCGL_i$  = DCGL for radionuclide  $i$

The results of the activity fraction/DCGL calculations are presented in Table 6-24.



Table 6-24 Activity Fractions/DCGLs

| Nuclide        | SG<br>composite<br>frac/DCGL | PZR<br>composite<br>frac/DCGL | PD-T4<br>composite<br>frac/DCGL | RC Exhaust<br>Vent<br>composite<br>frac/DCGL | RC IX<br>Piping<br>composite<br>frac/DCGL | Makeup<br>Storage<br>Tank<br>frac/DCGL |
|----------------|------------------------------|-------------------------------|---------------------------------|----------------------------------------------|-------------------------------------------|----------------------------------------|
| Ag-108m        | 0.00E+00                     | 0.00E+00                      | 4.55E-09                        | 1.17E-08                                     | 1.10E-09                                  | 1.99E-09                               |
| C-14           | 1.09E-13                     | 1.28E-11                      | 2.66E-12                        | 2.99E-10                                     | 2.93E-11                                  | 1.12E-11                               |
| Co-60          | 4.47E-08                     | 9.80E-07                      | 8.27E-07                        | 4.00E-07                                     | 6.49E-07                                  | 1.23E-06                               |
| Cs-137         | 3.42E-11                     | 1.54E-09                      | 1.26E-07                        | 3.60E-06                                     | 1.42E-09                                  | 7.17E-08                               |
| Ni-63          | 3.95E-09                     | 3.86E-09                      | 3.82E-09                        | 2.09E-09                                     | 3.88E-09                                  | 3.76E-09                               |
| Sr-90          | 0.00E+00                     | 6.38E-13                      | 0.00E+00                        | 0.00E+00                                     | 2.51E-13                                  | 6.88E-12                               |
| Tc-99          | 3.63E-12                     | 2.32E-11                      | 1.09E-10                        | 0.00E+00                                     | 4.87E-11                                  | 1.20E-11                               |
| H-3            | -                            | -                             | -                               | -                                            | -                                         | 3.00E-11                               |
| Fe-55          | -                            | -                             | -                               | -                                            | -                                         | 1.76E-11                               |
| Am-241         | -                            | -                             | -                               | -                                            | -                                         | 1.38E-10                               |
| Pu-<br>239/240 | -                            | -                             | -                               | -                                            | -                                         | 1.11E-10                               |
| <b>Totals</b>  | <b>4.87E-08</b>              | <b>9.86E-07</b>               | <b>9.61E-07</b>                 | <b>4.02E-06</b>                              | <b>6.56E-07</b>                           | <b>1.30E-06</b>                        |

The Relative Dose Fractions (RDFs) were calculated by dividing the fractions presented in Table 6-24 for each radionuclide by the totals for each sample presented in Table 6-24. The RDFs for each radionuclide in each sample are presented in Table 6-25.

Table 6-25 Relative Dose Fractions

| Nuclide    | SG composite RDF | PZR composite RDF | PD-T4 composite RDF | RC Exhaust Vent composite RDF | RC IX Piping composite RDF | Makeup Storage Tank RDF |
|------------|------------------|-------------------|---------------------|-------------------------------|----------------------------|-------------------------|
| Ag-108m    | 0.00E+00         | 0.00E+00          | 4.73E-03            | 2.92E-03                      | 1.68E-03                   | 1.53E-03                |
| C-14       | 2.24E-06         | 1.30E-05          | 2.77E-06            | 7.45E-05                      | 4.46E-05                   | 8.60E-06                |
| Co-60      | 9.18E-01         | 9.94E-01          | 8.60E-01            | 9.96E-02                      | 9.90E-01                   | 9.40E-01                |
| Cs-137     | 7.03E-04         | 1.56E-03          | 1.31E-01            | 8.97E-01                      | 2.16E-03                   | 5.50E-02                |
| Ni-63      | 8.12E-02         | 3.92E-03          | 3.97E-03            | 5.21E-04                      | 5.92E-03                   | 2.89E-03                |
| Sr-90      | 0.00E+00         | 6.47E-07          | 0.00E+00            | 0.00E+00                      | 3.83E-07                   | 5.28E-06                |
| Tc-99      | 7.46E-05         | 2.36E-05          | 1.14E-04            | 0.00E+00                      | 7.42E-05                   | 9.18E-06                |
| H-3        | 0.00E+00         | 0.00E+00          | 0.00E+00            | 0.00E+00                      | 0.00E+00                   | 2.30E-05                |
| Fe-55      | 0.00E+00         | 0.00E+00          | 0.00E+00            | 0.00E+00                      | 0.00E+00                   | 1.35E-05                |
| Am-241     | 0.00E+00         | 0.00E+00          | 0.00E+00            | 0.00E+00                      | 0.00E+00                   | 1.06E-04                |
| Pu-239/240 | 0.00E+00         | 0.00E+00          | 0.00E+00            | 0.00E+00                      | 0.00E+00                   | 8.50E-05                |

The RDFs for Co-60 and Cs-137 were summed for each sample. The RDFs for the remaining radionuclides were summed for each sample. The results of the calculations are presented in Table 6-26.

Table 6-26 Radionuclides of Concern (ROCs) and Insignificant Dose Contributors (IDCs)

| Nuclide                 | SG composite | PZR composite | PD-T4 composite | RC Exhaust Vent composite | RC IX Piping composite | Makeup Storage Tank sample |
|-------------------------|--------------|---------------|-----------------|---------------------------|------------------------|----------------------------|
| ROCs (Co-60 and Cs-137) | 9.19E-01     | 9.96E-01      | 9.91E-01        | 9.96E-01                  | 9.92E-01               | 9.95E-01                   |
| Remainder (IDCs)        | 8.13E-02     | 3.95E-03      | 8.82E-03        | 3.51E-03                  | 7.72E-03               | 4.67E-03                   |

Based upon this evaluation, the only two ROCs are Cs-137 and Co-60. The IDC dose in five out of the six samples is less than 1 percent. The sixth sample is 8 percent of the dose. Because this evaluation was based on a dose limit of 15 mrem/year, no adjustment (reduction) in the DCGLs is necessary or will be performed.



### 6.14 Surrogate DCGLs (RAI Response)

Nickel-63 activity has been taken into account by using the easy to detect Co-60. The calculation of the DCGL<sub>surrogate</sub> is documented in CR-139.

As shown in LTP Table 6-5, Ni-63 comprises 90% of the total activity. The sum of the fractions of Co-60, Ni-63 and Cs-137 is equal to 99.3% of the total activity. The remaining radionuclides are considered insignificant contributors. Cobalt-60 will be used as the surrogate for Ni-63. Using the data in LTP Table 6-5, the Ni-63/Co-60 ratio equals 55.3. Solving Equation 5-2 using the DCGLs for Co-60 and Ni-63 in LTP Table 6-17 and the Ni-63/Co-60 ratio of 55.3 is shown below.

$$\text{DCGL}_{\text{Co-60 surrogate}} = 2.37\text{E} + 04 \times \frac{2.53\text{E}+08}{(55.3 \times 2.37\text{E}+04)+2.53\text{E}+08} = 2.36\text{E}4 \text{ dpm}/100 \text{ cm}^2$$

### 6.15 Additional Considerations Concerning Preservation

As described in Section 6.1, the analyses presented in this chapter consider the scenario in which NSS is scrapped immediately after license termination to be the worst-case scenario from a dose perspective. In adopting a building reuse analogy for the preservation scenario, MARAD considers the 70-year exposure timeframe postulated in NUREG-1496 to be applicable to NSS. Given that NSS will be nearly 70-years old at the anticipated license termination date, and that the typical lifespan of oceangoing ships is less than half of NSS' current age, it is prudent to consider whether NSS can be preserved for such a lengthy period. This discussion focuses on experiences with preserved vessels and does not consider examples of long-lived operating commercial ships, such as on the Great Lakes, where at least one commercially active hull is over 115 years old.<sup>28</sup>

The first oceangoing ship to be constructed with an all-iron hull is reputedly the SS *Great Britain* of 1845. *Great Britain* was constructed by the renowned British engineer Isambard Kingdom Brunel. In addition to its wrought iron hull construction (wood was used for decks and masts), *Great Britain* was principally propelled by steam. Here again the ship was innovative, featuring a rudimentary screw propeller vice paddle wheels mounted to the ship's sides. Important to our consideration of the potential longevity of NSS, *Great Britain* survives to this day and is displayed as a static museum ship in the drydock in Bristol, where it was built. Although restored and with many features recreated, its original hull is substantially intact. Thus, the world's first iron-hulled oceangoing ship is also its oldest surviving iron-hulled ship.

The more common use of iron in the early 19th century was the composite hull, in which iron frames support a wood-sheathed hull. This form of construction gave way to a widespread use of all-iron hulls beginning in the 1850s. The use of steel as a primary hull material began in the mid-1870s but took a period of some 30 years before becoming the dominant form of large merchant and naval ship construction. There are numerous preserved vessels from this period, spanning the full range of vessel types. These ships are preserved both afloat and ashore. The oldest such ship that is in seagoing condition today is *Star of India*, maintained by the San Diego Maritime Museum, and originally built in 1863. This ship has always been waterborne.

There are much older preserved ships in existence. Among the oldest of these are Egyptian funeral barges recovered from archeological sites – these are some 4,000 years old. There are many Viking longboats,

<sup>28</sup> The *St. Marys Challenger* was originally constructed in 1906 as *William P. Snyder*. The vessel operated until 2013 as a self-propelled steam-powered freighter. Its machinery was removed over the winter of 2013-2014, with the hull converted into a barge. The barge, keeping the name *St Marys Challenger*, is paired with a tug to form an articulated tug-barge unit, and is still operating in 2023.



also recovered from archeological sites, that are some 1,000 years old. Shipwrecks recovered from the sea and restored as museums include *Mary Rose* (1511) and *Vasa* (1628). These examples are not fully relevant to NSS because they involved some aspect of loss of the vessel and exposure to the environment (note – this also applies to *Great Britain*). They do, however, serve to indicate an interest by the public in preserving old ships. The key factor in any individual ship's longevity, particularly for large vessels preserved afloat, is proper and continuing maintenance. This especially includes periodic drydocking to allow for inspection and repair of the underwater hull.

Concentrating on more modern examples of preserved steel-hulled ships, there are numerous US warships preserved around the country, most of which are afloat. The oldest of these is the 1895-built USS *Olympia*, flagship of Admiral Dewey at the 1898 Battle of Manila Bay. This ship is preserved in Philadelphia. The next oldest preserved major warship afloat is battleship *Texas*, of 1914. From 1948 to present, *Texas* was preserved in a basin adjacent to the upper reaches of the Houston Ship Channel. The ship will be relocated, most likely to a seawater berth, after its current drydocking period is completed. These vessels offer a realistic present-day scenario for the potential longevity of NSS, which was completed in 1962. *Olympia* is 67 years older than NSS, while *Texas* is 48 years older. These vessels were preserved soon after the end of their active service lives, which was 1948 for *Texas*, and 1922 for *Olympia*. *Olympia* has not been drydocked since 1945, whereas *Texas* was drydocked in 1988, and is again on drydock in 2023. By comparison, NSS ended service in 1970, at the conclusion of a drydocking availability. The ship has been maintained in protective storage and active decommissioning from 1970 to present, with a 13-year period of public display; all in seawater locations. Since 1970 the ship has been drydocked four (4) times: 1975, 1994, 2008, and 2020.

On any static vessel, the area of the hull which is most subject to deterioration is the wind-water interface (waterline). This area is similar to the splash zone of fixed marine structures, and is subject to continuous wave action, leading to repeated wetting of the steel surfaces. Inevitably this action leads to corrosion, causing both erosion and pinholing of the steel surface if the ship is not maintained. Both *Olympia* and *Texas* have suffered significant problems in this area, and both have required substantial repairs to their hull at the waterline area. There are generally two approaches to maintaining a museum ship hull; the first involving periodic drydocking for inspection and repairs, and the second involving repairs with the ship afloat, typically using cofferdams to isolate those sections of the hull needing repair. *Olympia* has followed the second approach, whereas *Texas* has used a combination of both methods.

The service history of NSS' hull structure is mixed. Hull pitting was observed early in the ship's career. Sometime prior to 1970, the ship was fitted with a first-generation impressed current cathodic protection system, which was intended to minimize further deterioration of the underwater hull plating. The system was groomed and deemed to be functioning satisfactorily at the 1975 drydocking. That drydocking was performed to prepare the hull for a fifty-year retention period in a MARAD reserve fleet, in accordance with the mothballing criteria of RG 1.86. Among other things, all the ship's through-hull connections were fitted with welded steel blanks. From the onset of protective storage, *SAVANNAH'S* hull was better prepared for extended drydocking intervals than most museum ships in normal experience. Despite this good preparation, there was a significant cathodic protection system failure while the ship was in museum service, resulting in extensive pitting and leaks. The hull leaks were the proximate cause for the ship's removal and drydocking in 1994. Over the course of the three protective storage drydockings in 1994, 2008 and 2020, MARAD: a) prepared the ship's underwater hull surfaces to bare metal and repainted using highly-effective marine coatings; b) effected long-term weld repairs to deteriorated shell plating and rivets, c) removed the ship's propeller to reduce the potential for electrolytic corrosion of the hull, and d) replaced and upgraded the components and controllers for the ship's cathodic protection system. MARAD completed scantling assessments and evaluations of the ship's hull structure in 2008 and again in 2020 to ensure that the hull is in suitable condition for the static services of protective storage or future



preservation. MARAD also conducts annual diver-based underwater surveys to monitor the condition of the hull.

Considering the extensive work performed on NSS' hull, and the future option for afloat hull maintenance and repair, combined with the experiences of existing museum ships with afloat preservation service lives of at least seventy-five (75) years, MARAD believes that a seventy-year preservation period for NSS after license termination is reasonable. Table 6-27 projects the effects of radiological decay over the seventy years, in ten-year increments for each radionuclide of interest.

Table 6-27 Activity Fractions Remaining Over Time

| Radionuclide | LT | 10 y     | 20 y     | 30 y     | 40 y     | 50 y     | 60 y     | 70 y     |
|--------------|----|----------|----------|----------|----------|----------|----------|----------|
| H-3          | 1  | 5.69E-01 | 3.23E-01 | 1.84E-01 | 1.05E-01 | 5.95E-02 | 3.38E-02 | 1.92E-02 |
| Fe-55        | 1  | 7.67E-02 | 5.89E-03 | 4.52E-04 | 3.47E-05 | 2.66E-06 | 2.04E-07 | 1.57E-08 |
| C-14         | 1  | 9.99E-01 | 9.98E-01 | 9.96E-01 | 9.95E-01 | 9.94E-01 | 9.93E-01 | 9.92E-01 |
| Co-60        | 1  | 2.68E-01 | 7.21E-02 | 1.94E-02 | 5.19E-03 | 1.39E-03 | 3.74E-04 | 1.01E-04 |
| Ni-63        | 1  | 9.33E-01 | 8.71E-01 | 8.12E-01 | 7.58E-01 | 7.07E-01 | 6.60E-01 | 6.16E-01 |
| Sr-90        | 1  | 7.85E-01 | 6.16E-01 | 4.83E-01 | 3.79E-01 | 2.98E-01 | 2.34E-01 | 1.83E-01 |
| Tc-99        | 1  | 1.00E+00 | 1.00E+00 | 1.00E+00 | 1.00E+00 | 1.00E+00 | 1.00E+00 | 1.00E+00 |
| Ag-108m      | 1  | 9.83E-01 | 9.67E-01 | 9.51E-01 | 9.35E-01 | 9.19E-01 | 9.04E-01 | 8.88E-01 |
| Cs-137       | 1  | 7.95E-01 | 6.32E-01 | 5.02E-01 | 3.99E-01 | 3.17E-01 | 2.52E-01 | 2.00E-01 |
| Am-241       | 1  | 9.84E-01 | 9.68E-01 | 9.53E-01 | 9.38E-01 | 9.23E-01 | 9.08E-01 | 8.94E-01 |
| Pu-239/240   | 1  | 1.00E+00 | 9.99E-01 | 9.99E-01 | 9.99E-01 | 9.99E-01 | 9.98E-01 | 9.98E-01 |



Another evaluation was performed to estimate the effects of decay over time. Cobalt-60 and Cs-137 are the dominant dose contributors at the ship. Table 6-23 shows that the fraction of Co-60 remaining after only ten years decay is equal to 26.8%. This evaluation assumes that the decay over time is dominated by Cs-137. Assuming that the DCGL from residual radioactivity at License Termination is equal to an annual dose of 15 mrem, the annual dose will decrease over time with the half-life of Cs-137. Table 6-28 presents the results of the calculation.

**Table 6-28      Annual Dose Over Time (mrem)**

| <b>LT</b> | <b>10 y</b> | <b>20 y</b> | <b>30 y</b> | <b>40 y</b> | <b>50 y</b> | <b>60 y</b> | <b>70 y</b> |
|-----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 15        | 11.9        | 9.5         | 7.5         | 6.0         | 4.8         | 3.8         | 3.0         |

### 6.16 References

- 6-1 Regulatory Guide 1.179, *Standard Format and Contents for License Termination Plans for Nuclear Power Reactors*, Rev. 2, July 2019
- 6-2 NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, Rev. 2, April 2018
- 6-3 NUREG-1496, *Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for License Termination of NRC-Licensed Nuclear Facilities*, Volume 1, July 1997
- 6-4 NUREG-1640, *Radiological Assessments for Clearance of Materials from Nuclear Facilities*, Volume 1, 2003 and Volume 2, 2004
- 6-5 Joint MARAD-EPA *National Guidance: Best Management Practices for Preparing Vessels Intended to Create Artificial Reefs*, May 2006.
- 6-6 CR-109, RSCS TSD 19-031, *N.S. SAVANNAH RCCV Characterization*, Revision 1, February 2020
- 6-7 STS-198, *Characterization Plan 2018*, Revision 0, May 1, 2018
- 6-8 IAEA Safety Report Series No. 44, *Derivation of Activity Concentration Values for Exclusion, Exemption and Clearance*, April 2005
- 6-9 NUREG-1757, Volume 2, *Consolidated Decommissioning Guidance - Characterization, Survey, and Determination of Radiological Criteria*, Rev. 1, September 2006
- 6-10 CR-139, TSD No. 21-089, Revision 1, *Calculations to Support NS Savannah Surface Contamination DCGLs*, September 2022
- 6-11 Federal Guidance Report No. 11, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion*, EPA 520/1-88-020, September 1988
- 6-12 ICRP 23 *1975 Report on the Task Group on Reference Man*, 1975
- 6-13 EPA/600/P-95/002Fa, *Exposure Factors Handbook*, 1997
- 6-14 Federal Guidance Report No.12, *External Exposure to Radionuclides in Air, Water and Soil*, EPA-402-R-93-081, 1993

**License Termination Plan – (STS-004-003)**

---

- 6-15 *Assessment of dust exposure in a steel plant in the eastern coast of peninsular Malaysia*, Work, Vol. 55, Issue No. 3, pp. 655-662, 2016
- 6-16 Johnson, D. et al., *Corrosion of Steel Shipwrecks in the Marine Environment: USS Arizona Part 1*, Material Performance, October 2006, Pages 2-6



## 7 UPDATE of the SITE-SPECIFIC DECOMMISSIONING COSTS

### 7.1 Introduction

In accordance with the underlying intent of 10 CFR 50.82(a)(9)(ii)(F), the guidance of *Regulatory Guide 1.179, Standard Format and Content for License Termination Plans for Nuclear Power Reactors* [Reference 7-1] and the guidance in NUREG-1700, *Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans*, [Reference 7-2], this chapter provides a summary of MARAD's site-specific decommissioning costs as of September 30, 2023.

In accordance with Reference 7-1, the LTP should address two principal factors: a) the estimated remaining costs to complete decommissioning at the time of LTP submittal,<sup>29</sup> and b) a comparison of those remaining costs to the funds available (set aside) for decommissioning. If there is a deficit, the licensee must indicate the means to provide adequate funding to complete decommissioning. The projected costs for decommissioning were determined in Calendar Year (CY) 2021 when the fixed price primary decommissioning services contract (aka TSIM)<sup>30</sup> was awarded. MARAD was then able to address the factors in its CY 2021 Decommissioning Funds Status Report [Reference 7-3]. In addressing the factors, MARAD described the scope of work covered by the TSIM and other minor contracts related to decommissioning and projected the costs of them all out to license termination. No deficit was identified. MARAD updated these projections in its CY 2022 Decommissioning Funds Status Report [Reference 7-4], and again, no deficit was identified. In each case, MARAD made allowance for potential requests for equitable adjustment (REA, aka change orders) when assessing whether the available balance of funds was adequate to complete decommissioning and license termination. This chapter further updates the projections, bringing them forward from December 31, 2022, to September 30, 2023. During this period, MARAD has settled several requests for equitable adjustment, and directed several change orders that noticeably reduced the available balance of funding. Nevertheless, MARAD still considers the available balance of funds described in the LTP to be adequate to complete decommissioning and license termination.<sup>31</sup> As a federal licensee, MARAD relies on federal appropriations for decommissioning funding, and the full faith and credit of the United States for financial assurance (see Reference [7-5]). This mechanism will remain in effect until the license is terminated.

As stated in Section 2.3 of Reference 7-3, the fixed price TSIM contract, with certain exceptions noted:

*... is intended to cover all remaining MARAD requirements to complete DECON-LT.*

The fixed price nature of the TSIM contract is such that any estimate of remaining costs on any given date is simply the value of future obligations or future invoices as of that date. Consequently, MARAD believes that new estimates are not required to meet the underlying intent of the regulation and has therefore not prepared a new engineering cost estimate. The following sections of this chapter apply this logic to the content requirements of References 7-1 and 7-2.

---

<sup>29</sup> For the purposes of this chapter, MARAD defines "time of LTP submittal" as September 30, 2023. This date is the end of federal FY 2023 and occurs within a reasonable span of the expected LTP submittal.

<sup>30</sup> This contract is in the same general form and scope as previous Technical Support for Integrated Management of Licensed Activities contracts awarded by MARAD and known by the acronym TSIM. Where it appears in the LTP, TSIM refers to the 2021 primary decommissioning services contract.

<sup>31</sup> By letter dated September 26, 2022, NRC provided its analysis of Reference 7-3, and concluded that MARAD had satisfied the 10 CFR 50.82 decommissioning funding assurance requirements as of December 31, 2021.



Note that MARAD will continue to submit CY Decommissioning Funds Status Reports on an annual basis until the license is terminated, which will provide NRC with updated decommissioning estimates if project costs change based on newly discovered requirements, or resolution of contract change orders / requests for equitable adjustment.

## 7.2 Estimated Remaining Decommissioning Costs

### 7.2.1 Previously Docketed Decommissioning Estimates

MARAD's Decommissioning Cost Estimate (DCE) was provided in Revision 1 to its *Post Shutdown Decommissioning Activities Report* (PSDAR) [Reference 7-6]. To-date, there have been no substantive changes to the previously docketed DCE, other than routine escalation over time, and reporting of actual costs.

#### 7.2.1.1 PSDAR Cost Estimate

In Reference 7-6 MARAD described its 2006 and 2008 Rough Order of Magnitude (ROM) estimates and provided a summary of the 2008 ROM as its DCE. That DCE was prepared for budget planning purposes, and not as an engineering estimate. It did, however, employ engineering estimate methodologies, including unit cost factors, commercial nuclear industry standards, scaling factors, and benchmarking of other power reactor decommissioning projects (e.g., Yankee Rowe, Connecticut Yankee and Big Rock Point). The 2006 ROM addressed each of the seven cost elements<sup>32</sup> whose evaluation is required in Reference 7-1. It was subjected to three (3) separate and independent<sup>33</sup> Verification & Validation studies, and its final revision incorporated the comments and recommendations received. The overall contingency factor was thirty (30) percent, and these adjustments carried forward into subsequent estimates. After the withdrawal of PSDAR Rev. 0, the 2006 ROM became the basis for the 2008 ROM included as the DCE in Reference 7-6.

Reference 7-6 also described in summary form the inherent difficulties present in the federal budgeting and Congressional appropriations processes. Beginning with the 2006 ROM, the DCE applied extremely conservative cost assumptions, with a direct intent to overestimate the cost of the project, as a means of assuring that appropriations would be sufficient to complete the work.

#### 7.2.1.2 Decommissioning Funds Status Reports

Beginning with CY 2009, MARAD has submitted Decommissioning Funds Status Reports on an annual basis. Each report updated the DCE using the NRC-specified escalation factors, and the DCE itself received a complete review and revision every five years. The most recent five-year DCE revision was deferred to the LTP (see Section 7-4 of this chapter).

In Section 4.1(B) of Reference 7-4, MARAD provided estimated costs to complete decommissioning as of December 31, 2022. This section is repeated in part in Section 7.2.2 of this chapter and is revised to make it current as of September 30, 2023. Those revisions in Section 7.2.2 are indicated by **bold text**. This revision accounts for the following additional obligations made during the nine month period of the update, and refined projections of future costs: a) settled TSIM requests for equitable adjustment; b) MARAD-directed TSIM change orders; c) layberthing services for the 2023

---

<sup>32</sup> The elements include: a) cost assumptions used including contingency factors; b) major decommissioning activities and tasks; c) unit cost factors; d) estimated costs of decontamination and removal of equipment and structures; e) estimated costs of waste disposal including any applicable disposal site surcharges; f) estimated final survey costs, and g) estimated total costs.

<sup>33</sup> V&Vs of the 2006 ROM were performed by the U.S. Department of Energy (Argonne National Lab), BAE Systems, and consultants affiliated with the Massachusetts Institute of Technology.



## License Termination Plan – (STS-004-003)

– 2024 period; d) additional costs in minor support contracts; e) additional obligations to support NRC fee recoveries; and f) refined salary and overhead projections.

### 7.2.2 Current Site-Specific Decommissioning Cost Estimate

As noted in Section 7-1, MARAD has not prepared a new engineering estimate to support the LTP. Instead, the LTP summarizes the estimated remaining, unobligated costs associated with the TSIM and other service contracts that support decommissioning. The italicized text below is repeated and revised from Reference 7-5. Revisions are shown in **bold text**. Table 7-1 summarizes the estimates.

*Subject to any negotiated change orders, the total costs to complete the decommissioning activities contained in the TSIM contract was **\$64,527,170.97** as of **September 30, 2023**. The awarded amount as of December 31, 2022, was **\$60,067,459.97**. The difference of **\$4,459,711.00** is the value of the outyear baseline services CLINs for performance years 3 through 5 of the contract,<sup>34</sup> and represents the primary estimate of remaining decommissioning costs. **Table 7-1 adjusts this upward as per footnote 34.***

*The value of the T&M line item was **\$5,261,410.42** as of **September 30, 2023**. MARAD estimates that an additional **\$1.0** million will be obligated to this line item over the course of the TSIM contract.*

*The estimated future costs for engineering review, independent oversight, field inspection, and independent regulatory analysis and review services through the projected License Termination is **\$0.5** million. The estimated future costs for MARAD payroll, {travel} and public affairs activities through the projected license termination is **\$2.1** million (note that travel was not included in Reference 7-3). The estimated cost of layberthing and utility services through the projected License Termination timeframe is **\$1.53** million.*

**Table 7-1 Estimated Remaining Decommissioning Costs as of September 30, 2023**

| Cost Category by Appropriation                      | Amount      |
|-----------------------------------------------------|-------------|
| <b>MARAD Annual Appropriations</b>                  |             |
| TSIM Baseline Services (CLIN 3-5)                   | \$6,164,964 |
| Layberthing and Utility Services<br>(to 03/31/2026) | \$1,500,000 |
| Subtotal                                            | \$7,664,964 |
| <b>MARAD DECON Appropriation</b>                    |             |
| TSIM T&M Projection                                 | \$1,000,000 |
| REAs                                                | \$3,000,000 |
| MARAD Support Contracts                             | \$750,000   |

<sup>34</sup> CLINs 003, 004, 005 are among the five line items funded by MARAD's annual protective storage appropriation. Future funding for these CLINs will be provided by the FY 2024, and 2025 appropriations. CLIN 003 was partially funded during FY 2023; the table reflects the outstanding balance to be funded in FY 2024. The line also includes the estimate to fund CLIN 005 to the March 31, 2026, end of the contract performance period; it is currently priced only to September 30, 2025.

### License Termination Plan – (STS-004-003)

|                                        |              |
|----------------------------------------|--------------|
| MARAD Payroll, Travel & Public Affairs | \$2,200,000  |
| Interagency Agreement (NRC)            | \$500,000    |
| Subtotal                               | \$7,450,000  |
| Total                                  | \$15,114,964 |

#### 7.2.2.2 Cost Elements of the Decommissioning Estimate in relation to the Fixed Price Services Contract

Both Reference 7-1 and Reference 7-2 require confirmation that the estimate of remaining decommissioning costs evaluate seven elements, which are not meant to be all-inclusive. The seven elements are:

- (1) Cost assumptions used, including a contingency factor;
- (2) Major decommissioning activities and tasks;
- (3) Unit cost factors;
- (4) Estimated costs of decontamination and removal of equipment and structures;
- (5) Estimated costs of waste disposal, including applicable disposal site surcharges;
- (6) Estimated final survey costs; and,
- (7) Estimated total costs.

As noted in Section 7.2.1.1, MARAD's confirms that its DCE included the above elements. Although MARAD has not prepared a new engineering estimate for the LTP, the balance of this section discusses how the seven elements are considered within the context of MARAD's current activities. Note that element (7) is addressed in the immediately preceding subsection.

As described in Reference 7-3, the TSIM contract is made up of nine (9) contract line items (CLIN). Eight (8) of the CLINs are fixed price. CLIN 0009 is a Time & Material item that provides for supplemental labor, materials, and services to perform work within the scope of the contract, but not included in the fixed price award. To date, the item has provided for, among other things, COVID-19 facility protocols, including enhanced cleaning and disinfection, and maintenance and repairs beyond the fixed price baseline of preventive maintenance, inspections and surveys that support facility operations during decommissioning. Five (5) of the fixed price CLINs provide baseline services and labor; each has a one-year period of performance that corresponds to the contract anniversary date. The remaining three (3) fixed price CLINs provide the bulk of decommissioning services and cover the entire contract period of performance.

The Contractor's price proposal addresses elements (1) and (3). Note that element (3) is subsumed within the cost estimating process employed by the Contractor to develop its fixed price proposal. Except for element (7), the three fixed price decommissioning CLINs address the remainder of these elements and are described below. Note that cost elements may be supported by more than one line item.

##### 7.2.2.2.1 CLIN 0006 TSIM Decommissioning Support

This line item provides labor, materials, and supplies to perform dismantlement activities in Phase II of the DECON-LT project. It also includes all costs to package Low Level Radioactive Waste (LLRW) and remove it from the ship to the transport conveyance. In the case of the Reactor Pressure Vessel (RPV), this includes the personnel, materials, and logistics services



associated with landing the RPV package onto land and transferring it to rail as the final transportation mode. This line item supports elements (2) and (4).

**7.2.2.2.2 CLIN 0007 Decommissioning – License Termination**

This is an activity-based line item that specifically addresses elements (2), (4), and (6) through performance milestones. The seven major activity groups defined in this CLIN are:

- Mobilization and D&D Preparations
- Energy (to the extent not covered by MARAD in its layberth contract)
- Major Component Removal
- Major Component and Structure Decontamination
- Minor Component Removal
- Decommissioning Equipment and Tools
- License Termination and Demobilization

The seven major activity groups have been subdivided into 36 discrete payment milestones, which are paid upon milestone completion. The License Termination and Demobilization activity group includes the comprehensive costs for preparation, submittal, review and approval of the LTP, planning, performance and submittal of Final Status Surveys, and support for NRC confirmatory surveys.

**7.2.2.2.3 CLIN 0008 Waste Disposal**

This line item provides for the transportation and disposal of all waste generated by decommissioning activities. This line item supports element (5).

**7.3 Decommissioning Funding**

**7.3.1 Funds Available to Complete Decommissioning**

As of September 30, 2023, the MARAD DECON-LT appropriation balance of funds available is \$18,516,532.71.

As of September 30, 2023, the MARAD annual baseline activities (protective storage) appropriation balance of funds available is \$700,000. Projected appropriations in FY 2024, 2025 and 2026 are \$9.0 million, for total projected baseline activities funding of approximately \$9.7 million. MARAD currently anticipates continuing to request protective storage funding through FY 2027.

For both the DECON and protective storage accounts, funds will carryover and will be available until expended.

**7.3.2 Comparison to Estimated Remaining Costs**

With respect to the DECON-LT appropriation, the funds available exceed the estimated remaining costs. After deducting the estimated remaining DECON costs from Table 7-1, the approximate balance of funds available for decommissioning is \$11.0 million.

With respect to the baseline activities appropriation, future appropriations are expected to be adequate for the estimated costs.

#### 7.4 Regulatory Commitments

In Reference 7-3, MARAD committed to provide its revised DCE in the LTP. With submission of the LTP, this commitment is completed.

#### 7.5 Future Escalation of Estimates

As required by 10 CFR 50.75(f)(1), MARAD submitted Reference 7-3 on March 29, 2022. Section 3.4 of that report addresses the seven required reporting items of the regulation, including the formula-based escalation of estimated decommissioning costs. For CY 2021, MARAD temporarily deferred performing the escalation calculation, as described in Sections 3.1 and 3.4 of Reference 7-3 and stated that it would address future formula-based escalations in the LTP.<sup>35</sup> Based on the discussions contained in this chapter, MARAD believes it has met the underlying intent of 10 CFR 50.75(a), which is to provide reasonable assurance that resources are available for decommissioning. Because MARAD is relying upon the contract fixed price to calculate remaining decommissioning costs when such costs are required to be reported, and because the TSIM contract does not include escalation or inflation-adjustment clauses, MARAD believes that there is no added-value to performing formula-based escalation calculations for the few years remaining before license termination.

#### 7.6 References

- 7-1 Regulatory Guide 1.179, *Standard Format and Content for License Termination Plans for Nuclear Power Reactors*, Revision 2 – July 2019
- 7-2 NUREG-1700, *Standard Review Plan for License Termination Plan*, Revision 2, April 2018
- 7-3 Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated March 29, 2022 - *Submittal of Decommissioning Funds Status Report for Calendar Year (CY) 2021*
- 7-4 Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated March 29, 2023 - *Submittal of Decommissioning Funds Status Report for Calendar Year (CY) 2022*
- 7-5 Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated March 31, 2011 – *Submittal of Decommissioning Funds Status Report for CY 2010 and updated Governmental Statement of Intent for Decommissioning Financial Assurance* (ML1109400076)
- 7-6 Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated December 11, 2008, *Submittal of Post Shutdown Decommissioning Activities Report*, Revision 1

---

<sup>35</sup> When the CY 2021 decommissioning funds status report was submitted, MARAD anticipated that it would submit the LTP before the end of CY 2022. This was based on the further expectation that the NHPA PA would be executed in CY 2021, and that the PA was a prerequisite to the LTP submittal. The PA was not executed in CY 2022, and therefore the CY 2022 decommissioning funds status report was submitted before the LTP. Consequently, the CY 2022 decommissioning funds status report continued the deferral of the formula-based escalation of the decommissioning cost estimate.



## 8 SUPPLEMENT to the ENVIRONMENTAL REPORT

### 8.1 Introduction

In accordance with the underlying intent of 10 CFR 50.82(a)(9)(ii)(G), the guidance of *Regulatory Guide 1.179, Standard Format and Contents for License Termination Plans for Nuclear Power Reactors* [Reference 8-1] and the guidance in NUREG-1700, *Standard Review Plan for License Termination Plan*, [Reference 8-2], this chapter provides a summary of MARAD's environmental analyses in support of decommissioning and license termination activities, with emphasis on MARAD's 2019 Supplemental Environmental Assessment (SEA).

References 8-1 and 8-2 describe the content required for this chapter. Summarizing from these references, the LTP must submit a supplement to the environmental report (ER) describing any new information or significant environmental changes associated with the site-specific termination activities. As described in 10 CFR 51.53, the term ER refers to the licensee's "Environmental Report—Operating License Stage" (see 10 CFR 51.53(b)), and the supplement refers to the separate 10 CFR 51.53(d) document, entitled "Supplement to Applicant's Environmental Report—Post Operating License Stage". The supplement must:

- a. Describe in detail the environmental impact of the site-specific termination activity.
- b. Compare the impact with previously analyzed termination activities (see NUREG-0586, "Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities," Supplement 1, "Regarding the Decommissioning of Nuclear Power Reactors," issued November 2002) (Ref. 17).
- c. Analyze the environmental impact of the site-specific activity. Include alternative actions and any mitigating actions.

The NSS was constructed and operated when there were no AEC regulations for environmental protection. On July 18, 1974, the AEC promulgated 10 CFR Part 51-Licensing and Regulatory Policy and Procedures for Environmental Protection. The regulations were intended to implement the revised Guidelines of the Council on Environmental Quality published in the FEDERAL REGISTER on August 1, 1973, pertaining to preparation of environmental impact statements pursuant to the National Environmental Policy Act of 1969 (NEPA). Promulgation of these regulations was over three years after the NSS's final shutdown in November 1970. The impact of the new Part 51 was recognized when MARAD proposed the first significant licensing action for the NSS which was a license amendment request for a Possession-only License in 1976. This request was developed after both permanent cessation of NSS operations on December 3, 1971, and promulgation of 10 CFR Part 51 in 1974.

It is instructive to provide the following timeline that shows the timing relationship of AEC's development of 10 CFR Part 51 and MARAD's development of NEPA compliance documents as shown below:

- August 1, 1973 – The Council on Environmental Quality (CEQ) publishes the first guidelines for preparation of Environmental Impact Statements (EIS) pursuant to NEPA.
- June 1974 – The AEC publishes Regulatory Guide 1.86 Termination of Operating Licenses for Nuclear Reactors. This document contains no discussion of NEPA compliance.
- August 19, 1974 – The effective date of the original 10 CFR Part 51 Licensing and Regulatory Policy and Procedures for Environmental Protection.



### License Termination Plan – (STS-004-003)

---

- March 17, 1976 – MARAD submits its Possession-only License amendment request, the first major licensing action by MARAD after promulgation of 10 CFR Part 51.
- April 13, 1976 – MARAD submits an Environmental Assessment (EA) to NRC for consideration as part of the Possession-only License.<sup>36</sup> The Possession-only License is issued on May 19, 1976. This EA is repurposed and updated for subsequent license amendments and renewals until MARAD submits its revised PSDAR in 2008. The exception was License Amendment 9 in 1981. That amendment request included a site-specific EIS related to operation of NSS as a museum, hotel, and restaurant.
- March 12, 1984 – NRC publishes the revised 10 CFR 51 regulations in the Federal Register with a proposed effective date not later than June 7, 1984.
- October 16, 2003 – MARAD contractor WPI produces a screening-level bounding analysis of NSS decommissioning against the NRC Final Generic Environmental Impact Statement on Decommissioning Nuclear Facilities (1988) and its Supplement (2002).
- March 2008 – MARAD publishes an EA and Finding of No Significant Impact (FONSI – dated May 6, 2008) regarding NSS Decommissioning. MARAD submits these documents to NRC on October 3, 2008 [Reference 8-3].
- December 11, 2008 – MARAD submits its revised PSDAR.
- April 2019 – MARAD publishes SEA and FONSI regarding NSS Decommissioning.

Both MARAD and NRC are federal agencies, each with its own NEPA responsibilities. The 1974 AEC regulations acknowledged this in a footnote, which stated “*Where the “applicant”, as used in this part, is a Federal agency, different arrangements for implementing NEPA may be made, pursuant to the Guidelines established by the Council on Environmental Quality.*” The 1974 AEC regulations established the requirements for Environmental Reports at the Construction Permit Stage (10 CFR 51.20) and Operating License Stage (10 CFR 51.21). Retroactive ERs were not required, and consequently MARAD never docketed an ER for either stage. The absence of an Operating License Stage ER goes directly to the LTP acceptance criteria. Existing licensees were required to submit an ER at the next major licensing action. For NSS, the first major licensing action after 10 CFR 51 became effective occurred in 1976 with the application for a Possession-only License. At that time, MARAD was completing work under RG 1.86 to place the NSS facility into a condition of mothballed protective storage. It is not clear, and there is no direct statement in any of the license amendments issued from 1976 onwards, that the ER submitted as part of the Possession-only License is considered an Operating License Stage ER. Internal MARAD correspondence surrounding the 1976 amendment suggests that MARAD subrogated its NEPA compliance to NRC’s licensing actions; a position the agency maintained until contemporary DECON planning began (see Chapter 2 of this LTP for a description of the DECON planning effort).

Among other things, Section 102 of NEPA requires all federal agencies to include in every recommendation or report on proposals for ... major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on --

- (i) reasonably foreseeable environmental effects of the proposed agency action;

---

<sup>36</sup> No copy of this letter has yet been found in MARAD files, ADAMS, or the NRC public document room. Its content is inferred, with confidence, from available internal agency correspondence of the same timeframe contained in folders related to the Possession-only License amendment request.



- (ii) any reasonable foreseeable adverse environmental effects which cannot be avoided should the proposal be implemented;
- (iii) a reasonable range of alternatives to the proposed agency action, including an analysis of any negative environmental impacts of not implementing the proposed agency action in the case of a no action alternative, that are technically and economically feasible, and meet the purpose and need of the proposal;
- (iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity; and,
- (v) any irreversible and irretrievable commitments of Federal resources which would be involved in the proposed agency action should it be implemented.

It is certainly true that NEPA compliance evolved and became more sophisticated over time. By subrogating its NEPA compliance to NRC licensing actions in 1976, MARAD acted in accordance with the common understanding of NEPA of that time. When MARAD resumed decommissioning consideration in 2002, it was apparent that the older interpretation was no longer appropriate, and that the agency would require its own NEPA analysis and conclusions to support the decommission action. This approach was consistent with contemporary MARAD and DOT NEPA compliance requirements. In 2005 MARAD entered into a reimbursable working agreement with the DOT Volpe Center to produce an EA in support of decommissioning planning. This work reached the stage of public comment in August 2006, with public meetings in the port cities of Norfolk, VA, Wilmington, NC and North Charleston, SC as part of the decommissioning site selection process. Shortly thereafter, the effort was forestalled by the same conditions which prompted the withdrawal of PSDAR Rev. 0. It was eventually completed in March 2008, with a corresponding FONSI issued in May 2008. Section 8.3 of this chapter describes the 2008 EA and FONSI in more detail.

The 2008 EA analyzed effects at several possible decommissioning locations. The PSDAR Rev. 1 submittal included a commitment to prepare a supplement to the EA once a decommissioning site was selected. NSS was moved to Baltimore in May 2008, within the context of preparing the ship for extended protective storage (SAFSTOR) – consistent with the EA and with the PSDAR Rev. 1 submitted later in that year (see Section 8.4 of this chapter). With respect to DECON, it would be nearly ten years before MARAD was in a position to consider potential sites for the major industrial dismantlement activities leading towards termination of the NS-1 license. This length of time itself necessitated a new look at the 2008 EA.

The funds appropriated in FY 2017 supported development of CR-137, *Supplemental Environmental Assessment and Finding of No Significant Impact* [Reference 8-4]. The supplement was specifically prepared to support DECON, and included considerations not previously addressed, such as the modification of the ship's cargo holds and other spaces to support DECON requirements for waste material handling and packaging, as opposed to performing those functions on adjacent land. The SEA and FONSI were published in April 2019 and are described in Section 8.5 of this chapter.

Taken together, the 2008 EA/FONSI and 2019 SEA/FONSI adequately describe the site-specific impacts of NSS license termination activities. MARAD requests that these documents together be considered the 10 CFR 51.53(d) "Supplement to Applicant's Environmental Report—Post Operating License Stage." In this context, MARAD affirms that there is no new information or significant environmental changes associated with the site-specific termination activities up to the submission of the LTP; nor does MARAD expect there to be any new information or significant environmental changes in the period leading to license termination.



## **8.2 Purpose**

This chapter summarizes MARAD's previously docketed environmental report (the 2008 EA and FONSI), the environmental considerations described in its PSDAR, and describes the 2019 SEA and FONSI. Collectively, these documents are considered the 10 CFR 51.53(d) "Supplement to Applicant's Environmental Report—Post Operating License Stage." The chapter concludes that there is no new information or significant environmental change associated with the site-specific decommissioning and license termination activities presented in this LTP.

## **8.3 Initial Environmental Assessment**

The 2008 EA was derived from the incomplete draft of the 2006 DECON EA and was completed for the purpose of supporting MARAD's decision-making on decommissioning. While decommissioning, as a condition of the NS-1 license, was not a discretionary act by MARAD, the timing and methodology to be employed were actions which required independent NEPA analysis by MARAD. The actions themselves were limited to the NRC decommissioning methods of SAFSTOR, DECON and ENTOMB, as well as the statutorily-required No Action<sup>37</sup> alternative. The EA was prepared in accordance with MARAD and DOT NEPA compliance requirements. The EA drew heavily on the NRC GEIS and its supplement. For each decommissioning method, the environmental impacts were considered based on locating NSS in an east coast port city with existing industrial facilities suitable for receiving the ship, and performing the activities necessary to complete the method chosen – to include transportation of waste packages to disposal facilities at Clive, UT and Barnwell, SC. In this respect the EA, even though prepared by MARAD, mirrored the requirements for an NRC-prepared EA, as described in 10 CFR 51.30. The EA also met the generic requirements for an applicant's environmental report, as described in 10 CFR 51.45. The EA considered the following range of impacts: air quality, water quality, navigation, hazardous materials, public health & safety, socioeconomics & environmental justice, coastal resources, wildlife & vegetation, and historic resources (NHPA) within the port complexes of Hampton Roads, VA, Baltimore, MD, and Charleston, SC. The EA also included a Section 4(f) analysis pursuant to the Department of Transportation Act (49 U.S.C. Sec. 303(c)).

MARAD prepared and published a Finding of No Significant Impact based on the EA. The FONSI documented MARAD's conclusion that the proposed federal action to decommission the NSS was consistent with existing national environmental policies and objectives set forth in Section 101(a) of the NEPA. MARAD concluded that the proposed action would not significantly affect the quality of the human environment or otherwise include any condition requiring consultation pursuant to Section 102(2)(c) of NEPA. As noted previously, MARAD submitted the EA and FONSI to NRC in October 2008 for its information and use.

## **8.4 Post-Shutdown Decommissioning Activities Report**

The PSDAR [Reference 8-5] was submitted on December 11, 2008. Within the PSDAR, MARAD described its intention to return NSS to a condition of protective storage based on contemporary SAFSTOR criteria. The option to transition to DECON was discussed in the PSDAR but was not the focus of agency efforts at the time. The PSDAR described MARAD's planned decommissioning operations and summarized the conclusions of the Initial EA. In Section 1.3, the PSDAR states the following:

---

<sup>37</sup> Under the No Action alternative, all work on NSS would cease and the ship would be returned to MARAD's James River Reserve Fleet site for indefinite retention (note, the retention time was indeterminate but remained bounded by the 60-year rule).



*On May 14, 2008 (see Reference d), the Maritime Administration published notice of the availability of the Finding of No Significant Impact (FONSI), Reference (e), derived from the March 2008 Environmental Assessment (EA) regarding the Decommissioning of the Nuclear Ship Savannah, Reference (f). The FONSI documents the Agency's conclusion that the proposed federal action to decommission the NSS is consistent with existing national environmental policies and objectives as set forth in Section 101(a) of the National Environmental Policy Act of 1969, as amended (NEPA). The Agency concluded that the proposed action will not significantly affect the quality of the human environment or otherwise include any condition requiring consultation pursuant to Section 102(2)(c) of NEPA.*

*Because the NSS is a federally-owned facility, NEPA required that the Maritime Administration prepare an evaluation of the available alternatives for the NSS prior to the Agency making an executive decision on decommissioning. A draft EA was released for public comment in 2006. Like Revision 0 of the PSDAR, that EA emphasized the DECON approach. The 2008 final EA incorporates public comments received, and expands the discussion and evaluation of the SAFSTOR decommissioning alternative. The EA has been independently evaluated by the Maritime Administration and determined to adequately and accurately discuss the environmental issues and impacts of the proposed project. Because the Agency concluded that the proposed action will not significantly affect the quality of the human environment or otherwise include any condition requiring consultation, preparation of an Environmental Impact Statement, pursuant to NEPA, was not required. The FONSI was published instead.*

Section 7.3 of the PSDAR summarizes the Environmental Impacts Conclusions as follows:

*... the potential environmental impacts associated with decommissioning the NSS have already been postulated in and will be bounded by the Finding of No Significant Impact (FONSI), Reference (e), which based on the Environmental Assessment (EA) regarding the Decommissioning of the Nuclear Ship Savannah, Reference (f).*

*The EA documents the available decommissioning alternatives for the NSS. The EA has been independently evaluated by the Maritime Administration and determined to adequately and accurately discuss the environmental issues and impacts of the proposed project.*

### **8.5 Supplement Environmental Assessment**

In 2017, the President's Budget Request included funding for DECON and license termination. Prior to the 2017 budget approval, MARAD affirmed internally that a supplement to the 2008 EA (SEA) would be required to: a) account for the passage of ten years from the initial EA, b) more fully evaluate the effects of the DECON process, and c) identify suitable locations to carry out the DECON work. Decommissioning funds were appropriated in March 2017 and allowed MARAD to contract for the analysis. In April 2019,<sup>38</sup> MARAD completed and published CR-137, *Supplemental Environmental Assessment and Finding of No Significant Impact* [Reference 8-4]. This document clearly states that the proposed action is to decommission NSS and terminate the NS-1 license using the DECON method, and that the preferred location to carry out these activities is Baltimore, MD. It describes:

---

<sup>38</sup> Numerous reports to NRC state that Phase I officially began on October 1, 2017. The decommissioning activities carried out by MARAD from the effective date of appropriations availability (May 2017) were limited to those activities determined to be within the scope of the 2008 EA and the PSDAR. DECON-specific activities commenced only after the 2019 EA/FONSI was complete and published.



- An analysis of the potential environmental consequences that may result from implementation of the alternatives for proposed decommissioning actions and all reasonably foreseeable, connected actions; and,
- The identified and analyzed potential effects on the natural and human environment in sufficient detail to determine the significance of impacts on the affected environment so that a preferred alternative and location may be selected and the decommissioning of NSS's nuclear power plant may be implemented.

Section 8.5.1 describes the Proposed Action and Alternatives evaluated in the SEA. Section 8.5.2 describes the conclusion of the SEA and FONSI.

(RAI Response) The latest Supplemental EA and FONSI were submitted to the NRC on May 21, 2024.

#### 8.5.1 Proposed Action and Alternatives Evaluated in the SEA

As described in the SEA, its purpose is to evaluate the Proposed Action:<sup>39</sup>

*... to reduce residual radioactivity to levels that allow termination of the NRC license. Low Level Radioactive Waste (LLRW) would be segregated and enclosed while still onboard the vessel, removed from the vessel via crane directly onto the transportation mode (rail, highway, barge), and transported to licensed/permitted facilities for final disposal following Federal and/or State regulations.*

The SEA assumes the project would be completed in three phases:

- Phase 1 would include pre-decommissioning planning, engineering, hazardous materials abatement, infrastructure preparation, and license amendment actions (which would be completed at Pier 13, Baltimore, MD) that takes about two years.
- Phase 2 would include the removal of the systems, structures, and components related to the nuclear power plant and disposal of these items at licensed radioactive waste disposal facilities in the United States, which takes about four years.
- Phase 3 would include a final status survey conducted by MARAD and a confirmatory survey conducted by an independent verification contractor for the NRC. Following these survey activities, the NRC would review the results of these surveys and if LTP requirements were met, the NRC would terminate the license.

The SEA concentrated its review on Phase 2 activities. The DECON approach in the SEA is refined from the less-specific approach described in the 2008 EA. Significantly, the SEA considered the impacts of waste material handling and packaging (i.e., waste management) occurring: 1) solely on the vessel; 2) solely on land adjacent to the vessel; or 3) partially on the vessel and partially on land. Rigging, i.e., crane service, was not included in this impact consideration as it was separately considered under the site screening criteria. The SEA describes MARAD's choice of Option 1. In selecting this option, MARAD minimized impacts to adjacent property and avoided any need to extend the licensed envelope beyond the existing boundary. This option also necessitated the conversion of cargo holds 3 and 4 as described in the SEA. The SEA differs from the 2008 EA in

<sup>39</sup> Again, as in the 2008 EA, the statutory "No Action" alternative is also evaluated. MARAD did not include an alternative to seek an exemption to the decommissioning requirement.



several other areas and again reflects a more mature project approach gained from experience during NSS protective storage operations. Among the differences are:

- The Barnwell, SC waste repository is dropped from consideration; the Waste Control Specialists repository in Andrews, TX is added.
- Site screening criteria were refined. The principal screening criteria included: existing industrial facility characteristics and permitted uses, adequate waterway access without need for dredging, laydown space for a 100 ton landside crane and adjacent space for decommissioning activities (principally parking and truck access), adequate infrastructure for a 1,000 ton crane (either floating or land/pierside polar), multiple transportation options available (road, rail, barge), remote access, isolated from residential housing, and proximity to Baltimore to minimize relocation costs.

Under these factors, the port of Charleston, SC was dropped from consideration, and the port of Philadelphia, PA was added. Each of the three ports considered, Baltimore, Philadelphia and Hampton Roads, are considered a Proposed Action Alternative in the SEA.

The SEA presents a review and analysis of the potential environmental impacts associated with the three Proposed Action Alternative locations, as well as the No-Action Alternative. The SEA documents MARAD's evaluation and assessment of the potential environmental impacts associated with the decommissioning of NSS's nuclear power plant.

NEPA, CEQ regulations, and MARAD's procedures for implementing the NEPA specify that an EA should only address those resource areas potentially subject to impacts. In addition, the level of analysis should be commensurate with the anticipated level of environmental impact.

The location of all three Proposed Action Alternatives was in developed areas along a waterfront with restricted access. Given these locations, the SEA described that construction of new facilities and dredging would not be required because all three locations have existing infrastructure and deep water to accommodate NSS and support decommissioning. Therefore, the proposed Federal action would not be expected to involve major construction activities at the alternative locations; instead, there would only be minor alterations to the NSS itself to aid in decommissioning actions.

MARAD determined that five environmental resources would be reasonably foreseeable and potentially affected by the Proposed Action. The SEA evaluated the following five resources in detail:

- Water Resources;
- Biological Resources;
- Air Quality;
- Waste Management; and,
- Health and Safety.

The environmental consequences associated with implementation of the Proposed Action and the No-Action Alternative are compared below in Table 8-1.

Table 8-1 Summary of Impacts

| Resource Area        | Baltimore, MD,<br>Preferred Alternative                                                                      | Hampton Roads, VA,<br>Alternative                                                                            | Philadelphia, PA,<br>Alternative                                                                             | No-Action<br>Alternative |
|----------------------|--------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|--------------------------|
| Water Resources      | Minimal adverse impacts                                                                                      | Minimal adverse impacts                                                                                      | Minimal adverse impacts                                                                                      | No significant impacts   |
| Biological Resources | No reasonably foreseeable takes are expected for marine mammals.<br><br>No effect on Essential Fish Habitat. | No reasonably foreseeable takes are expected for marine mammals.<br><br>No effect on Essential Fish Habitat. | No reasonably foreseeable takes are expected for marine mammals.<br><br>No effect on Essential Fish Habitat. | No significant impacts   |
| Air Quality          | Insignificant temporary impacts                                                                              | Insignificant temporary impacts                                                                              | Insignificant temporary impacts                                                                              | No impacts               |
| Waste Management     | No significant impacts                                                                                       | No significant impacts                                                                                       | No significant impacts                                                                                       | No impacts               |
| Health and Safety    | No significant impacts                                                                                       | No significant impacts                                                                                       | No significant impacts                                                                                       | No impacts               |

Using the same considerations that in all three potential locations, the NSS would be decommissioned at a commercial facility with all actions taking place on coastal land with controlled and limited access, MARAD determined that because no major construction or modifications to facilities would reasonably be required, the SEA required no detailed evaluation of the following resources:

- *Cultural Resources - There would be no effects to cultural resources at any industrial facility; Section 106 for the vessel is ongoing in a separate coordinated action;*
- *Land Use - There would be no change in land use as a result of the Proposed Action;*
- *Geology, Soils and Seismicity - There would be no effects to these resources;*
- *Aesthetics and Visual Resources - The vessel does not have aesthetic value that would be negatively affected. The Proposed Action does not have an effect on the existing visual character or quality of the possible decommissioning sites and their surroundings;*
- *Socioeconomics - The project would not have a negative effect on the state, local and regional economy, housing, or community services;*
- *Environmental Justice - This addresses environmental and human health conditions in minority and low-income communities; the Proposed Action would occur at an existing facility and would not require construction of new facilities within minority or low income communities. Waste disposal routes are discussed in Chapter 3 and would not have an impact on environmental justice. Thus, environmental justice concerns are not applicable;*



- *Transportation - The Proposed Action would not result in increased traffic or number of personnel at the vessel's current location or the decommissioning facilities' locations; waste transportation is part of decommissioning and discussed under waste management;*
- *Noise - The Proposed Action is considered a routine vessel movement and the decommissioning of its nuclear power plant would not generate any noise above and beyond what is routinely generated at these facilities;*
- *Utilities - There is no need to provide additional utilities for the Proposed Action;*
- *Emergency Services - There would be no effect on emergency services resulting from the Proposed Action; and,*
- *Wetlands and floodplains - The Proposed Action would not affect wetlands or floodplains.*

The SEA also analyzed cumulative impacts within the regions associated with each port complex. The analysis combined the Proposed Action with the impacts of other known past, present, and reasonably foreseeable future actions for each region, and concluded that there would be no cumulative effects in any analysis category.

NEPA requires consideration of possible conflicts between the Proposed Action and the Objectives of Federal, State, Regional and Local Land Use Plans, Policies and Controls. MARAD considered the following Federal Acts, Executive Orders, Policies and Plans: a) NEPA, b) Clean Water Act, c) Clean Air Act and General Conformity Rule, d) Coastal Zone Management Act, e) Endangered Species Act, f) Migratory Bird Treaty Act, g) Marine Mammal Protection Act, h) NHPA, and i) Executive Order 12372 (Intergovernmental Review of Federal Programs). State, Local and Regional Plans, Policies and Controls considered included Coastal Zone Management, Endangered Species, and Air Quality Management.

Other impacts considered included Energy Requirements and Conservation Potential, Irreversible or Irretrievable Commitment of Natural or Depletable Resources, the Relationship between Local Short-Term Use of the Human Environment and Maintenance and Enhancement of Long-Term Natural Resource Productivity, the Means to Mitigate and/or Monitor Adverse Environmental Impacts, and Any Probable Adverse Environmental Effects that cannot be Avoided and are not Amenable to Mitigation

#### 8.5.2 Conclusion of the SEA and FONSI

The SEA concluded the following:

*Overall, no significant environmental impacts are expected to occur as a result of the Proposed Action. NSS is listed in the National Register of Historic Places. Through consultation with the NRC, the National Park Service, the Advisory Council on Historic Preservation, and the Maryland Historical Trust, which serves as the SHPO [State Historic Preservation Office], a Programmatic Agreement [PA] will be implemented as mitigation efforts for DECON-LT. MARAD is in the process of finalizing the details of the PA, which will formally document the agreed upon mitigation measures required for Section 106 compliance.*

*The Proposed Action would comply with all Federal and state regulations, guidelines, and agreements. All Proposed Action Alternatives are environmentally equal. However, Baltimore, MD is the Preferred Alternative because the vessel is already there and may not need towing. There would be minor differences with respect to towing distances and waste transportation and disposals depending on the alternatives; however, none of the differences would produce significant impacts. Based on the findings from this EA, a FONSI shall be prepared.*



The FONSI concluded:

*Conclusion and Approval: After careful and thorough consideration of the facts contained herein, and in the Supplemental EA, the undersigned finds that the proposed federal action is consistent with existing national environmental policies and objectives set forth in Section 101(a) of NEPA and that it will not significantly affect the quality of the human environment of [SIC or] otherwise include any condition requiring consultation pursuant to Section 102(2)(c) of NEPA. Therefore, a FONSI is warranted, and preparation of an EIS, pursuant to NEPA is not required. This FONSI is based on the attached Supplemental EA, which has been independently evaluated by MARAD and determined to adequately and accurately discuss the environmental issues and impacts of the proposed project. MARAD takes full responsibility for the accuracy, scope, and content of the attached Supplemental EA.*

### 8.5.3 RAI Responses

#### 8.5.3.1 Air Quality

Prior to the award of the DECON-LT contract, MARAD determined that an air quality permit was not required, and none was obtained.

In normal ship operations (i.e., the ship's baseline protective storage condition), the NSS operates exclusively on electrical power supplied from shore, and does not rely on onsite electricity generation, including from fossil-fuel driven generators. The ship itself does not generate air emissions. Occasional de minimis emissions occur from ship maintenance and repair activities that require welding or burning operations. For these operations, Maryland does not require an air quality permit.

For decommissioning operations situated within the ship's footprint, a separate industrial electrical panel and shore connection was established. Most of the decommissioning tools and equipment were powered by electricity, and they were not a source of air emissions. The equipment exception involved torch and plasma cutting operations, which were performed as part of the dismantlement of the interior structure of the neutron shield tank; release of the RPV from its welded supports; removal of the Steam Generator risers and downcomers, and removal of a section of the Pressurizer shell. All of this activity employed engineered controls to filter the emissions, primarily for the control of airborne radioactivity. The controls were augmented to address issues of carbon monoxide build-up in certain situations. The engineered controls also served to capture particulate matter and sparks. Other steel cutting not listed above employed cold-cutting methods, such as electric reciprocating saws.

Air emissions also arose from transient operations involving truck transportation and crane operations. In all instances, these emissions were literally offsite; i.e., they occurred outside the licensed site boundary formed by the ship's hull. Nevertheless, these emissions were produced as a result of decommissioning activities. These emissions were anticipated in both the 2008 and 2019 environmental assessments, and considered de minimis, without the need for an air quality permit.

#### 8.5.3.2 Water Resources - Coastal Zone Management Act (CZMA)

Prior to the issuance of the Supplemental EA and FONSI, Maryland did not raise the issue of CZMA with MARAD or its contractor. After the documents were issued (but before they were publicly released), the Maryland Department of Natural Resources (DNR) raised the matter. This was resolved in a series of discussions, meetings, and email from May through July 2019. MARAD's Office of Environment led the discussions, which were concluded in an exchange of



---

**License Termination Plan – (STS-004-003)**

---

emails between DNR and MARAD on July 31, 2019. An image of that exchange is included below the next page. MARAD continued its dialog with the state during the project execution, principally acting through Maryland Department of the Environment (MDE), but also offered opportunities for DNR to review work in progress and tour the site.

**From:** [Gilson, Kristine \(MARAD\)](#)  
**To:** ["Joseph Abe -DNR-"](#)  
**Cc:** ["david.tancabel@maryland.gov"](#); ["lisa.hoerger@maryland.gov"](#); ["hnelson@maryland.gov"](#); ["shertz@mdot.state.md.us"](#)  
**Subject:** RE: NS Savannah follow up  
**Date:** Wednesday, July 31, 2019 10:01:00 AM

---

We're going to go ahead and finalize the EA, but will keep you posted on any information that may be of interest. As always, we are available to respond to any questions should they arise. Thank you.

Kris Gilson, REM, CHMM  
Office of Environment  
MAR-410, Mail Drop #1  
Maritime Administration  
Department of Transportation  
Southeast Federal Center, West Bldg  
1200 New Jersey Ave SE  
Washington, DC 20590  
Phone 202-366-1939  
Cell 202-603-2402  
[kristine.gilson@dot.gov](mailto:kristine.gilson@dot.gov)

**From:** Joseph Abe -DNR- [mailto:[joseph.abe@maryland.gov](mailto:joseph.abe@maryland.gov)]

**Sent:** Thursday, July 18, 2019 1:58 PM

**To:** Gilson, Kristine (MARAD) <[kristine.gilson@dot.gov](mailto:kristine.gilson@dot.gov)>

**Cc:** [david.tancabel@maryland.gov](mailto:david.tancabel@maryland.gov); [lisa.hoerger@maryland.gov](mailto:lisa.hoerger@maryland.gov); [hnelson@maryland.gov](mailto:hnelson@maryland.gov); [shertz@mdot.state.md.us](mailto:shertz@mdot.state.md.us)

**Subject:** Re: NS Savannah follow up

Thanks so much Kris. From my perspective, this is exactly the kind of information that you agreed to send to us to give us a better picture of what the project involves, timelines and who has been informed. This a great example of federal-state coordination. I will forward to interested colleagues and get back to you if they have any questions.

Best, Joe

On Thu, Jul 18, 2019 at 1:31 PM Gilson, Kristine (MARAD) <[kristine.gilson@dot.gov](mailto:kristine.gilson@dot.gov)> wrote:

Good afternoon,

Apologies for the delay in following up to our last phone conversation. I'm attaching an overview PowerPoint which provides some background information that may be useful to you. The second attachment is a list of outreach efforts that have been undertaken over the years. Please advise at your earliest convenience if you have additional questions or if the attached is sufficient to address any potential concerns. Also, I'm currently on a loaner laptop, so I may not have been able to include everyone that was originally on your list of potentially interested colleagues.

Please forward as necessary. Thanks.

Kris Gilson, REM, CHMM  
Maritime Administration  
Office of Environment

8.5.3.3 Water Resources - National Pollutant Discharge Elimination System (NPDES) Permit

MARAD planned for no discharges of wastewater during decommissioning. Wastewater was generated from decommissioning activities beginning in Phase I. That water was collected into drums and retained onboard as legacy waste for disposal under the DECON-LT (Phase II and III) contract. Drummed wastewater has been handled in two ways; it was either packaged into intermodals and transported to Clive for disposal, or the contents were transferred into the contaminated liquid collection system constructed early in Phase II. In the latter case, the liquid was transferred to tanker trucks and transported to Erwin for thermal processing. The contaminated liquid system was removed in 2023. All remaining wastewater will be managed via steel or plastic containers.

MARAD consulted with the MDE throughout 2019 – 2020 on the matter of incidental discharges from the NSS. MARAD operational ships are covered by the U.S. Environmental Protection Agency (EPA) Vessel General Permit (VGP) process, which is a form of an NPDES permit. Because the NSS is not operational in the conventional sense, and is stationary, the permitting authority is the State of Maryland. In normal operations, the only incidental discharges from the NSS are stormwater and HVAC condensate. MDE concluded that a permit was not required in those cases. Consequently, MARAD does not have a National Pollutant Discharge Elimination System permit for the NSS or any other relevant wastewater management permit.

8.5.3.4 Federally listed or proposed species

Table 3-2 “Biological Resource Impact Study” is incorrectly numbered, and should be Table 3-4 in Appendix A. The conclusion “may affect but not likely to adversely affect and no reasonably foreseeable takes” applies to the species described in Section 3.2.2 of the Supplemental EA, for each of the port complex alternatives (Baltimore, MD; Hamptons Roads, VA; and Philadelphia, PA).

Comments from the National Marine Fisheries Service and/or U.S. Fish and Wildlife Service were sought (see Appendix A, page 69 of 110 of the SEA). A response from USFWS is found in Appendix A, on page 83 of the SEA.

8.5.3.5 Vessel Traffic

The proposed action required vessel traffic to or from the NSS.

MARAD has employed barge cranes for several heavy lifts. These are all complete except for a future evolution that will: a) reinstall the Containment Vessel Cupola Head and Shield Ring, and then b) remove the Reactor Compartment hatch operating mechanism and stow it in inside Cargo Hold 1. These are routine vessel movements within the harbor complex, which have employed local vessels except for the equipment staged for the Reactor Pressure Vessel lift. A total of five barge lifts will have been completed, as follows: a) removal of Cupola Head and Shield Ring, one day, March 2020; b) removal of CRDM tower, one day, June 2022; c) removal of RPV head, one day, September, 2022; d) removal of RPV, transport package down-ending (staged alongside the NSS), and transfer to adjacent Pier 11 for transload to shore, five days (including mobilization), November 2022; and e) reinstallation of Cupola Head and Shield Ring plus removal of hatch operating mechanisms, 3 days, TBD 2026.

The Supplemental EA does not directly address this activity, which represents routine movement of vessels.



8.5.3.6 Number of Workers Supporting Decommissioning

MARAD believes it is important to note the distinction between NSS and typical land-based reactor decommissioning sites, which are often the major producers of economic activity within their locality. NSS, by its nature, is an itinerant facility, with no long-standing economic ties to any specific community. Although the ship has had a longtime presence in the Port of Baltimore, its impact to the local and regional economy has been quite small, even with decommissioning factored in. Activities within the port generated total economic activity of some \$70 billion in 2023, and supported over 51,000 direct, indirect, and induced jobs (CR-171, [Reference 8-6]). In contrast, by the end of FY 2026, NSS activities will have represented about \$156 million over a nearly 20-year period. The annual average of less than \$8 million is statistically insignificant to the port's economic activity. MARAD's conclusion that the decommissioning will have no negative effect on the state, local and regional economy (i.e., the removal of NSS as an economic activity after license termination) can be clearly seen in this context.

As noted in numerous annual reports, MARAD considers the baseline protective storage condition to be a decommissioning activity. From 2008 to present, there have been, on average, about thirteen (13) individuals assigned on a full-time basis to NSS, of which twelve (12) are domiciled within the Baltimore-Washington locality. These are considered the only permanent staff. From among these persons, three (3) are MARAD employees, who will return to duty at the MARAD HQ in Washington when the project ends about six (6) months after the license is terminated. The remainder are contractors, several of whom are expected to retire. The credentialed merchant mariners make up five (5) of the number, and these individuals are expected to compete within their respective unions for positions on U.S. flag merchant ships.

The DECON project has seen a fluctuating level of employment depending on the phase of the project, and circumstances such as the COVID pandemic. With limited exceptions, MARAD expects the workers associated with DECON to end their NSS employment by the time of license termination. During Phase I (October 1, 2017 – March 31, 2021), the full-time staff was increased by about fourteen (14) persons. In the expanded mix, all but three (3) were domiciled locally. These persons are contracted to remain through license termination (anticipated December 2025). Most of them will remain throughout the post-LT demobilization and ship redelivery period.

Industrial activities in Phase I to modify and outfit the ship employed local ship repair and industrial service (welding, HVAC, electrical, etc.) contractors. Employment averaged about 50 persons during Phase I, including the expanded full time professional staff. During the height of the COVID-19 pandemic emergency, MARAD limited the shipboard complement to 35 persons. During this period, two work shifts were engaged, to keep the workforce within the restricted complement. The restriction was increased to 45 persons in April 2021, effective concurrent with the DECON-LT contract award, and initiation of Phase II.

The shipboard employment restriction was ended in early 2022. Employment then peaked during the heavy Phase II dismantlement activities, with an average daily attendance of about 80 persons through to the end of 2022. The DECON craft labor was drawn from several subcontractors and specialty contractors, all but two of whom were within the local and regional area. Following removal of the Reactor Pressure Vessel and later the Reactor Coolant System piping, the use of specialty contractors was discontinued. The general craft labor remains in place, and is expected to continue to the end of CY 2024.



#### 8.5.3.7 Waste Shipments

There have been 25 truck shipments of low level waste to Clive, UT. MARAD estimates there will be two more truck shipments of low level waste to Clive, UT.

There was one rail shipment of the reactor pressure vessel to Clive, UT.

There have been six liquid waste truck shipments to EnergySolutions LLC, Erwin, TN.

There has been one radium sources shipment to EnergySolutions LLC, Bear Creek Processing Facility, Oak Ridge, TN. These sources were discovered in July 2008 during a routine radiation survey and were associated with the ship's steering gear. In June 2024, the sources were shipped as greater than Class A waste. They were not part of the nuclear power plant and might be found on other conventional ships of the NSS's era. This waste was not related to decommissioning.

The majority of shipping has occurred. The remainder should be similar in nature. Waste shipments during decommissioning have conformed to the analysis included in the 2008 EA, Section 4.1.1.2.

### 8.6 *Impact to PSDAR*

Despite some refinement to decommissioning plans between the 2008 submittal of the PSDAR [Reference 8-5] and the 2017 commencement of activities, the DECON project remains within the scope of the PSDAR. The 2019 SEA did not identify any significant impacts beyond those already identified in the PSDAR. Thus, the 2019 SEA did not have any material impact to the PSDAR environmental considerations, and MARAD has concluded that completing decommissioning and license termination will not significantly affect the quality of the human environment.

As described in Chapter 3 of the LTP, MARAD will complete dismantlement activities prior to submittal of the LTP to NRC. Based on its experience conducting the Phase 2 activities described in the PSDAR and SEA, MARAD affirms that there is no new information or significant environmental change associated with the site-specific termination activities, nor is any such information or change foreseeable during the conduct of Phase 3 activities.

### 8.7 *Environmental Considerations Regarding Vessel Disposition*

Chapter 6 of the LTP discusses in some detail the potential end-state conditions of NSS, and the disposition alternatives that MARAD will pursue after the license is terminated. Although the disposition actions are not subject to NRC jurisdiction, they are obviously of interest to NRC when considering the LTP, and the request to terminate the license. The actions are, however, subject to NHPA consultation through the NSS PA, to which NRC is a signatory party. MARAD published a Final Programmatic Environmental Assessment covering its Ship Disposal activities in August 2009. This EA considers the environmental effects of vessel disposition via Ship Recycling, Ship Donation, Ship Sale for Use, Artificial Reefing and SINKEX. MARAD carries out its current ship disposal activities within the context of this EA and is preparing a comprehensive review and update to the EA in 2023. The disposition of NSS will be performed in accordance with the provisions of the updated EA.

### 8.8 *Conclusion*

Overall, decommissioning the NSS complies with all Federal and state regulations, guidelines, and agreements. No significant environmental impacts are expected to occur as a result of decommissioning and terminating the license of the NSS.



The SEA adequately described and analyzed the potential environmental impacts associated with decommissioning NSS and experience in Phase 2 to demonstrate that there is no new information or significant environmental changes associated with decommissioning and terminating the license of the NSS. Therefore, no new supplement is required, at this time.

### **8.9 References**

- 8-1 Regulatory Guide 1.179, *Standard Format and Content for License Termination Plans for Nuclear Power Reactors*, Revision 2 – July 2019
- 8-2 NUREG-1700, *Standard Review Plan for License Termination Plan*, Revision 2, April 2018
- 8-3 Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated October 3, 2008, - *Submittal of Finding of No Significant Impact and Environmental Assessment* (ML082810182)
- 8-4 CR-137, *Supplemental Environmental Assessment and Finding of No Significant Impact*, April 2019
- 8-5 Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated December 11, 2008, *Submittal of Post Shutdown Decommissioning Activities Report*, Revision 1
- 8-6 CR-171, *2023 Economic Impact of Port of Baltimore MD*, Martin Associates, March 2024

## **9 PORTIONS of FACILITY RELEASED prior to LTP APPROVAL**

No parts of the facility were released for use before approval of the LTP under 10 CFR 50.82(a)(9)(ii)(H).



## 10 LTP AREAS that cannot be changed without NRC APPROVAL

Chapter 10 lists the LTP areas that cannot be changed without NRC approval. In Section 1.2, NUREG-1700 [Reference 10-1] states, in part:

*In accordance with 10 CFR 50.82(a)(10), the LTP is approved by license amendment. Recognizing that there may be a need to make changes to the LTP following its approval by the NRC, the licensee should include a provision in the LTP that concerns such changes. Appendix 2 [(sic) B], "LTP Areas That Cannot Be Changed Without NRC Approval," sets out such a provision that the NRC finds acceptable.*

For the NSS, the LTP areas that cannot be changed without NRC approval are derived from Appendix B of the NUREG.

MARAD will update the LTP in accordance with 10 CFR 50.71(e). After NRC approval, MARAD may make changes to the LTP, without prior NRC approval, in accordance with the criteria in 10 CFR 50.59, 10 CFR 50.82(a)(6), and 10 CFR 50.82(a)(7). Additionally, MARAD may make changes to the LTP without prior approval provided the proposed changes do not meet any of the following criteria:

- Require Commission approval under 10 CFR 50.59.
- Result in the potential for significant environmental impacts that have not previously been reviewed.
- Detract or negate the reasonable assurance that adequate funds will be available for decommissioning.
- Decrease a survey unit area classification (i.e., impacted to not impacted; Class 1 to Class 2; Class 2 to Class 3; or Class 1 to Class 3) without providing NRC a minimum 14 calendar day notification before implementing the change in classification.
- (RAI response) Increase the derived concentration guideline levels and related minimum detectable concentrations (MDCs) for both scan and fixed measurement methods. If MDCs are increased (relative to what was approved) the licensee should request NRC approval.
- Increase the radioactivity level, relative to the applicable derived concentration guideline level, at which an investigation occurs.
- Change the statistical test applied to a test other than the Sign test. Note that the Wilcoxon Rank Sum test will not be used at the NSS.
- Increase the approved Type I decision error. Only Scenario A will be used in the FSS of the NSS. Therefore, changing the Type II error when using Scenario B is not applicable and does not require NRC approval.
- Change the approach used to demonstrate compliance with the dose criteria (e.g., change from demonstrating compliance using derived concentration levels to demonstrating compliance using a dose assessment that is based on final concentration data).
- Change parameter values or pathway dose conversion used to calculate the dose such that the resultant dose is lower than in the approved LTP and if a dose assessment is being used to demonstrate compliance with the dose criteria.

**10.1 References**

10-1 NUREG-1700, *Standard Review Plan for License Termination Plan*, Revision 2, April 2018



## 11 Submittals Supporting LTP Approval

### 11.1 References

- 11-1. Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated June 27, 2024, *License Amendment Request No. LAR 2023-01, Response to Requests for Additional Information*
- 11-2. Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated October 16, 2024, *License Amendment Request No. LAR 2023-01, Response to the Second Request for Additional Information*
- 11-3. Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated December 19, 2024, *License Amendment Request No. LAR 2023-01, Additional Response to Request for Additional Information 2-4(b) - CR-176, Metallurgical Samples Evaluation*
- 11-4. Letter from Mr. Erhard W. Koehler (MARAD) to U.S. Nuclear Regulatory Commission (NRC), dated December 19, 2024, *License Amendment Request No. LAR 2023-01, Confirmation of Information*
- 11-5. *Environmental Assessment for the License Termination Plan for the Nuclear Ship SAVANNAH in Baltimore, Maryland*, dated December 19, 2024

Attachment 1. ModelRisk Summary Report

## ModelRisk Simulation Report

Date: Monday, June 10, 2024 09:51:56

By: Eric L. Darois

### Summary

|                           |                                                    |  |
|---------------------------|----------------------------------------------------|--|
| Name of model             | NSS He calc for DCGLs for TSD 21-089 06-10-24.xlsx |  |
| Date last modified        | 6/10/2024                                          |  |
| Author                    | Pete Hollenbeck                                    |  |
| # of simulations          | 2                                                  |  |
| # of sheets in the report | 2                                                  |  |
| Number of Inputs          | 10                                                 |  |
| Number of Outputs         | 88                                                 |  |
| Simulations Start Time    | 06/10/2024 09:48:42                                |  |
| Simulations End Time      | 06/10/2024 09:50:01                                |  |
| Simulations Duration      | 0:01:19                                            |  |

| Simulation Name   | Removal Worker | Remediation Worker |
|-------------------|----------------|--------------------|
| Number of samples | 10000          | 10000              |
| Seed              | 1986508366     | 4217390038         |

See next nine pages of 11 by 17 inches sheets of ModelRisk Statistics Output.



ModelRisk Statistics Results

| Range Name     | External Dose Factor Comp. Rem.                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |
|----------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| Variable Name  | Ag-108m                                                                                                                  | Am-241                                                                                                                   | C-14                                                                                                                     | Co-60                                                                                                                    | Cs-137                                                                                                                   | Fe-55                                                                                                                    | H-3                                                                                                                      | Cs-137                                                                                                                   | Ni-63                                                                                                                    | Pu-239/240                                                                                                               | Sr-90                                                                                                                    | Tc-99                                                                                                                    |
| Cell reference | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:549 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:550 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:551 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:552 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:553 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:554 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:555 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:556 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:557 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:558 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:559 | <a href="#">NBS He calc for DCGs for TSD 21-001</a><br><a href="#">06-10-24.xlsx!Component removal</a><br>worker!A10:560 |
| Variable Type  | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   | Output                                                                                                                   |
| Location       |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |
| Mean           | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| Minimum        | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| Maximum        | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| # of Errors    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| # of Filtered  | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| Spread         |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |
| St. dev.       | 2.15483E-12                                                                                                              | 0                                                                                                                        | 0                                                                                                                        | 3.23668E-12                                                                                                              | 3.43742E-13                                                                                                              | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| Variance       | 4.64329E-24                                                                                                              | 0                                                                                                                        | 0                                                                                                                        | 1.04761E-23                                                                                                              | 1.18159E-25                                                                                                              | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| Risk ratio     | 0 N/A                                                                                                                    | N/A                                                                                                                      |                                                                                                                          | 0                                                                                                                        | 0 N/A                                                                                                                    | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      |
| CoV            | 1.62506E-13 N/A                                                                                                          | N/A                                                                                                                      |                                                                                                                          | 1.76752E-13                                                                                                              | 7.49384E-14 N/A                                                                                                          | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      |
| Shape          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |
| Skewness       | 1.000150029 N/A                                                                                                          | N/A                                                                                                                      |                                                                                                                          | -1.000150029                                                                                                             | 1.000150029 N/A                                                                                                          | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      |
| Kurtosis       | 0.99959988 N/A                                                                                                           | N/A                                                                                                                      |                                                                                                                          | 0.99959988                                                                                                               | 0.99959988 N/A                                                                                                           | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      | N/A                                                                                                                      |
| Percentiles    |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |                                                                                                                          |
| 1%             | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 3%             | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 5%             | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 8%             | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 10%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 15%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 20%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 25%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 30%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 35%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 40%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 45%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 50%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 55%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 60%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 65%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 70%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 75%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 80%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 85%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 90%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 92%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 95%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 97%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |
| 99%            | 13.26                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 18.312                                                                                                                   | 4.587                                                                                                                    | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        | 0                                                                                                                        |

ModelRisk Statistics Results

| Range Name     | External Dose Factor Rem. Worker                                                                              |                 |        |              |                 |                 |        |        |            |        |        |
|----------------|---------------------------------------------------------------------------------------------------------------|-----------------|--------|--------------|-----------------|-----------------|--------|--------|------------|--------|--------|
| Variable Name  | Ag-108m                                                                                                       | Am-241          | C-14   | Co-60        | Cs-137          | Fe-55           | H-3    | Ni-63  | Pu-239/240 | Sr-90  | Tc-99  |
| Cell reference | <a href="#">N55:He.xls for DCGIs for TSD 21-688</a><br><a href="#">06-10-24.xlsx\Remediation Worker\AH146</a> |                 |        |              |                 |                 |        |        |            |        |        |
| Variable Type  | Output                                                                                                        | Output          | Output | Output       | Output          | Output          | Output | Output | Output     | Output | Output |
| Location       |                                                                                                               |                 |        |              |                 |                 |        |        |            |        |        |
| Mean           |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| Minimum        |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| Maximum        |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| # of Errors    |                                                                                                               | 0               | 0      | 0            | 0               | 0               | 0      | 0      | 0          | 0      | 0      |
| # of Filtered  |                                                                                                               | 0               | 0      | 0            | 0               | 0               | 0      | 0      | 0          | 0      | 0      |
| Spread         |                                                                                                               |                 |        |              |                 |                 |        |        |            |        |        |
| St. dev.       |                                                                                                               | 2.15483E-12     | 0      | 0            | 3.23668E-12     | 3.43742E-13     | 0      | 0      | 0          | 0      | 0      |
| Variance       |                                                                                                               | 4.64329E-24     | 0      | 0            | 1.04761E-23     | 1.18159E-25     | 0      | 0      | 0          | 0      | 0      |
| Risk ratio     |                                                                                                               | 0 N/A           | N/A    | 0            | 0               | 0 N/A           | N/A    | N/A    | N/A        | N/A    | N/A    |
| CofV           |                                                                                                               | 1.62506E-13 N/A | N/A    | 0            | 1.76752E-13     | 7.49384E-14 N/A | N/A    | N/A    | N/A        | N/A    | N/A    |
| Shape          |                                                                                                               |                 |        |              |                 |                 |        |        |            |        |        |
| Skewness       |                                                                                                               | 1.000150029 N/A | N/A    | -1.000150029 | 1.000150029 N/A | N/A             | N/A    | N/A    | N/A        | N/A    | N/A    |
| Kurtosis       |                                                                                                               | 0.99959988 N/A  | N/A    | 0.99959988   | 0.99959988 N/A  | N/A             | N/A    | N/A    | N/A        | N/A    | N/A    |
| Percentiles    |                                                                                                               |                 |        |              |                 |                 |        |        |            |        |        |
| 1%             |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 3%             |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 5%             |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 8%             |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 10%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 15%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 20%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 25%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 30%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 35%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 40%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 45%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 50%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 55%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 60%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 65%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 70%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 75%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 80%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 85%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 90%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 92%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 95%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 97%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |
| 99%            |                                                                                                               | 13.26           | 0      | 0            | 18.312          | 4.587           | 0      | 0      | 0          | 0      | 0      |



ModelRisk Statistics Results

| Range Name     | Ingestion Dose Factor Comp. Rem.                                                                         | Am-241                                                                                                   | C-14                                                                                                     | Co-60                                                                                                    | Cs-137                                                                                                   | Fe-55                                                                                                    | H-3                                                                                                      | Ni-63                                                                                                    | Pu-239/240                                                                                               | Sr-90                                                                                                    | Tc-99                                                                                                    |
|----------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| Variable Name  | Ag-108m                                                                                                  |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |
| Cell reference | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10549</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10550</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10551</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10552</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10543</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10548</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10547</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10544</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10549</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10545</a> | <a href="#">N55 He calc for DCG's for TSD 21-089<br/>06-10-24.xlsx!Component removal<br/>worker10546</a> |
| Variable Type  | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   |
| Location       |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |
| Mean           |                                                                                                          | 0.006403741                                                                                              | 3.058874153                                                                                              | 0.001753257                                                                                              | 0.022630695                                                                                              | 0.041966261                                                                                              | 0.000509812                                                                                              | 5.3779E-05                                                                                               | 0.000484943                                                                                              | 2.971833019                                                                                              | 0.11968156                                                                                               |
| Minimum        |                                                                                                          | 5.7853E-07                                                                                               | 0.000276346                                                                                              | 1.58394E-07                                                                                              | 2.04451E-06                                                                                              | 3.79133E-06                                                                                              | 4.60577E-08                                                                                              | 4.85853E-09                                                                                              | 4.3811E-08                                                                                               | 0.000268483                                                                                              | 1.08123E-05                                                                                              |
| Maximum        |                                                                                                          | 0.019960165                                                                                              | 9.534369939                                                                                              | 0.005464822                                                                                              | 0.070538835                                                                                              | 0.130806905                                                                                              | 0.001589062                                                                                              | 0.000167627                                                                                              | 0.001511546                                                                                              | 9.26306673                                                                                               | 0.373041913                                                                                              |
| # of Errors    |                                                                                                          | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        |
| # of Filtered  |                                                                                                          | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        |
| Spread         |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |
| St. dev.       |                                                                                                          | 0.004099278                                                                                              | 1.958101766                                                                                              | 0.001122327                                                                                              | 0.014486769                                                                                              | 0.026864201                                                                                              | 0.00032635                                                                                               | 3.4426E-05                                                                                               | 0.000310431                                                                                              | 1.902383423                                                                                              | 0.076612722                                                                                              |
| Variance       |                                                                                                          | 1.68041E-05                                                                                              | 3.834162526                                                                                              | 1.25962E-06                                                                                              | 0.000209866                                                                                              | 0.000721685                                                                                              | 1.06505E-07                                                                                              | 1.18515E-09                                                                                              | 9.63673E-08                                                                                              | 3.619062688                                                                                              | 0.005869509                                                                                              |
| Risk ratio     |                                                                                                          | 1.820667468                                                                                              | 1.820667468                                                                                              | 1.820667468                                                                                              | 1.820667468                                                                                              | 1.820667468                                                                                              | 1.820667468                                                                                              | 1.820667468                                                                                              | 1.820667468                                                                                              | 1.820667468                                                                                              | 1.820667468                                                                                              |
| CoFV           |                                                                                                          | 0.64013806                                                                                               | 0.64013806                                                                                               | 0.64013806                                                                                               | 0.64013806                                                                                               | 0.64013806                                                                                               | 0.64013806                                                                                               | 0.64013806                                                                                               | 0.64013806                                                                                               | 0.64013806                                                                                               | 0.64013806                                                                                               |
| Shape          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |
| Skewness       |                                                                                                          | 0.442330266                                                                                              | 0.442330266                                                                                              | 0.442330266                                                                                              | 0.442330266                                                                                              | 0.442330266                                                                                              | 0.442330266                                                                                              | 0.442330266                                                                                              | 0.442330266                                                                                              | 0.442330266                                                                                              | 0.442330266                                                                                              |
| Kurtosis       |                                                                                                          | 2.427788079                                                                                              | 2.427788079                                                                                              | 2.427788079                                                                                              | 2.427788079                                                                                              | 2.427788079                                                                                              | 2.427788079                                                                                              | 2.427788079                                                                                              | 2.427788079                                                                                              | 2.427788079                                                                                              | 2.427788079                                                                                              |
| Percentiles    |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |
| 1%             |                                                                                                          | 0.000126778                                                                                              | 0.060558111                                                                                              | 3.47101E-05                                                                                              | 0.000448032                                                                                              | 0.000830828                                                                                              | 1.0093E-05                                                                                               | 1.06469E-06                                                                                              | 9.80068E-06                                                                                              | 0.058834913                                                                                              | 0.002369398                                                                                              |
| 3%             |                                                                                                          | 0.000373657                                                                                              | 0.178484807                                                                                              | 0.000102302                                                                                              | 0.001320497                                                                                              | 0.002448724                                                                                              | 2.97475E-05                                                                                              | 3.138E-06                                                                                                | 2.82964E-05                                                                                              | 0.173405971                                                                                              | 0.006983399                                                                                              |
| 5%             |                                                                                                          | 0.000622449                                                                                              | 0.297324992                                                                                              | 0.000170418                                                                                              | 0.002199721                                                                                              | 0.004079154                                                                                              | 4.95542E-05                                                                                              | 4.71369E-05                                                                                              | 0.28864524                                                                                               | 0.011633142                                                                                              | 0.000119353                                                                                              |
| 8%             |                                                                                                          | 0.001018958                                                                                              | 0.48672537                                                                                               | 0.000278977                                                                                              | 0.003600976                                                                                              | 0.006677635                                                                                              | 8.11209E-05                                                                                              | 8.55727E-06                                                                                              | 7.71638E-05                                                                                              | 0.472875461                                                                                              | 0.000195383                                                                                              |
| 10%            |                                                                                                          | 0.001230917                                                                                              | 0.587972122                                                                                              | 0.000337008                                                                                              | 0.004350038                                                                                              | 0.008066691                                                                                              | 9.79954E-05                                                                                              | 1.03373E-05                                                                                              | 9.32151E-05                                                                                              | 0.571241208                                                                                              | 0.000236025                                                                                              |
| 15%            |                                                                                                          | 0.001799472                                                                                              | 0.85955384                                                                                               | 0.000492671                                                                                              | 0.006359301                                                                                              | 0.011792659                                                                                              | 0.000143259                                                                                              | 1.51121E-05                                                                                              | 0.000136271                                                                                              | 0.835094991                                                                                              | 0.000345044                                                                                              |
| 20%            |                                                                                                          | 0.002373921                                                                                              | 1.133950509                                                                                              | 0.000649947                                                                                              | 0.00838939                                                                                               | 0.015557248                                                                                              | 0.000188992                                                                                              | 1.99363E-05                                                                                              | 0.000179773                                                                                              | 1.101683625                                                                                              | 0.000455194                                                                                              |
| 25%            |                                                                                                          | 0.002950271                                                                                              | 1.409255427                                                                                              | 0.000807744                                                                                              | 0.010426199                                                                                              | 0.019334297                                                                                              | 0.000234876                                                                                              | 2.47765E-05                                                                                              | 0.000223419                                                                                              | 1.369154663                                                                                              | 0.000565707                                                                                              |
| 30%            |                                                                                                          | 0.003605837                                                                                              | 1.722399612                                                                                              | 0.000967229                                                                                              | 0.012742956                                                                                              | 0.023630482                                                                                              | 0.000287067                                                                                              | 3.0282E-05                                                                                               | 0.000273063                                                                                              | 1.673388241                                                                                              | 0.00069141                                                                                               |
| 35%            |                                                                                                          | 0.004204533                                                                                              | 2.008378826                                                                                              | 0.001151144                                                                                              | 0.014858738                                                                                              | 0.027553978                                                                                              | 0.00033473                                                                                               | 3.53099E-05                                                                                              | 0.000318402                                                                                              | 1.951229835                                                                                              | 0.000806209                                                                                              |
| 40%            |                                                                                                          | 0.004797846                                                                                              | 2.291786833                                                                                              | 0.001313585                                                                                              | 0.016955496                                                                                              | 0.031442197                                                                                              | 0.000381964                                                                                              | 4.02926E-05                                                                                              | 0.000363332                                                                                              | 2.226573386                                                                                              | 0.000919975                                                                                              |
| 45%            |                                                                                                          | 0.00543519                                                                                               | 2.596226724                                                                                              | 0.001488081                                                                                              | 0.019207856                                                                                              | 0.035618964                                                                                              | 0.000432704                                                                                              | 4.5645E-05                                                                                               | 0.000411597                                                                                              | 2.522350354                                                                                              | 0.001042185                                                                                              |
| 50%            |                                                                                                          | 0.006020543                                                                                              | 2.875832184                                                                                              | 0.001648343                                                                                              | 0.021276482                                                                                              | 0.039455015                                                                                              | 0.000479305                                                                                              | 5.05609E-05                                                                                              | 0.000455925                                                                                              | 2.793999561                                                                                              | 0.001154425                                                                                              |
| 55%            |                                                                                                          | 0.006649587                                                                                              | 3.176307757                                                                                              | 0.001820567                                                                                              | 0.023499513                                                                                              | 0.043577393                                                                                              | 0.000529385                                                                                              | 5.58436E-05                                                                                              | 0.000503561                                                                                              | 3.085925016                                                                                              | 0.001275042                                                                                              |
| 60%            |                                                                                                          | 0.007240079                                                                                              | 3.45836791                                                                                               | 0.001982235                                                                                              | 0.025586299                                                                                              | 0.047447121                                                                                              | 0.000576395                                                                                              | 6.08026E-05                                                                                              | 0.000548278                                                                                              | 3.359959067                                                                                              | 0.001388268                                                                                              |
| 65%            |                                                                                                          | 0.007853593                                                                                              | 3.751424891                                                                                              | 0.002150207                                                                                              | 0.027754444                                                                                              | 0.05146772                                                                                               | 0.000625237                                                                                              | 6.59549E-05                                                                                              | 0.000594738                                                                                              | 3.644677029                                                                                              | 0.001505907                                                                                              |
| 70%            |                                                                                                          | 0.008510049                                                                                              | 4.064994458                                                                                              | 0.002329936                                                                                              | 0.030074349                                                                                              | 0.055769741                                                                                              | 0.000677499                                                                                              | 7.14679E-05                                                                                              | 0.00064445                                                                                               | 3.949323884                                                                                              | 0.001631781                                                                                              |
| 75%            |                                                                                                          | 0.009261896                                                                                              | 4.424128958                                                                                              | 0.002535781                                                                                              | 0.032731361                                                                                              | 0.060696891                                                                                              | 0.000737355                                                                                              | 7.77819E-05                                                                                              | 0.000701386                                                                                              | 4.298239109                                                                                              | 0.001775946                                                                                              |
| 80%            |                                                                                                          | 0.010134064                                                                                              | 4.840737594                                                                                              | 0.002774569                                                                                              | 0.035813587                                                                                              | 0.066412558                                                                                              | 0.00080679                                                                                               | 8.51065E-05                                                                                              | 0.000767434                                                                                              | 4.702993029                                                                                              | 0.001943182                                                                                              |
| 85%            |                                                                                                          | 0.011068373                                                                                              | 5.287028749                                                                                              | 0.00303037                                                                                               | 0.039115416                                                                                              | 0.072535455                                                                                              | 0.000881171                                                                                              | 9.29528E-05                                                                                              | 0.000838187                                                                                              | 5.136584841                                                                                              | 0.002122334                                                                                              |
| 90%            |                                                                                                          | 0.012192324                                                                                              | 5.823906223                                                                                              | 0.003338093                                                                                              | 0.043087436                                                                                              | 0.079901152                                                                                              | 0.000970651                                                                                              | 0.000102392                                                                                              | 0.000923302                                                                                              | 5.658185314                                                                                              | 0.002337849                                                                                              |
| 92%            |                                                                                                          | 0.012749135                                                                                              | 6.089878262                                                                                              | 0.00349054                                                                                               | 0.045055197                                                                                              | 0.083550159                                                                                              | 0.00101498                                                                                               | 0.000107068                                                                                              | 0.000965469                                                                                              | 5.916589043                                                                                              | 0.002444616                                                                                              |
| 95%            |                                                                                                          | 0.013798187                                                                                              | 6.590978606                                                                                              | 0.003777756                                                                                              | 0.048762525                                                                                              | 0.090425011                                                                                              | 0.001098496                                                                                              | 0.000115878                                                                                              | 0.001044911                                                                                              | 6.403430434                                                                                              | 0.002645769                                                                                              |
| 97%            |                                                                                                          | 0.014739696                                                                                              | 7.040709143                                                                                              | 0.004035528                                                                                              | 0.052089799                                                                                              | 0.096595095                                                                                              | 0.001173452                                                                                              | 0.000123785                                                                                              | 0.00111621                                                                                               | 6.840363761                                                                                              | 0.002826301                                                                                              |
| 99%            |                                                                                                          | 0.016340331                                                                                              | 7.805284476                                                                                              | 0.004473761                                                                                              | 0.057746414                                                                                              | 0.107084696                                                                                              | 0.001300881                                                                                              | 0.000137227                                                                                              | 0.001237423                                                                                              | 7.583182885                                                                                              | 0.003133219                                                                                              |



ModelRisk Statistics Results

| Range Name     | Ingestion Dose Factor Rem. Worker                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |        |      |       |        |       |     |       |            |       |       |  |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|------|-------|--------|-------|-----|-------|------------|-------|-------|--|
| Variable Name  | Ag-108m                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Am-241 | C-14 | Co-60 | Cs-137 | Fe-55 | H-3 | Ni-63 | Pu-239/240 | Sr-90 | Tc-99 |  |
| Cell reference | <div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div><div><div></div><div></div><div></div><div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div></div> |        |      |       |        |       |     |       |            |       |       |  |



ModelRisk Statistics Results

| Range Name     | Inhalation Dose Factor Comp. Rem.                                                                        |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |             |
|----------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|-------------|
| Variable Name  | Ag-108m                                                                                                  | Am-241                                                                                                   | C-14                                                                                                     | Co-60                                                                                                    | Cs-137                                                                                                   | Fa-255                                                                                                   | H-3                                                                                                      | Ni-63                                                                                                    | Pu-239/240                                                                                               | Sr-90                                                                                                    | Tc-99                                                                                                    |             |
| Cell reference | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5149</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5150</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5141</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5142</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5143</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5148</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5147</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5144</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5149</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5145</a> | <a href="#">NNS He calc for DCGs for TSD 21-000<br/>06-10-24.xlsx!Component removal<br/>worker!T5146</a> |             |
| Variable Type  | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   | Output                                                                                                   |             |
| Location       |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |             |
| Mean           |                                                                                                          | 0.065160724                                                                                              | 102.0794638                                                                                              | 0.000479773                                                                                              | 0.050274136                                                                                              | 0.007341215                                                                                              | 0.000617581                                                                                              | 1.47165E-05                                                                                              | 0.001446126                                                                                              | 98.67681497                                                                                              | 0.298582432                                                                                              | 0.001913399 |
| Minimum        |                                                                                                          | 0.005868137                                                                                              | 9.192904032                                                                                              | 4.32066E-05                                                                                              | 0.004527505                                                                                              | 0.000661123                                                                                              | 5.56171E-05                                                                                              | 1.32531E-06                                                                                              | 0.000130233                                                                                              | 8.886473897                                                                                              | 0.026889244                                                                                              | 0.000172367 |
| Maximum        |                                                                                                          | 0.280626628                                                                                              | 439.6239601                                                                                              | 0.002066233                                                                                              | 0.2165148                                                                                                | 0.03161629                                                                                               | 0.002659725                                                                                              | 6.33791E-05                                                                                              | 0.006228006                                                                                              | 424.9698281                                                                                              | 1.285900083                                                                                              | 0.008242949 |
| # of Errors    |                                                                                                          | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0           |
| # of Filtered  |                                                                                                          | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0                                                                                                        | 0           |
| Spread         |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |             |
| St. dev.       |                                                                                                          | 0.035370185                                                                                              | 55.41021167                                                                                              | 0.000260428                                                                                              | 0.027289529                                                                                              | 0.003984918                                                                                              | 0.000335232                                                                                              | 7.98831E-06                                                                                              | 0.000784978                                                                                              | 53.56320462                                                                                              | 0.162074869                                                                                              | 0.001038941 |
| Variance       |                                                                                                          | 0.00125105                                                                                               | 3070.291558                                                                                              | 6.78227E-08                                                                                              | 0.000744718                                                                                              | 1.58796E-05                                                                                              | 1.1238E-07                                                                                               | 6.3813E-11                                                                                               | 6.1619E-07                                                                                               | 2869.016889                                                                                              | 0.026268263                                                                                              | 1.0794E-06  |
| Risk ratio     |                                                                                                          | 1.47065564                                                                                               | 1.47065564                                                                                               | 1.47065564                                                                                               | 1.47065564                                                                                               | 1.47065564                                                                                               | 1.47065564                                                                                               | 1.47065564                                                                                               | 1.47065564                                                                                               | 1.47065564                                                                                               | 1.47065564                                                                                               | 1.47065564  |
| CoV            |                                                                                                          | 0.542814486                                                                                              | 0.542814486                                                                                              | 0.542814486                                                                                              | 0.542814486                                                                                              | 0.542814486                                                                                              | 0.542814486                                                                                              | 0.542814486                                                                                              | 0.542814486                                                                                              | 0.542814486                                                                                              | 0.542814486                                                                                              | 0.542814486 |
| Shape          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |             |
| Skewness       |                                                                                                          | 1.211327766                                                                                              | 1.211327766                                                                                              | 1.211327766                                                                                              | 1.211327766                                                                                              | 1.211327766                                                                                              | 1.211327766                                                                                              | 1.211327766                                                                                              | 1.211327766                                                                                              | 1.211327766                                                                                              | 1.211327766                                                                                              | 1.211327766 |
| Kurtosis       |                                                                                                          | 4.880990723                                                                                              | 4.880990723                                                                                              | 4.880990723                                                                                              | 4.880990723                                                                                              | 4.880990723                                                                                              | 4.880990723                                                                                              | 4.880990723                                                                                              | 4.880990723                                                                                              | 4.880990723                                                                                              | 4.880990723                                                                                              | 4.880990723 |
| Percentiles    |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |                                                                                                          |             |
| 1%             |                                                                                                          | 0.014692257                                                                                              | 23.01659035                                                                                              | 0.000108178                                                                                              | 0.011335671                                                                                              | 0.001655276                                                                                              | 0.00013925                                                                                               | 3.31823E-06                                                                                              | 0.000326068                                                                                              | 22.24937087                                                                                              | 0.067323527                                                                                              | 0.000431561 |
| 3%             |                                                                                                          | 0.019535962                                                                                              | 30.60464088                                                                                              | 0.000143842                                                                                              | 0.015072786                                                                                              | 0.002200984                                                                                              | 0.000185158                                                                                              | 4.41217E-06                                                                                              | 0.000433566                                                                                              | 29.58448618                                                                                              | 0.089518575                                                                                              | 0.000573837 |
| 5%             |                                                                                                          | 0.022479565                                                                                              | 35.21602824                                                                                              | 0.000165515                                                                                              | 0.017343894                                                                                              | 0.002532619                                                                                              | 0.000213057                                                                                              | 5.07698E-06                                                                                              | 0.000498894                                                                                              | 34.04216063                                                                                              | 0.103006883                                                                                              | 0.000660301 |
| 8%             |                                                                                                          | 0.025881632                                                                                              | 40.54563831                                                                                              | 0.000190565                                                                                              | 0.019968727                                                                                              | 0.002915907                                                                                              | 0.000245301                                                                                              | 5.84533E-06                                                                                              | 0.000574397                                                                                              | 39.19411703                                                                                              | 0.118595992                                                                                              | 0.000760231 |
| 10%            |                                                                                                          | 0.02784654                                                                                               | 43.62382174                                                                                              | 0.000205032                                                                                              | 0.021484732                                                                                              | 0.00313728                                                                                               | 0.000263924                                                                                              | 6.2891E-06                                                                                               | 0.000618004                                                                                              | 42.16969434                                                                                              | 0.127599679                                                                                              | 0.000817947 |
| 15%            |                                                                                                          | 0.031691073                                                                                              | 49.64658937                                                                                              | 0.000233339                                                                                              | 0.024450945                                                                                              | 0.003570417                                                                                              | 0.000300362                                                                                              | 7.15738E-06                                                                                              | 0.000703327                                                                                              | 47.99170305                                                                                              | 0.145216274                                                                                              | 0.000930874 |
| 20%            |                                                                                                          | 0.035470174                                                                                              | 55.56685239                                                                                              | 0.000261164                                                                                              | 0.027366675                                                                                              | 0.003996183                                                                                              | 0.000336179                                                                                              | 8.01089E-06                                                                                              | 0.000787197                                                                                              | 53.71462398                                                                                              | 0.162533043                                                                                              | 0.001041878 |
| 25%            |                                                                                                          | 0.038981352                                                                                              | 61.06739212                                                                                              | 0.000287017                                                                                              | 0.030075691                                                                                              | 0.004391763                                                                                              | 0.000369458                                                                                              | 8.80388E-06                                                                                              | 0.000865121                                                                                              | 59.03181238                                                                                              | 0.178622122                                                                                              | 0.001145014 |
| 30%            |                                                                                                          | 0.042348421                                                                                              | 66.3421741                                                                                               | 0.000311808                                                                                              | 0.032673521                                                                                              | 0.004771108                                                                                              | 0.00040137                                                                                               | 9.56433E-06                                                                                              | 0.000939847                                                                                              | 64.1307683                                                                                               | 0.194050859                                                                                              | 0.001243916 |
| 35%            |                                                                                                          | 0.04617668                                                                                               | 72.3394457                                                                                               | 0.000339995                                                                                              | 0.035627177                                                                                              | 0.005202412                                                                                              | 0.000437654                                                                                              | 1.04289E-05                                                                                              | 0.001024809                                                                                              | 69.92813084                                                                                              | 0.211592879                                                                                              | 0.001356365 |
| 40%            |                                                                                                          | 0.049920473                                                                                              | 78.2043962                                                                                               | 0.000367561                                                                                              | 0.038515665                                                                                              | 0.005624199                                                                                              | 0.000473137                                                                                              | 1.12745E-05                                                                                              | 0.001107896                                                                                              | 75.597583                                                                                                | 0.228747859                                                                                              | 0.001466332 |
| 45%            |                                                                                                          | 0.053614693                                                                                              | 83.99168608                                                                                              | 0.000394761                                                                                              | 0.041365905                                                                                              | 0.006040402                                                                                              | 0.00050815                                                                                               | 1.21088E-05                                                                                              | 0.001189882                                                                                              | 81.19196321                                                                                              | 0.245675682                                                                                              | 0.001574844 |
| 50%            |                                                                                                          | 0.05782504                                                                                               | 90.58752968                                                                                              | 0.000425761                                                                                              | 0.044614358                                                                                              | 0.006514753                                                                                              | 0.000548055                                                                                              | 1.30597E-05                                                                                              | 0.001283323                                                                                              | 87.56794536                                                                                              | 0.264968524                                                                                              | 0.001698516 |
| 55%            |                                                                                                          | 0.062119617                                                                                              | 97.31532633                                                                                              | 0.000457382                                                                                              | 0.047927798                                                                                              | 0.006998594                                                                                              | 0.000588758                                                                                              | 1.40296E-05                                                                                              | 0.001378634                                                                                              | 94.07148212                                                                                              | 0.28464733                                                                                               | 0.001824662 |
| 60%            |                                                                                                          | 0.066532213                                                                                              | 104.2280104                                                                                              | 0.000489872                                                                                              | 0.051332295                                                                                              | 0.007495731                                                                                              | 0.000630579                                                                                              | 1.50262E-05                                                                                              | 0.001476563                                                                                              | 100.7537434                                                                                              | 0.30486693                                                                                               | 0.001954275 |
| 65%            |                                                                                                          | 0.070955191                                                                                              | 111.1569576                                                                                              | 0.000522438                                                                                              | 0.054744802                                                                                              | 0.007994038                                                                                              | 0.0006725                                                                                                | 1.60251E-05                                                                                              | 0.001574724                                                                                              | 107.4517257                                                                                              | 0.325134101                                                                                              | 0.002084193 |
| 70%            |                                                                                                          | 0.075564262                                                                                              | 119.9440139                                                                                              | 0.000563737                                                                                              | 0.059072427                                                                                              | 0.008625974                                                                                              | 0.000725661                                                                                              | 1.72919E-05                                                                                              | 0.001699207                                                                                              | 115.9458801                                                                                              | 0.350836241                                                                                              | 0.00224895  |
| 75%            |                                                                                                          | 0.083491703                                                                                              | 130.7964015                                                                                              | 0.000614743                                                                                              | 0.064417228                                                                                              | 0.009406441                                                                                              | 0.000791318                                                                                              | 1.88565E-05                                                                                              | 0.001852949                                                                                              | 126.4365214                                                                                              | 0.382579474                                                                                              | 0.002452433 |
| 80%            |                                                                                                          | 0.091228095                                                                                              | 142.9160764                                                                                              | 0.000671706                                                                                              | 0.070386168                                                                                              | 0.010278048                                                                                              | 0.000864642                                                                                              | 2.06037E-05                                                                                              | 0.002024644                                                                                              | 138.1522072                                                                                              | 0.418029524                                                                                              | 0.002679676 |
| 85%            |                                                                                                          | 0.100217237                                                                                              | 156.9982822                                                                                              | 0.000737892                                                                                              | 0.077321654                                                                                              | 0.011290793                                                                                              | 0.00094984                                                                                               | 2.26339E-05                                                                                              | 0.002224142                                                                                              | 151.7650061                                                                                              | 0.459219975                                                                                              | 0.002943718 |
| 90%            |                                                                                                          | 0.11288726                                                                                               | 176.8468832                                                                                              | 0.00083118                                                                                               | 0.08709709                                                                                               | 0.012718238                                                                                              | 0.001069924                                                                                              | 2.54954E-05                                                                                              | 0.002505331                                                                                              | 170.9519871                                                                                              | 0.517277133                                                                                              | 0.003315879 |
| 92%            |                                                                                                          | 0.120472261                                                                                              | 188.7293906                                                                                              | 0.000887028                                                                                              | 0.092949225                                                                                              | 0.013572789                                                                                              | 0.001141813                                                                                              | 2.72085E-05                                                                                              | 0.002673666                                                                                              | 182.438411                                                                                               | 0.552033468                                                                                              | 0.003538676 |
| 95%            |                                                                                                          | 0.135015495                                                                                              | 211.512525                                                                                               | 0.000994109                                                                                              | 0.104169919                                                                                              | 0.015211276                                                                                              | 0.001279651                                                                                              | 3.04931E-05                                                                                              | 0.002996427                                                                                              | 204.4621075                                                                                              | 0.618674136                                                                                              | 0.003965896 |
| 97%            |                                                                                                          | 0.148722983                                                                                              | 232.9863961                                                                                              | 0.001095036                                                                                              | 0.1147458                                                                                                | 0.016755605                                                                                              | 0.001409568                                                                                              | 3.35889E-05                                                                                              | 0.003300641                                                                                              | 225.2201829                                                                                              | 0.681485209                                                                                              | 0.004368495 |
| 99%            |                                                                                                          | 0.175944678                                                                                              | 275.6313501                                                                                              | 0.001295467                                                                                              | 0.13574844                                                                                               | 0.019822488                                                                                              | 0.00166757                                                                                               | 3.97369E-05                                                                                              | 0.003904777                                                                                              | 266.4436384                                                                                              | 0.806221699                                                                                              | 0.005168088 |



ModelRisk Statistics Results

| Range Name Inhalation Dose Factor Rem. Worker |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |             |
|-----------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------|
| Variable Name                                 | Ag-108m                                                                                         | Am-241                                                                                          | C-14                                                                                            | Co-60                                                                                           | Cs-137                                                                                          | Fe-55                                                                                           | H-3                                                                                             | Ni-63                                                                                           | Pu-239/240                                                                                      | Sr-90                                                                                           | Tc-99                                                                                           |             |
| Cell reference                                | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> | <a href="#">N55.Hr.cals for DCGLs for TSD 21-689<br/>06-10-24.xlsx!Remediation Worker TSD49</a> |             |
| Variable Type                                 | Output                                                                                          | Output                                                                                          | Output                                                                                          | Output                                                                                          | Output                                                                                          | Output                                                                                          | Output                                                                                          | Output                                                                                          | Output                                                                                          | Output                                                                                          | Output                                                                                          |             |
| Location                                      |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |             |
| Mean                                          |                                                                                                 | 0.001307163                                                                                     | 2.047774593                                                                                     | 9.62454E-06                                                                                     | 0.001008529                                                                                     | 0.000147269                                                                                     | 1.2389E-05                                                                                      | 2.95221E-07                                                                                     | 2.90101E-05                                                                                     | 1.97951544                                                                                      | 0.005989741                                                                                     | 3.83958E-05 |
| Minimum                                       |                                                                                                 | 9.40202E-05                                                                                     | 0.147290163                                                                                     | 6.92264E-07                                                                                     | 7.25404E-05                                                                                     | 1.05926E-05                                                                                     | 8.91105E-07                                                                                     | 2.12343E-08                                                                                     | 2.08661E-06                                                                                     | 0.142380491                                                                                     | 0.000430824                                                                                     | 2.76169E-06 |
| Maximum                                       |                                                                                                 | 0.005286612                                                                                     | 8.281898035                                                                                     | 3.89249E-05                                                                                     | 0.004078835                                                                                     | 0.000595607                                                                                     | 5.01055E-05                                                                                     | 1.19397E-06                                                                                     | 0.000117327                                                                                     | 8.005834767                                                                                     | 0.024224552                                                                                     | 0.000155286 |
| # of Errors                                   |                                                                                                 | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0           |
| # of Filtered                                 |                                                                                                 | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0                                                                                               | 0           |
| Spread                                        |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |             |
| St. dev.                                      |                                                                                                 | 0.000716623                                                                                     | 1.122646371                                                                                     | 5.27644E-06                                                                                     | 0.000552903                                                                                     | 8.0737E-05                                                                                      | 6.79201E-06                                                                                     | 1.61848E-07                                                                                     | 1.59042E-05                                                                                     | 1.085224825                                                                                     | 0.003283741                                                                                     | 2.10496E-05 |
| Variance                                      |                                                                                                 | 5.13548E-07                                                                                     | 1.260334874                                                                                     | 2.78408E-11                                                                                     | 3.05702E-07                                                                                     | 6.51846E-09                                                                                     | 4.61314E-11                                                                                     | 2.61948E-14                                                                                     | 2.52942E-10                                                                                     | 1.177712921                                                                                     | 1.0783E-05                                                                                      | 4.43086E-10 |
| Risk ratio                                    |                                                                                                 | 1.502360891                                                                                     | 1.502360891                                                                                     | 1.502360891                                                                                     | 1.502360891                                                                                     | 1.502360891                                                                                     | 1.502360891                                                                                     | 1.502360891                                                                                     | 1.502360891                                                                                     | 1.502360891                                                                                     | 1.502360891                                                                                     | 1.502360891 |
| CoV                                           |                                                                                                 | 0.548227512                                                                                     | 0.548227512                                                                                     | 0.548227512                                                                                     | 0.548227512                                                                                     | 0.548227512                                                                                     | 0.548227512                                                                                     | 0.548227512                                                                                     | 0.548227512                                                                                     | 0.548227512                                                                                     | 0.548227512                                                                                     | 0.548227512 |
| Shape                                         |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |             |
| Skewness                                      |                                                                                                 | 1.232168839                                                                                     | 1.232168839                                                                                     | 1.232168839                                                                                     | 1.232168839                                                                                     | 1.232168839                                                                                     | 1.232168839                                                                                     | 1.232168839                                                                                     | 1.232168839                                                                                     | 1.232168839                                                                                     | 1.232168839                                                                                     | 1.232168839 |
| Kurtosis                                      |                                                                                                 | 5.013047761                                                                                     | 5.013047761                                                                                     | 5.013047761                                                                                     | 5.013047761                                                                                     | 5.013047761                                                                                     | 5.013047761                                                                                     | 5.013047761                                                                                     | 5.013047761                                                                                     | 5.013047761                                                                                     | 5.013047761                                                                                     | 5.013047761 |
| Percentiles                                   |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |                                                                                                 |             |
| 1%                                            |                                                                                                 | 0.000305191                                                                                     | 0.478106435                                                                                     | 2.2471E-06                                                                                      | 0.000235467                                                                                     | 3.43838E-05                                                                                     | 2.89254E-06                                                                                     | 6.8927E-08                                                                                      | 6.77317E-06                                                                                     | 0.462169554                                                                                     | 0.001398461                                                                                     | 8.9645E-06  |
| 3%                                            |                                                                                                 | 0.000382316                                                                                     | 0.598927679                                                                                     | 2.81496E-06                                                                                     | 0.000294972                                                                                     | 4.30729E-05                                                                                     | 3.62351E-06                                                                                     | 8.63454E-08                                                                                     | 8.48481E-06                                                                                     | 0.578963423                                                                                     | 0.001751863                                                                                     | 1.12299E-05 |
| 5%                                            |                                                                                                 | 0.000439937                                                                                     | 0.689196074                                                                                     | 3.23922E-06                                                                                     | 0.000339429                                                                                     | 4.95647E-05                                                                                     | 4.18964E-06                                                                                     | 9.93591E-08                                                                                     | 9.76361E-06                                                                                     | 0.666222872                                                                                     | 0.002015899                                                                                     | 1.29224E-05 |
| 8%                                            |                                                                                                 | 0.000506659                                                                                     | 0.793721719                                                                                     | 3.73049E-06                                                                                     | 0.000390908                                                                                     | 5.70818E-05                                                                                     | 4.80202E-06                                                                                     | 1.14428E-07                                                                                     | 1.12444E-05                                                                                     | 0.767264328                                                                                     | 0.002321636                                                                                     | 1.48823E-05 |
| 10%                                           |                                                                                                 | 0.000540195                                                                                     | 0.846258779                                                                                     | 3.97742E-06                                                                                     | 0.000416782                                                                                     | 6.08601E-05                                                                                     | 5.11987E-06                                                                                     | 1.22002E-07                                                                                     | 1.19887E-05                                                                                     | 0.818050153                                                                                     | 0.002475307                                                                                     | 1.58674E-05 |
| 15%                                           |                                                                                                 | 0.000631401                                                                                     | 0.989139678                                                                                     | 4.64896E-06                                                                                     | 0.000487151                                                                                     | 7.11356E-05                                                                                     | 5.9843E-06                                                                                      | 1.42601E-07                                                                                     | 1.40128E-05                                                                                     | 0.956168356                                                                                     | 0.002893234                                                                                     | 1.85464E-05 |
| 20%                                           |                                                                                                 | 0.000708939                                                                                     | 1.110608984                                                                                     | 5.21986E-06                                                                                     | 0.000546975                                                                                     | 7.98713E-05                                                                                     | 6.71918E-06                                                                                     | 1.60113E-07                                                                                     | 1.57336E-05                                                                                     | 1.073588684                                                                                     | 0.003248531                                                                                     | 2.08239E-05 |
| 25%                                           |                                                                                                 | 0.000776178                                                                                     | 1.215944773                                                                                     | 5.71494E-06                                                                                     | 0.000598853                                                                                     | 8.74467E-05                                                                                     | 7.35647E-06                                                                                     | 1.75299E-07                                                                                     | 1.72259E-05                                                                                     | 1.17541328                                                                                      | 0.003556638                                                                                     | 2.2799E-05  |
| 30%                                           |                                                                                                 | 0.000851045                                                                                     | 1.333229392                                                                                     | 6.26618E-06                                                                                     | 0.000656615                                                                                     | 9.58814E-05                                                                                     | 8.06604E-06                                                                                     | 1.92207E-07                                                                                     | 1.88874E-05                                                                                     | 1.288788412                                                                                     | 0.003899696                                                                                     | 2.49981E-05 |
| 35%                                           |                                                                                                 | 0.000925212                                                                                     | 1.449418414                                                                                     | 6.81227E-06                                                                                     | 0.000713839                                                                                     | 0.000104237                                                                                     | 8.76898E-06                                                                                     | 2.08958E-07                                                                                     | 2.05334E-05                                                                                     | 1.401104467                                                                                     | 0.004239549                                                                                     | 2.71766E-05 |
| 40%                                           |                                                                                                 | 0.001000609                                                                                     | 1.567533355                                                                                     | 7.36741E-06                                                                                     | 0.00077201                                                                                      | 0.000112732                                                                                     | 9.48358E-06                                                                                     | 2.25986E-07                                                                                     | 2.22067E-05                                                                                     | 1.515282243                                                                                     | 0.004585035                                                                                     | 2.93913E-05 |
| 45%                                           |                                                                                                 | 0.001073549                                                                                     | 1.68180011                                                                                      | 7.90446E-06                                                                                     | 0.000828287                                                                                     | 0.000120949                                                                                     | 1.01749E-05                                                                                     | 2.4246E-07                                                                                      | 2.38255E-05                                                                                     | 1.625740106                                                                                     | 0.004919265                                                                                     | 3.15338E-05 |
| 50%                                           |                                                                                                 | 0.001158066                                                                                     | 1.814202424                                                                                     | 8.52675E-06                                                                                     | 0.000893495                                                                                     | 0.000130471                                                                                     | 1.09759E-05                                                                                     | 2.61548E-07                                                                                     | 2.57012E-05                                                                                     | 1.75372901                                                                                      | 0.005306542                                                                                     | 3.40163E-05 |
| 55%                                           |                                                                                                 | 0.001231955                                                                                     | 1.929955577                                                                                     | 9.07079E-06                                                                                     | 0.000950503                                                                                     | 0.000138796                                                                                     | 1.16762E-05                                                                                     | 2.78235E-07                                                                                     | 2.7341E-05                                                                                      | 1.865623725                                                                                     | 0.00564512                                                                                      | 3.61867E-05 |
| 60%                                           |                                                                                                 | 0.001331849                                                                                     | 2.086447447                                                                                     | 9.8063E-06                                                                                      | 0.001027575                                                                                     | 0.00015005                                                                                      | 1.2623E-05                                                                                      | 3.00796E-07                                                                                     | 2.9559E-05                                                                                      | 2.016899199                                                                                     | 0.006102859                                                                                     | 3.91209E-05 |
| 65%                                           |                                                                                                 | 0.001431955                                                                                     | 2.243271915                                                                                     | 1.05434E-05                                                                                     | 0.001104811                                                                                     | 0.000161329                                                                                     | 1.35718E-05                                                                                     | 3.23405E-07                                                                                     | 3.17797E-05                                                                                     | 2.168496184                                                                                     | 0.00656157                                                                                      | 4.20613E-05 |
| 70%                                           |                                                                                                 | 0.001539256                                                                                     | 2.411366606                                                                                     | 1.13334E-05                                                                                     | 0.001187598                                                                                     | 0.000173417                                                                                     | 1.45888E-05                                                                                     | 3.47639E-07                                                                                     | 3.4161E-05                                                                                      | 2.33098772                                                                                      | 0.007053247                                                                                     | 4.52131E-05 |
| 75%                                           |                                                                                                 | 0.001672628                                                                                     | 2.620305378                                                                                     | 1.23154E-05                                                                                     | 0.0012905                                                                                       | 0.000188444                                                                                     | 1.58528E-05                                                                                     | 3.77761E-07                                                                                     | 3.7121E-05                                                                                      | 2.532961866                                                                                     | 0.007664393                                                                                     | 4.91307E-05 |
| 80%                                           |                                                                                                 | 0.001830626                                                                                     | 2.86782167                                                                                      | 1.34788E-05                                                                                     | 0.001412402                                                                                     | 0.000206244                                                                                     | 1.73503E-05                                                                                     | 4.13444E-07                                                                                     | 4.06275E-05                                                                                     | 2.772227615                                                                                     | 0.008388378                                                                                     | 5.37717E-05 |
| 85%                                           |                                                                                                 | 0.002027314                                                                                     | 3.175949074                                                                                     | 1.4927E-05                                                                                      | 0.001564155                                                                                     | 0.000228404                                                                                     | 1.92145E-05                                                                                     | 4.57866E-07                                                                                     | 4.49926E-05                                                                                     | 3.070084105                                                                                     | 0.009289651                                                                                     | 5.9549E-05  |
| 90%                                           |                                                                                                 | 0.002280028                                                                                     | 3.57184555                                                                                      | 1.67877E-05                                                                                     | 0.001759134                                                                                     | 0.000256875                                                                                     | 2.16097E-05                                                                                     | 5.14941E-07                                                                                     | 5.06011E-05                                                                                     | 3.452784032                                                                                     | 0.010447648                                                                                     | 6.69721E-05 |
| 92%                                           |                                                                                                 | 0.002418089                                                                                     | 3.788129095                                                                                     | 1.78042E-05                                                                                     | 0.001865654                                                                                     | 0.00027243                                                                                      | 2.29182E-05                                                                                     | 5.46122E-07                                                                                     | 5.36652E-05                                                                                     | 3.661858125                                                                                     | 0.011080278                                                                                     | 7.10274E-05 |
| 95%                                           |                                                                                                 | 0.002703674                                                                                     | 4.235521264                                                                                     | 1.99069E-05                                                                                     | 0.002085994                                                                                     | 0.000304605                                                                                     | 2.56249E-05                                                                                     | 6.10621E-07                                                                                     | 6.00032E-05                                                                                     | 4.094337222                                                                                     | 0.0123889                                                                                       | 7.9416E-05  |
| 97%                                           |                                                                                                 | 0.003009324                                                                                     | 4.714346202                                                                                     | 2.21574E-05                                                                                     | 0.002321816                                                                                     | 0.00033904                                                                                      | 2.85218E-05                                                                                     | 6.79652E-07                                                                                     | 6.67866E-05                                                                                     | 4.557201329                                                                                     | 0.013789463                                                                                     | 8.8394E-05  |
| 99%                                           |                                                                                                 | 0.003585907                                                                                     | 5.617608419                                                                                     | 2.64028E-05                                                                                     | 0.002766672                                                                                     | 0.000404                                                                                        | 3.39865E-05                                                                                     | 8.09872E-07                                                                                     | 7.95828E-05                                                                                     | 5.430354805                                                                                     | 0.016431505                                                                                     | 0.00010533  |



ModelRisk Statistics Results

| Range Name     | Total Dose Factor Comp. Rem.                                                                       |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |
|----------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| Variable Name  | Ag-108m                                                                                            | Am-241                                                                                             | C-14                                                                                               | Co-60                                                                                              | Cs-137                                                                                             | Fe-55                                                                                              | H-3                                                                                                | Ni-63                                                                                              | Pu-239/240                                                                                         | Sr-90                                                                                              | Tc-99                                                                                              |
| Cell reference | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS40</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS40</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS41</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS42</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS43</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS44</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS47</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS44</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS49</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS45</a> | <a href="#">N55:He calc for DCG's for TSD 21-089-66-10-24.xlsx!Component removal worker TAKS46</a> |
| Variable Type  | Output                                                                                             | Output                                                                                             | Output                                                                                             | Output                                                                                             | Output                                                                                             | Output                                                                                             | Output                                                                                             | Output                                                                                             | Output                                                                                             | Output                                                                                             | Output                                                                                             |
| Location       |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |
| Mean           | 13.33156446                                                                                        | 105.1383379                                                                                        | 0.002233031                                                                                        | 18.38490483                                                                                        | 4.636307476                                                                                        | 0.001127393                                                                                        | 6.84954E-05                                                                                        | 0.001931069                                                                                        | 101.648648                                                                                         | 0.418263991                                                                                        | 0.003141892                                                                                        |
| Minimum        | 13.26912005                                                                                        | 11.46322729                                                                                        | 0.000137475                                                                                        | 18.32203822                                                                                        | 4.589216086                                                                                        | 0.000135177                                                                                        | 4.21686E-06                                                                                        | 0.000267385                                                                                        | 11.08876309                                                                                        | 0.057723339                                                                                        | 0.000403403                                                                                        |
| Maximum        | 13.54704727                                                                                        | 442.6909084                                                                                        | 0.006585517                                                                                        | 18.55505549                                                                                        | 4.73177784                                                                                         | 0.00340168                                                                                         | 0.000202003                                                                                        | 0.006769117                                                                                        | 427.9495055                                                                                        | 1.423810164                                                                                        | 0.009743939                                                                                        |
| # of Errors    | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  |
| # of Filtered  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  | 0                                                                                                  |
| Spread         |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |
| St. dev.       | 0.035694649                                                                                        | 55.48698534                                                                                        | 0.001157604                                                                                        | 0.031171088                                                                                        | 0.027243022                                                                                        | 0.000472868                                                                                        | 3.55081E-05                                                                                        | 0.000850334                                                                                        | 53.63796279                                                                                        | 0.180757705                                                                                        | 0.00131623                                                                                         |
| Variance       | 0.001274108                                                                                        | 3078.805542                                                                                        | 1.34005E-06                                                                                        | 0.000971637                                                                                        | 0.000742182                                                                                        | 2.23604E-07                                                                                        | 1.26082E-09                                                                                        | 7.23068E-07                                                                                        | 2877.031053                                                                                        | 0.032673348                                                                                        | 1.73246E-06                                                                                        |
| Risk ratio     | 0.006476015                                                                                        | 1.432575826                                                                                        | 1.453482701                                                                                        | 0.004234765                                                                                        | 0.015626164                                                                                        | 1.124125994                                                                                        | 1.453482701                                                                                        | 1.177364089                                                                                        | 1.432368342                                                                                        | 1.153341105                                                                                        | 1.118394837                                                                                        |
| CofV           | 0.002677454                                                                                        | 0.527752164                                                                                        | 0.518400367                                                                                        | 0.001695472                                                                                        | 0.005876017                                                                                        | 0.419434449                                                                                        | 0.518400367                                                                                        | 0.440343736                                                                                        | 0.527680042                                                                                        | 0.432161766                                                                                        | 0.418929067                                                                                        |
| Shape          |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |
| Skewness       | 1.190729239                                                                                        | 1.209601504                                                                                        | 0.443854555                                                                                        | 0.909213376                                                                                        | 0.444988523                                                                                        | 0.644016433                                                                                        | 0.443854555                                                                                        | 1.015373934                                                                                        | 1.209582222                                                                                        | 0.954509098                                                                                        | 0.753188873                                                                                        |
| Kurtosis       | 4.819871708                                                                                        | 4.872509406                                                                                        | 2.499878649                                                                                        | 4.101109882                                                                                        | 2.459513136                                                                                        | 3.366423256                                                                                        | 2.499878649                                                                                        | 4.37551982                                                                                         | 4.872443376                                                                                        | 4.219076534                                                                                        | 3.680920041                                                                                        |
| Percentiles    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |                                                                                                    |
| 1%             | 13.28002722                                                                                        | 26.12177829                                                                                        | 0.000354123                                                                                        | 18.3332454                                                                                         | 4.593240599                                                                                        | 0.000297493                                                                                        | 1.08623E-05                                                                                        | 0.000572261                                                                                        | 25.2661996                                                                                         | 0.12161327                                                                                         | 0.000873408                                                                                        |
| 3%             | 13.28472427                                                                                        | 33.51435858                                                                                        | 0.000499232                                                                                        | 18.33922207                                                                                        | 4.595940065                                                                                        | 0.000395317                                                                                        | 1.53133E-05                                                                                        | 0.000722302                                                                                        | 32.40957489                                                                                        | 0.157049829                                                                                        | 0.001146188                                                                                        |
| 5%             | 13.28824604                                                                                        | 37.85404576                                                                                        | 0.000589192                                                                                        | 18.34287006                                                                                        | 4.598093537                                                                                        | 0.000450764                                                                                        | 1.80727E-05                                                                                        | 0.000821495                                                                                        | 36.5969826                                                                                         | 0.177760341                                                                                        | 0.001298659                                                                                        |
| 8%             | 13.29160057                                                                                        | 43.43512504                                                                                        | 0.000716209                                                                                        | 18.34726786                                                                                        | 4.600496869                                                                                        | 0.000524141                                                                                        | 2.19688E-05                                                                                        | 0.000929461                                                                                        | 41.99721409                                                                                        | 0.201091302                                                                                        | 0.001502101                                                                                        |
| 10%            | 13.2936799                                                                                         | 46.4400047                                                                                         | 0.000789686                                                                                        | 18.34950872                                                                                        | 4.602245324                                                                                        | 0.00056372                                                                                         | 2.42226E-05                                                                                        | 0.000986715                                                                                        | 44.89597513                                                                                        | 0.215328385                                                                                        | 0.001599137                                                                                        |
| 15%            | 13.29811326                                                                                        | 52.8364371                                                                                         | 0.000968089                                                                                        | 18.35458867                                                                                        | 4.606232047                                                                                        | 0.0006408                                                                                          | 2.96949E-05                                                                                        | 0.001119166                                                                                        | 51.08631637                                                                                        | 0.244089235                                                                                        | 0.001819278                                                                                        |
| 20%            | 13.3017443                                                                                         | 58.54316764                                                                                        | 0.001125106                                                                                        | 18.35864233                                                                                        | 4.609854104                                                                                        | 0.000712367                                                                                        | 3.45112E-05                                                                                        | 0.001224509                                                                                        | 56.59310703                                                                                        | 0.267836519                                                                                        | 0.002002052                                                                                        |
| 25%            | 13.30516699                                                                                        | 64.08965517                                                                                        | 0.001282429                                                                                        | 18.36217852                                                                                        | 4.613611612                                                                                        | 0.000776038                                                                                        | 3.93369E-05                                                                                        | 0.001316545                                                                                        | 61.96216897                                                                                        | 0.287043885                                                                                        | 0.002175475                                                                                        |
| 30%            | 13.30882832                                                                                        | 69.42764007                                                                                        | 0.001452309                                                                                        | 18.36572952                                                                                        | 4.617769268                                                                                        | 0.00083637                                                                                         | 4.45478E-05                                                                                        | 0.001403568                                                                                        | 67.12674128                                                                                        | 0.306866884                                                                                        | 0.002343411                                                                                        |
| 35%            | 13.31241762                                                                                        | 75.26327656                                                                                        | 0.001612222                                                                                        | 18.36939574                                                                                        | 4.621577254                                                                                        | 0.000895838                                                                                        | 4.94529E-05                                                                                        | 0.001500433                                                                                        | 72.77430887                                                                                        | 0.327301966                                                                                        | 0.002494885                                                                                        |
| 40%            | 13.31623201                                                                                        | 81.05971653                                                                                        | 0.001777766                                                                                        | 18.37303419                                                                                        | 4.625465862                                                                                        | 0.000950792                                                                                        | 5.45308E-05                                                                                        | 0.001593851                                                                                        | 78.3632141                                                                                         | 0.348400452                                                                                        | 0.002652374                                                                                        |
| 45%            | 13.32011263                                                                                        | 87.2819173                                                                                         | 0.001940618                                                                                        | 18.37661066                                                                                        | 4.629423885                                                                                        | 0.001010217                                                                                        | 5.9526E-05                                                                                         | 0.001687286                                                                                        | 84.3929471                                                                                         | 0.368323658                                                                                        | 0.002807447                                                                                        |
| 50%            | 13.32426152                                                                                        | 93.52288334                                                                                        | 0.002113473                                                                                        | 18.38007617                                                                                        | 4.633601303                                                                                        | 0.001071291                                                                                        | 6.48282E-05                                                                                        | 0.001781463                                                                                        | 90.42801966                                                                                        | 0.389240114                                                                                        | 0.002971408                                                                                        |
| 55%            | 13.3285124                                                                                         | 100.2448317                                                                                        | 0.002292102                                                                                        | 18.38389504                                                                                        | 4.63790014                                                                                         | 0.001136759                                                                                        | 7.03074E-05                                                                                        | 0.001881708                                                                                        | 96.91806755                                                                                        | 0.411102883                                                                                        | 0.003142038                                                                                        |
| 60%            | 13.33287974                                                                                        | 107.3185586                                                                                        | 0.002467911                                                                                        | 18.38758489                                                                                        | 4.641720368                                                                                        | 0.001199194                                                                                        | 7.57001E-05                                                                                        | 0.001991751                                                                                        | 103.7557272                                                                                        | 0.432923138                                                                                        | 0.003311369                                                                                        |
| 65%            | 13.33768095                                                                                        | 114.3263875                                                                                        | 0.002635294                                                                                        | 18.39191326                                                                                        | 4.645859702                                                                                        | 0.001262289                                                                                        | 8.08344E-05                                                                                        | 0.002100004                                                                                        | 110.5292727                                                                                        | 0.456417068                                                                                        | 0.003487611                                                                                        |
| 70%            | 13.34325174                                                                                        | 123.1231901                                                                                        | 0.002832347                                                                                        | 18.3968211                                                                                         | 4.650550614                                                                                        | 0.001337852                                                                                        | 8.68787E-05                                                                                        | 0.002234761                                                                                        | 119.0297355                                                                                        | 0.485353323                                                                                        | 0.003685155                                                                                        |
| 75%            | 13.34976968                                                                                        | 133.8740416                                                                                        | 0.00304408                                                                                         | 18.40194293                                                                                        | 4.655418409                                                                                        | 0.001419439                                                                                        | 9.33734E-05                                                                                        | 0.002385104                                                                                        | 129.4401233                                                                                        | 0.517167762                                                                                        | 0.003913168                                                                                        |
| 80%            | 13.3577566                                                                                         | 145.8826651                                                                                        | 0.003283065                                                                                        | 18.40856022                                                                                        | 4.661166523                                                                                        | 0.001516461                                                                                        | 0.000100704                                                                                        | 0.00256268                                                                                         | 141.0390214                                                                                        | 0.554456764                                                                                        | 0.004176358                                                                                        |
| 85%            | 13.36723339                                                                                        | 160.0930776                                                                                        | 0.003541074                                                                                        | 18.4163194                                                                                         | 4.667415983                                                                                        | 0.001621498                                                                                        | 0.000108618                                                                                        | 0.002783138                                                                                        | 154.7625507                                                                                        | 0.599976338                                                                                        | 0.004500485                                                                                        |
| 90%            | 13.37996802                                                                                        | 180.4186266                                                                                        | 0.003861582                                                                                        | 18.42734402                                                                                        | 4.674650736                                                                                        | 0.001767986                                                                                        | 0.000118449                                                                                        | 0.003084145                                                                                        | 174.4222077                                                                                        | 0.664255008                                                                                        | 0.004922345                                                                                        |
| 92%            | 13.38684864                                                                                        | 191.9134811                                                                                        | 0.004016822                                                                                        | 18.43288823                                                                                        | 4.678454594                                                                                        | 0.001851435                                                                                        | 0.000123211                                                                                        | 0.003242699                                                                                        | 185.5186051                                                                                        | 0.697594095                                                                                        | 0.005151249                                                                                        |
| 95%            | 13.40205959                                                                                        | 215.2548427                                                                                        | 0.004315259                                                                                        | 18.44462783                                                                                        | 4.684981475                                                                                        | 0.001995765                                                                                        | 0.000132365                                                                                        | 0.003574784                                                                                        | 208.1045472                                                                                        | 0.766952406                                                                                        | 0.005610941                                                                                        |
| 97%            | 13.41632004                                                                                        | 236.47995                                                                                          | 0.004590527                                                                                        | 18.4557055                                                                                         | 4.691575758                                                                                        | 0.002123797                                                                                        | 0.000140809                                                                                        | 0.003912375                                                                                        | 228.6040903                                                                                        | 0.831996872                                                                                        | 0.006015429                                                                                        |
| 99%            | 13.44400072                                                                                        | 279.294846                                                                                         | 0.005050364                                                                                        | 18.47658941                                                                                        | 4.702760314                                                                                        | 0.002429902                                                                                        | 0.000154914                                                                                        | 0.004521721                                                                                        | 269.9905235                                                                                        | 0.958750062                                                                                        | 0.006862075                                                                                        |



ModelRisk Statistics Results

| Range Name     | Total Dose Factor Rem. Worker                                                                 |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |
|----------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Variable Name  | Ag-108m                                                                                       | Am-241                                                                                        | C-14                                                                                          | Co-60                                                                                         | Cs-137                                                                                        | Fe-55                                                                                         | H-3                                                                                           | Ni-63                                                                                         | Pu-239/240                                                                                    | Sr-90                                                                                         | Tc-99                                                                                         |
| Cell reference | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK546</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK550</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK551</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK552</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK547</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK548</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK549</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK547</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK548</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK549</a> | <a href="#">[N55:He calc for DCGs for TSD 21-000; AG-10-24.xlsx]Remediation Worker-TAK548</a> |
| Variable Type  | Output                                                                                        | Output                                                                                        | Output                                                                                        | Output                                                                                        | Output                                                                                        | Output                                                                                        | Output                                                                                        | Output                                                                                        | Output                                                                                        | Output                                                                                        | Output                                                                                        |
| Location       |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |
| Mean           | 13.26773531                                                                                   | 5.118307023                                                                                   | 0.001769564                                                                                   | 18.33572548                                                                                   | 4.629273476                                                                                   | 0.000524144                                                                                   | 5.42792E-05                                                                                   | 0.000515802                                                                                   | 4.962674996                                                                                   | 0.126127442                                                                                   | 0.001270977                                                                                   |
| Minimum        | 13.26048032                                                                                   | 0.442447844                                                                                   | 4.77117E-06                                                                                   | 18.31241355                                                                                   | 4.587075471                                                                                   | 5.25762E-06                                                                                   | 1.4635E-07                                                                                    | 1.17686E-05                                                                                   | 0.428382316                                                                                   | 0.002444846                                                                                   | 1.60248E-05                                                                                   |
| Maximum        | 13.28226267                                                                                   | 15.06413859                                                                                   | 0.005665229                                                                                   | 18.38621747                                                                                   | 4.722501267                                                                                   | 0.001659177                                                                                   | 0.000173774                                                                                   | 0.001599509                                                                                   | 14.59576345                                                                                   | 0.39330639                                                                                    | 0.004006753                                                                                   |
| # of Errors    | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             |
| # of Filtered  | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             | 0                                                                                             |
| Spread         |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |
| St. dev.       | 0.00415156                                                                                    | 2.254902289                                                                                   | 0.001119038                                                                                   | 0.014456138                                                                                   | 0.026785166                                                                                   | 0.000325476                                                                                   | 3.43251E-05                                                                                   | 0.000309968                                                                                   | 2.188003294                                                                                   | 0.076466375                                                                                   | 0.000784047                                                                                   |
| Variance       | 1.72354E-05                                                                                   | 5.084584335                                                                                   | 1.25225E-06                                                                                   | 0.00020898                                                                                    | 0.000717445                                                                                   | 1.05935E-07                                                                                   | 1.17821E-09                                                                                   | 9.608E-08                                                                                     | 4.787358414                                                                                   | 0.005847107                                                                                   | 6.1473E-07                                                                                    |
| Risk ratio     | 0.000830448                                                                                   | 1.197670346                                                                                   | 1.766639755                                                                                   | 0.002104959                                                                                   | 0.015473558                                                                                   | 1.738013123                                                                                   | 1.766639755                                                                                   | 1.676293351                                                                                   | 1.197566541                                                                                   | 1.689940815                                                                                   | 1.725472211                                                                                   |
| CofV           | 0.000312906                                                                                   | 0.440556278                                                                                   | 0.632380447                                                                                   | 0.000788414                                                                                   | 0.005786041                                                                                   | 0.620967028                                                                                   | 0.632380447                                                                                   | 0.600943488                                                                                   | 0.440891917                                                                                   | 0.606262788                                                                                   | 0.616885381                                                                                   |
| Shape          |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |
| Skewness       | 0.39056389                                                                                    | 0.418116813                                                                                   | 0.404048772                                                                                   | 0.40263953                                                                                    | 0.404090167                                                                                   | 0.403504547                                                                                   | 0.404048772                                                                                   | 0.401822161                                                                                   | 0.417330609                                                                                   | 0.402361056                                                                                   | 0.403237711                                                                                   |
| Kurtosis       | 2.445358042                                                                                   | 2.774600526                                                                                   | 2.421914085                                                                                   | 2.421460142                                                                                   | 2.421998928                                                                                   | 2.421403822                                                                                   | 2.421914085                                                                                   | 2.421924396                                                                                   | 2.771021032                                                                                   | 2.421584912                                                                                   | 2.421351729                                                                                   |
| Percentiles    |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |                                                                                               |
| 1%             | 13.26095574                                                                                   | 1.074421767                                                                                   | 4.46045E-05                                                                                   | 18.31337972                                                                                   | 4.587991587                                                                                   | 2.27062E-05                                                                                   | 1.36819E-06                                                                                   | 3.43833E-05                                                                                   | 1.040023327                                                                                   | 0.007723548                                                                                   | 6.22509E-05                                                                                   |
| 3%             | 13.26143289                                                                                   | 1.497061439                                                                                   | 0.000108909                                                                                   | 18.31424605                                                                                   | 4.589510004                                                                                   | 4.08599E-05                                                                                   | 3.34064E-06                                                                                   | 5.441E-05                                                                                     | 1.448355093                                                                                   | 0.012373925                                                                                   | 0.000106573                                                                                   |
| 5%             | 13.26178953                                                                                   | 1.775579219                                                                                   | 0.000170142                                                                                   | 18.31509996                                                                                   | 4.591015847                                                                                   | 5.92293E-05                                                                                   | 5.21889E-06                                                                                   | 7.43662E-05                                                                                   | 1.718517546                                                                                   | 0.017086031                                                                                   | 0.000150454                                                                                   |
| 8%             | 13.26217791                                                                                   | 2.109123955                                                                                   | 0.000268444                                                                                   | 18.31630254                                                                                   | 4.593338973                                                                                   | 8.68866E-05                                                                                   | 8.23419E-06                                                                                   | 9.88631E-05                                                                                   | 2.041328673                                                                                   | 0.023377333                                                                                   | 0.000217739                                                                                   |
| 10%            | 13.26243411                                                                                   | 2.265898843                                                                                   | 0.000327414                                                                                   | 18.31710241                                                                                   | 4.594726873                                                                                   | 0.000104804                                                                                   | 1.0043E-05                                                                                    | 0.000117308                                                                                   | 2.192943743                                                                                   | 0.027827731                                                                                   | 0.000260321                                                                                   |
| 15%            | 13.26305604                                                                                   | 2.688401302                                                                                   | 0.000495621                                                                                   | 18.31931274                                                                                   | 4.59877073                                                                                    | 0.000154469                                                                                   | 1.52025E-05                                                                                   | 0.000163288                                                                                   | 2.60303903                                                                                    | 0.03920873                                                                                    | 0.000381249                                                                                   |
| 20%            | 13.26370155                                                                                   | 3.051192997                                                                                   | 0.000663289                                                                                   | 18.32148268                                                                                   | 4.602784937                                                                                   | 0.000203291                                                                                   | 2.03456E-05                                                                                   | 0.000209889                                                                                   | 2.956642604                                                                                   | 0.050789844                                                                                   | 0.000499076                                                                                   |
| 25%            | 13.26430767                                                                                   | 3.378676059                                                                                   | 0.000830537                                                                                   | 18.32364148                                                                                   | 4.60679256                                                                                    | 0.000251644                                                                                   | 2.54757E-05                                                                                   | 0.000257155                                                                                   | 3.275706758                                                                                   | 0.062257115                                                                                   | 0.000615079                                                                                   |
| 30%            | 13.26494836                                                                                   | 3.694873721                                                                                   | 0.001005347                                                                                   | 18.32595857                                                                                   | 4.610984481                                                                                   | 0.000301986                                                                                   | 3.08378E-05                                                                                   | 0.000306109                                                                                   | 3.581033936                                                                                   | 0.074495213                                                                                   | 0.00073746                                                                                    |
| 35%            | 13.26556908                                                                                   | 4.006697699                                                                                   | 0.001173492                                                                                   | 18.32798415                                                                                   | 4.615001969                                                                                   | 0.000349823                                                                                   | 3.59954E-05                                                                                   | 0.00035027                                                                                    | 3.882421716                                                                                   | 0.085285409                                                                                   | 0.000851075                                                                                   |
| 40%            | 13.2661499                                                                                    | 4.326053839                                                                                   | 0.001345612                                                                                   | 18.33022278                                                                                   | 4.619118823                                                                                   | 0.000400696                                                                                   | 4.1275E-05                                                                                    | 0.000397804                                                                                   | 4.193781586                                                                                   | 0.097147165                                                                                   | 0.000972927                                                                                   |
| 45%            | 13.26677926                                                                                   | 4.630878561                                                                                   | 0.001511956                                                                                   | 18.33239375                                                                                   | 4.623121413                                                                                   | 0.000448591                                                                                   | 4.63774E-05                                                                                   | 0.0004443                                                                                     | 4.490422971                                                                                   | 0.108415902                                                                                   | 0.001090643                                                                                   |
| 50%            | 13.26743182                                                                                   | 4.937020392                                                                                   | 0.001693501                                                                                   | 18.33470165                                                                                   | 4.627445046                                                                                   | 0.000500633                                                                                   | 5.19461E-05                                                                                   | 0.000493241                                                                                   | 4.78798685                                                                                    | 0.120658111                                                                                   | 0.001215407                                                                                   |
| 55%            | 13.26807257                                                                                   | 5.257019769                                                                                   | 0.001863127                                                                                   | 18.33686691                                                                                   | 4.631507349                                                                                   | 0.000550996                                                                                   | 5.71491E-05                                                                                   | 0.000539548                                                                                   | 5.100348202                                                                                   | 0.132115374                                                                                   | 0.001335445                                                                                   |
| 60%            | 13.26868939                                                                                   | 5.585915106                                                                                   | 0.002029613                                                                                   | 18.33919276                                                                                   | 4.635511402                                                                                   | 0.000601922                                                                                   | 6.22559E-05                                                                                   | 0.000589209                                                                                   | 5.415656389                                                                                   | 0.144417449                                                                                   | 0.001457536                                                                                   |
| 65%            | 13.26933438                                                                                   | 5.912361021                                                                                   | 0.002201985                                                                                   | 18.34125124                                                                                   | 4.639624922                                                                                   | 0.000649118                                                                                   | 6.75432E-05                                                                                   | 0.0006355                                                                                     | 5.73350372                                                                                    | 0.155541629                                                                                   | 0.001572396                                                                                   |
| 70%            | 13.26996706                                                                                   | 6.270255366                                                                                   | 0.002376487                                                                                   | 18.3435692                                                                                    | 4.643770476                                                                                   | 0.000700487                                                                                   | 7.28958E-05                                                                                   | 0.000683316                                                                                   | 6.078495893                                                                                   | 0.167571182                                                                                   | 0.001696874                                                                                   |
| 75%            | 13.27065927                                                                                   | 6.673732392                                                                                   | 0.002560422                                                                                   | 18.34587808                                                                                   | 4.648208455                                                                                   | 0.00075317                                                                                    | 7.85378E-05                                                                                   | 0.000734111                                                                                   | 6.471499594                                                                                   | 0.179839021                                                                                   | 0.001821431                                                                                   |
| 80%            | 13.27146228                                                                                   | 7.086867363                                                                                   | 0.002771894                                                                                   | 18.34868365                                                                                   | 4.65327106                                                                                    | 0.000816126                                                                                   | 8.50244E-05                                                                                   | 0.000793252                                                                                   | 6.873341747                                                                                   | 0.194660272                                                                                   | 0.001973511                                                                                   |
| 85%            | 13.2723682                                                                                    | 7.506626143                                                                                   | 0.003014364                                                                                   | 18.35183579                                                                                   | 4.659084535                                                                                   | 0.000886743                                                                                   | 9.24619E-05                                                                                   | 0.000861663                                                                                   | 7.338321599                                                                                   | 0.211352851                                                                                   | 0.002143746                                                                                   |
| 90%            | 13.27345202                                                                                   | 8.178821764                                                                                   | 0.003319221                                                                                   | 18.35569621                                                                                   | 4.666329912                                                                                   | 0.00097491                                                                                    | 0.000101813                                                                                   | 0.000944124                                                                                   | 7.926876593                                                                                   | 0.231732797                                                                                   | 0.002357472                                                                                   |
| 92%            | 13.27408367                                                                                   | 8.485791757                                                                                   | 0.003475541                                                                                   | 18.35773005                                                                                   | 4.670142045                                                                                   | 0.001020325                                                                                   | 0.000106608                                                                                   | 0.00098697                                                                                    | 8.229516386                                                                                   | 0.242420369                                                                                   | 0.002462962                                                                                   |
| 95%            | 13.27510565                                                                                   | 9.072445568                                                                                   | 0.003773592                                                                                   | 18.36156639                                                                                   | 4.677201297                                                                                   | 0.001105378                                                                                   | 0.000115575                                                                                   | 0.001069403                                                                                   | 8.801093992                                                                                   | 0.262702733                                                                                   | 0.002672464                                                                                   |
| 97%            | 13.2760414                                                                                    | 9.62092159                                                                                    | 0.00402349                                                                                    | 18.36484093                                                                                   | 4.683265266                                                                                   | 0.00117911                                                                                    | 0.000123416                                                                                   | 0.001139391                                                                                   | 9.335257399                                                                                   | 0.280020949                                                                                   | 0.002848164                                                                                   |
| 99%            | 13.27776159                                                                                   | 10.75969147                                                                                   | 0.00446775                                                                                    | 18.37042757                                                                                   | 4.693875922                                                                                   | 0.001306635                                                                                   | 0.000137043                                                                                   | 0.001258008                                                                                   | 10.44037331                                                                                   | 0.30952165                                                                                    | 0.003154801                                                                                   |



ModelRisk Statistics Results

| Range Name     |  | Ingestion for Comp. Rem. Worker                                                                            |                                                                                                            | Inhalation for Comp. Rem. Worker                                                                           |                                                                                                            | Rem. Worker                                                                                                |                                                                                                  | Ingestion for Comp. Rem. Worker                                                                  |                                                                                                  | Inhalation for Comp. Rem. Worker                                                                 |                                                                                                  | Rem. Worker                                                                                      |                                                                                                  |
|----------------|--|------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Variable Name  |  | Ingestion for Comp. Rem. Worker                                                                            |                                                                                                            | Inhalation for Comp. Rem. Worker                                                                           |                                                                                                            | Rem. Worker                                                                                                |                                                                                                  | Ingestion for Comp. Rem. Worker                                                                  |                                                                                                  | Inhalation for Comp. Rem. Worker                                                                 |                                                                                                  | Rem. Worker                                                                                      |                                                                                                  |
| Variable Name  |  | Inadvertent (Secondary) Ingestion rate                                                                     | Surface area factor                                                                                        | Air Concentration                                                                                          | Inhalation rate                                                                                            | Surface area factor                                                                                        | Air Concentration                                                                                | Inadvertent (Secondary) Ingestion rate                                                           | Surface area factor                                                                              | Air Concentration                                                                                | Inhalation rate                                                                                  | Surface area factor                                                                              | Air Concentration                                                                                |
| Cell reference |  | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Component removal<br/>worker D527]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Component removal<br/>worker D528]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Component removal<br/>worker D531]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Component removal<br/>worker D532]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Component removal<br/>worker D533]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Remediation Worker D534]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Remediation Worker D535]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Remediation Worker D536]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Remediation Worker D537]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Remediation Worker D538]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Remediation Worker D539]</a> | <a href="#">[N55:He calc for DCGIs for TSD 21-009<br/>06-10-24.xlsx Remediation Worker D540]</a> |
| Variable Type  |  | Input                                                                                                      | Input                                                                                                      | Input                                                                                                      | Input                                                                                                      | Input                                                                                                      | Input                                                                                            | Input                                                                                            | Input                                                                                            | Input                                                                                            | Input                                                                                            | Input                                                                                            | Input                                                                                            |
| Location       |  |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |
| Mean           |  | 0.009945402                                                                                                | 0.20816358                                                                                                 | 0.002271981                                                                                                | 1.197920819                                                                                                | 0.208467491                                                                                                | 0.002272012                                                                                      | 0.009991789                                                                                      | 1.197828665                                                                                      | 0.208502084                                                                                      | 0.002272012                                                                                      | 0.009991789                                                                                      | 1.197828665                                                                                      |
| Minimum        |  | 1.48434E-06                                                                                                | 0.102388174                                                                                                | 0.000214149                                                                                                | 0.605030579                                                                                                | 0.102328263                                                                                                | 0.000292758                                                                                      | 6.92157E-07                                                                                      | 0.614786186                                                                                      | 0.102141887                                                                                      | 0.000292758                                                                                      | 6.92157E-07                                                                                      | 0.614786186                                                                                      |
| Maximum        |  | 0.019996391                                                                                                | 0.340269377                                                                                                | 0.004999613                                                                                                | 1.787775392                                                                                                | 0.343181757                                                                                                | 0.004998983                                                                                      | 0.019997954                                                                                      | 1.798114703                                                                                      | 0.33933036                                                                                       | 0.004998983                                                                                      | 0.019997954                                                                                      | 1.798114703                                                                                      |
| # of Errors    |  | 0                                                                                                          | 0                                                                                                          | 0                                                                                                          | 0                                                                                                          | 0                                                                                                          | 0                                                                                                | 0                                                                                                | 0                                                                                                | 0                                                                                                | 0                                                                                                | 0                                                                                                | 0                                                                                                |
| # of Filtered  |  | 0                                                                                                          | 0                                                                                                          | 0                                                                                                          | 0                                                                                                          | 0                                                                                                          | 0                                                                                                | 0                                                                                                | 0                                                                                                | 0                                                                                                | 0                                                                                                | 0                                                                                                | 0                                                                                                |
| Spread         |  |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |
| St. dev.       |  | 0.005780002                                                                                                | 0.047067177                                                                                                | 0.000968401                                                                                                | 0.243908635                                                                                                | 0.047148882                                                                                                | 0.00097232                                                                                       | 0.005811019                                                                                      | 0.244637237                                                                                      | 0.047316891                                                                                      | 0.00097232                                                                                       | 0.005811019                                                                                      | 0.244637237                                                                                      |
| Variance       |  | 3.34084E-05                                                                                                | 0.002215319                                                                                                | 9.378E-07                                                                                                  | 0.059491422                                                                                                | 0.002223017                                                                                                | 9.45406E-07                                                                                      | 3.37679E-05                                                                                      | 0.059847378                                                                                      | 0.002238888                                                                                      | 0.002223017                                                                                      | 9.45406E-07                                                                                      | 3.37679E-05                                                                                      |
| Risk ratio     |  | 1.600130493                                                                                                | 0.610947024                                                                                                | 1.208196733                                                                                                | 0.551883859                                                                                                | 0.610345424                                                                                                | 1.22047276                                                                                       | 1.603793729                                                                                      | 0.558089888                                                                                      | 0.612391824                                                                                      | 1.22047276                                                                                       | 1.603793729                                                                                      | 0.558089888                                                                                      |
| CofV           |  | 0.581173297                                                                                                | 0.226106687                                                                                                | 0.426236302                                                                                                | 0.20360998                                                                                                 | 0.226168988                                                                                                | 0.427955452                                                                                      | 0.581579471                                                                                      | 0.204233914                                                                                      | 0.226937258                                                                                      | 0.427955452                                                                                      | 0.581579471                                                                                      | 0.204233914                                                                                      |
| Shape          |  |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |
| Skewness       |  | 0.014562044                                                                                                | 0.173598869                                                                                                | 0.618631891                                                                                                | 0.015430632                                                                                                | 0.17682351                                                                                                 | 0.626203548                                                                                      | -0.006945223                                                                                     | 0.02542133                                                                                       | 0.171340702                                                                                      | 0.015430632                                                                                      | 0.17682351                                                                                       | 0.626203548                                                                                      |
| Kurtosis       |  | 1.793792266                                                                                                | 2.36496695                                                                                                 | 2.766100182                                                                                                | 2.416967028                                                                                                | 2.35580827                                                                                                 | 2.747176746                                                                                      | 1.789254888                                                                                      | 2.411613772                                                                                      | 2.351744789                                                                                      | 2.416967028                                                                                      | 2.35580827                                                                                       | 2.747176746                                                                                      |
| Percentiles    |  |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                            |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |                                                                                                  |
| 1%             |  | 0.000218957                                                                                                | 0.117046822                                                                                                | 0.000691075                                                                                                | 0.686595687                                                                                                | 0.117008021                                                                                                | 0.000696522                                                                                      | 0.000211553                                                                                      | 0.686719267                                                                                      | 0.118613683                                                                                      | 0.000696522                                                                                      | 0.000211553                                                                                      | 0.686719267                                                                                      |
| 3%             |  | 0.000609344                                                                                                | 0.127754888                                                                                                | 0.000845965                                                                                                | 0.746407637                                                                                                | 0.127601451                                                                                                | 0.000852074                                                                                      | 0.000599673                                                                                      | 0.750475056                                                                                      | 0.127194721                                                                                      | 0.000852074                                                                                      | 0.000599673                                                                                      | 0.750475056                                                                                      |
| 5%             |  | 0.001042522                                                                                                | 0.134641955                                                                                                | 0.000951305                                                                                                | 0.793364287                                                                                                | 0.13470751                                                                                                 | 0.000948173                                                                                      | 0.00045393                                                                                       | 0.787820934                                                                                      | 0.133789466                                                                                      | 0.000948173                                                                                      | 0.00045393                                                                                       | 0.787820934                                                                                      |
| 8%             |  | 0.001677325                                                                                                | 0.142156284                                                                                                | 0.001069356                                                                                                | 0.841443165                                                                                                | 0.142705577                                                                                                | 0.001062242                                                                                      | 0.001554126                                                                                      | 0.838069992                                                                                      | 0.141767894                                                                                      | 0.001062242                                                                                      | 0.001554126                                                                                      | 0.838069992                                                                                      |
| 10%            |  | 0.00202283                                                                                                 | 0.146786069                                                                                                | 0.001138826                                                                                                | 0.8682814                                                                                                  | 0.146800199                                                                                                | 0.001133985                                                                                      | 0.00192117                                                                                       | 0.864583566                                                                                      | 0.146862282                                                                                      | 0.001133985                                                                                      | 0.00192117                                                                                       | 0.864583566                                                                                      |
| 15%            |  | 0.0028734                                                                                                  | 0.156070268                                                                                                | 0.001277735                                                                                                | 0.926278649                                                                                                | 0.156396454                                                                                                | 0.001276065                                                                                      | 0.002896083                                                                                      | 0.927641933                                                                                      | 0.156081498                                                                                      | 0.001276065                                                                                      | 0.002896083                                                                                      | 0.927641933                                                                                      |
| 20%            |  | 0.003872966                                                                                                | 0.164747252                                                                                                | 0.001406476                                                                                                | 0.976877367                                                                                                | 0.165106038                                                                                                | 0.001402582                                                                                      | 0.003895872                                                                                      | 0.979034715                                                                                      | 0.164375683                                                                                      | 0.001402582                                                                                      | 0.003895872                                                                                      | 0.979034715                                                                                      |
| 25%            |  | 0.004913111                                                                                                | 0.172072577                                                                                                | 0.001518372                                                                                                | 1.02090955                                                                                                 | 0.172496533                                                                                                | 0.001522298                                                                                      | 0.0049483                                                                                        | 1.023217399                                                                                      | 0.171895959                                                                                      | 0.001522298                                                                                      | 0.0049483                                                                                        | 1.023217399                                                                                      |
| 30%            |  | 0.005854297                                                                                                | 0.179600591                                                                                                | 0.001640684                                                                                                | 1.062783877                                                                                                | 0.179683553                                                                                                | 0.001643506                                                                                      | 0.005884968                                                                                      | 1.06204129                                                                                       | 0.179340633                                                                                      | 0.001643506                                                                                      | 0.005884968                                                                                      | 1.06204129                                                                                       |
| 35%            |  | 0.006922062                                                                                                | 0.186285133                                                                                                | 0.001762161                                                                                                | 1.101214772                                                                                                | 0.186454907                                                                                                | 0.001756861                                                                                      | 0.00694295                                                                                       | 1.098727893                                                                                      | 0.1863352                                                                                        | 0.001756861                                                                                      | 0.00694295                                                                                       | 1.098727893                                                                                      |
| 40%            |  | 0.007915341                                                                                                | 0.193037606                                                                                                | 0.001874228                                                                                                | 1.137628068                                                                                                | 0.193067263                                                                                                | 0.001863958                                                                                      | 0.0079004532                                                                                     | 1.134204367                                                                                      | 0.193604354                                                                                      | 0.001863958                                                                                      | 0.0079004532                                                                                     | 1.134204367                                                                                      |
| 45%            |  | 0.008943825                                                                                                | 0.199587984                                                                                                | 0.001992188                                                                                                | 1.169666518                                                                                                | 0.199742756                                                                                                | 0.001977179                                                                                      | 0.008913063                                                                                      | 1.167164695                                                                                      | 0.200102835                                                                                      | 0.001977179                                                                                      | 0.008913063                                                                                      | 1.167164695                                                                                      |
| 50%            |  | 0.009968962                                                                                                | 0.206030814                                                                                                | 0.002117334                                                                                                | 1.200052556                                                                                                | 0.206516723                                                                                                | 0.002103224                                                                                      | 0.009950709                                                                                      | 1.196727071                                                                                      | 0.206578554                                                                                      | 0.002103224                                                                                      | 0.009950709                                                                                      | 1.196727071                                                                                      |
| 55%            |  | 0.010971137                                                                                                | 0.212813636                                                                                                | 0.002248685                                                                                                | 1.229017809                                                                                                | 0.212889031                                                                                                | 0.002236869                                                                                      | 0.010979703                                                                                      | 1.227863056                                                                                      | 0.213346187                                                                                      | 0.002236869                                                                                      | 0.010979703                                                                                      | 1.227863056                                                                                      |
| 60%            |  | 0.012030097                                                                                                | 0.219787932                                                                                                | 0.002387793                                                                                                | 1.259842848                                                                                                | 0.219573024                                                                                                | 0.00238377                                                                                       | 0.012083207                                                                                      | 1.257690905                                                                                      | 0.220068381                                                                                      | 0.00238377                                                                                       | 0.012083207                                                                                      | 1.257690905                                                                                      |
| 65%            |  | 0.012916331                                                                                                | 0.226465555                                                                                                | 0.002535887                                                                                                | 1.293559131                                                                                                | 0.227190546                                                                                                | 0.002528028                                                                                      | 0.013045804                                                                                      | 1.292239565                                                                                      | 0.227606502                                                                                      | 0.002528028                                                                                      | 0.013045804                                                                                      | 1.292239565                                                                                      |
| 70%            |  | 0.013898953                                                                                                | 0.234178981                                                                                                | 0.002693214                                                                                                | 1.329005268                                                                                                | 0.234327375                                                                                                | 0.002690975                                                                                      | 0.014019777                                                                                      | 1.330790028                                                                                      | 0.234797464                                                                                      | 0.002690975                                                                                      | 0.014019777                                                                                      | 1.330790028                                                                                      |
| 75%            |  | 0.014901825                                                                                                | 0.242527427                                                                                                | 0.002871945                                                                                                | 1.369103428                                                                                                | 0.24262333                                                                                                 | 0.002887084                                                                                      | 0.014983281                                                                                      | 1.370298186                                                                                      | 0.242924013                                                                                      | 0.002887084                                                                                      | 0.014983281                                                                                      | 1.370298186                                                                                      |
| 80%            |  | 0.015909037                                                                                                | 0.251375658                                                                                                | 0.003089411                                                                                                | 1.412306636                                                                                                | 0.251416474                                                                                                | 0.00311022                                                                                       | 0.016001612                                                                                      | 1.415393365                                                                                      | 0.251531176                                                                                      | 0.00311022                                                                                       | 0.016001612                                                                                      | 1.415393365                                                                                      |
| 85%            |  | 0.016944107                                                                                                | 0.260613305                                                                                                | 0.003370984                                                                                                | 1.464998661                                                                                                | 0.261586607                                                                                                | 0.003365016                                                                                      | 0.016958917                                                                                      | 1.468849111                                                                                      | 0.261527555                                                                                      | 0.003365016                                                                                      | 0.016958917                                                                                      | 1.468849111                                                                                      |
| 90%            |  | 0.01797447                                                                                                 | 0.272659982                                                                                                | 0.003696982                                                                                                | 1.530571035                                                                                                | 0.272846735                                                                                                | 0.003700912                                                                                      | 0.018040434                                                                                      | 1.532464842                                                                                      | 0.273369299                                                                                      | 0.003700912                                                                                      | 0.018040434                                                                                      | 1.532464842                                                                                      |
| 92%            |  | 0.018427332                                                                                                | 0.277927537                                                                                                | 0.003852605                                                                                                | 1.561822294                                                                                                | 0.279498097                                                                                                | 0.003874756                                                                                      | 0.018443866                                                                                      | 1.56156356                                                                                       | 0.278395773                                                                                      | 0.003874756                                                                                      | 0.018443866                                                                                      | 1.56156356                                                                                       |
| 95%            |  | 0.019039441                                                                                                | 0.288643468                                                                                                | 0.004139338                                                                                                | 1.611002916                                                                                                | 0.289179948                                                                                                | 0.004177551                                                                                      | 0.019039758                                                                                      | 1.615191207                                                                                      | 0.289290451                                                                                      | 0.004177551                                                                                      | 0.019039758                                                                                      | 1.615191207                                                                                      |
| 97%            |  | 0.019415441                                                                                                | 0.298125029                                                                                                | 0.004419265                                                                                                | 1.652296556                                                                                                | 0.298965494                                                                                                | 0.004433111                                                                                      | 0.019439777                                                                                      | 1.657585347                                                                                      | 0.299150769                                                                                      | 0.004433111                                                                                      | 0.019439777                                                                                      | 1.657585347                                                                                      |
| 99%            |  | 0.019785691                                                                                                | 0.311857069                                                                                                | 0.004773152                                                                                                | 1.711522126                                                                                                | 0.313256138                                                                                                | 0.004759763                                                                                      | 0.019827637                                                                                      | 1.707425896                                                                                      | 0.313378208                                                                                      | 0.004759763                                                                                      | 0.019827637                                                                                      | 1.707425896                                                                                      |