National Aeronautics and
Space Administration

NASA/Navy Benchmarking Exchange (NNBE)

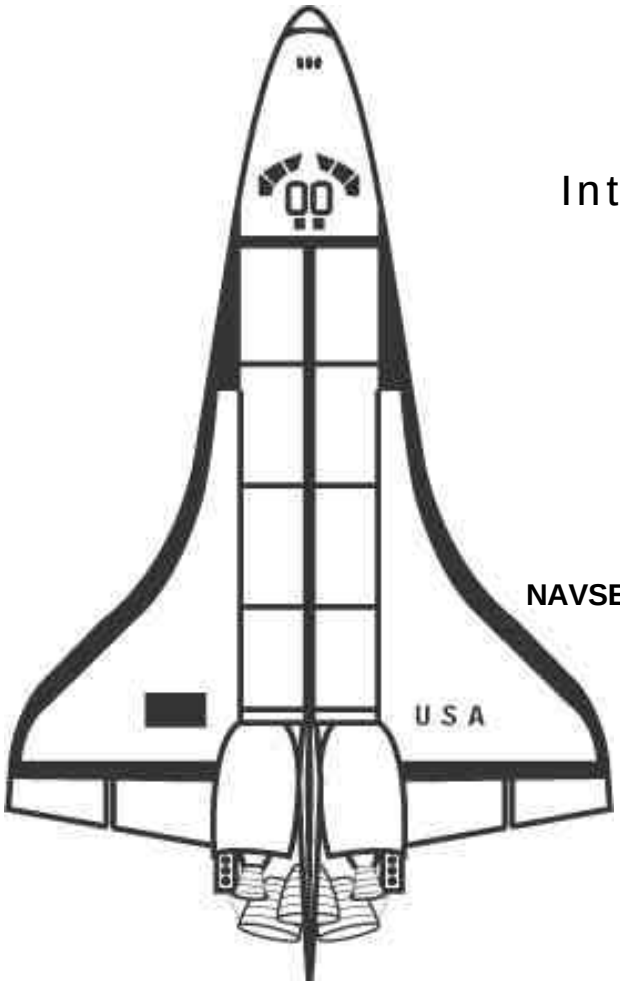
Volume I

Interim Report | December 20, 2002

Navy Submarine Program Safety Assurance

NNBE Benchmarking Team

NASA Office of Safety & Mission Assurance and
NAVSEA 92Q Submarine Safety & Quality Assurance Division



Acknowledgement

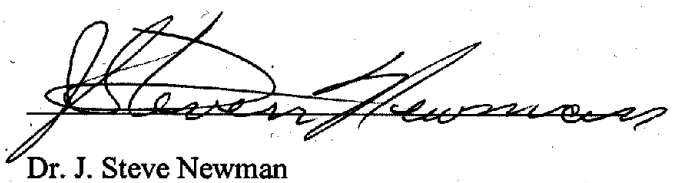
The NASA Benchmarking Team gratefully acknowledges the cooperation and outstanding support of Team Submarine[1] during this phase of the NASA/Navy Benchmarking Exchange. Team Submarine coordinated and hosted numerous meetings and site visits enabling the NASA team to acquire a large volume of relevant information in a relatively short period of time. Members of the core Navy team supported all events and provided continuity and assistance in understanding the subtleties of Navy processes and practices. In addition, Team Submarine reviewed this Interim Report for accuracy and in many cases offered clarifying text. The NASA team anticipates that this exchange will form the basis for further development of ongoing relationships between our communities.

[1] NAVSEA Headquarters; Supervisor of Shipbuilding (SUPSHIP) – Groton; Electric Boat; Portsmouth Naval Shipyard; Submarine Maintenance, Engineering, Planning, and Procurement (SUBMEPP); Ship Availability Planning and Engineering Center (SHAPEC); NAVSEA Logistics Center (NAVSEALOGCEN).

Signature Page

The undersigned participated in developing the content and verifying the accuracy of the process attributes presented in section 3 of this Interim Report and the comparisons provided in section 4.1. The undersigned also attest to their organization's commitment to pursue the additional benchmarking exchange activities discussed in section 2 of this report.

NASA Team Lead



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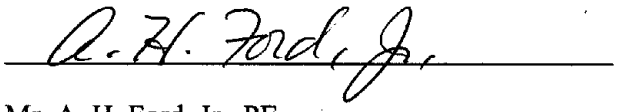

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The opportunities discussed in section 4.2 of this document represent the consensus of the NASA core benchmarking team membership.

Executive Summary

The NASA/Navy Benchmarking Exchange (NNBE) was undertaken to identify practices and procedures and to share lessons learned in the Navy's submarine and NASA's human space flight programs. The NNBE focus is on safety and mission assurance policies, processes, accountability, and control measures. This report is an interim summary of activity conducted through October 2002, and it coincides with completion of the first phase of a two-phase fact-finding effort.

In August 2002, a team was formed, co-chaired by senior representatives from the NASA Office of Safety and Mission Assurance and the NAVSEA 92Q Submarine Safety and Quality Assurance Division. The team closely examined the two elements of submarine safety (SUBSAFE) certification: 1.) new design/construction (initial certification) and 2.) maintenance and modernization (sustaining certification), with a focus on: 1.) Management and Organization, 2.) Safety Requirements (technical and administrative), 3.) Implementation Processes, 4.) Compliance Verification Processes, and 5.) Certification Processes.

The overall schedule and agenda supported early NASA benchmarking of the Navy. The activity to date included numerous meetings at the Washington Navy Yard (WNY), as well as trips to Groton, CT, and Portsmouth Naval Shipyard (PNS) in Kittery, ME. In addition, the NAVSEA team was hosted at the NASA Aerospace Safety Advisory Panel (ASAP) meetings at Johnson Space Center, Houston, TX, November 5-7, 2002.

NASA's examination resulted in identification of the following key attributes of the Navy submarine safety program:

- Safety requirements are clearly documented and achievable, with minimal use of waivers or tailoring.
- Requirements are implemented through capable and carefully controlled processes.
- Compliance is verified through rigorous in-line management control and assurance processes.
- Compliance is also verified independently of program management by a separate compliance verification organization.
- A strong safety culture exists with emphasis (training and awareness) on understanding and learning from past failures (e.g., USS THRESHER).
- A centralized technical authority and a large operational experience base facilitate continuous learning and improvement in design, manufacturing, and operations.

Potential opportunities for NASA to consider, based on observed Navy practices, are listed below and discussed in Section 4 of this report:

- Development of functional safety requirements for future human rated space systems.
- Implementation of the NAVSEA organizational model for compliance verification.
- Examination of the proposed compliance verification approach for Orbital Space Plane.
- Expansion and management restructuring of lessons learned within NASA.
- Incorporation of noted NASA and Navy program failure case studies in lessons learned training.
- Consideration of the NAVSEA knowledge retention approach (increased FTE ceiling authorization for hiring) as part of the Administrator's workforce management initiative.

During the remaining portion of this activity, the NASA team will participate as observers during a SUBSAFE certification audit and conduct follow-on discussions concerning Naval Reactors safety processes, quality assurance, software, and human factors. NASA will host the Navy team at Kennedy Space Center (KSC), the Michoud Assembly Facility (MAF) in New Orleans, LA, Stennis Space Center, MS, and Thiokol in Ogden, UT. Separate subject matter expert trips are planned to benchmark software development and assurance, and human factors. The NNBE is expected to be completed by May-June of 2003, followed by a final joint NASA/Navy report in the August-September 2003 time frame.

TABLE OF CONTENTS

Acknowledgement ii

Signature Page iii

Executive Summary iv

Table of Contents v

List of Figures vi

List of Tables vi

1.0 Introduction 1
- 1.1 Motivation 1
- 1.2 Method 2
- 1.3 Scope 5

2.0 Background 8
- 2.1 Orientation 8
- 2.2 Submarine Hazards and Organizations That Manage Hazards 8

3.0 Summaries and Key Observations 15
- 3.1 SUBSAFE Program 15
- 3.2 Management and Organization 19
- 3.3 Safety Requirements 25
- 3.4 Implementation Processes 26
- 3.5 Compliance Verification Processes 37
- 3.6 Certification Processes 43
- 3.7 Naval Reactors 48

4.0 Context and Opportunities 50
- 4.1 Comparative Context - Differences 50
- 4.2 Potential Opportunities 55
- 4.3 Rationale/Value of Potential Opportunities 60

Appendices: 64

A Initiating Letter and Attachment 65
B Summary of Key Observations 69
C Team Membership 75
D Key Documents Reviewed/Exchanged 76
E NNBE Acronyms and Terms 82

LIST OF FIGURES

Figure 1.1 USS THRESHER (SSN 593) 2
Figure 1.2 STS-51L Challenger 2
Figure 2.1 Naval Sea Systems Command, November 2002 (Unofficial Org. Chart) 9
Figure 2.2 High-Level Submarine Hazards and Organizational Responsibilities for Mitigation & Management 10
Figure 3.1 SUBSAFE Program Timeline 16
Figure 3.2 SUBSAFE Elements 17
Figure 3.3 Functional Relationship Between Submarine Program Managers/Senior Management and the SUBSAFE Program 19
Figure C.1 NASA/Navy Benchmark Exchange Team: Tactical Planning Meeting August 15, 2002, Washington, DC. 75

LIST OF TABLES

Table 1.1 Interim Accomplishment Status 5
Table 4.1 Rationale/Value of Potential Opportunities 60

NASA/NAVY Benchmarking Exchange (NNBE) Interim Report

1.0 Introduction

1.1 Motivation

Notable similarities exist between human space flight and nuclear submarine programs. Both spacecraft and submarines operate in extreme environments, both require integration of complex systems and subsystems, and both must maintain the highest levels of safety and reliability in order to perform their missions. The Navy has continued to operate safely and effectively in resource-constrained and declining-production environments. Furthermore, as NASA explores the application of nuclear propulsion and power for space exploration, lessons learned from the Navy's nuclear safety program could be beneficial. Thus, given the current management challenges NASA is facing, the Agency might benefit from an in-depth examination of the engineering management, safety, and mission assurance (SMA)[2] practices employed by the Navy submarine force.

The design, test, operation, and maintenance of submarine and human space flight programs have many attributes in common:

- Missions are of national importance,
- Safety is essential - severe consequences are associated with critical system failure,
- Operating environments are inherently hazardous (hostile),
- Nuclear energy systems are currently in-use/are planned for expanded use,
- People and the surrounding environment need to be protected from hazards,
- Complex, tightly coupled systems are involved,
- People play a critical role in complex processes,
- System requirements include highly reliable, long-term operations,
- Mission models include both new design/construction and ongoing/sustained operation of fleets,
- Operational integrity must be sustained throughout maintenance/modernization cycles,
- Operational integrity also must be sustained throughout management challenges such as downsizing, production decline, budget constraints, and workforce instabilities,
- Parts obsolescence is an ongoing challenge,
- New material applications continue to push the envelope,
- Modular components provided by multiple vendors present a systems engineering challenge,
- NASA and the Navy operate under Federal procurement regulations, and
- NASA and the Navy were both directed to have an independent compliance assurance program and organization for the safety of space and submarine operations, respectively.

[2] In NASA parlance SMA includes safety, reliability, maintainability, and quality assurance.

It should also be noted that there are important differences to be aware of when comparing NAVSEA and NASA programs and operations. Submarine and human space flight programs have different:

- Degrees of reliance on evolution and legacy of design,
- Opportunities for intervention and recovery from critical failures,
- Weight and volume criticalities,
- Cultural environments,
- Technical responsibility, authority, and accountability,
- Safety and mission assurance requirements management,
- Verification and compliance approaches,
- Program management, organization, and integration of safety and mission assurance activities, and
- Design approaches (deterministic versus probabilistic).

These similarities and differences are discussed in further detail (section 4.0) as context for the key observations and opportunities provided in this benchmarking exchange.

Navy submarines and NASA's human space flight programs have, in general, demonstrated outstanding safety records over sustained time periods. However, both Navy and NASA operational experience has been punctuated by a few significant failure events [e.g., USS THRESHER (SSN-593), USS SCORPION (SSN-589), Apollo-1 pad fire, STS-51L Challenger] that have led to increased focus on safety.

Figure 1.1 USS THRESHER (SSN 593).

Figure 1.2 STS-51L Challenger.

In August 2002, NASA began a two-way benchmarking exchange exploring life-cycle safety management paradigms, including a rigorous examination of relevant organizational structure, risk management processes, safety policies and procedures, work processes, tools, techniques, verification and compliance processes, and certification processes. The initiating letter from the NASA Administrator to the Secretary of the Navy is shown in Appendix A.

1.2 Method

Management Direction and Framework for Benchmarking

A management team was formed to direct the overall NNBE. This team is co-chaired by senior representatives from the NASA Office of Safety and Mission Assurance and the NAVSEA 92Q Submarine Safety and Quality Assurance Division. The NNBE

Management Team developed a common "lens for analysis" to address the overall goals set forth in the Administrator's letter. The exchange is looking at new design/construction (initial certification) and maintenance/modernization (sustaining certification). Five topics are being examined in detail:

1) Management and Organization,
2) Safety Requirements (technical and administrative),
3) Implementation Processes,
4) Compliance Verification Processes, and
5) Certification Processes.

Within this framework the Submarine Safety (SUBSAFE) Program represented a major area of interest and focus. Additionally, the Naval Nuclear Propulsion Program safety and assurance activities are being examined within the context of new design/construction and maintenance/modernization.

Approach

The NNBE Management Team identified a specific data gathering approach that includes the following areas and activities: 1.) document exchange, 2.) Navy-hosted information exchange events, 3.) NASA-hosted information exchange events, 4.) subject matter expert technical exchange meetings (e.g., software, quality assurance, human factors, etc.), and 5.) on-line collaboration (eGov).

Exchange Activity To Date

As of the date of this interim report, the NNBE Management Team has met six times beginning with the kickoff meeting at the Washington Navy Yard (WNY) on August 13-15, 2002. The overall schedule and agenda was front-loaded with Navy-hosted events to support early NASA benchmarking. Initial NASA benchmarking team meetings at the WNY covered NAVSEA Headquarters' roles in both new design/construction and maintenance/modernization. From September 17-19, 2002, NASA observed the SUBSAFE Working Group meetings in Washington, DC. NAVSEA 08 Naval Reactors gave the NASA team an overview briefing on October 1, 2002, and NASA and NAVSEA 08 are in the process of following up on interest items identified in the initial meeting. The NASA team went to Groton, CT, to observe NAVSEA conduct SUBSAFE functional audits of the Supervisor of Shipbuilding - Groton and Electric Boat Corporation (September 23-27, 2002). The team returned for examination of new design/construction activities at Electric Boat on October 16-18, 2002.

From October 21-23, 2002, the NASA team reviewed submarine engineering, maintenance planning, and logistics activities at Portsmouth Naval Shipyard (PNS) in Kittery, ME. The site visit also included discussions with Submarine Maintenance Engineering, Planning and Procurement (SUBMEPP) and Ship Availability Planning and Engineering Center (SHAPEC). Finally, the NASA team met with the Naval Sea Logistics Center Detachment in Portsmouth, NH.

To kickoff the NASA-hosted events, the NAVSEA benchmarking team was hosted at the NASA Aerospace Safety Advisory Panel (ASAP) meetings at Johnson Space Center, Houston, TX, November 5-7, 2002.

Next Steps - NASA Team Phase-2 (January - June 2003)

During phase-2, the NASA team will complete its assessment activity by participating as observers during a certification audit of the USS ASHEVILLE that is scheduled to occur in February 2003, at Puget Sound Naval Shipyard, Bremerton, WA. In addition, follow-on discussions are proposed for the following areas:

- Naval Reactors Safety Processes: details of Naval Reactors safety, quality assurance, and new-design methodologies and processes.

- Quality Assurance: collaboration opportunities in the areas of supplier risk evaluation, workmanship criteria, and corrective action approaches.

- Software: exchange of approaches for requirements definition and flow-down, and approaches for implementation of software verification and validation processes.

- Human Factors: collaboration opportunity with NAVSEA 03 (Human Systems Integration in System Design) to evaluate and develop possible human/system interface technical standards, policies, and processes.

- Specialized Technical Discussions: Expert-to-expert technical interchange meetings in specialized technical areas such as software, quality assurance, human factors, supplier audit, and other specific technologies (e.g., explosive bolt pyro-technology).

Next Steps - Navy Team Phase-2 (January – June 2003)

The Navy is currently in the process of identifying additional items for further investigation based on attending the ASAP meetings conducted at JSC.

During phase-2, NASA will host the Navy team at Kennedy Space Center (KSC) during the first week of January and again during the last week of February (tentative dates). KSC events will include a Flight Readiness Review (FRR), work authorization, and implementation, work control and review processes, critical process management, and human factors discussions. Other trips are planned to the Michoud Assembly Facility (MAF), in New Orleans, LA, Stennis Space Center, MS, and Thiokol in Ogden, UT. Each trip will address multiple topics and processes. In addition, separate subject matter expert trips are planned to benchmark software development and assurance, and human factors.

Next Steps - Continued On-Line Collaboration

The on-line collaboration (eGov) of NAVSEA experts with NASA counterparts has begun and is anticipated to expand throughout phase-2 of the NNBE. It is anticipated that there will be long-term collaboration among Navy and NASA subject matter experts using NASA PBMA-KMS work groups.

Report Organization

Following this section, section 2 provides background orientation for the reader concerning key organizations within the NAVSEA submarine domain. Also included is a high level overview of submarine hazards and the organizations and processes in place to mitigate those hazards. Section 3 contains detailed summaries and key observations developed by the NASA team based on Navy-hosted benchmarking events conducted through October 31, 2002. In section 4, the NASA team describes potential opportunities for the Agency to build upon selected NAVSEA processes and best practices.

1.3 Scope

Table 1.1 presents a comparison between the NASA NNBE mission objectives, (contained in the Administrator's letter and attachment) and the accomplishments to date.

Table 1.1

INTERIM ACCOMPLISHMENT STATUS	
Excerpts from O'Keefe Letter	**Status**
Benchmark Navy nuclear submarine program with focus on safety and mission assurance policies, processes, accountability, and control measures that can assist NASA in meeting current human space flight challenges.	Largely accomplished. Gained an understanding of the *Navy-side* of the benchmark equation. While an understanding/documentation of NASA's current SMA processes exist, a formal, direct comparison has not been conducted in this report.
Develop a set of "lessons learned" that could be effectively applied to NASA's human space flight programs.	Potential opportunities identified. See section 4.
Understand the nuclear Navy top-down approach for ensuring accountability and control in safety critical areas. Understand the flow-down of top-level safety philosophy and requirements.	Accomplished. Addressed in section 2.2 and section 3.1.
Understand the overarching risk management posture or logic employed in making decisions concerning competing and often conflicting program dimensions of cost control, schedule, mission capability, and safety.	Accomplished. Multiple discussions in section 3.

INTERIM ACCOMPLISHMENT STATUS	
Excerpts from O'Keefe Letter	**Status**
Understand the cultural dimensions of the SUBSAFE Program.	Accomplished. See sections 1.3, and 4.
Acquire a process-level understanding of safety, risk management, and mission assurance processes within the Navy nuclear submarine SUBSAFE Program.	Accomplished for SUBSAFE Program. See section 3.1. Additional data acquisition in progress for NAVSEA 08 portion of safety, risk management, and mission assurance processes.
Understand the policies, procedures, practices, and processes for 1.) definition of requirements, 2.) verification of ongoing implementation, and 3.) certification of operational readiness. Clearly identify organizational accountability and responsibilities for SUBSAFE implementation.	Accomplished. See section 3.1 and 3.3.
Understand the authority and relationships between various control boards and processes responsible for hardware design, software design, manufacturing processes, test/certification, and operations.	Accomplished. See section 3. NAVSEA technical design processes examined for the USS VIRGINIA and SSGN Conversion programs. See section 3.2 and 3.3.
Understand the role of systems engineering authority within the Trident program for integrating and managing change.	NAVSEA systems engineering roles examined specifically for USS VIRGINIA and SSGN Conversion programs. (Trident processes are similar.) See section 3.2.
Understand the organizational responsibilities and processes employed for configuration management of requirements baselines.	Accomplished. NAVSEA systems engineering roles identified specifically for USS VIRGINIA and SSGN Conversion programs. See section 3.2.
Explore and understand the policies, processes, and controls implemented for assuring the ongoing capability of people in critical processes.	Accomplished. Examined NAVSEA and EB approaches to management control during downsizing. See section 3.2.5.
Need to understand approaches for ensuring a reliable (human reliability) and capable workforce in terms of health, stress, overtime, extended duty, physical, and psychological work environment.	Not yet fully explored. Additional information to be acquired in phase-2. See discussion (Next Steps - Phase-2) above.
Need to understand the administrative or management approaches implemented to ensure that critical processes maintain necessary staffing levels to function in a stable, capable, and controlled manner.	Accomplished. Examined NAVSEA and EB approaches to management control during downsizing. See section 3.2.5.

INTERIM ACCOMPLISHMENT STATUS	
Excerpts from O'Keefe Letter	**Status**
... and maintaining a skilled and motivated workforce in the face of budget and schedule pressures – much as was experienced by the nuclear submarine program during a downturn in production in the early 1990's.	Accomplished. Examined NAVSEA and EB approaches to management control during downsizing. See section 3.2.5.
… related to the critical issues facing NASA of maintaining product quality and safety, accomplishing required performance and safety upgrades.	Partially understood. Additional work in phase-2. See section 3.4.4.
… furthermore, as NASA explores the application of nuclear propulsion and power for space exploration, lessons learned from the Navy nuclear safety program could be beneficial.	Partially understood. Additional work in phase-2.

2.0 Background

2.1 Orientation

Naval Sea Systems Command (NAVSEA), largest of the Navy's five systems commands, is located at the Washington Navy Yard, in Washington, DC. NAVSEA is the organization responsible for designing, acquiring, maintaining, and modernizing ships and systems for the Navy in accordance with Fleet and Office of Chief of Naval Operations (OPNAV) Sponsor needs and requirements. The Program Executive Officer for Submarines (PEO SUB) is responsible for acquisition of new submarines and systems. The Deputy Commander for Submarines (NAVSEA 92) is responsible for support of in-service submarines and systems. Currently, RADM Phil Davis is "doubled hatted" in these roles. Figure 2.1 shows the overall NAVSEA organizational chart as of October 31, 2002. [3]

Two commercial firms currently build submarines: General Dynamics Electric Boat Corporation in Groton, CT, and Northrop Grumman Newport News Shipbuilding, located in Newport News, VA.

Submarine maintenance and modernization occurs at a number of different locations around the world. Major work is typically performed at Naval (i.e., government) shipyards. Today there are four operational Naval shipyards: Portsmouth Naval Shipyard, Kittery, ME; Norfolk Naval Shipyard, Portsmouth, VA; Puget Sound Naval Shipyard, Bremerton, WA; and Pearl Harbor Naval Shipyard & Intermediate Maintenance Facility, Honolulu, HI.

Key NAVSEA organizations referred to in this report are identified below:

NAVSEA 92:	Submarine Directorate
NAVSEA 92Q:	SUBSAFE/Quality Assurance
NAVSEA 92T:	Technical
NAVSEA 08:	Naval Reactors
NAVSEA 05:	Ship Design, Integration and Engineering
NAVSEA 04:	Logistics, Maintenance & Industrial Operations
NAVSEA 03:	Human Systems Integration in System Design
PMS:	Program Managers (e.g., PMS-398 is the Program Manager for the SSGN Ohio Class Conversion)

2.2 Submarine Hazards and Organizations That Manage Them

Submarine hazards are identified, and risks are mitigated, throughout all levels of the Navy. Figure 2.2 identifies major high-level hazard categories and the organizational responsibilities for mitigation and management of the hazards within NAVSEA.

[3] At the time this report is being prepared NAVSEA is undergoing a reorganization that will result in changes in the organizational designators.

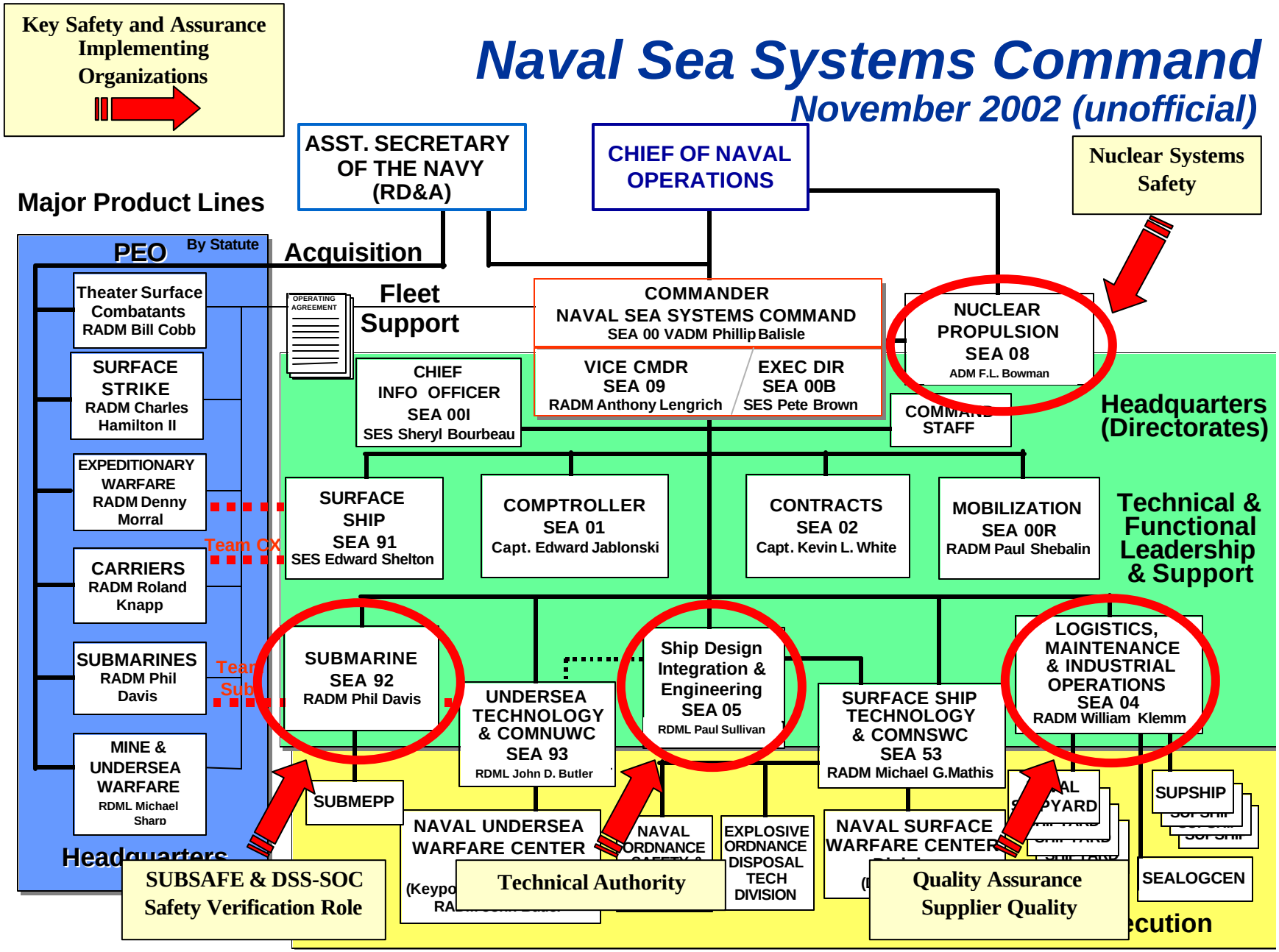
Key Safety and Assurance Implementing Organizations
Naval Sea Systems Command
November 2002 (unofficial)
ASST. SECRETARY OF THE NAVY (RD&A)
CHIEF OF NAVAL OPERATIONS
Nuclear Systems Safety
Major Product Lines
PEO
By Statute
Acquisition
Theater Surface Combatants RADM Bill Cobb
SURFACE STRIKE RADM Charles Hamilton II
EXPEDITIONARY WARFARE RADM Denny Morral
CARRIERS RADM Roland Knapp
SUBMARINES RADM Phil Davis
MINE & UNDERSEA WARFARE RDML Michael Sharp
Team CX
Team Sub
OPERATING AGREEMENT
Fleet Support
COMMANDER NAVAL SEA SYSTEMS COMMAND SEA 00 VADM Phillip Balisle
VICE CMDR SEA 09 RADM Anthony Lengrich
EXEC DIR SEA 00B SES Pete Brown
CHIEF INFO OFFICER SEA 00I SES Sheryl Bourbeau
NUCLEAR PROPULSION SEA 08 ADM F.L. Bowman
COMMAND STAFF
Headquarters (Directorates)
SURFACE SHIP SEA 91 SES Edward Shelton
COMPTROLLER SEA 01 Capt. Edward Jablonski
CONTRACTS SEA 02 Capt. Kevin L. White
MOBILIZATION SEA 00R RADM Paul Shebalin
Technical & Functional Leadership & Support
SUBMARINE SEA 92 RADM Phil Davis
UNDERSEA TECHNOLOGY & COMNUWC SEA 93 RDML John D. Butler
Ship Design Integration & Engineering SEA 05 RDML Paul Sullivan
SURFACE SHIP TECHNOLOGY & COMNSWC SEA 53 RADM Michael G.Mathis
LOGISTICS, MAINTENANCE & INDUSTRIAL OPERATIONS SEA 04 RADM William Klemm
SUBMEPP
NAVAL UNDERSEA WARFARE CENTER
NAVAL ORDNANCE
EXPLOSIVE ORDNANCE DISPOSAL TECH DIVISION
NAVAL SURFACE WARFARE CENTER
SUPSHIP
SEALOGCEN
Headquarters
SUBSAFE & DSS-SOC Safety Verification Role
Technical Authority
Quality Assurance Supplier Quality

Figure 2.1

High-Level Submarine Hazards and Organizational Responsibilities for Mitigation & Management

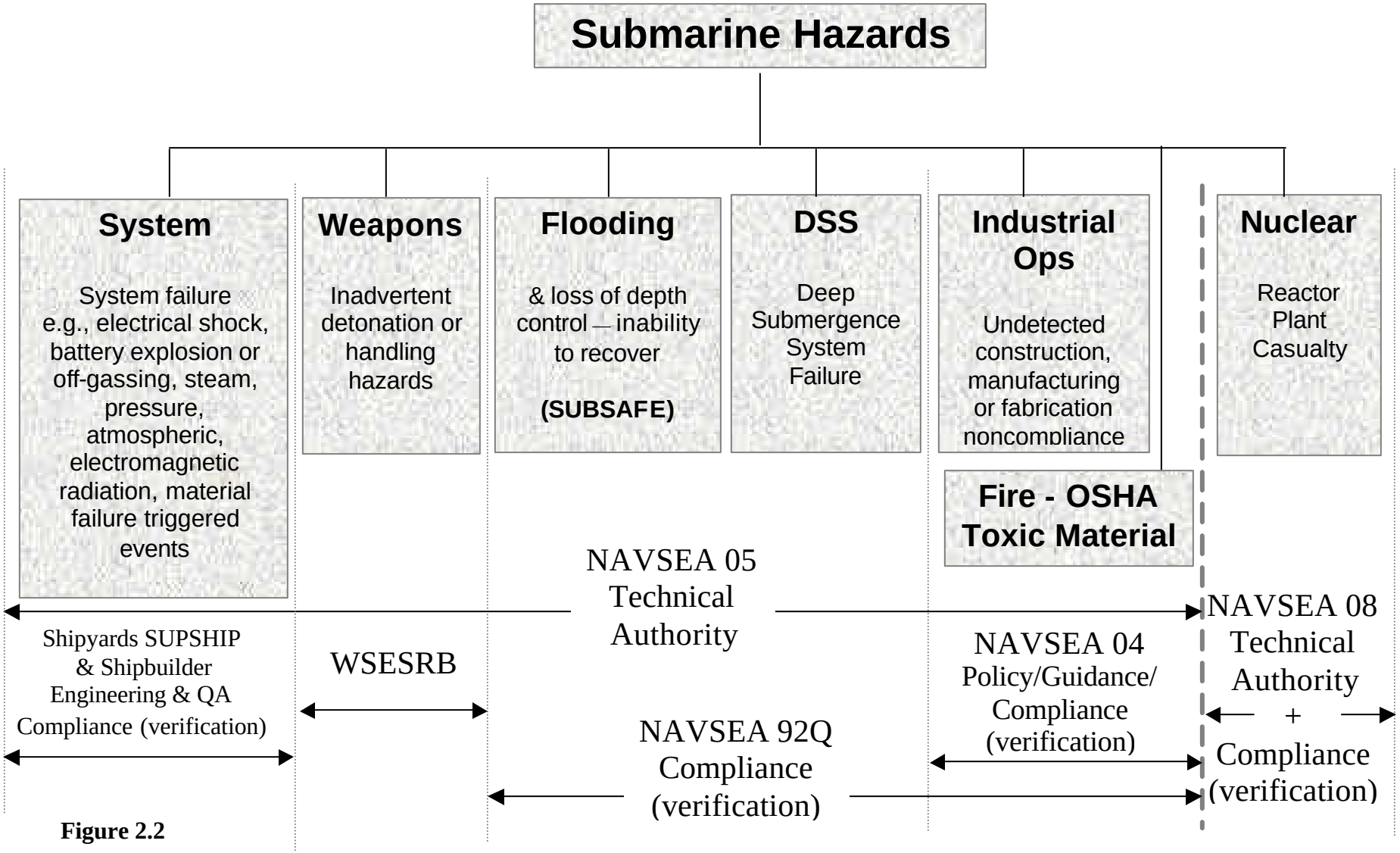

Figure 2.2

While this report explores many of the submarine hazard domains, it does not investigate the subjects of fire or weapons safety.

One management practice employed by NAVSEA is the use of boundaries to bring focus to specific categories of hazards. For example, SUBSAFE Boundary Books[4] are used to identify components and systems that could play a role in a flooding incident. The paragraphs below outline the governing requirements documents, organizational boundaries, technical authority, compliance verification responsibilities, and key assurance processes associated with the Navy submarine program.

It is important to note that each of the NAVSEA organizations shown in figure 2.2, and discussed below, performs its duties as a support and control organization, ultimately serving the submarine life-cycle manager (the program manager) and the submarine operator (the Fleet Type Commander).

2.2.1 Flooding Prevention and Ability To Recover From Flooding

The submarine safety program technical and administrative requirements identified in the SUBSAFE Manual[5] are designed to provide *maximum reasonable assurance* that 1.) seawater is kept out of the submarine (i.e., uncontrolled flooding does not occur), and 2.) the submarine can recover from a flooding casualty (e.g., loss of depth control).

This is achieved through initial SUBSAFE certification of each submarine prior to final delivery to the Navy, and by sustaining SUBSAFE certification throughout the life of the submarine. The NAVSEA 05 organization is the final authority for the technical requirements contained in the SUBSAFE Manual. Implementation of the SUBSAFE requirements is the responsibility of all persons and organizations involved in the submarine's life cycle: designers, program managers, program technical directors, submarine operators, and organizations involved in the acquisition, supply, logistics support, maintenance, refit, modernization, and overhaul of submarines.

NAVSEA 92Q has overall responsibility for overseeing the SUBSAFE Program and verifying compliance with its requirements. At each facility performing SUBSAFE work, a local SUBSAFE Program Director (SSPD) provides oversight for work at that facility and is responsible for independently verifying compliance with SUBSAFE requirements. NAVSEA 92Q audits policies, procedures and practices at each facility as well as the effectiveness of the oversight provided by the local SSPD. Key processes and practices used in administering the SUBSAFE Program include SUBSAFE functional audits, SUBSAFE certification audits, the Re-entry Control process (configuration management), the URO-MRC process (mandatory inspections and tests), annual SUBSAFE training, and the use of SUBSAFE Boundary Books. These topics are discussed in greater detail in section 3.1.

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[4] e.g., NAVSEA S9SSB-X9-SCB-010/(N) SSCB, Submarine Safety Certification Boundary Book – SSBN726 Class.

[5] NAVSEA 0924-062-0010, "Submarine Safety (SUBSAFE) Requirements Manual."

2.2.2 Deep Submergence System Crew Safety

The Deep Submergence System (DSS) program scope includes deep submergence research vehicles (e.g., *Alvin)* and diver lockout and dry deck facilities that may be incorporated in a submarine. DSS Scope of Certification (SOC) requirements are set out in the DSS-SOC Manual.[6] As described in the manual, the intent is "…to provide maximum reasonable assurance that a material or procedural failure that imperils the operators or occupants will not occur. Certification ensures that conditions adversely affecting the safety of DSS personnel are mitigated and verifies that no recognizable unsafe conditions exist. The certification process also establishes maximum reasonable assurance that DSS personnel may be recovered without injury if there is an accident."

Key areas of focus include hazards associated with explosion, implosion, off-gassing of materials, electrical systems, and the quality of breathing air. The technical authority for DSS-SOC requirements resides with NAVSEA 05. Implementation of the DSS-SOC requirements is the responsibility of designers, program managers, program technical directors, operators, and organizations involved in the maintenance/modernization of both submarines and deep submergence vehicles. NAVSEA 92Q and the facility-based SUBSAFE Program Directors are responsible for independently verifying compliance with the DSS-SOC requirements.

2.2.3 Systems Safety and Hazard Analysis

It is important to note that the ship specification or "ship spec" for each new class of submarine is built upon the evolution of ship specs from previous class designs, updated for war fighting and mission capability, technical advances, and lessons learned.

This reflects the continuous process of risk identification and mitigation through successive design, build, and operate cycles. Both "best practices" and "lessons learned" are captured and included in the next revision of the ship specs and sub-tier requirements documents to provide continual process improvement in submarine platform requirements.

For new design programs, such as the VIRGINIA Class submarine or the OHIO Class submarine conversion to SSGN, general systems hazards (excluding flooding, DSS, weapons, and nuclear propulsion) are addressed through the safety processes found in Military Standard 882D.[7] Responsibilities reside with new submarine program managers, their design (technical) directors, and the subordinate system safety integrated product team (IPT) leads. Technical risk management in the design process addresses safety assurance. Formal programmatic risk management is conducted for new class design

[6] NAVSEA SS800-AG-MAN-010/P-9290, "System Certification Procedures and Criteria Manual for Deep Submergence Systems."
[7] MIL-STD-882D - Department of Defense Standard Practice for System Safety, February 10, 2000.

systems in accordance with DoD 5000.2-R.[8] However, the focus is primarily on programmatic risks as opposed to safety risk management because mitigation of safety risks has been effectively addressed in the ship specs which capture successive generations of "design, build, and operate" lessons learned, as mentioned above.

Within a given program management team, key systems safety processes include: the system safety IPT, Material Safety Review Panel, Risk Management IPT, Software Safety IPT, and the Safety Certification Process Action Team. Key planning documents include: System Safety Plan, and the Material Selection Requirements Plan (MSRP).

2.2.4 Weapons Safety

Weapons safety is not a focus of this benchmarking assessment; however, the following synopsis is provided for completeness. Explosives safety rules and regulations include various NAVSEA ordnance manuals and guidance documents. Technical authority for weapons safety requirements resides within the NAVSEA 05 organization. Within a NAVSEA design team, implementation of the weapons safety requirements is the responsibility of program managers, program technical directors, and weapons IPT leads. The key certifying body is the Weapons System Explosives Safety Review Board (WSESRB). Key organizations include the Weapons System Integration Team (SIT) and the Software Safety Technical Review Panel, which implement the formal weapons certification process.

2.2.5 Reactor Safety

NAVSEA 08 is a joint Navy/Department of Energy organization that is responsible for all aspects of Navy nuclear propulsion, including research, design, construction, testing, training, operation, maintenance, and the ultimate disposition of nuclear propulsion plants. Reactor safety is fundamentally addressed in each aspect of NAVSEA 08's responsibilities. For example, propulsion plant design features include inherent self-regulation for stability, equipment redundancy, and rugged design for battle shock. As another example, the nuclear propulsion plants are operated and maintained by highly trained crews, who receive over a year of academic and hands-on training before qualification. Subsequently, operators receive periodic training to maintain their proficiency. A summary of NAVSEA 08's practices regarding reactor safety can be found in Admiral Hyman G. Rickover's (the founder and director of NAVSEA 08 for 34 years) testimony to Congress on May 24, 1979, following the reactor accident at Three Mile Island.

2.2.6 Manufacturing/Construction/Integration Compliance

NAVSEA 04, including the Naval Sea Logistics Centers, provides policy guidance and technical leadership in areas concerning industrial operations, logistics, quality assurance, material control, and supplier control. NAVSEA 04 manages the operation of the Naval

[8] DoD 5000.2-R – "Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs," 10 June 2001.

shipyards and directly manages quality assurance activities and material control. Work performed at Naval shipyards is predominately maintenance, overhaul, and modernization. The Supervisor of Shipbuilding, also managed by NAVSEA 04, oversees contract performance in private shipyards such as Electric Boat and Newport News Shipbuilding, where construction, maintenance, and modernization work are performed. Key overarching quality assurance requirements documents are defined by activity and include:

- Naval Shipyard Quality Program Manual, [9]
- SUPSHIPs Operations Manual, Chapter 11, Contract Quality Assurance Program, [10]
- Quality Program Requirements[11]
- Quality Management Systems - Requirements [12]
- Joint Fleet Maintenance Manual, Volume V, Quality Maintenance[13]

The quality assurance organizations of the various activities play a key role in validating compliance with SUBSAFE Program requirements and in compiling the objective quality evidence or OQE necessary to support SUBSAFE and/or DSS-SOC certification.

[9] NAVSEA-TL855-AA-STD-010, Naval Shipyard Quality Program Manual.
[10] S0300-B2-MAN-01A, SUPSHIPs Operations Manual, Chapter 11, Contract Quality Assurance Program.
[11] MIL-Q-9858A, Quality Program Requirements.
[12] ISO 9001-2000 Quality Management Systems - Requirements.
[13] CINCLANTFLT/CINCPACFLTINST 4790.3, Joint Fleet Maintenance Manual, Volume V, Quality Maintenance.

3.0 Summaries and Key Observations

Building on the benchmarking framework and approach described in section 1, the basic elements of the submarine Navy's safety and mission assurance function has been separated into the following seven topic areas:

3.1 SUBSAFE Program
3.2 Management and Organization
3.3 Safety Requirements
3.4 Implementation Processes
3.5 Compliance Verification/Work Review Processes
3.6 Compliance Certification Processes
3.7 Naval Reactors

The purpose of this section is to document all factual information gathered during the site visits. Discussions are in the form of summaries, and topics or elements may be further expanded into sub-topic or sub-element descriptions. Key observations are provided following each element and/or sub-element. Given the great depth of detail presented here, the reader may wish to scan the composite of all key observations tabulated in Appendix B, and refer to Section 3 when further detail is required.

3.1 SUBSAFE Program

The fundamental purpose of the SUBSAFE Program is to provide *maximum reasonable assurance* that 1.) seawater is kept out of the submarine (i.e., uncontrolled flooding does not occur), and 2.) the submarine can recover from a flooding casualty (e.g., loss of depth control). Figure 3.1 depicts the development and key events in the evolution of the SUBSAFE Program.

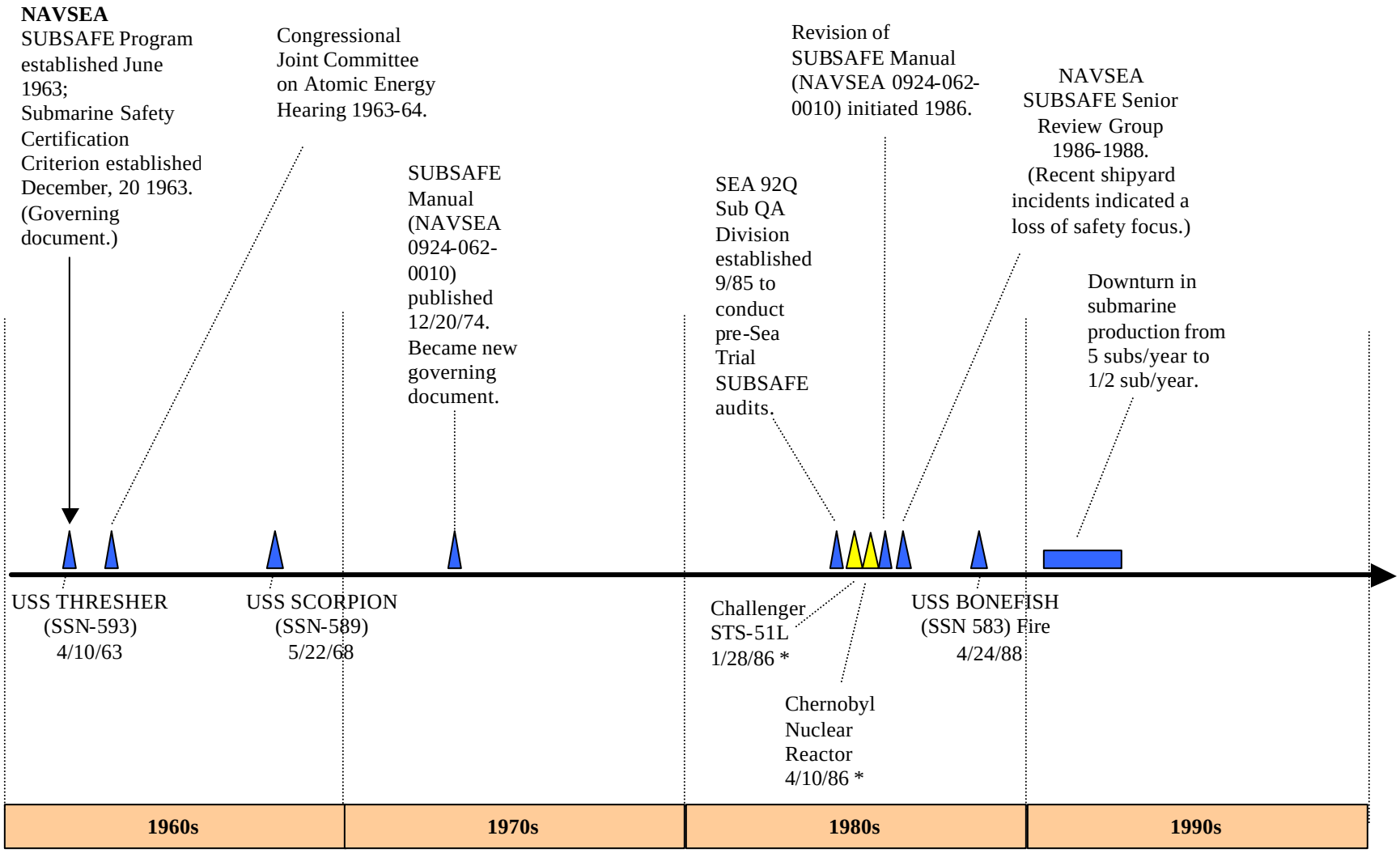
The SUBSAFE Manual identifies the technical and administrative submarine safety certification criteria that must be satisfied to permit NAVSEA's initial certification of the submarine, and their recommendation for unrestricted operations, as well as the technical and administrative requirements that must be met during the ship's operational life to maintain the certification.

The SUBSAFE Program is a program of work discipline, material control, and documentation founded on solid technical requirements.

Work Discipline

Work discipline implies a knowledge of the requirements and compliance with those requirements, not just for the tradesman on the deck plates working with the hardware, but everyone who performs any kind of work associated with submarines. Individuals have a responsibility to know which, if any, SUBSAFE requirements pertain to their work and to comply with those requirements.

SUBSAFE Program Timeline



** NAVSEA used these events to re-focus the SUBSAFE Program.*

Figure 3.1

Material Control

Material Control involves everything required to ensure that correct material is installed correctly. It begins with ensuring the contracts that purchase material invoke appropriate requirements, all the way through receipt inspection, marking, storage, handling, and finally, installation in the submarine. The installing activity (i.e., field organization) is ultimately held responsible for ensuring that correct material is installed correctly.

Documentation

SUBSAFE documentation is in two forms, i.e., 1.) Selected Record Drawings & Data, and 2.) Objective Quality Evidence (OQE). Selected Record Drawings & Data are created when the submarine is designed and consists of such things as system diagrams, SUBSAFE mapping drawings, SUBSAFE Certification Boundary Books, Ship Systems Manuals, etc. These selected records are kept current throughout the life of the submarine. Objective Quality Evidence is created when work is performed (either new construction or overhaul/maintenance) and consists of such things as weld records, nondestructive evaluation (NDE) records, mechanical assembly records, test forms and technical work documents (in which data is recorded), and waivers & deviations, etc.

Technical Requirements

Specific requirements are defined for the ship's pressure hull and supporting structure, systems and components either containing or exposed to seawater, and systems critical to operability to recover from a flooding casualty. These technical requirements identify system boundaries, specified fabrication, NDE, and material control performed. Also included are approval authority requirements for changes and departures from approved designs. The technical requirements are invoked by the ship specification to trigger the necessary processes used by the shipbuilder/maintenance activity. These processes result in compilation of the required OQE to achieve and maintain certification. OQE is any statement of fact, either quantitative or qualitative, pertaining to the quality of a product or service based on verifiable observations, measurements, or tests.

Three elements are used to sustain SUBSAFE certification throughout the life of a submarine (see figure 3.2): 1.) the Re-entry Control Process, 2.) the Unrestricted Operations/ Maintenance Requirements Cards (URO/MRC) Program, and 3) Audits (Functional and Certification).

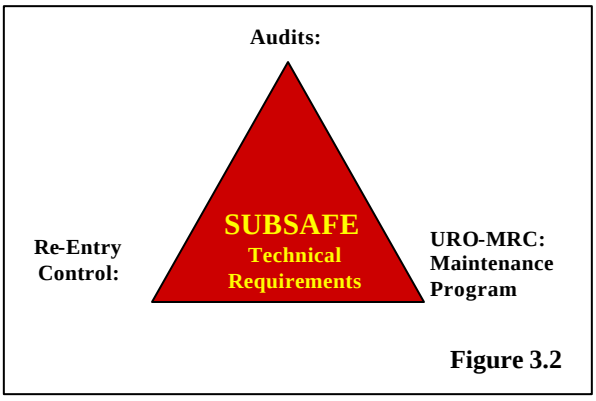


Figure 3.2

Re-entry Control Process

This process is used to control work within the SUBSAFE boundary after the component, system, or submarine has been certified to comply with SUBSAFE requirements. Work that actually or potentially changes the approved configuration of any part of the SUBSAFE certification boundary is performed under re-entry control. OQE is used to verify that:

- Work was authorized and planned,
- Work was accomplished in accordance with specified instructions,
- Documentation and certification for the work has been reviewed for completeness by an independent party,
- Testing documentation has been reviewed for accuracy and completeness, and
- All certifications related to the re-entry control process have been reviewed for correctness and verified to be complete before the re-entry is closed.

Re-entry control is a tool that helps maintain work discipline, establish personal accountability, and collect objective quality evidence. The purpose of re-entry control is to provide maximum reasonable assurance that areas disturbed within the SUBSAFE boundary are restored to a fully certified condition.

URO/MRC Program

This program provides the minimum requirements for maintenance of submarine certification for continued unrestricted operation to authorized test depth. The program assures continued acceptability of the material condition of the submarine hull integrity boundary, and of those items that affect recoverability by the accomplishment of periodic inspections and test and/or maintenance. The URO/MRC's provide specific requirements as to when, where, and how a test or inspection shall be conducted, the extent of test or inspection, the criteria for acceptance, the required monitoring intervals, and the requirements for recording and reporting data. The URO/MRC Program is the technical basis for continued unrestricted operation of the submarine. A submarine can be prohibited from submerging if URO/MRC requirements are not met, unless a waiver is approved by NAVSEA.

Audits

Functional audits to examine policies, procedures, and practices are performed on a periodic basis at all activities involved in SUBSAFE work. This includes the design/construction yards, shipbuilders, the Supervisor of Shipbuilding (SUPSHIP), Naval shipyards, NAVSEA HQ, and the Fleet Type Commander (TYCOM). Certification audits are performed on all submarines at the completion of: 1.) new build (design/construction yard) and 2.) major maintenance/modernization work (shipyard). Audits cover the certification of the design, material, fabrication, and testing. The basis for certification is the OQE as discussed above.

The SUBSAFE Program also includes training and qualification processes and requirements. Only select activities are allowed to perform SUBSAFE work, as recognized in NAVSEA Note 5000. All of these activities, including the authorized design yards, shipbuilders, public shipyards, SUPSHIP, engineering/logistics field activities and TYCOM are responsible for developing and implementing necessary instructions and procedures to meet the requirements of the SUBSAFE Program. In support of these responsibilities a SUBSAFE Program Director (SSPD) is assigned at each activity involved in the SUBSAFE Program.

Key Observations: SUBSAFE Program

- The SUBSAFE concept addresses specific flooding/recovery hazards and places special life-cycle emphasis on controlling those hazards. Other hazard control boundaries exist on a submarine as shown in figure 2.2.
- There is clarity, uniformity, and consistency of submarine safety requirements and responsibilities. Tailoring by program managers is not permitted without NAVSEA 05 and 92Q approval.
- There is a strong, independent "audit to requirements" assurance organization.
- There is a community-wide (contractor and government) understanding of SUBSAFE requirements and a commitment to compliance.
- The SUBSAFE Program and implementing organization (NAVSEA 92Q) are relatively immune to budget pressures – no certification, no submarine.
- There is a strong, community-wide (contractor and government), continuing emphasis on safety through periodic systematic examination of previous failures and incidents.
- Annual SUBSAFE training is a requirement for the NAVSEA Headquarters submarine community.

3.2 Management and Organization

As shown in figure 3.3, NAVSEA 92 reports directly to the Commander, Naval Sea Systems Command (NAVSEA). NAVSEA 92Q is responsible to NAVSEA 92 for the implementation, administration, and coordination of the non-reactor plant portions of the SUBSAFE Program, and for ensuring compliance with SUBSAFE requirements. The SUBSAFE Program is guided and directed by the Submarine Safety Steering Task Group (SSSTG), which is chaired by the Deputy Commander for Submarines (NAVSEA 92).

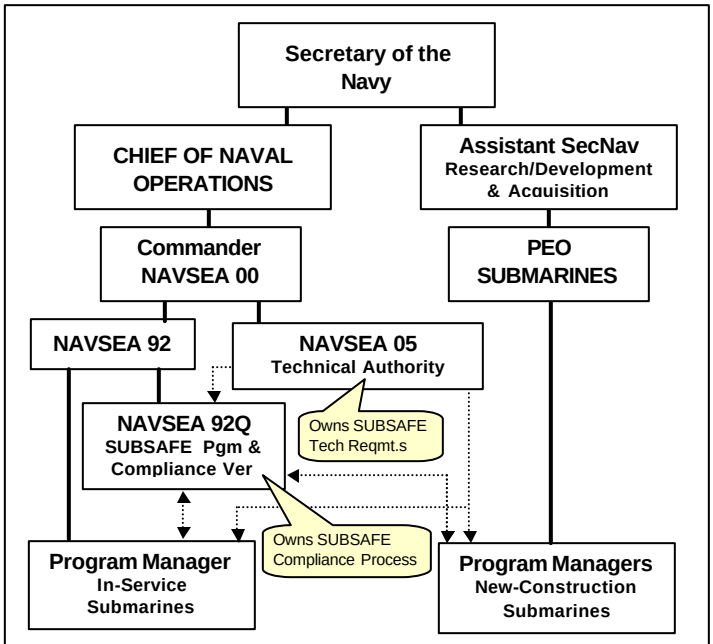


Figure 3.3 Functional Relationship Between Submarine Program Managers/Senior Mgmt & SUBSAFE Program

Each NAVSEA Submarine Program Manager (PMS) retains responsibility for executing the SUBSAFE Program for assigned ships. New-construction submarine program managers, such as SEAWOLF (PMS-350) and VIRGINIA (PMS-450), report directly to PEO Submarines. As shown in figure 3.3, the PEO Submarines reports to the Assistant Secretary of Navy for Research, Development, and Acquisition. The NAVSEA 92Q organization reports by way of an independent path through NAVSEA 92 and NAVSEA 00 to the Chief of Naval Operations. For new construction, NAVSEA 92Q (as well as NAVSEA 05 and NAVSEA 04) provides matrixed support directly to PEO Submarines. In-service submarine program managers (e.g., PMS-392) report to NAVSEA 92. Although they are in the same organization, NAVSEA 92Q maintains its independence from the in-service program managers.

Cognizant NAVSEA technical codes provide technical assistance to the PMSs and to NAVSEA 92Q as requested to ensure timely resolution of problems. The final authority for the technical requirements of the SUBSAFE Program resides with NAVSEA 05.

3.2.1 Technical Authority

Submarine design, material, and process requirements are contained in the ship specification and/or documents cited as applicable references (see section 3.3.2). As noted previously, the responsibility for establishing and maintaining technical requirements (SUBSAFE fabrication standards, material specifications, etc.) is vested in the NAVSEA 05 organization, and in some cases, is formally delegated with a specifically defined scope of authority to organizations such as NAVSEA 92T or NAVSEA-managed field activities.

It is important to note that NAVSEA 05 owns the technical requirements, separately from line program management (new design) and/or organizations implementing maintenance/modernization activities. Also, program managers and implementing organizations have no authority to "tailor" or waive SUBSAFE or DSS requirements without submitting a formal request through the NAVSEA 05 organization. To improve efficiency and facilitate NAVSEA downsizing, some authority has been formally delegated to implementing organizations (e.g. SUPSHIP Groton or PNS) to disposition non-conformances within specified limits.

Key Observations: Technical Authority

- The NAVSEA organizational structure provides a capable, centralized, independent, technical authority that is responsible for developing and documenting technical requirements and standards, and providing requirements clarity and accountability.
- There exists community-wide acceptance that NAVSEA 05 is the technical requirements owner.
- Any delegation of technical authority from NAVSEA 05 to implementing organizations is clearly documented.

- The centralized technical authority provides a powerful means to capture, document, and use lessons learned to improve future ship designs.

3.2.2 Independent Compliance Verification

Compliance with critical SUBSAFE and DSS design and process requirements is independently verified by a highly capable, centralized organization, namely NAVSEA 92Q. NAVSEA 92Q is the owner of the SUBSAFE and DSS processes. It administers the programs and monitors for compliance.

NAVSEA 92Q serves as an independent compliance verification organization. It functions to assure that policies, procedures, and practices are in accordance with SUBSAFE and DSS requirements, and that they are followed. Compliance is verified through the implementation of rigorous functional and certification audit processes. Through the requirements stipulated in the SUBSAFE Manual, this organizational structure is passed down to each of the SUBSAFE certified activities. The SUBSAFE Program Director (SSPD) at each activity is responsible back to SEA92Q to ensure that the SUBSAFE Program requirements are established and maintained internally, with independent internal quality assurance activities verifying compliance.

NAVSEA 08 accomplishes its compliance function using a combination of field office and headquarters team audits, in addition to each facility performing self-assessments and internal audits.

Key Observations: Independent Compliance Verification

- The NAVSEA management organizational structure provides a highly capable and independent safety compliance verification/assessment organization that serves as a key management control for SUBSAFE certified activities.
- The compliance verification process is the responsibility of an entity separate from program management and the operators (the Fleet Type Commanders) of submarines.
- Audit activities draw on expertise distributed across the Navy laboratories, shipyards, and other field activities.

3.2.3 Safety Management Philosophy

The Navy defines both the "what" and the "how" in the development and implementation of safety, in general, and the SUBSAFE Program, in particular. This applies equally to both the new design/construction and maintenance/modernization activities described in this report.

Key Observations: Safety Management Philosophy

- Contractors are not given latitude in meeting SUBSAFE and other critical safety system requirements because the leverage gained in the areas of technical excellence and risk mitigation achieved through the many generations of submarine specifications would be lost with such an approach.

3.2.4 Cultural Attributes

The SUBSAFE Program infuses the submarine Navy with safety requirements uniformity, clarity, focus, and accountability.

The Navy's safety culture is embedded in the military, Civil Service, and contractor community through: 1.) clear, concise, non-negotiable requirements, 2.) multiple, structured audits that hold personnel at all levels accountable for safety, and 3.) annual training with strong, emotional lessons learned from past failures. Together, these processes serve as powerful motivators that maintain the Navy's safety culture at all levels.

In the submarine Navy, many individuals understand safety on a first-hand and personal basis. The Navy has had over a hundred thousand individuals that have been to sea in submarines. In fact, many of the submarine designers and senior managers at both the contractors and NAVSEA routinely are onboard each submarine during its sea trials. In addition, the submarine Navy conducts annual training, revisiting major mishaps and lessons learned, including USS THRESHER (SSN-593), Space Shuttle Challenger, and USS BONEFISH (SS-582). NAVSEA uses the USS THRESHER loss as the basis for annual mandatory training. During training, personnel watch a video on the USS THRESHER, listen to a two-minute long audiotape of a submarine's hull collapsing, and are reminded that people were dying as this occurred. These vivid reminders, posters, and other observances throughout the submarine community help maintain the safety focus, and it continually renews the safety culture.

The Navy has a traditional military discipline and culture. The NAVSEA organization also is oriented to compliance with institutional policy requirements. In the submarine Navy there is a uniformity of training, qualification requirements, education, etc., which reflects a single mission or product line, i.e., building and operating nuclear powered submarines.

Key Observations: Cultural Attributes

- Safety is central to the culture of the entire Navy submarine community, including builders, designers, maintainers, and operators.
- In addition to the loss of the USS THRESHER and the USS BONEFISH fire, the Navy has made extensive use of the Challenger mishap in its safety training.

3.2.5 Restructure and Downsizing

The NASA team met with both Navy and contractor organizations to discuss the impact and subsequent innovations implemented in response to the order of magnitude decrease in the Navy's acquisition of submarines in the early 1990s. The following paragraphs describe these meetings with NAVSEA Headquarters and Electric Boat.

NAVSEA

Beginning in the early 1990's (post Cold War) the Nation experienced a "peace dividend" with a subsequent call for reduction in the DoD mission, structure, and organization. Consequently, NAVSEA formally initiated a restructuring and downsizing of its entire workforce, which inevitably affected the size of the NAVSEA submarine community. The overall objective was to reduce the size and structure of the organization while assuring that critical defense technologies would be maintained. This was accomplished over several years and in a number of discrete steps.

The first step was a reduction in the number of managerial levels (groups, subgroups, and divisions) that existed within NAVSEA Headquarters. The net effect was the flattening of the organization from the previous structure that had as many as 11 management layers between the Secretary of the Navy and the working level engineer. The resulting organization provided the required increase in efficiency and flexibility. This initial restructuring at NAVSEA Headquarters was followed by a major reorganization in 1992 of the Navy laboratories that involved transforming the labs from fundamental research and development entities to warfare centers. These warfare centers, each with distinct and identifiable product lines, now report to NAVSEA.

The next significant event was a series of DoD base closures, including four Navy shipyards, with an attendant loss of significant numbers of engineering personnel assigned to NAVSEA.

Beginning in 1995, and in response to these downsizing events, NAVSEA undertook a formally structured approach to assure continued support of critical defense technologies. This was accomplished through the development of a warfighting system engineering hierarchy that defined the necessary engineering capability requirements.

By 1998 NAVSEA began to address the aging workforce issue and a serious loss of talent. At this time NAVSEA was losing approximately 750 engineers per year through retirement and resignations. NAVSEA began by refocusing on its core equities or competencies:

- Setting technical standards and policies,
- Certifying/validating delivered products, and
- Providing a vision for the future, i.e., technology infusion/evolution.

Additionally, the following new engineering categories and career paths were defined:

- Research and development
- Science and technology (early stage technology development, i.e., discovery and adventure)
- Subject matter experts
- Systems engineering
- Engineering management

Most importantly, NAVSEA actively sought and obtained approval to overstaff its engineering skill sets with new or recent college graduates in order to provide for a logical and systematic transition of its aging workforce. As a result, NAVSEA began an active recruitment program to hire engineering professionals. By 1999 NAVSEA had reached the breakeven point and by 2002 hired 1000 new engineers with a net gain of 300. This innovative approach allowed its skilled and experienced engineers to train and mentor the engineering new hires and provide critical knowledge transfer while sustaining its core competencies.

Key Observations: NAVSEA Restructure & Downsizing

- NAVSEA conducted a logical and structured downsizing approach that identified core competencies and the engineering workforce requirements necessary to assure continued support of critical defense technologies.
- NAVSEA overstaffed its engineering skill sets with recent college graduates to allow the skilled work force to train new hires while maintaining core competencies.

Electric Boat Corporation

The NASA team met with the President and senior management staff of Electric Boat to discuss their management approach to the downturn in submarine production from five submarines a year to one-half submarines per year that occurred in the early 1990s. The impact of that downturn cannot be overstated. In contrast to NAVSEA, where designers and subject matter experts could shift to other projects and future designs, EB did not have this option because its sole purpose is submarine production. For EB the downturn became a matter of survival, and EB realized that it needed to implement cultural as well as management changes.

This management challenge was driven by a sense of urgency to demonstrate to the parent corporation (General Dynamics) that EB could make money. Working closely with the Navy, EB management and the labor unions came together under this shared sense of urgency.

Staff reductions were implemented and pink slips were issued based not only on union rules governing seniority, but also the need to retain critical skills. The EB white-collar staff was also reduced after an internal analysis based on individual skills, experience, and training determined each individual's value to the company. Thus, senior EB management made reductions not only at the hourly workforce level, but also within each layer of management. Throughout the difficult and painful staff reduction process, EB management was careful to ensure that core competencies were retained.

At the same time the staff was reduced, EB implemented a shift to greater company-wide use of digital technology in design, manufacturing, and administrative processes. The digital shift was combined with a process re-engineering initiative that streamlined cumbersome internal processes and achieved operating efficiencies.

Currently, EB is seeking opportunities to broaden its business base by moving to submarine maintenance/modernization to supplement the low-rate new design/construction environment.

Key Observations: EB Restructure & Downsizing

- The Navy worked closely with EB to ensure that a logical and structured approach was employed to downsize the workforce. There was no "magic pill" for what was a painful downsizing process.
- Changes that were made at EB were driven by the need to survive as a business unit within the General Dynamics Corporation. Union and corporate management worked together to determine the optimum mix of competencies, seniority, and management for the restructure and survival of the company.
- Having clearly defined, well-documented technical and procedural requirements assisted the Navy and EB during the restructuring and downsizing transition.

3.3 Safety Requirements

3.3.1 Safety Requirements Management

As noted previously, the NAVSEA 05 organization is the technical authority responsible for all technical requirements including those contained in the SUBSAFE and DSS-SOC manuals.

Within the submarine Navy, design safety requirements are not typically tailored from project-to-project or shipyard-to-shipyard. Design safety requirements are not a matter of debate with each new submarine or human-rated deep submersible system. Safety requirements are virtually outside the trade-space for program/project managers.

The safety requirements set includes strict life-cycle configuration management requirements (re-entry control) and periodic maintenance requirements identified in the SUBSAFE Manual as URO/MRCs (Unrestricted Operations/Maintenance Requirements Cards). The SUBMEPP organization maintains the URO/MRCs through delegation from NAVSEA 05. A more detailed description of the functions and responsibilities of SUBMEPP is provided in section 3.4.3.

It is also important to note that other safety requirements exist, such as those for weapons and general hazard categories, as discussed in section 2.2 of this report.

Key Observations: Safety Requirements Management

- Critical safety requirements and implementation methods are clearly defined.
- Critical safety requirements are protected, and program managers cannot tailor them or trade them against other technical or programmatic variables.

3.3.2 Submarine Safety Design Criteria

As noted previously, the ship specification or "ship spec" for each new class of submarine is built upon the ship specifications from previous classes of nuclear, deep-diving submarines. The ship spec reflects the continuous process of design risk identification and mitigation through many successive design, build, and operation cycles. The ship spec contains the best that can be achieved given lessons learned from previous designs, extensive operational data, and a structured effort on all fronts to identify and mitigate hazards and risks in new design components.

There does not exist a single (human rating) design guidance document that describes functional design requirements for system and sub-system redundancy (i.e., fault tolerance), structural factors of safety, or crew escape or rescue provisions. While no single human rating design criteria or guidance document was identified, the ship spec references a suite of documents that govern a new design and which includes as a minimum: 1.) the SUBSAFE Manual, 2.) the DSS-SOC Manual, and process standards such as 3.) MIL-STD-882D, 4.) the Material Control Standard,[14] and 5.) the Welding Standard.[15]

Key Observations: Submarine Safety Design Criteria

- There does not exist a single (stand alone) document that proscribes NAVSEA human rating design safety criteria or standards.
- The existing operational design attributes, compiled in the most recent ship specification, represent the *de facto*, evolved human rating design standard.

3.4 Implementation Processes

3.4.1 Design Approach

Evolutionary Design

Lessons learned from the development and operation of submarine systems over the past century have evolved into current processes, practices, and requirements that have served to reduce operational risk and uncertainty.

General Process

A typical NAVSEA design team includes employees from within NAVSEA Headquarters, experts resident at the Naval laboratories, and experienced design yard contractors. The NAVSEA ship's design manager and most of the team are NAVSEA 05 employees. Memoranda of Agreement (MOA) are typically used when laboratory workers and other organizations are required to participate on the design team. The

[14] NAVSEA 0948-LP-045-7010, Material Control Standard (Non-Nuclear)
[15] NAVSEA T9074-AD-GIB-010/1688, Requirements for Fabrication, Welding and Inspection of Submarine Structure.

ship's design manager leads the technical team and employs Major Area Teams (MATs) consisting of multiple Systems Integration Teams (SITs).

This organizational structure is mirrored in the design yard, creating a collaboration of customer and contractor, with NAVSEA maintaining ultimate technical authority. Each SIT may have one or more integrated product team (IPT). Individual IPTs in turn call upon the independent technical analysis and evaluation support of experts located at various Navy laboratories. Systems engineering takes place within the MATs, SITs and IPTs. In effect, the ship's design manager serves as the systems engineer. The Change Control Board represents the key system engineering management forum.

VIRGINIA Class Design Evolution

The original plan was to build 30 SEAWOLF submarines as a follow-on to the 688-LOS ANGELES Class attack submarines, but only three were actually funded and built. The end of the Cold War contributed to the decision to limit production. Both NAVSEA and EB realized that a change had to be made in how submarines are designed and produced. The VIRGINIA Class submarine is now intended as the follow-on ship design to the SEAWOLF Class and will augment and replace retiring 688s. The review for the VIRGINIA Class included the design/build concept and affordability at low production rates.

Electric Boat, contracted as the VIRGINIA Design Yard, developed design/build teams including experts from its design community and NAVSEA technical expertise to ensure the design was technically optimized. Experts from the shipyard were employed to ensure fabrication/construction efficiencies were captured in the design. Design/build represents a full commitment to concurrent engineering principles and practices, involving all of the stakeholders in the design, including designers, fabricators, suppliers, operators, maintainers, and approval authorities.

As part of the effort to achieve an affordable design, NAVSEA engaged its contractor team to examine requirements in search of ways to reduce cost while maintaining safety requirements. As the program progressed towards construction, development of a contractor construction partnership was established in which Electric Boat and Newport News Shipbuilding cooperated instead of competing for the contract. Newport News Shipbuilding was brought to the design/build team to further ensure that fabrication efficiencies supported its construction processes.

The partnership enabled:

1) Early collaboration between the government buyer and the design/build team.
2) Early collaboration in the concept development phase to assure "design for manufacturability/maintainability," and
3) Examination of safety requirements documents to seek ways to reduce costs while maintaining the intent and force of the requirements (e.g., approval of equivalent contractor processes or procedures).

Key Observations: Design Approach

- New ship designs are evolutionary. Lessons are learned and applied from one submarine class to the next.
- The VIRGINIA contract partnership agreement (EB and Newport News Shipbuilding) enabled a strong degree of collaboration.
- The newest design class, VIRGINIA, employs design for manufacturability (six-sigma) concepts. NAVSEA and EB consider the approach, referred to as design/build, as critical to achieving affordability.
- Early and continual collaboration between government and contractors reduces programmatic risk by emphasizing and strengthening design for manufacturability.

3.4.2 Processes/Tools

EB Quantitative Methods

Quantitative safety assessments are essentially deterministic in the Navy submarine program and driven by the following three documents: 1.) the SUBSAFE Manual, 2.) the DSS-SOC Manual, and 3.) DOD MIL-STD-882.

A traditional hazard/impact evaluation process is used for safety assessment. It consists of the following steps: 1.) hazard analyses, 2.) identification of hazards and recommendation(s) for resolution or acceptance, 3.) resolutions or acceptance of hazards and 4.) hazard/impact closure. Resolutions may involve: a.) design modifications to resolve hazard/impact, b.) tests to verify hazard impact on risk acceptability, and c.) actions/procedures and training to resolve issue/hazard.

Reliability predictions are performed separately for humans and hardware. Human reliability assessments are based on Swain's THERP (Technique for Human Error Rate Prediction). Hardware reliability assessments rely on electronic parts prediction using PRISM, a computer tool developed by the Reliability Analysis Center.

Mission reliability/operational availability is performed with the following computer tools: TIGER (NAVSEA Monte Carlo program), and RAPTOR (ARINC Monte Carlo program). Other reliability analyses used include FMECA (failure modes and effects criticality analysis), fault tree analysis using Fault Tree Plus (ItemSoft), COTS (commercial off-the-shelf) obsolescence & sparing analysis, and Reliability Calculator developed by Electric Boat. Hardware maintainability analysis is based on DOD's MIL-HDBK-470.

Key Observations: EB Quantitative Methods

- Traditional safety/hazard assessments are used and rely extensively on the vast historic data (design/build/test/maintenance and operational experience) of the US Navy Submarine Program.
- Reliability and maintainability assessments are performed according to traditional DOD methods and also rely heavily on the vast historic data of the program.
- Probabilistic Risk Assessment does not appear to be used at any significant level.
- Risk assessment is applied qualitatively/categorically using a DOD-prescribed 5x5 likelihood versus consequence matrix that is similar to the one used by NASA.

NAVSEA HQ Role in Software Development and Certification

The ship control system on SEAWOLF is a limited "fly-by-wire" design (analogous to an aircraft flight control system). The steering and diving system is driven by computers, but it can be decoupled and revert back to a traditional system completely controlled by hydraulics. The USS VIRGINIA is the first submarine that will be primarily fly-by-wire. With the advent of the VIRGINIA program, NAVSEA was asked to develop a software verification and assurance plan for the ship control system. To assist in this endeavor, a software safety certification process action team or PAT was also established including NAVSEA 05U, NAVSEA 92Q, and the Program Manager. The challenge was to identify the basis for certifying ship control software systems. The team looked at how software interacted with systems within the SUBSAFE and recovery system boundaries, in particular steering and diving. Ten rules were developed pertaining to control of critical submarine functionality (e.g., flood control, maneuverability, emergency blow control, etc.). An overarching rule was to assure that software could not wrest control of the submarine from the crew. In a related effort, the NAVSEA Chief Engineer (SEA05) and PEO SUB jointly chartered the Safety of Flight Industry Survey Team to conduct a benchmarking review of aviation industry best practices to assist in developing the NAVSEA approach. The current NAVSEA process does not yet reflect the results from the Safety of Flight industry survey because the results of this survey are still being documented and reported within NAVSEA.

Multiple boards and control processes were established at the NAVSEA level to address various aspects of the software design challenge, including: 1.) the VIRGINIA design team software safety IPT, 2.) the safety certification PAT, 3.) the Safety of Flight Team, 4.) the WSESRB software safety review panel, and 5.) the submarine software safety technical review panel (SSS-TRP).

Key Observations: NAVSEA HQ Role in Software Development and Certification

- The VIRGINIA Class represents the first NAVSEA application of fully fly-by-wire technology for ship control system design; accordingly, its software management and control processes are evolving.

- The current approach represents a comprehensive and conservative management approach to assuring software capability and fidelity.

EB Software Development and Implementation Assurance

The Electric Boat software engineering, testing, and software quality assurance functions are all responsible to one vice president with several directors. The safety function is responsible to a different vice president. The software engineering department is matrixes personnel to various departments to cover these functions as needed. The benefit of having all software personnel managed by a central manager is the ability to manage the resources, balancing and trading off where needed.

While there are many advantages to having a centralized core software group, drawbacks include: 1.) a single string organizational approach toward implementing software assurance (including software safety) that is vulnerable to changes in personnel, and 2.) separate reporting to management from matrixed software assurance and safety functions that can lead to confusion. However, each director still has the responsibility for providing OQE that software development is implemented properly.

There is heavy use of EB personnel at the contractor/vendor sites with inspections at the source. This eliminates waiting for delivery, discovery of problems, and the return of unsatisfactory items. Requirements are very detailed and include safety critical criteria. Procurement is trained to ask for (and expects) high quality Hazard Analyses even for software. Suppliers are checked for the health and viability, they are certified, and their core knowledge examined and checked for maintainability. All this leads to a long-term relationship with known vendors, and each works to support the other.

The EB software development processes, including software assurance, can be described as follows. Ship specs come in with little to no software specifications. A ship spec is broken down into component specs with software identified to the component level. The EB software team then creates performance-based (vs. functional-based) specifications for the software. The request for proposal (RFP) has standard software clauses, which detail how the software is to be developed (including quality assurance, configuration management, and verification & validation). EB provides a template for the expected vendor software development plan. Separate software costs are requested, but a software-specific work breakdown structure (WBS) is not always supplied for software integral to a major system component.

The vendors are challenged to demonstrate capability in software even when it is not a primary deliverable. Subcontractor management must show the roll down of EB's software qualification requirements. This tends to increase subcontractor management costs but pays off in the long run. If a sole or single source is to be selected, the RFP is skipped and the software spec and WBS are written into the purchase order. The RFP evaluation has both technical and cost evaluation criteria that are project dependent. The contract is let with EB software specs and WBS built in. Also, included is a list of expected deliverables including metrics (with specifics on which ones and how and when

to measure), products, test reports, and approval needs (requirements, design, test procedures and results, estimates for regression testing, etc.). Vendors are also asked for a Preliminary Hazard Analysis.

A software statement of work (SOW) is created for each component, and the software development plan is examined to assure it contains all that the template provided to the contractors/vendors required. This software development plan is levied on the vendors and must include an organizational layout, configuration management, quality assurance, test plans, system safety plans, and, if required, software safety plans. The EB software team, like its hardware counterpart, is stationed with the vendors and works with them on a day-to-day basis. Weekly software status telecommunications and video teleconferences are held to keep EB software management informed and up to date. Peer reviews are held for all software products. Safety and assurance are involved with all peer reviews, both in-house and at the vendors.

Safety analyses consist of safety scenarios, fault tree analysis (FTA), and selected failure modes and effects analyses (FMEAs). Hazards are first postulated from historical experience and data, corrective maintenance records, and operational experience. The TIGER[16] tool is used for modeling operational availability and failure rates where there are few historical data available.

Analyses are performed on software requirements and design, as well as any changes to the requirements or design. For the VIRGINIA Class submarine ship control system, EB also has Navy Independent Verification and Validation (IV&V). The Navy Program Office (PMS450) provides an independent check of the critical software through assignments to its Naval laboratories.

Because of the team-oriented Integrated Product and Process Development (IPPD) process used for VIRGINIA Class development, this IV&V effort is conducted within the scope of the Ship Control System IPT rather than reporting separately to a higher level of management. Certification begins once code and unit testing are complete, and integration with the hardware allows for requirements verification. Systems certification and environmental quality assurance checks are also performed.

Key Observations: EB Software Development and Implementation Assurance

- EB implements a very rigorous software contracting process that assures that safety requirements are appropriately flowed-down and met at each level (i.e., Navy to EB to subcontractors).

<u>EB Digital Design and Engineering Environment</u>

EB has worked hard to improve its communication and data maintenance. To help maintain expertise, much of it is built into the large suite of tools it has assembled for design, analysis, visualization, testing, and simulation. EB's shift away from traditional

[16] TIGER is a reliability/availability modeling tool developed and used by NAVSEA

draftsmanship, and its heavy reliance on 3-D design suites, has helped maintain and communicate its work within a distributed design and manufacturing environment. EB also uses video telecommunications in conjunction with its 3-D simulations on a regular basis to conduct design discussions and work interactively as a distributed team.

Key Observations: EB Digital Design and Engineering Environment

- EB use of software-based design tools (e.g., CATIA) has helped them maintain and communicate its work within a distributed engineering design, manufacturing, and maintenance environment.

Human Factors in the Design Process

The Navy considers the human/system interfaces for both operators and maintainers as an integral part of the submarine design. Requirements have evolved over successive generations of submarine design. The SUBSAFE and DSS-SOC manuals provide human factors engineering requirements related to critical SUBSAFE systems maintenance tasks and related tasks for operation of equipment during emergency conditions. The formalization of a dedicated human interface analysis approach in overall design is a relatively new endeavor.

In October 2002, a new organization, NAVSEA 03 Human Systems Integration in System Design, was created within NAVSEA. The NAVSEA 03 mission is to optimize total system performance and life cycle cost by ensuring that the operator is engineered into the system, from the beginning of the ship design process through upgrades and enhancements. NAVSEA 03 will establish corporate NAVSEA policy, technical standards, human performance metrics, and ensure usability of Navy systems. The Navy has made the investment in NAVSEA 03 to shape the Navy's future by institutionalizing optimal staffing, transitioning technology, and advocating human/system interface as an essential element of total ship engineering.

Currently, the Navy is consciously engineering maintenance and operations activities into its newest design, the VIRGINIA Class. EB is using computer aided design tools to determine how maintenance and operations will be performed prior to the fabrication of system designs. This allows the Navy to consider the human-system interfaces in early concept design, make decisions and trades that maintain safety, optimize efficiency, optimize crew size, and minimize cost throughout the system life cycle.

Key Observations: Human Factors

- NAVSEA systematically considers life-cycle human/machine interface requirements in the design of submarines.
- NAVSEA 03 – "Human Systems Integration in System Design" was created to ensure that human/system interface is an essential element in total ship systems engineering.
- Human Factors Engineering requirements, unique to SUBSAFE and deep submergence systems, are included in the SUBSAFE and DSS-SOC manuals.

3.4.3 Work Planning and Authorization Processes (Maintenance/Modernization)

The Navy plans its maintenance/modernization tasks well in advance of task completion. The Navy's "fast start strategy" requires that one hundred percent of the first sixty days of task instructions be written, reviewed, and authorized prior to the submarine reaching an industrial facility (e.g., dry dock). Additionally, planning for sixty percent of all work that will be done during an availability (e.g., non-operational maintenance period, major overhaul, etc.) must be completed prior to the submarine reaching the industrial facility. The advance planning process and the work instruction review process provide layers of defense that allow for the early detection and correction of potential errors, hazards, and safety problems before the ship reaches the facility, before maintenance/modernization tasks are initiated, or before an accident occurs.

The Navy's fast start strategy also allows them to prepare long-range plans and forecast the need for materials, parts, and personnel resources. By specifically identifying and writing task instructions far in advance, and by keeping detailed information about each component unit (procedures required, number of hours to install, and certification required), the Navy knows exactly how many personnel are needed and their training requirements. Using this information and data on workforce reductions and attrition, the Navy can project the training needed to maintain the minimal core of certified professionals to safely perform maintenance and modernization tasks.

SUBMEPP

Navy Submarine Maintenance Engineering, Planning and Procurement (SUBMEPP) is responsible for planning what work will be done during maintenance overhauls and when it will be done. SUBMEPP develops and maintains maintenance standards and test procedures (with integrated SUBSAFE, DSS-SOC and URO/MRC requirements) that support class maintenance plans with further definition of the minimum technical requirements that have to be achieved for a particular maintenance action. Maintenance standards are provided to the Ship Availability Planning, and Engineering Center (SHAPEC) as definition of what work in the class maintenance plan is to be conducted. SUBMEPP maintains the class maintenance plan that is used as a basis for the development of an availability work package that is provided to SHAPEC. SHAPEC then provides technical work instructions to Portsmouth Naval Shipyard (PNS), and all other shipyards where depot level submarine maintenance is performed, with details on how the work specified in the class maintenance plan is to be conducted. The SHAPEC process is discussed in detail in the next section.

Although collocated at PNS, SUBMEPP is a separate entity that reports to NAVSEA 92. SUBMEPP is jointly funded by NAVSEA 92 and the Fleet Type Commanders (TYCOMs). NAVSEA 05 has a MOA with SUBMEPP (through NAVSEA 92T) to delegate technical authority for certain issues to SUBMEPP. Any issues outside of SUBMEPP's defined technical authority are referred back to NAVSEA for resolution.

SUBMEPP maintains the Joint Fleet Maintenance Manual (JFMM) for the TYCOMs. The JFMM document supports performance of maintenance carried out by the Fleet (outside of shipyards). SUBMEPP also supports the TYCOMs by identifying maintenance work that can be scaled back or deferred to the next availability to meet budget or schedule constraints while maintaining mission capability and safety requirements.

SUBMEPP heavily employs Reliability Centered Maintenance (RCM) to achieve cost savings by leveraging multi-class reliability data developed over the years that supersede ultraconservative maintenance plan requirements originally developed in the late 1960's. RCM is conducted at the local component, system, and ship level to identify "applicable and effective maintenance tasks that are necessary to achieve required reliability of systems or equipment."[17]

SUBMEPP also employs other standard tools and techniques in maintenance planning such as FMEA and root cause analysis, but only at the component level. FMEA does include human factors as a failure mode where it is considered a credible failure.

NAVSEA 92Q conducts functional audits of SUBMEPP to validate its processes and maintenance standards. In essence, all audits of Naval shipyards are implicitly an audit of SUBMEPP, as its products are used by all. SUBMEPP is involved in sustaining certification, but it is not directly involved in the certification process.

In summary, the SUBMEPP organization has the following overall roles and responsibilities:

- Establish and maintain Class Maintenance Plans,
- Maintain baseline and ship-specific work packages (depot level),
- Maintain inventories, schedules, and refit work packages (intermediate maintenance activity level),
- Develop maintenance standards,
- Administer the URO/MRC program,
- Employ Reliability-Centered Maintenance (RCM) principles and practices,
- Implement Condition-Based Maintenance (CBM),
- Establish testing procedures and maintain test documents,
- Provide material procurement support, and
- Provide maintenance data collection/review/trend analysis and feedback mechanisms for continuous improvement.

Key Observations: SUBMEPP

- SUBMEPP advanced planning is a key element in ensuring submarine safety. This approach provides management, engineers, and technicians ample time to evaluate

[17] SUBMEPP 9081-083-0589, "SUBMEPP Reliability Centered Maintenance Handbook."

task steps and detect/correct procedural errors, thereby increasing the likelihood that activities will be performed safely. This approach also ensures that needed parts, tools, and personnel are available when the task will be performed.
- SUBMEPP is the "detail" organization (e.g., checking tolerances and factors of safety) assuring that the right maintenance work is done when it needs to be done and in the right way.
- SUBMEPP advanced planning also provides valuable data that allows the Navy to make informed decisions concerning workforce staffing, training, and retention.

Ship Availability Planning and Engineering Center (SHAPEC)

NAVSEA established SHAPEC by ship class (surface ships, carriers, and submarines) to:

- Streamline the process for determining technical, planning, and material requirements for ship work,
- Standardize planning products, practices, and procedures,
- Ensure sharing and reuse of planning products by both government and private sector customers for depot level ship work and development of appropriate metrics, and
- Provide libraries of reusable planning products for use by all ship maintenance activities.

Portsmouth Naval Shipyard is the single activity responsible for implementation of the SSN 688 Class SHAPEC process for development and maintenance of class planning products. This includes centralized development of selected, reusable maintenance, modernization, and repair planning products for SSN 688 Class availabilities at geographically dispersed sites. SHAPEC establishes product development guidelines, maintains a Planning Product Library, and when workload demands, subcontracts to other activities (usually other public shipyards) to develop SSN 688 Class advance planning products. The SHAPEC process has significantly reduced the cost of availability planning through centralized development and reuse of planning products. If a large number of VIRGINIA Class submarines are constructed, SHAPEC may expand to provide work planning for this class as well.

PNS has also developed the Baseline Project Management Plan (BPMP) which represents the advanced planning process applied to all types of major availabilities including Depot Modernization Periods (DMPs), Engineered Overhauls (EOHs), and Engineered Refueling Overhauls (EROs). The BPMP assigns a project team, led by a project superintendent, for each submarine availability. This project superintendent is the single individual responsible for all maintenance activities performed on a submarine, including all SUBSAFE work, during its time in the shipyard.

SHAPEC uses NAVSEA's primary technical requirements and directives (e.g., DDGOS,[18] the SUBSAFE Manual, etc.) and URO/MRCs in its centralized planning to:

- Ensure consistency of work instructions and planning products,
- Ensure best practices, lessons learned, and the most efficient production processes are available to all activities involved,
- Integrate corporate feedback into advance planning products, and
- Emphasize reusability of non-nuclear planning products for availabilities in multiple regions for similar work, eliminating duplication of planning.

Performance of the SHAPEC function requires PNS to interface with Fleet Commanders, SSN 688 Class Planning Yard (design agent), SUBMEPP, other shipyards, and the NAVSEA program manager in areas of funding, specifications and overall process requirements.

The SHAPEC process requires shipyard technical support organizations to provide:

- Engineering and planning support to implement and maintain SHAPEC products,
- Planning products for new and emergent work during an availability,
- Test procedures and test planning support,
- Networked production schedules,
- Technical problem resolution (i.e. Trouble Desk),
- Material management/procurement,
- Resolutions for departures from specifications,
- Certifications, and
- Planning support for nuclear/non-nuclear interface work.

Key Observations: SHAPEC

- SHAPEC was created to place the detailed planning for maintenance/modernization availabilities for the SSN 688 Class of ship under one entity. This process has reduced cost, complexity, and redundancy of efforts, and it has made available the best practices, lessons learned, and most efficient production processes available to all public shipyards performing maintenance activity.

3.4.4 Upgrade/Modernization: NAVSEA Fleet Modernization Program

The Navy's Fleet Modernization Program (FMP) closely parallels the Shuttle Upgrades Program. The goals of the FMP are to:

- Improve safety, reliability, maintainability, habitability, and environmental compliance of ships and equipment,
- Improve ships' capabilities and material condition by installation of approved alterations/ modifications, and

[18] Deep Diving SSBN/SSN Submarines (DDGOS) General Overhaul Specifications

– Increase fleet readiness by improving standardization within ship classes.

The FMP is documented in the Fleet Modernization Management and Operations Manual.[19] This manual defines the policy, processes and procedures for accomplishing all changes, modifications, and alterations to ships and equipment in the fleet. Coupled to the FMP is an OPNAVINST (Chief of Naval Operations Instruction) that provides the categorization and criteria for ranking candidate ship alterations (SHIPALTs).

A SHIPALT is generated when any change in hull, machinery, equipment, or fittings involves a change in the design, material, number, location, or relationship of component parts of an assembly. The SHIPALT process maintains configuration management for any change or modification during concept proposal, application, approval, and funding phases through final accomplishment. SHIPALTS can be for something as simple as a change in a bolt grade, or as complex as the addition of a new weapon system. The process is basically the same for the full range.

Key Observations: NAVSEA Fleet Modernization Program

- NAVSEA manages configuration of modernization efforts via use of a well-documented SHIPALT process.
- Priority is placed on safety, reliability, maintainability, habitability, and environmental compliance.
- The FMP is oriented toward long-term upgrade planning (5 -10 year horizon).

3.5 Compliance Verification Processes

The certification processes for both new submarine construction and certification after a maintenance/modernization activity are rigorous and contain multiple checks and control processes to assure that work has been performed in accordance with all requirements, and in particular, the SUBSAFE and DSS-SOC requirements. The scope of compliance verification includes work control and review processes including quality assurance, inspection, and surveillance. In both cases OQE forms the paper trail or documented basis to support certification decision makers.

3.5.1 Electric Boat Quality

The new design/construction OQE acquisition process was examined for the commercial shipyard (Electric Boat) case. Principal government participants include the Supervisor of Shipbuilding (SUPSHIP), the NAVSEA 92Q SUBSAFE organization, the NAVSEA 08 Naval Reactors Program, and the submarine program manager.

EB performs the work and accordingly plays a central role in the certification process. Key EB organizations include the SUBSAFE Director, Supplier Quality, and Quality Assurance (inspection). Others include the Quality Certification group that maintains

[19] Document # SL720-AA-MAN-010/020, "Fleet Modernization Management and Operations Manual."

OQE records, and the Material Management organization that oversees material control. Supplier Quality conducts intensive audits of EB's critical suppliers. Quality Assurance conducts in-process inspections of work conducted at EB.

SUPSHIP Groton performs ongoing oversight of EB contract performance including SUBSAFE functional audits, SUBSAFE certification audits for each submarine as it approaches completion, inspection/auditing of work performed, and procedure reviews. SUPSHIP also assigns delegations (subcontracts) to DCMA to perform inspections at selected suppliers and for selected commodities.

NAVSEA 08 has a resident office at EB that performs ongoing oversight of work performed at EB. The NAVSEA 08 Naval Reactor Program also conducts functional audits of critical suppliers. NAVSEA 08 also assigns delegations to DCMA to perform quality assurance surveillance and inspections at critical suppliers. It should be emphasized that the NAVSEA 08 quality program operates independent of and in parallel with the non-nuclear quality program activities. Additional information on NAVSEA 08 is provided in section 3.7.

Key Observations: Electric Boat Quality

- SUPSHIP serves as a strong, independent, government quality assurance oversight organization located at the contractor's facility.
- NAVSEA 08 represents a second strong, independent, government quality assurance oversight organization also located at the contractor's facility.
- Multiple assurance processes (EB, SUPSHIP, DCMA, and NAVSEA) extend down into the EB supply chain.

3.5.2 Portsmouth Naval Shipyard (PNS) Quality

PNS implements a rigorous quality management process. For non-nuclear work, the process is based on an extension of basic quality management process contained in ISO 9001 (1994). For nuclear work, more rigorous controls are specified, as appropriate, based on the complexity and critical nature of the task being performed.

Requirements for quality assurance are contained in NAVSEA TL855-AA-STD-010, Naval Shipyard Quality Program Manual (QPM) implemented at PNS by Technical Specification 0942-899-017E. Requirements for the critique and trouble report process at PNS are detailed in Chapter 1.10 of NAVSHIPYD INSTRUCTION 4730.14, Work and Test Manual (WTM). These requirements come from the parent documents NAVSEA 4700.17, Preparation and Review of Trouble Reports, NAVSEA 0905-485-6010, Manual for the Control of Testing and Ship Conditions, and the QPM.

The PNS QPM addresses production quality assurance (QA), engineering QA, critique and trouble report processes, audit and surveillance programs, inspections, and material receipt inspection. PNS conducts metrics-based quality performance measurements using a database-driven, Quality Performance System that was developed corporately by all the Naval shipyards.

The non-nuclear quality function at PNS is distributed across multiple organizations. These groups come together in the SUBSAFE Improvement Committee (SSIC) and the Quality Council. The Quality Council/SSIC is a team comprised of the Engineering Quality Division (Code 200Q), the SUBSAFE Director (Code 200S), the Non-nuclear Inspection Division (Code 133), the QA Engineering and Analysis Division (Code 136), the Test Engineering and Planning Division (Code 246), and the Production Resources Support Office (Code 904). The SSIC and the Quality Council meet twice a month. Significant quality issues are formally presented to the Shipyard Commander (Code 100) and senior shipyard management monthly in a Quality Performance Meeting.

A key feature of the PNS quality program is the critique process, a management tool designed to address and correct quality problems within the shipyard. PNS follows NAVSEA guidance and conducts approximately 140 non-nuclear critiques per year. The critique process is used to evaluate, document, and disposition material, process engineering, and work execution problems. The process results in issuing a critique report, and some events that are critiqued are also documented in trouble reports. Trouble reports are associated with significant problems involving personnel injury, equipment damage, or those that provide a significant lesson learned for other shipyards. Trouble reporting is standardized across all Navy shipyards to document and disseminate the most significant problems as lessons learned. Critique and Trouble Report meetings are conducted within a day or two of problem occurrence. Trouble Reports (TRs) are then transmitted to and shared with other Naval shipyards.

Important to the success of each critique is an initial investigation into the facts of the event. The meetings begin with independent statements provided by the personnel involved in the problem. The emphasis of the process is to quickly identify all of the relevant facts and consequently the problems associated with the event so that subsequent casual analysis yields appropriate and effective corrective actions.

Important to the success of each critique is an initial investigation into the matter. The meetings kick off with statements provided by and questioning of the personnel involved in the problem. The local union agreement subjects union members to the critique process; however, the results of the critique process cannot be used in disciplinary actions against a worker.

Determining why the mistake occurred is the most difficult part of the critique process. Critique chairpersons are trained in root cause analysis, but despite investigating various root cause analysis tools, PNS has not found a clear winner. PNS generally arrives at the answers by iteratively asking “Why?” the problem occurred in order to drill down to the root cause (the “Five Whys"). Root cause is also revisited during review and issue of the reports, done in a weekly meeting of a Critique and Trouble Report Review Board, consisting of PNS organizational codes 136, 200S, 200Q, 904 and 246.

Notification of a problem that could have an impact at another shipyard is required within 24 hours by submission of a Preliminary TR. Issuance of a final TR, including root cause

analysis, determination of problem scope, and identification of preventive measures is required within 10 days. For the most severe problems, PNS convenes an Incident Review Board (IRB) comprised of the regular critique panel members plus all senior management. The IRB process involves development of a problem-cause corrective action matrix. IRB TRs require sign-off by all levels of PNS management before being sent out to other shipyards.

The Quality Performance System (QPS) measures quality performance at PNS and other shipyards. Each shipyard's information is available to the others. The QPS database specifically tracks personnel and process deficiencies. It does not document equipment failures, engineering analysis, or lifting and handling problems. The QP Index (QPI) is an overall quality index that is designed to track quality performance compared to an expected or normal quality goal. QPS is populated by entering all deficiency documentation over the entire range of severity, for example, critique and trouble reports, deficiency reports, and surveillance reports. QPS data is regularly analyzed to identify emerging trends or problem areas that should be addressed proactively. While QPS is populated by a single organization at some other shipyards, PNS employs a decentralized approach with part-time responsibility assigned to several organizations across the shipyard.

PNS runs each availability as a smaller, dedicated shipyard using the Project Management concept. PNS shop personnel are directly supervised by the project Zone Manager when assigned to a project. The PNS shops become invested in the ship, and a sense of pride develops that fosters quality throughout the maintenance activity.

PNS quality also performs material receipt inspection/certification services for the Level 1[20]/SUBSAFE Stock Program, which supplies material to all Level 1 and SUBSAFE material installation activities. PNS quality conducts audits of selected processes (mandated by the QPM) that normally are not reviewed in a SUBSAFE certification audit, such as metrology and calibration. PNS Procurement Quality Control (PQC) processes ensure the adequacy and certification of all Level 1 material. The Naval Inventory Control Program orders material and components for maintenance with DCMA involvement. PNS performs a material receipt inspection program that includes non-destructive test and evaluation at three levels: 1.) generic, 2.) semi-quantitative analysis, and 3.) full quantitative analysis of Level 1 critical materials and materials used within the SUBSAFE boundary.

The Re-entry Control (REC) certification process involves task group instructions (TGI) for work and quality assurance testing to be done within the SUBSAFE boundary. REC paperwork tracks work and testing, and final certification requires the signature of the PNS QA Office.

[20] Level 1 – any material or equipment critical to safety and/or mission.

Key Observations: PNS Quality

- PNS quality processes are integrated into maintenance availability activities in order to achieve maximum assurance of compliance.
- Discipline and individual worker integrity are considered critical to the quality assurance process.
- Honest mistakes are not punished. Not reporting mistakes can subject a worker to discipline because the Navy emphasizes full disclosure in the reporting process in order to be able to promptly identify and fix problems. Workers are made aware of the consequences for failure to report.
- The Project Management approach provides workers with a sense of continuity and pride of ownership for the work to be performed on a given submarine.
- The Navy uses a standardized trouble reporting system across all shipyard/repair facilities. This standardized process helps facilitate the sharing of significant problems with other shipyards.

3.5.3 Naval Sea Logistics Center Detachment Portsmouth

The Naval Sea Logistics Center (NAVSEALOGCEN) Detachment Portsmouth is a field activity of the NAVSEA Logistics Directorate (SEA 04) and serves as the Naval Sea Technical Agent for developing, maintaining, and assessing life-cycle logistics support policies, procedures, and data systems. It was created to be the interface between engineering and logistics, and it performs a wide range of logistic support functions working closely with the Navy and other government organizations to correct systemic problems and to identify design procedural enhancements. NAVSEALOGCEN is located in Portsmouth, NH, and is a fully operational organization under a Director who reports to the Commanding Officer of the NAVSEA Logistics Center in Mechanicsburg, PA. This detachment develops and administers the supplier past performance automated information systems described below.

Product Data Reporting and Evaluation Program (PDREP)

The PDREP is an automated information system designed to track quality and delivery performance on material/services procured by the Navy. Data is collected from all Naval Systems Commands on a daily basis and is maintained in the following records on the database: Contractor CAGE Information, Debarment/Suspension, Contract Delivery Data, DLA Contractor Alert List, GIDEP Alerts, Material Inspection Records, Product Quality Deficiency Reports, Qualified Product List, Special Quality Data, Surveys, and Test Reports. The application offers a wide selection of standard, management, and graphical reports. Also, a powerful ad-hoc feature allows users to design their own reports.

Feedback is a means of providing PDREP users the opportunity to request modifications to reports or to make suggestions that would enhance any NAVSEALOGCEN

application/program. The Feedback site assigns the appropriate knowledge expert for completion/resolution.

Level 1/SUBSAFE Verification

The Level 1/SUBSAFE verification system is a web enabled information system for verifying Level 1/SUBSAFE material markings at the end user level (e.g., shipyards, fleet, etc.). This verification is a last check to assure material has been certified as Level 1/ SUBSAFE prior to being installed on a ship. The Level 1/SUBSAFE verification program allows end-users to access the Product Data Reporting and Evaluation Program (PDREP) database to retrieve the information they need when they need it. This innovative approach provides round-the-clock coverage and has increased customer satisfaction.

Supplier Audit Program

The Supplier Audit Program is focused primarily on process control. It is not intended to take the place of pre-award surveys, product-oriented surveys, or quality system reviews. Participation in the Supplier Audit Program is open to NAVSEA, Naval Inventory Control Point, and public and private shipyards that have a responsibility to monitor the procurement of critical, controlled material. Primary participants include NAVSEA, Electric Boat Corporation, Newport News Shipbuilding, Naval Inventory Control Point, Portsmouth Naval Shipyard, Norfolk Naval Shipyard, Puget Sound Naval Shipyard, Pearl Harbor Naval Shipyard, and DCMA.

Red/Yellow/Green (RYG) Program

The RYG Program is a Navy/Air Force automated tool designed to help reduce the risk of the government receiving nonconforming products and late shipments. RYG classifies the risk degree by assigning a color to a contractor's historical quality and delivery performance in individual Federal Stock Classifications (FSCs). Red is high risk, yellow is moderate risk, and green is low risk. A neutral label is applied to either the quality/delivery classification under the following conditions: 1.) if the contractor is a first-time offeror for the FSC, 2.) if there is no quality/delivery history available for the FSC, or 3.) if available quality/delivery history for the FSC is outside the RYG evaluation time frame. The Logistics Center acts as a clearinghouse with little or no input into the supporting data. Each Vendor is notified of its commodity grade and allowed to challenge or verify within 30 days. Vendors get detailed information down to line item number. Thus far, the Logistics Center has been challenged three times in court and has won. The process goes after value, not low bidders.

Past Performance Information Retrieval System (PPIRS)

NAVSEALOGCEN also administers a web-enabled application, PPIRS, which allows the rapid retrieval of contractor past performance information. The data are available to all source selection officials across the entire Federal government. The system is also a

central warehouse used to retrieve performance assessment reports received from the four recognized Federal report card collection systems, which are:

- National Aeronautics and Space Administration (NASA) Past Performance Data Base (PPDB),
- National Institutes of Health (NIH) Contractor Performance System (CPS),
- Army's Past Performance Information Management System (PPIMS), and
- Contractor Performance Assessment Reporting System (CPARS) used by the Navy, USMC, Air Force, DLA and other defense agencies.

Contract Performance Assessment Reporting System (CPARS)

The CPARS is a Web-enabled application that collects and manages a library of automated contractor performance records. CPARS assesses a contractor's performance and provides a record, both positive and negative, on a given contract during a specific period of time. Each assessment is based on objective facts and is supported by program and contract management data such as: cost performance reports, customer comments, quality reviews, technical interchange meetings, financial solvency assessments, construction/production management reviews, contractor operations reviews, functional performance evaluations, and earned contract incentives.

Key Observations: NAVSEALOGCEN

- DoD has a single, consistent logistics program for purchasing hardware and materials.
- The Navy LOGCEN has standardized supply chain evaluation (contractor performance) monitoring across the command.
- The Navy and its prime contractors use receiving inspection information to grade sub-tier contractors and suppliers.
- CPARS provides source evaluation boards access to past performance for large contracts.
- To date, the RYG Program has withstood the scrutiny of courts during three legal challenges.

3.6 Certification Processes

The submarine Navy definition of “certification” or the “certification process” can be summarized as follows:

- A *written statement* attesting that the ship or system has met all requirements,
- Based upon *objective quality evidence* that documents that deliberate steps were taken to comply with requirements,
- Performed initially upon delivery to the Navy and then *sustained* throughout the life of the ship or system.[21]

[21] NAVSEA 0924-062-0010, "Submarine Safety (SUBSAFE) Requirements Manual."

It should be noted that the certification process not only applies to SUBSAFE requirements, but also involves an overall "material condition readiness" process that certifies that systems, in addition to those covered by SUBSAFE (i.e., DSS-SOC, weapons, Naval Reactors, etc.,), are ready to support safe operations.

The following sections describe the SUBSAFE certification process within the two general categories of this report: 1.) new design/construction certification, and 2.) maintenance/modernization or in-service certification.

3.6.1 New Design/Construction SUBSAFE Certification

New design/construction certification is primarily centered on assuring that the submarine design, materials, fabrication, and testing meet all SUBSAFE requirements prior to the submarine's delivery to the Type Commander (TYCOM) for Fleet operations.

The new design/construction submarine certification process was examined for the private shipyard, i.e., the Electric Boat case. Principal government participants include SUPSHIP, NAVSEA 92Q SUBSAFE organization, NAVSEA 08 Naval Reactors Program, the submarine program manager, and the ship's force (crew).

The ultimate certification responsibility is vested with the Program Executive Officer for submarines (PEO SUB). PEO SUB makes the decision in consultation with the program manager and other NAVSEA organizations (05, 92Q, 92T and 08). After new design/construction certification for unrestricted operations, the submarine is turned over to TYCOM who is responsible for sustaining certification throughout its operating life.

The certification process is based on three fundamental elements: 1.) Confidence that the ship designer's and the shipbuilder's policies, procedures, and practices conform to SUBSAFE requirements, 2.) Objective quality evidence that demonstrates compliance with SUBSAFE requirements during the design and construction of the submarine, and 3.) Configuration management during construction through the re-entry control process.

Confidence in the policies, procedures, and practices of the ship designer and shipbuilder is achieved through constant surveillance and audits by the Supervisor of Shipbuilding, review of technical products by the Program Manager and NAVSEA 05, and through periodic functional audits by NAVSEA 92Q. The purpose of functional audits is to confirm that an activity's policies, procedures, and practices comply with SUBSAFE Program requirements, and are "healthy" and capable of producing certifiable design products and certifiable hardware.

For each new construction submarine, certification audits are conducted. Using a structured audit plan, audit personnel examine the objective quality evidence produced during construction, including detailed vertical audits of selected critical submarine components, to confirm that SUBSAFE requirements have been met for that particular submarine. The certification audit process begins with SUPSHIP who conducts "modular

certification activity" as distinct modules (sections of the submarine) are completed. Following the build-up and qualification of modules, a Phase I NAVSEA 92Q SUBSAFE certification audit may take place (typically oriented to pressure hull integrity, valves, and piping). The final, or Phase II NAVSEA 92Q SUBSAFE certification audit precedes Fast Cruise[22] typically by four to six weeks. SUPSHIP internal certification audits are conducted prior to both the Phase I and Phase II NAVSEA SUBSAFE certification audits. As these audits are conducted, audit cards (non-conformances) are generated by both SUPSHIP and NAVSEA 92Q. Certain SUBSAFE audit cards must be adjudicated to the satisfaction of NAVSEA prior to the start of Fast Cruise.

The re-entry control process is invoked with completion of the first pretest inspection on a given component or subsystem. From that point forward the hardware is under formal re-entry control (REC) configuration management. This configuration management continues throughout the remainder of the construction process, Fast Cruise, Sea Trials, and ultimately throughout the operational life of the ship.

Fast Cruise provides an opportunity for the ship's crew to take sole command of the ship. Remaining dockside, but with no outside contact, the crew performs all of its functions with respect to operating the vessel. Within a week after completion of Fast Cruise, the submarine goes to sea to perform Alpha Sea Trials. Sea trials are designed to demonstrate the submarine's capabilities in small, incremental steps throughout the design-operating envelope. The Alpha Sea Trials are followed closely by Bravo Sea Trials, then a return to a dry dock facility for necessary work. Following the dry dock period, the submarine undergoes Charlie Sea Trials and ultimately is delivered to the TYCOMs (COMSUBLANT or COMSUBPAC). The period of time from start of Fast Cruise to delivery is typically three months.

Key Observations: New Design/Construction SUBSAFE Certification

- The SUBSAFE certification process involves a focused, independent audit organization (NAVSEA 92Q) to verify process capability and discipline. This same organization conducts detailed vertical audits of selected critical submarine components during certification audits.
- Multiple NAVSEA certification processes operate in parallel to ensure safety and operational readiness.
- REC is invoked early in the certification process.

[22] Fast Cruise - an integrated operational simulation conducted by the crew alongside the pier.

3.6.2 Maintenance/Modernization SUBSAFE Certification

The SUBSAFE certification audit process applies to all maintenance/overhaul/ modernization work performed within the SUBSAFE boundary, from the simplest repair on an individual component (e.g., a Technical Availability (TAV)) to a significant maintenance/overhaul/modernization availability accomplished in a Naval Shipyard such as:

- **A Depot Modernization Period (DMP)**
  Typically requires 10 to 12 months to conduct.
- **An Engineered Refueling Overhaul (ERO)**
  Typically requires 20 months to complete.
- **A Selected Restricted Availability (SRA)**[23]
  Typically takes two months to complete

An availability greater than six months in duration is typically termed a "Major Depot Availability" and requires a NAVSEA 92Q SUBSAFE certification audit. For these types of availabilities, NAVSEA certifies to the Type Commander that the work performed by the NAVSEA managed field activity (e.g., a Naval Shipyard) meets all SUBSAFE requirements. Upon confirmation by the Type Commander that SUBSAFE certification requirements have been sustained for those parts of the submarine not worked by the NAVSEA managed field activity, the Type Commander reinstates the SUBSAFE certification of the submarine.

An availability of less than six months in duration (an SRA is a typical example) is termed a "Minor Depot Availability" and does not require a NAVSEA 92Q SUBSAFE certification audit. These types of availabilities do, however, require the quality assurance organization within the NAVSEA field activity accomplishing the work to perform an audit of the work. The Type Commander also audits the work. Upon completion of work, the NAVSEA managed field activity certifies to the Type Commander that all of its work meets SUBSAFE requirements. When NAVSEA 92Q functionally audits the field activity, a check on the efficacy and health of this process is performed.

The maintenance/modernization SUBSAFE certification process was examined for the Portsmouth Naval Shipyard (PNS) case. Principal government participants include the PNS SUBSAFE Director and the PNS Quality, Engineering, and Operations organizations. Other key players include NAVSEA 92Q, the NAVSEA Shipyard Representative's Office (NSRO), and the Naval Reactors Representative's Office (NRRO).

The PNS SUBSAFE certification process involves multiple tracks of external assurance and audit activity, as well as several internal PNS surveillance and assurance processes.

[23] It should be noted that some SRAs are completed in private shipyards.

PNS uses an internal risk management process called the PreRequisite List (PRL) process. This process is a PNS-owned internal risk management process keyed to critical milestones ("evolutions") in the maintenance cycle (e.g., dry docking, undocking [or flooding the dry dock], Integrated Propulsion Plant testing, Fast Cruise, and Sea Trials). Prior to each critical milestone (key event), all shops and codes must certify that work and testing needed to support that key event are complete, or have been waived by the appropriate technical codes with the approval of shipyard management.

The shipyard employs a phased certification approach beginning with an Undock Audit (focus on hull structure and hull & backup valves), followed by an Integrated Propulsion Plant Test Program (IPPTP) Audit (which consists of over 100 Task Group Instructions and a selected vertical audit), and finally, a Shipyard Certification Audit (involving vertical audits of selected hull cuts, air valves, and sea valves). These audits are conducted in advance of the 92Q SUBSAFE audit. At the time of the 92Q audit, PNS internal audit cards may be in-work, but 95% of all re-entry control packages must be complete prior to requesting the audit be performed.

The NAVSEA 92Q SUBSAFE audit includes a broad sampling audit to spot-check compliance with requirements as well as an in-depth, vertical audit of at least three critical components. Examples include pressure hull cuts, emergency main ballast tank blow system valves/piping, SUBSAFE seawater system valves/piping, ship control system, and complex components such as the 3-inch Launcher and the Trash Disposal Unit. In parallel with SUBSAFE certification activity, the ship's crew must successfully pass a series of Ship Force Tests, examining and verifying crew operational capability.

Prior to NAVSEA concurrence for proceeding to Fast Cruise, the Submarine Availability Completion Manual Appendix A must be submitted to the NAVSEA Program Manager. As noted earlier, certain shipyard and/or NAVSEA 92Q audit cards must be closed out prior to Fast Cruise. The squadron, the ship, the shipyard, the program manager, NAVSEA 92T, NAVSEA 92Q, and NAVSEA 92 must all concur prior to Fast Cruise.

During Fast Cruise problems may be identified and must be resolved before final certification. Carefully scripted Sea Trials are designed to exercise the performance envelope ("angles and dangles") where other problems may be identified that also must be corrected prior to certification for unrestricted operations. Upon completion and close out of all work, testing, and mandatory SUBSAFE audit cards, the final message is sent recommending unrestricted operations.

The in-service certification process not only certifies that SUBSAFE requirements have been met, but also includes a "material condition readiness" process that verifies that systems in addition to those covered by the SUBSAFE Program are ready to support safe operations.

Key Observations: Maintenance/Modernization SUBSAFE Certification

- Each individual project superintendent (dedicated 100% to work for a single availability) conducts advance planning for compliance with SUBSAFE requirements. This approach provides for focus, continuity, and clear accountability.
- The SUBSAFE certification process involves a focused, independent compliance verification organization (NAVSEA 92Q) to verify process capability and discipline. This same organization conducts vertical audits of selected critical submarine components during certification.
- Multiple NAVSEA certification processes operate in parallel to ensure safety and operational readiness.
- REC (re-entry control) is invoked as a vehicle to ensure that any work accomplished within the SUBSAFE boundary is planned, executed, and tested in a controlled and deliberate manner.

3.7 Naval Reactors

NAVSEA 08 Naval Reactors (NR) is the Navy code responsible for all naval ship reactors, their prototype and Moored Training Ship plants, and their associated radioactive materials. NAVSEA 08 establishes requirements and verifies implementation of requirements for reactor design, construction, testing, installation, training, operation, maintenance, and disposal. NAVSEA 08 also directs two Department of Energy laboratories: Bettis (near Pittsburgh, PA) and Knolls (near Schenectady, NY).

The success of NAVSEA 08 relies on the selection of the most highly qualified people and the assignment and assumption of full responsibility by all members. Training is given great emphasis. NAVSEA 08 uses the Challenger accident as a part of its training program along with Diane Vaughn's book, "A Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA." NAVSEA 08 points to its safety record relative to that of the civilian world's nuclear activities. The Navy has logged 126,000,000 miles of safe travel using nuclear propulsion – nearly the distance from the sun to Mars.

A basic tenet of the NAVSEA 08 culture is to make every person acutely aware of the consequences of substandard quality and unsafe conditions. Each person is assigned responsibility for assuring the highest levels of safety and quality. NAVSEA 08 places strong emphasis on mainstreaming safety and quality assurance into its culture rather than segregating it into separate groups. The discipline of adhering to written procedures and requirements is enforced, with any deviations receiving careful, thorough, formal, and documented consideration.

NAVSEA 08 field offices at shipyards, laboratories, and other major program facilities are considered a part of the headquarters organization, and they provide the means for facilitating headquarters oversight of facility operations. These field offices are headed

by senior personnel from the Washington Navy Yard headquarters who often return there after their field duty to fill the highest management and technical positions.

NAVSEA 08 has integrated the safety process throughout its organization. The commanding officers of nuclear powered ships, nuclear support and maintenance activities, and NAVSEA 08 field offices communicate directly with the Director on issues they are investigating. Issues are confronted while they are small to prevent larger problems from occurring. The communication chain is direct and enforced. Corrective actions follow a closed loop corrective action process that addresses the root cause of an issue, assigns a corrective action, tracks application of the corrective action, and subsequently evaluates the effectiveness of that action. Issues are tracked back to requirements and training for improvements. NAVSEA 08 tracks and trends concerns and initiatives, and it evaluates the practices and processes that outside nuclear organizations employ.

Each organization within NAVSEA 08 is "safety-directed." There is an escalation process that encourages (actually demands) raising issues and minority opinions to the "front office" without retribution.

Key Observations: NAVSEA 08 Naval Reactors

- NAVSEA 08 relies on highly qualified, highly trained people who are held personally accountable for safety.
- The NAVSEA 08 management hierarchy (including support management, e.g., Public Communications Director) is technically trained and qualified in nuclear engineering and experienced in nuclear reactor operating principles, requirements, and design.
- Problem awareness is essential to high degrees of safety and reliability. NAVSEA 08 demands that problems be raised to the proper levels when they happen and promotes the airing of minority opinions.

Note: Further review of NAVSEA 08 is currently scheduled to take place during phase-2 of the NNBE effort. Additional details and key observations regarding NAVSEA 08 will be included in the final report.

4.0 Context and Opportunities

4.1 Comparative Context - Differences

As noted in the introductory section of this report, the submarine Navy and NASA's human space flight programs have a number of factors in common, the most important of which is a dedication and commitment to safety while conducting missions of national importance in very hostile and hazardous environments.

However, a number of significant differences (e.g., managerial, organizational, and cultural) exist between NASA and the submarine Navy. It is necessary to further examine and understand these key differences in detail in order to provide the proper contextual background against which the key observations and opportunities developed from this benchmarking exchange can be appropriately evaluated.

Management Approach

In the SUBSAFE and Nuclear programs, the Navy generally defines both the safety requirements "what" and the "how" for critical safety items where the Navy has knowledge of what is required to deliver a safe system. Where new technology is being developed and the "how" has not been established, the Navy reviews and approves the basic approach that is recommended by its contractor(s). Particular emphasis is placed on strict compliance with mandatory requirements.

The flexibility of "how" designers, constructors, and maintainers conduct work only exists in systems outside the SUBSAFE and nuclear boundaries. When shown necessary through experience or analysis, the "how" can be changed through a formal, well-defined process. This applies equally to both the new design/construction and maintenance/modernization activities. NASA, on the other hand, has in recent years moved toward a number of new and innovative contracting approaches that specify the safety requirements "what," but provide the contractor/subcontractor teams with a level of flexibility in determining the "how" with regard to critical and non-critical systems.

Technical Requirements Authority

The Navy maintains a central technical requirements authority (including SUBSAFE requirements) via NAVSEA 05 separate from individual program and project managers. This results in a single set of technical SUBSAFE requirements that are applicable to both new construction and maintenance availabilities. Conversely, NASA has a distributed network of policy and technical standards documents that are the responsibility of various headquarters functional management organizations and center-based engineering organizations. Individual NASA program or project managers have full engineering and technical requirements authority and establish their own unique technical requirements based on higher-level policy guidance. While NAVSEA 08

organizationally has project officers (or program managers in NASA terminology) and technical directors that report directly to the Director, they both hold responsibility for safety.

Safety Roles

NAVSEA 92Q has important responsibilities concerning requirements definition, conducting analysis, providing direction to field activities, etc. NAVSEA 92Q flows down NAVSEA 05 technical requirements. NAVSEA 92Q is responsible for the issuance and revision, as necessary, of the SUBSAFE and DSS-SOC manuals, which contain the policies, procedures, practices and technical requirements for the respective systems.

NAVSEA 92Q is also the Navy's primary compliance organization for SUBSAFE and deep submergence safety, that is, its function is to assure that policies, procedures, practices, and technical requirements are implemented in accordance with SUBSAFE and Deep Submergence Systems (DSS) requirements. Compliance assurance is achieved through the implementation of a rigorous, no-nonsense functional and certification audit process.

While NAVSEA 92Q has a strong identity as an independent compliance verification organization, the NASA Office of Safety and Mission Assurance (OSMA), and its center-based counterparts have multiple (and some times conflicting) roles and responsibilities that include: 1.) in-line consultant, 2.) in-line direct technical support, and 3.) independent compliance verification.

NAVSEA 08 takes a different approach from either NASA or NAVSEA 92Q. Reactor safety is the primary responsibility of all personnel at NAVSEA 08. While NAVSEA 08 performs functions that are not traditionally associated with reactor safety, all of these functions ultimately support reactor safety. For example, by providing program management for reactor plant work, NAVSEA 08 ensures that pressures from budgets and schedules do not impact reactor safety. Likewise, although there is a separate safety organization within NAVSEA 08, it is an independent and equal voice in design and operation decisions, and it does not impose after-the-fact safety requirements or interpretations. Additionally, it serves as a coordinator, interpreter, corporate memory, and occasionally, an advocate for specific capabilities in a system of interlocking responsibility in which everyone from the director to the most junior operator is accountable for reactor safety.

NAVSEA 08 has the Naval Reactors Representative's Office (NRRO) perform independent compliance verification for various aspects of its responsibilities. In addition, headquarters conducts periodic and event-driven inspections and audits of fleet, vendor, and other activities, including the effectiveness of lower-tier auditing functions. The Nuclear Propulsion Examining Board in each of the Atlantic and Pacific Fleets performs fleet and facility assessment in close coordination with, and in accordance with the requirements and specifications of, NAVSEA 08.

Tailoring

For all submarine programs, the Navy establishes a single set of SUBSAFE technical and procedural requirements that are not subject to tailoring by program managers. NASA policies allow tailoring and negotiating requirements for individual programs. The NASA program manager has the latitude to tailor and negotiate requirements during the program formulation phase, as codified in NPG 7120.5B.

Waivers

For new construction submarines, NAVSEA does not normally accept waivers to the top-level SUBSAFE requirements. In rare cases a waiver to a SUBSAFE technical requirement is accepted, and then only when based on sound technical rationale and with the concurrence of the technical authority (NAVSEA 05) and the SUBSAFE Office (NAVSEA 92Q). For in-service submarines, NAVSEA accepts departures from specifications on SUBSAFE requirements after careful technical analysis and approval of the departure. The departure from specification may or may not have limitations imposed upon it (e.g., fix upon return to port, ship limited in depth until fixed, ship's speed limited until fixed, etc.). The Space Shuttle Program does accept waivers to its program requirement baseline, however, it employs similar management controls that include development of technical rationale, presentation to appropriate review boards, and formal management approval.

Awareness of Risk and Consequences of Failure

NASA has relatively few people who have had the opportunity to fly in space, while the Navy has had thousands individuals who have been to sea in a nuclear powered submarine. There are a significant number of people (both military and civilian) in the Navy whose personal safety has been dependent on the safe operation of a submarine. In addition, many of the submarine senior managers, designers, and shipyard workers, both contractors and NAVSEA personnel, routinely ride onboard submarines during Sea Trials following construction and maintenance availabilities.

Certification Processes

Before each submarine completes a maintenance availability, the Navy conducts horizontal and vertical audits in the SUBSAFE boundaries to verify compliance with safety requirements. These independent compliance verification audits impact the workforce by increasing emphasis on the quality and fidelity of work execution. This scrutiny serves to elevate individual motivation and attention to details.

A vertical audit, as accomplished by NAVSEA 92Q, is a "core drill" investigation of selected critical components in which compliance with requirements is tracked to the lowest level, such as described in the following notional example:

- Who installed the component?
- Who inspected the work?
- Where are the individuals' training and certification records?
- Where is the test data for the component?
- Where are the certification test records (objective quality evidence)?
- Who performed the tests, and what were the individuals' qualifications?
- Who witnessed the test?
- What is the material heritage?
- Where are the lot acceptance fracture toughness test data? etc.

NAVSEA 08 conducts similar audits before key events such as initial reactor criticality.

In addition, in both the SUBSAFE and NAVSEA 08 approaches, background processes (e.g., audits and on-scene observations) continuously evaluate critical processes and correct any problems with work accomplishment or documentation required to validate the acceptability of prior work.

NASA does not routinely conduct vertical audits of selected critical components as a pre-launch milestone in the Space Shuttle Program, nor does NASA routinely conduct vertical audits for other space vehicles. However, NASA does conduct detailed investigations similar to vertical audits in the case of specific anomalies that may be identified in pre-launch processing or as a result of data from previous flights.

Safety Awareness Training

As discussed in Section 3, NAVSEA uses the USS THRESHER loss as a powerful training tool, emotional lesson, and organizational motivator – all with the purpose of helping the Navy to ground and sustain its safety culture. As a part of this training, personnel are required to watch a video, listen to the audio of the collapse of a submarine's hull and compartments, and are reminded that people were dying while this occurred. The NAVSEA 08 Naval Reactors Program has never experienced a reactor accident, but nevertheless includes training based on lessons learned from program experiences. NAVSEA 08 also looks outside its program for lessons learned from events such as Three Mile Island, Chernobyl, and the Army SL-1 reactor. NASA has a similar painful memory with the Challenger loss, but NASA has not yet incorporated it as part of a formal, institutionalized training tool for emphasizing safety and motivating personnel. The Navy, however, does incorporate the Challenger loss into its safety awareness training.

Levels of Contractor Insight

As demonstrated by the Navy's comprehensive approach to SUBSAFE, weapons systems, nuclear reactor systems, and its certification process, the Navy imposes a high level of "insight" into its contractor activities to assure safety and program success. When compared to NASA's insight continuum[24], the Navy implements contractor "insight" to a penetration level of 3 or 4. The NASA Space Shuttle and International Space Station Programs implement comparable penetration levels; however, preliminary NASA planning discussions for the Orbital Space Plane (OSP) have involved consideration of lower levels of insight.

[24] In the language of the NASA Insight Continuum - see below:

MSFC HB 3173, page 57: Definitions of "Insight Level"

Technical Penetration Level 0 - No Penetration
- Accept performing organization's tasks at face value (based on assessment that no penetration is required)
- Contractor develops and implements verification plan

Technical Penetration Level 1 - Low Penetration
- Participate in reviews and technical interchange meetings and assess only the data presented
- Perform periodic audits on predefined processes
- Chair board or serve as board member, or RID writer, at a formal review
- Participate in resolution and closure of issues
- Review verification plan and its implementation

Technical Penetration Level 2 - Intermediate Penetration
- Perform low penetration tasks with addition of daily or weekly involvement to identify and resolve issues
- Review verification plan, its implementation, and selected verification closure data

Technical Penetration Level 3 - In Depth Penetration
- Perform all tasks at the intermediate penetration level
- Perform methodical review of details
- Develop independent models to check and compare vendor data, as required
- Review verification plans and their implementation and concur in all verification closure data

Technical Penetration Level 4 - Total Penetration
- Perform a complete and independent evaluation of each task
- Perform independent review of all verification documentation (including closure data) and witness verification testing

4.2 Potential Opportunities

The following discussion offers potential improvement and enhancement opportunities for NASA to consider as its human space flight programs continue to evolve and advance. These opportunities are not meant to imply inadequacy of current NASA safety processes, but rather to support areas where the submarine Navy's experience could benefit NASA human spaceflight programs.

Opportunities have been organized into three topical groups:

Group I: Requirements and Compliance
Group II: Lessons Learned & Knowledge Retention
Group III: Process Improvement

Group I: Requirements and Compliance

The Navy manages portions of programs that affect safe operations using a simple, two-part management philosophy based on 1.) clear and realistic requirements definition and 2.) independent verification of compliance. Individual NASA programs create requirements baselines, but have historically found it necessary to waive many program requirements that cannot be met, while mitigating the risks associated with those waivers through other means.

Opportunity #1.1: Functional Safety Requirements for Future Human Rated Space Systems

The NAVSEA ship specification (including the SUBSAFE and DSS-SOC manuals) is the *de facto* submarine human rating design requirements document. This "ship spec" reflects best practice that has evolved by incorporating known and postulated risks, knowledge of current technology and design practices, results of tests and actual operations, and lessons learned.

NASA may wish to explore a similar approach in developing a corporate-level human rating safety guidance document[25] for future NASA human space flight programs. This safety requirements document would be based on the functional design attributes of current and past NASA human-rated space flight systems. The document would define specific functional safety requirements (e.g., functional redundancy, intervention capability, abort/escape capability), and it would require formal and rigorous audits and assessments to verify implementation of, and compliance with those requirements.

Under this approach NASA program managers would not be allowed to unilaterally waive these requirements. Disposition of waiver requests pertaining to specific, critical

[25] The team notes that a draft policy guidance document is currently in-work, entitled "Human Rating Requirements for Space Flight Systems" .

safety functional design requirements might be the responsibility of a (new) corporate-level, NASA HQ Human Space Flight Safety Review Board or equivalent forum.

References: Key Observation Sections 3.3.1 and 3.3.2

Opportunity #1.2: NAVSEA Model for Compliance Verification Organization

The NAVSEA model involves a separation of program authority, technical authority (i.e. binding technical policy requirements), and independent compliance verification for the elements essential to safe submarine operations. NASA may wish to explore the potential benefits associated with a variant on this model. While it may not be practical for NASA to achieve centralized technical authority as accomplished in the NAVSEA model, NASA may wish to adopt the concept of a centrally controlled, separately funded, independent safety compliance organization (independent of program management authority) to verify the implementing organization's functional capabilities, and to verify compliance with the program/project baseline safety and mission assurance requirements.

The NAVSEA 92Q analog (organization, staffing, functions, processes, etc.) may be useful for NASA to consider in moving toward an independent safety requirements compliance verification organization for all programs involving human space flight operations, including future NASA human rated space systems (e.g., Orbital Space Plane) currently under development where innovative contracting approaches may be employed.

References: Key Observation Section 3.2.2

Opportunity #1.3: Compliance Verification for New NASA Human Rated Programs

A central theme in the NAVSEA model for success revolves around the application of high levels of government oversight (compliance verification and approval authority) into contractor activity for all critical submarine processes. Nowhere is this approach more pronounced, and the evidence of success more apparent, than in the nuclear reactor program area. The Navy's insistence on full government insight and individual ownership, accountability, and attention to detail (started under Admiral Rickover) has ensured unparalleled success in nuclear reactor safety.

As NASA considers the levels of oversight that it will impose on its new human rated space flight programs and potential future nuclear propulsion programs, a further understanding of the Navy's approach may be appropriate. Specifically, the recent (preliminary) program management deliberations concerning Orbital Space Plane Program "level of insight" (see footnote on p.54) may provide an ideal opportunity for further investigation and comparison.

Group II: Lessons Learned/Knowledge Retention

The NAVSEA centralized technical authority approach directly facilitates institutional lessons learning. As pointed out in observations in sections 3.2.1, and 3.4.1, NAVSEA mitigates risk through continuous learning and improvements to design based on extensive operational experience. This engineering/technology knowledge base is a central element in the ongoing success of the Navy submarine program. This success is based on a stable, central organization to document operational experience (NAVSEA 05) and establish technical requirements.

Opportunity #2.1: Lessons Learned Management at NASA[26]

The recent GAO report "Survey of NASA's Lessons Learned Process"[27] highlighted fundamental weaknesses in the collection and sharing of lessons learned in NASA by program and project managers.

Recognizing current efforts to improve the NASA lessons learned process, NASA may wish to move forward with an expanded initiative, under the leadership of the NASA Chief Engineer and center-based engineering organizations, to build (future) and reconstruct (past) project management, engineering, and technology narrative histories for NASA programs and projects. The development of a viable NASA lessons learned knowledge-base (not database) would become the basis for requirements development for future NASA space and aeronautical systems.

Such an effort would begin with development of a consistent taxonomy or framework for information acquisition and analysis. Using the framework, the effort would begin developing histories for recent NASA programs and projects, eventually reaching back to Apollo, Gemini, and Mercury.

It would also be necessary to strengthen policies related to the use and implementation of lessons learned. A top-level policy document could be complemented by an implementation level policy guidance document providing practical guidance on how to approach the subject of lessons learned within the program/project environment.

References:Key Observation Section 3.2.1, 3.2.4, 3.4.1

Opportunity #2.2: Lessons Learned Training

NASA may wish to explore the possibility of developing safety/mission success lessons learned training courses for small groups of trainees based on noted NASA failures including the Challenger (STS 51L) loss, the 1967 Apollo 1 (Apollo 204) fire, 1970 Apollo 13 mishap, the 1986 (manufactured) Hubble Space Telescope mirror incident, and

[26] The opportunities identified in this section seek the same outcomes embodied in the NASA "Strategic Human Capital Plan" pillars and goals (#6 and #7).

[27] "NASA Lessons Learned Survey Results," GAO-01-1015R Survey of NASA's Lessons Learned Process, September 5, 2001.

the more recent Lewis Spacecraft, Mars Climate Orbiter, and Mars Polar Lander mishaps. Consider required annual participation by selected NASA employees and program/project management teams (including contractors) in one or more training sessions. Also consider offering training sessions based on the NAVSEA 08 "Challenger Launch Decision" (Diane Vaughn) training seminar and the USS BONEFISH Fire accident investigation videotape. Space systems, submarines, and other transportation modalities (airplanes, ships, trains) can be addressed in an integrated curriculum that includes the study of multi-modal failures in complex, tightly coupled systems.

References:Key Observation Section 3.2.4

Opportunity # 2.3: Knowledge Retention (FTE Ceiling Authorization for Hiring)[28]

During the late 1980's and early 1990's, NAVSEA faced a critical loss of engineering and management skills as a result of both imposed downsizing and impending aging work force issues. NAVSEA's approach for retaining critical knowledge was to employ a mentoring approach. In order for this approach to work, it was necessary for NAVSEA to obtain approval to increase its hiring ceiling (not its overall budget) allowing them the flexibility to hire young engineers while retaining the experienced engineers necessary to mentor and provide essential knowledge transfer. NASA may wish to investigate the potential benefits of adopting this approach.

References: Key Observation Sections 3.2.5

Group III: Process Improvement

NASA may wish to consider the following opportunities to implement several broad-based process improvements.

Opportunity #3.1*:* NAVSEA Logistic Center

NASA has an opportunity to leverage the extensive vendor quality history database available at the NAVSEA Logistics Center to assist in supplier selection and evaluation. The development and application of this database is embodied in the following processes and programs:

- Product Data Reporting and Evaluation Program
- Level 1/SUBSAFE Verification System (may not be not applicable to NASA)
- Supplier Audit Program
- Red/Yellow/Green Program
- Contract Performance Assessment Reporting System, and
- Past Performance Information Retrieval System (PPIRS).

NASA is currently participating in the PPIRS. Discussions are underway to determine the feasibility of obtaining access for the NASA quality assurance community to these

[28] Opportunity may complement the July 2002, "NASA Human Capital Legislative Proposal" by providing a way to train and mentor new employees enabling retention of corporate knowledge.

valuable resources. This opportunity will provide assists NASA managers in selecting qualified, proven suppliers and vendors.

References:Key Observation Sections 3.5.3

Opportunity # 3.2: Software Contracting Approach

Based on the ship specifications passed down from the Navy, the prime contractor creates detailed software specifications. The prime contractor then passes down very detailed procurement specifications to its subcontractors. To further assure that the work is being completed correctly, each organization has a group located at the next lower level to oversee and assure the quality of the work in progress. NASA should consider reviewing future software contract language and structure to insure an appropriate level of specification detail and implementation assurance consistent with the NAVSEA approach.

NASA also may wish to consider the NAVSEA approach of requiring standardized software development and assurance clauses in RFPs. In addition, requiring the use of a standardized template for software development plans provides an important extra step in ensuring software safety.

References:Key Observation Sections 3.4.2

Opportunity # 3.3: Human Factors

NAVSEA has recently established a human factors organization (NAVSEA 03) to emphasize the life-cycle human/system interface. NASA may wish to consider collaboration with NAVSEA 03 to develop possible human/system interface technical standards, policies, and processes for NASA.

Evaluate how mission goals, function analysis, task analysis, and maintenance/operation tasks were developed and modeled in the VIRGINIA Class. Apply lessons learned from the VIRGINIA Class and NAVSEA 03 studies to the NASA Orbital Space Plane (OSP) program. Include human/system interface as an integral part of total OSP vehicle design to optimize system performance, manning, and life cycle cost.

References: Key Observation Sections 3.4.2

Opportunity # 3.4: Quantitative Methods

NASA can improve its use of historic reliability and operational performance data, and the use of lessons learned from accident and mishaps, by centralizing this information and incorporating it into an Agency risk and reliability database to support design and risk assessment teams.

References:Key Observation Sections 3.4.2

4.3 Rationale/Value of Potential Opportunities

Table 4.1 provides a summary of the opportunities identified in this interim report and a brief description of the rationale and/or potential value. It is anticipated that other opportunities will emerge as the NNBE enters its second phase.

Table 4.1 Rationale/Value of Potential Opportunities
NASA/Navy Benchmarking Exchange Interim Report

Opportunity	Description	Rationale/Value
Requirements & Compliance		
1.1 Functional Safety Requirements for Future Human Rated Space Systems	Enhance current NASA efforts to develop corporate-level human rating functional design requirements by adding the NAVSEA evolutionary (successive ship class specification) dimension.	Establishes a clear, executable requirements baseline for future human rated space systems
1.2 NAVSEA Model for Compliance Verification Organization	Establish, for human rated space systems, a centrally controlled and separately funded independent safety compliance organization to verify the implementing organization's functional capabilities, and to verify compliance with the program /project baseline safety and mission assurance requirements.	Approach creates a clearly independent, unambiguous compliance assurance organization.
1.3 Compliance Verification for new NASA Human Rated Programs	Review current NASA planning versus NAVSEA approaches for compliance verification to be employed for the Orbital Space Plane program and potential future nuclear propulsion programs.	Assures that contract surveillance and compliance verification methods have a scope and rigor consistent with the goal of mitigating manageable risks in human space flight systems.

Table 4.1 Rationale/Value of Potential Opportunities NASA/Navy Benchmarking Exchange Interim Report		
Opportunity	**Description**	**Rationale/Value**
Lessons Learned & Knowledge Retention		
2.1 Lessons Learned Management at NASA	Move forward with current NASA planning to implement an aggressive NASA lessons learned/knowledge management initiative, under the leadership of the NASA Chief Engineer. Using NAVSEA "template" combine continuous learning with technical authority roles.	Facilitates requirements development for future NASA space and aeronautical systems. Enables programs to avoid past mistakes. Provides for centralized management and ownership of lessons learned within the engineering management/systems engineering organization.
2.2 Lessons Learned Training	Explore the possibility of developing safety/mission success lessons learned training courses for small groups of trainees based on noted NASA failures including the Challenger (STS 51L) loss, the 1967 Apollo 1 (Apollo 204) fire, 1970 Apollo 13 mishap, the 1986 (manufactured) Hubble Space Telescope mirror incident, and the more recent Lewis Spacecraft, Mars Climate Orbiter, and Mars Polar Lander mishaps.	Provides motivation and reinforces safety culture and discipline within NASA workforce. Provides greater understanding of failures in tightly coupled, complex system. Reinforces the need to address all areas of potential critical failure.
2.3 Knowledge Retention (FTE Ceiling Authorization for Hiring)	Obtain approval to increase its hiring ceiling (not its overall budget) allowing the flexibility to hire young engineers while retaining the experienced engineers necessary to mentor and provide essential knowledge transfer.	Provides means to retain corporate knowledge. Enables mentoring of new employees.

Table 4.1 Rationale/Value of Potential Opportunities NASA/Navy Benchmarking Exchange Interim Report		
Opportunity	**Description**	**Rationale/Value**
Process Improvement		
3.1 NAVSEA Logistic Center	Leverage the extensive vendor quality history database available at the NAVSEA Logistics Center to assist in supplier selection and evaluation.	Assists in selecting qualified, proven suppliers and vendors.
3.2: Software Contracting Approach	Review future software contract language and structure to insure an appropriate level of specification detail and implementation assurance consistent with the NAVSEA approach.	Ensures that appropriate software assurance processes are implemented throughout the software development life-cycle.
3.3: Human Factors	Collaborate with NAVSEA 03 to develop possible human/system interface technical standards, policies, and processes for NASA. Evaluate how mission goals, function analysis, task analysis, and maintenance/operation tasks were developed and modeled in the VIRGINIA Class.	Provides the opportunity for NASA and Navy to exchange lessons learned as each organization moves to provide additional focus on human factors in system program/project life cycle.
3.4: Tools/ Quantitative Methods	Improve NASA databases containing historic reliability and operational performance data, by centralizing information into an Agency risk and reliability database.	Enables use of historic reliability and operational performance data, to support design and risk assessment teams

Additional Reference Material:

- "Alternate Trajectories: Options for Competitive Sourcing of the Space Shuttle Program," RAND Corporation Executive Summary Report, Nov 6, 2002, http://www.rand.org/scitech/stpi/NASA/nasaExecSum_final.pdf.
- "Report by the International Space Station (ISS) Management and Cost Evaluation (ICME) Task Force to the NASA Advisory Council," A. Thomas Young (Chairman), et al., November 1, 2001.
- "International Space Station Independent Implementation Review, Presentation to the Code M Program Management Council," NASA, December 11, 2001.
- "Enhancing Mission Success – A Framework for the Future, A Report by the NASA Chief Engineer and the NASA Integrated Action Team," NASA, December 21, 2000.

Appendix A: Initiating Letter and Attachment
Appendix B: Summary of Key Observations
Appendix C: Team Membership
Appendix D: Key Documents Reviewed/Exchanged
Appendix E: NNBE Acronyms and Terms

Appendix A: Initiating Letter and Attachment

National Aeronautics and
Space Administration

Office of the Administrator
Washington, DC 20546-0001

June 13, 2002

The Honorable Gordon R. England
Secretary of the Navy
Washington, DC 20350-1000

Dear Mr. Secretary, Gordon

The Navy's nuclear submarine program and NASA's human space flight program have much in common. Both programs have missions that are vitally important to the Nation. Both use highly complex systems and operate in challenging physical environments. Most importantly, both programs are totally devoted and committed to safety.

Today, NASA's Space Shuttle and International Space Station program managers are facing many challenges, including maintaining product quality and safety, accomplishing required performance and safety upgrades, and maintaining a skilled and motivated workforce in the face of budget and schedule pressures. These issues are well understood by the Navy's nuclear submarine program managers who faced similar challenges during a downturn in production in the early 1990's.

I believe that NASA can learn much from the Navy's experience. To this end, I propose that NASA's Office of Safety and Mission Assurance, in coordination with the NASA Aerospace Safety Advisory Panel (ASAP), undertake a benchmarking study of the Navy's nuclear submarine programs. My goal is to develop a set of lessons learned that can be applied to benefit NASA's human space flight programs. I have enclosed a draft implementation plan that outlines how we would like to structure this study. Of course, this draft plan is open to further refinement and negotiations with your staff.

I, respectfully, seek your support and endorsement of this activity and welcome your suggestions for an appropriate point of contact and support personnel who could assist my staff in planning and conducting this benchmarking study.

Cordially,

Sean O'Keefe
Administrator

Enclosure Gordon, Glad appreciate your support of this effort — we stand to gain a lot!

Preliminary Implementation Plan: NASA Benchmarking Review of Nuclear Navy Safety and Mission Assurance Processes

Background

The Administrator recognized similarities between human spaceflight and nuclear submarine programs. Both operate in extreme environments, are composed of many complex subsystems, and must maintain the very highest levels of safety and reliability in order to perform their missions. While at OSD and serving as SECNAV, Mr. O'Keefe observed the Navy's ability to operate safely and effectively in resource constrained and declining production environments. Furthermore, as NASA explores the application of nuclear propulsion and power for space exploration, lessons learned from the Navy nuclear safety program could be beneficial. Thus, given the current management challenges NASA is facing, Mr. O'Keefe recognizes that NASA may benefit from a critical examination of the engineering management, safety, and mission assurance, approaches employed by the nuclear Navy.

Objective

Benchmark Navy nuclear submarine program with focus on safety and mission assurance policies, processes, accountability, and control measures that can assist NASA in meeting current human space flight challenges. Document and disseminate findings (lessons learned) to enable multi-level NASA organizational learning.

Approach:

1. Send a letter from the NASA Administrator to the Secretary of the Navy proposing the benchmarking review.
2. In parallel, arrange meeting between Flag/Senior Executive principals in order to scope the benchmarking activity and to agree on next steps. Identify prospective individuals (managers, process owners, operators) to interview during the assessment.
3. Conduct a series of technical interchange meetings and on-site visits to gather information and obtain insight into the associated processes of interest to NASA.
4. Complete factual review draft report for Navy review
5. Deliver final report to the NASA Administrator.

Themes

Overarching Safety and Risk Management Approach

Understand the nuclear Navy top-down approach for ensuring accountability and control in safety critical areas. Understand the flow-down of top level safety philosophy and requirements. Understand the overarching risk management posture or logic employed in making decisions concerning competing and often conflicting program dimensions of cost control, schedule, mission capability, and safety.

SUBSAFE Program

Understand the cultural dimensions of the SUBSAFE Program. Acquire a process-level understanding of safety, risk management, and mission assurance processes within the Navy nuclear submarine SUBSAFE Program. Understand the policies, procedures, practices, and processes for 1.) definition of requirements, 2.) verification of ongoing implementation, and 3.) certification of operational readiness. Clearly identify organizational accountability and responsibilities for SUBSAFE implementation.

Change Control Processes

Understand the authority and relationships between various control boards and processes responsible for hardware design, software design, manufacturing processes, test/certification, and operations. Understand the role of systems engineering authority within the Trident program for integrating and managing change. Understand the organizational responsibilities and processes employed for configuration management of requirements baselines.

People in the Process

Capable critical processes require capable people. Explore and understand the policies, processes, and controls implemented for assuring the ongoing capability of people in critical processes. Topics to include hiring, training, certification, and retention of critical skill individuals. Need to understand approaches for ensuring a reliable (human reliability) and capable workforce in terms of health, stress, overtime, extended duty, physical, and psychological work environment. Need to understand the administrative or management approaches implemented to ensure that critical processes maintain necessary staffing levels to function in a stable, capable, and controlled manner.

Scope

Potential Trident Submarine Program focus - similar in operational age and safety criticality to Space Shuttle program. Trident has a similar technology era pedigree, similar need to evolve (mission capability and safety upgrades) over time, and similar high reliability requirements. In order to facilitate real-time assessment of change control processes it is proposed that the review

narrow the focus to the SSGN Conversion Program, which is an ongoing activity to retrofit Trident D5 missile tubes to support Tomahawk cruise missile and special operations capabilities.

Locations/ facilities

Potential SSGN Conversion Program site visits might include: 1.) Naval Sea Systems Command in the Washington Navy Yard, 2.) Kings Bay, GA, and 3.) Electric Boat in Groton, CN.

Phase of Life-cycle

- Development (primarily upgrade development)
- Manufacturing/Manufacturing verification
- Pre-Operations Integration & Test/Certification
- Operations/Maintenance

Security Issues

An area requiring close coordination. Acquire a dedicated security liaison officer to support team activity. What level of clearance is required by the team members?

Timeline

Begin as soon as possible (depending on Navy response) and complete final report this summer.

Review Team Staffing (team composition/lead)

Proposed NASA/HQ/OSMA Programmatic IA Team plus at least one participant/observer from the Aerospace Safety Advisory Panel (ASAP).

Appendix B: Summary of Key Observations

Summary of Key Observations	
3.1	**SUBSAFE Program**
	- The SUBSAFE concept addresses specific flooding/recovery hazards and places special life-cycle emphasis on controlling those hazards. Other hazard control boundaries exist on a submarine as shown in figure 2.2. - There is clarity, uniformity, and consistency of submarine safety requirements and responsibilities. Tailoring by program managers is not permitted without NAVSEA 05 and 92Q approval. - There is a strong, independent "audit to requirements" assurance organization. - There is a community-wide (contractor and government) understanding of SUBSAFE requirements and a commitment to compliance. - The SUBSAFE Program and implementing organization (NAVSEA 92Q) are relatively immune to budget pressures - no certification, no submarine. - There is a strong, community-wide (contractor and government), continuing emphasis on safety through periodic systematic examination of previous failures and incidents. - Annual SUBSAFE training is a requirement for the NAVSEA Headquarters submarine community.
3.2	**Management and Organization**
	3.2.1 Technical Authority
	- The NAVSEA organizational structure provides a capable, centralized, independent, technical authority that is responsible for developing and documenting technical requirements and standards, and providing requirements clarity and accountability. - There exists community-wide acceptance that NAVSEA 05 is the technical requirements owner. - Any delegation of technical authority from NAVSEA 05 to implementing organizations is clearly documented. - The centralized technical authority provides a powerful means to capture, document, and use lessons learned to improve future ship designs.
	3.2.2 Independent Compliance Verification Organization
	- The NAVSEA management organizational structure provides a highly capable and independent safety compliance verification/assessment organization that serves as a key management control for SUBSAFE certified activities. - The compliance verification process is the responsibility of an entity separate from program management and the operators (the Fleet Type Commanders) of submarines. - Audit activities draw on expertise distributed across the Navy laboratories, shipyards, and other field activities.

Summary of Key Observations

	3.2.3	**Safety Management Philosophy**
	- Contractors are not given latitude in meeting SUBSAFE and other critical safety system requirements because the leverage gained in the areas of technical excellence and risk mitigation achieved through the many generations of submarine specifications would be lost with such an approach.	
	3.2.4	**Cultural Attributes**
	- Safety is central to the culture of the entire Navy submarine community, including builders, designers, maintainers, and operators. - In addition to the loss of the USS THRESHER and the USS BONEFISH fire, the Navy has made extensive use of the Challenger mishap in its safety training.	
	3.2.5	**EB Restructure & Downsizing**
	- The Navy worked closely with EB to ensure that a logical and structured approach was employed to downsize the workforce. There was no "magic pill" for what was a painful downsizing process. - Changes that were made at EB were driven by the need to survive as a business unit within the General Dynamics Corporation. Union and corporate management worked together to determine the optimum mix of competencies, seniority, and management for the restructure and survival of the company. - Having clearly defined, well-documented technical and procedural requirements assisted the Navy and EB during the restructuring and downsizing transition.	
	3.2.5	**NAVSEA Restructure & Downsizing**
	- NAVSEA conducted a logical and structured downsizing approach that identified core competencies and the engineering workforce requirements necessary to assure continued support of critical defense technologies. - NAVSEA overstaffed its engineering skill sets with recent college graduates to allow the skilled work force to train new hires while maintaining core competencies.	
3.3	**Safety Requirements**	
	3.3.1	**Safety Requirements Management**
	- Critical safety requirements and implementation methods are clearly defined. - Critical safety requirements are protected, and program managers cannot tailor them or trade them against other technical or programmatic variables.	
	3.3.2	**Submarine Safety Design Criteria**
	- There does not exist a single (stand alone) document that proscribes NAVSEA human rating design safety criteria or standards. - The existing operational design attributes, compiled in the most recent ship specification, represent the de facto, evolved human rating design standard.	

Summary of Key Observations

3.4 Implementation Processes

3.4.1 Design Approach

- New ship designs are evolutionary. Lessons are learned and applied from one submarine class to the next.
- The VIRGINIA contract partnership agreement (EB and Newport News Shipbuilding) enabled a strong degree of collaboration.
- The newest design class, VIRGINIA, employs design for manufacturability (six-sigma) concepts. NAVSEA and EB consider the approach, referred to as design/build, as critical to achieving affordability.
- Early and continual collaboration between government and contractors reduces programmatic risk by emphasizing and strengthening design for manufacturability.

3.4.2 Processes/Tools

Quantitative Methods

- Traditional safety/hazard assessments are used and rely extensively on the vast historic data (design/build/test/maintenance and operational experience) of the US Navy Submarine Program.
- Reliability and maintainability assessments are performed according to traditional DOD methods and also rely heavily on the vast historic data of the program.
- Probabilistic Risk Assessment does not appear to be used at any significant level.
- Risk assessment is applied qualitatively/categorically using a DOD-prescribed 5x5 likelihood versus consequence matrix that is similar to the one used by NASA.

Software Development

- The VIRGINIA Class represents the first NAVSEA application of fully fly-by-wire technology for ship control system design; accordingly, its software management and control processes are evolving.
- The current approach represents a comprehensive and conservative management approach to assuring software capability and fidelity.
- EB implements a very rigorous software contracting process that assures that safety requirements are appropriately flowed-down and met at each level (i.e., Navy to EB to subcontractors).
- EB use of software-based design tools (e.g., CATIA) has helped them maintain and communicate its work within a distributed engineering design, manufacturing, and maintenance environment.

Human Factors

- NAVSEA systematically considers life-cycle human/machine interface requirements in the design of submarines.
- NAVSEA 03 – "Human Systems Integration in System Design" was created to ensure that human/system interface is an essential element in total ship systems engineering.
- Human Factors Engineering requirements, unique to SUBSAFE and deep submergence systems, are included in the SUBSAFE and DSS-SOC manuals.

Summary of Key Observations

3.4.3 Work Planning and Authorization Processes (Maintenance/Modernization)

SUBMEPP

- SUBMEPP advanced planning is a key element in ensuring Submarine Safety. This approach provides management, engineers, and technicians ample time to evaluate task steps and detect/correct procedural errors, thereby increasing the likelihood that activities will be performed safely. This approach also ensures that needed parts, tools, and personnel are available when the task will be performed.
- SUBMEPP is the "detail" organization (e.g., checking tolerances and factors of safety) assuring that the right maintenance work is done when it needs to be done and in the right way.
- SUBMEPP advanced planning also provides valuable data that allows the Navy to make informed decisions concerning workforce staffing, training, and retention.

SHAPEC

- SHAPEC was created to place the detailed planning for maintenance/modernization availabilities for the SSN 688 Class of ship under one entity. This process has reduced cost, complexity, and redundancy of efforts, and it has made available the best practices, lessons learned, and most efficient production processes available to all public shipyards performing maintenance activity.

3.4.4 NAVSEA Fleet Modernization Program

- NAVSEA manages configuration of modernization efforts via use of a well-documented SHIPALT process.
- Priority is placed on safety, reliability, maintainability, habitability, and environmental compliance.
- The FMP is oriented toward long-term upgrade planning (5 -10 year horizon).

3.5 Compliance Verification Processes

3.5.1 EB Quality

- SUPSHIP serves as a strong, independent, government quality assurance oversight organization located at the contractor's facility.
- NAVSEA 08 represents a second strong, independent, government quality assurance oversight organization also located at the contractor's facility.
- Multiple assurance processes (EB, SUPSHIP, DCMA, and NAVSEA) extend down into the EB supply chain.

Summary of Key Observations

3.5.2 PNS Quality

- PNS quality processes are integrated into maintenance availability activities in order to achieve maximum assurance of compliance.
- Discipline and individual worker integrity are considered critical to the quality assurance process.
- Honest mistakes are not punished. Not reporting mistakes can subject a worker to discipline because the Navy emphasizes full disclosure in the reporting process in order to be able to promptly identify and fix problems. Workers are made aware of the consequences for failure to report.
- The Project Management approach provides workers with a sense of continuity and pride of ownership for the work to be performed on a given submarine.
- The Navy uses a standardized trouble reporting system across all shipyard/repair facilities. This standardized process helps facilitate the sharing of significant problems with other shipyards.

3.5.3 NAVSEALOGCEN

- DoD has a single, consistent logistics program for purchasing hardware and materials.
- The Navy LOGCEN has standardized supply chain evaluation (contractor performance) monitoring across the command.
- The Navy and its prime contractors use receiving inspection information to grade sub-tier contractors and suppliers.
- CPARS provides source evaluation boards access to past performance for large contracts.
- To date, the RYG Program has withstood the scrutiny of courts during three legal challenges.

3.6 Certification Processes

3.6.1 New Design/Construction SUBSAFE Certification

- The SUBSAFE certification process involves a focused, independent audit organization (NAVSEA 92Q) to verify process capability and discipline. This same organization conducts detailed vertical audits of selected critical submarine components during certification audits.
- Multiple NAVSEA certification processes operate in parallel to ensure safety and operational readiness.
- REC (re-entry control) is invoked early in the certification process.

Summary of Key Observations	
	3.6.2 Maintenance/Modernization SUBSAFE Certification
	- Each individual project superintendent (dedicated 100% to work for a single availability) conducts advance planning for compliance with SUBSAFE requirements. This approach provides for focus, continuity, and clear accountability. - The SUBSAFE certification process involves a focused, independent compliance verification organization (NAVSEA 92Q) to verify process capability and discipline. This same organization conducts vertical audits of selected critical submarine components during certification. - Multiple NAVSEA certification processes operate in parallel to ensure safety and operational readiness. - REC (re-entry control) is invoked as a vehicle to ensure that any work accomplished within the SUBSAFE boundary is planned, executed, and tested in a controlled and deliberate manner.
3.7	**NAVSEA 08 Naval Reactors**
	- NAVSEA 08 relies on highly qualified, highly trained people who are held personally accountable for safety. - The NAVSEA 08 management hierarchy (including support management, e.g., Public Communications Director) is technically trained and qualified in nuclear engineering and experienced in nuclear reactor operating principles, requirements, and design. - Problem awareness is essential to high degrees of safety and reliability. NAVSEA 08 demands that problems be raised to the proper levels when they happen and promotes the airing of minority opinions.

Appendix C: Team Membership

NASA Review Team

The NASA Office of Safety and Mission Assurance (OSMA) review team was led by Dr. J. Steven Newman, supported by core team members Mr. Stephen M. Wander, Mr. John Castellano. The NASA team also includes RADM Walter Cantrell USN (Ret.) and David Lengyel, Director of the NASA Aerospace Advisory Panel. Center-based core team members include Mr. Roy Malone and Mr. Vygantas Kulpa from Marshall Space Flight Center (MSFC), Mr. Randy Segert from KSC, and Mr. Michael Fodroci, from Johnson Space Center. NASA subject matter experts include Dr. Michael Stamatelatos (risk management), Ms. Faith Chandler (human factors), Ms. Martha Wetherholt and Ms. Alice Lee (software), and Mr. Tom Whitmeyer (quality). NASA Team executive secretary support was provided by Mr. Henry Hartt, BAE Systems and Mr. Don Vecellio, ARES Corporation.

Figure C.1 NASA/Navy Benchmark Exchange Team: Tactical Planning Meeting August 15, 2002, Washington, DC.

Photo M. Kowaleski

Navy Review Team

The Navy Team was led by CDR Tom Van Petten and Mr. Al Ford, and supported by Mr. Jim Lawrence, Mr. Brian Hughitt, and Mr. Angus Hendrick. Other key Navy participants included Mr. Steve Sites, Mr. Frank Tesoriero, Ms. Kathy Boyles, Mr. Steve Rotolo, Mr. Steve Southard, Mr. Lance Tracey, and Mr. Eric Snider. Navy Team logistics support was provided by Mr. Dan Rooney and Mr. Tom Bacus of Perot Systems.

NNBE Management Team

A management team was formed to direct the overall NNBE. This team is co-chaired by senior representatives from NASA's Office of Safety and Mission Assurance and the NAVSEA 92Q Submarine Safety and Quality Assurance Division. Principal NNBE management team members included Dr. J. Steven Newman, Mr. Stephen M. Wander, Mr. John Castellano, Mr. Al Ford, Mr. Jim Lawrence, Mr. Brian Hughitt, Mr. Henry Hartt, Mr. Don Vecellio, Mr. Dan Rooney, and Mr. Tom Bacus.

Appendix D: Key Documents Reviewed/Exchanged

NAVSEA HQ

1. NAVSEA 0924-062-0010 Rev C, Submarine Safety (SUBSAFE) Requirements Manual, dated 5 Aug 02. (FOUO)

2. NAVSEA SS800-AG-MAN-010/P-9290, Revision A, "System Certification Procedures and Criteria Manual for Deep Submergence Systems.

3. "Summary of Activities of the NAVSEA Submarine Safety Senior Review Group from October 1986 thru Janary 1988," September 1989.

4. "SUBSAFE Program Organization," presented at the Washington Navy Yard, August 13, 2002.

5. SUBSAFE Program Overview, presented by Al Ford, Deputy Director, SUBSAFE and Quality Assurance, August 13, 2002.

6. "Deep Submergence Systems Presentation," by Mr. Steve Southard, NAVSEA, August 13, 2002.

7. "Supervisors of Shipbuilding Conversion & Repair: DoD's Shipbuilding & Ship Repair Technical and Contracts Expertise" presentation of August 13, 2002.

8. "The Navy Ship Industrial Base," slide presentation to the NASA/NAVY Benchmarking Team on August 13, 2002.

9. "Submarine Personnel Qualification Program" presentation by Carl Haines, August 13, 2002.

10. "Generic Training and Educational Requirements" presentation of August 13, 2002.

11. "Material Procurement" presentation of August 13, 2002.

12. Memo dated 17 Jul 2002, from Commander, Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility to Commanding Officer, USS TOPEKA, Subject: Certification Continuity of USS TOPEKA (SSN 754), Availability 201.

13. Memo dated 30 Aug 2002, from Commander, Naval Sea Systems Command, Subject: Detailed Agenda for Submarine Safety Working Group (SSWG) Meeting of 17-19 September 2002.

14. NAVSEA INSTRUCTION 5400.95B, dated 01 May 2002, Subject: Naval Shipyard, SUPSHIP and Fleet Engineering and Technical Authority Policy.

15. NAVSEA INSTRUCTION 5450.55B, dated 18 Jun 01, Subject: Mission, Functions and Tasks of the Submarine Maintenance, Engineering, Planning and Procurement Activity (SUBMEPP), Portsmouth, NH.

16. Memo dated 7 Aug 00, from Commander, Naval Sea Systems Command to Commanding Officer Submarine Maintenance Engineering, Planning and Procurement (SUBMEPP) Activity, Subject: Delegation of Technical and Approval Authority to SUBMEPP, with enclosure.

17. Report dated 02 May 2002, SSN 688 Class Maintenance Plan Rev. List of All Effective Maintenance Requirements.

18. SAMPLE CMP DOCUMENT: "SSN688 Class Maintenance Plan Rev – List of All Effective Maintenance Requirements," 02 May 2002. (FOUO)

19. SAMPLE AP DOCUMENTS: "SSN688 Class Maintenance Requirements (SER 109-01), Ship System Work Description, SWLIN 708A01," Issue 05 Rev 06, p. 3 of 6, Nov 2000. (FOUO)

20. "URO CHANGE: 116 Jun 2002 - Periodic Maintenance Requirements Inventory URO/HIP Sorted by System" Report Date: 30 Jul 2002. (NO FORN)

21. "USS City of Corpus Christi (SSN705) ERO-1 CHGS 311 WP, Ship System Work Description – Issue Two (Re-issue), SWLIN 708A01," p. 4 of 10. (NO FORN)

22. "USS City Corpus Christi (SSN 705) RFN 01 Work Package Supplement, Shipyard Planning & Feedback Report," OWP Issue 02, URO Change No. 097, SWLIN 708A01 – Part 1, 27 Dec 01. (NO FORN)

23. SAMPLE MID DOCUMENTS: SUBMEPP MS No. 5510-081-073 Rev C Chg-2, "Submarine Maintenance Standard, MR Description: Restore Torpedo Tube Blow and Vent Isolation Ball Valves (ALP-274, 275, 276, and 277), Class: SSN688" 05/17/02. (FOUO)

24. SUBMEPP MS No. 7650-081-001 Rev G, "Submarine Maintenance Standard, MR Description: General Acceptance Criteria, Class: SSN21, SSBN726, SSN688, SSN683, MTS 626, 635, SSN774" 02/16/01. (FOUO)

25. URO MRC 008 MOD 40, "Unrestricted Operation (URO) Maintenance Requirement Card (MRC) URO MRC 008 MOD 40," Naval Sea Systems Command, p. 1 of 63, September 2002/Change 117.

26. "SWLIN-GCMA-Description Database Printout," p. 96 of 106, June 05, 2002.

27. "SUBSAFE - SUBMEPP Standardized Test Procedure, Test No: 708-2-1459, Rev/Chg: F2, Class: SSN688, Title: MK 67 Torpedo Tubes – Strength and Tightness Test," 03/27/02.

28. "SUBSAFE - SUBMEPP Standardized Test Procedure, Test No: 708-5-1466, Rev/Chg: D, Class: SSN688, Title: MK 67 Torpedo Tube Water Slug Firing (Submerged)," 02/08/02.

29. NAVSEA Viewgraph presentation regarding "Class Maintenance Planning."

30. NAVSEA Viewgraph of SUBMEPP Supported BPMP Milestones (Flow Chart).

31. NAVSEA Viewgraph of Availability Work Package Planning Process.

32. SUBMEPP Reliability Centered Maintenance (RCM) Analysis Risk Assessment Analysis, RCM Number: 55800902 Rev 0, printed 17-Oct-02. (FOUO)

33. SUBMEPP Command Overview, dated Oct 21, 2002.

34. Baseline AIM "Overview of Component Unit Identifiers," Work Packaging & Control (WPC) Process (Rev. 9311).

35. Uniform Industrial Process Instruction, "Critique Process; Problem Identification and Investigations," issued 05/30/02, Norfolk Naval Shipyard. (FOUO)

36. Submarine Maintenance Standard MS NO. 2560-081-047 REV C CHG-2, "MR Description: Restore main seawater hull valve hydraulic actuators," dated 9/21/01. (NOFORN)

37. SUBSAFE SUBMEPP Standardized Procedure, Test No. 714-3-1477 and DA-3-595A-1477, REV/CHG: E4, CLASS: SSN688 and SSBN726, "3-Inch Launcher – Grooming," dated 9/3/02.

ELECTRIC BOAT

38. Presentation Slides – "System Safety Electric Boat Corporation."

39. Presentation Slides – "Materials Management Overview Presented to NASA," Blair Decker, October 17, 2002.

40. Presentation Slides – "Reliability & Maintainability - Dept 408 RMA and System Safety Engineering - Supervisor: Steve Libby.

41. Presentation Slides – "Establishment and Maintenance of Supplier Ratings."

42. Presentation Slides – "Risk Management - The Electric Boat Sat-For-Sea Process."

43. Presentation Slides – "President's Staff" and other organization charts.

44. Presentation Slides – "Safety Requirements - Definition and Management Emphasis Flowdown to Subcontractors: QA Requirements, Software Assurance Requirements)."

SUBMEPP

45. "SUBMEPP Command Overview" Presentation by Capt Herbein, October 21, 2002.

46. "Delegation of Technical and Approval Authority to SUBMEPP" COM NAVSEA letter 9110 – Ser TSUB/213 – 7 Aug 00.

47. Portsmouth Naval Shipyard Organization Trees.

48. Submarine Maintenance Standard – MS NO. 2560-081-047 Rev C Change-2 9/21/01 ("Restore main sea water hull valve hydraulic actuators"). (NOFORN)

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Appendix E: NNBE Acronyms and Terms

ADS	Atmospheric Dive Suit
APU	Auxiliary Power Unit
ARC	Ames Research Center
ASAP	Aerospace Safety Advisory Panel
Availability	Availability of ship/depot for required maintenance
BESS	Basic Enlisted Submarine School
CA	Corrective Action
CAR	Corrective Action Report
CASREP	Casualty Report
CBM	Condition-Based Maintenance
CCB	Change Control Board
CDR	Critical Design Review
CIL	Critical Items List
CLCS	Computer Launch Control System
CLS	Contingency Landing Site
CM	Configuration Management
CoFR	Certification of Flight Readiness
COMSUBLANT	Commander Submarines, Atlantic
COMSUBPAC	Commander Submarines, Pacific
DCAA	Defense Contract Audit Agency
DDS	Dry Deck Shelter
DIP	Design Improvement Proposal
DSRV	Deep Submergence Rescue Vehicle
DSS-SOC	Deep Submergence System-Scope of Certification
ECP	Engineering Change Proposal
EQA	Engineering Quality Assurance
ET	External Tank
FDRD	Flight Definition Requirements Document
FMEA	Failure Modes and Effects Analysis
FR	Firing Room
FRR	Flight Readiness Review
FTA	Fault Tree Analysis
GD/EB	General Dynamics/Electric Boat
GMIP	Government Mandatory Inspection Point
GPC	General Purpose Computer
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
GSI	Government Source Inspection
HM&E	Hull, Mechanical and Electrical
IMA	Intermediate Maintenance Activity
INSRP	Interagency Nuclear Safety Review Panel
IPT	Integrated Product Team
ISE	In-Service Engineer

IV&V	Independent Verification and Validation (software)
JFMM	Joint Fleet Maintenance Manual
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LAR	Liaison Action Report
LaRC	Langley Research Center
LARS	Launch and Recovery System
LH2	Liquid Hydrogen
LI	Level I
LOX	Liquid Oxygen
L-X	X days to launch
MAF	Michoud Assembly Facility
MAT	Major Area Team
MAX Q	maximum dynamic pressure
MECO	Main Engine Cutoff
MET	Mission Elapsed Time
MGT	Management
MIC	Mission Integration Center
MLP	Mobile Launch Platform
MMP	Multi-Mission Platform
MMT	Mission Management Team
MOA	Memorandum of Agreement
MRB	Material Review Board
MRC	Maintenance Requirement Card
MRR	Mission Readiness Review
MSFC	Marshall Space Flight Center
MSRP	Material Selection Requirements Plan
NAVAIR	Naval Air Systems Command
NAVSEA 03:	Human Systems Integration in System Design
NAVSEA 04	Logistics, Maintenance, & Industrial Operations
NAVSEA 05	Ship Design, Integration and Engineering
NAVSEA 08	Naval Reactors
NAVSEA 92	Submarine Directorate
NAVSEA 92Q	SUBSAFE/Quality Assurance
NAVSEA 92T	Technical
NAVSEA	Naval Sea Systems Command
NAVSEALOGCEN	NAVSEA Logistics Center
NDE	Nondestructive Evaluation
NDT	Non-Destructive Testing
NEPA	National Environmental Policy Act
NEQA	NASA Engineering and Quality Audit
NNBE	NASA/Navy Benchmarking Exchange
NNPI	Nuclear Navy Propulsion Information
NPD	NASA Policy Directive
NPG	NASA Procedures and Guidelines

NPS	Nominal Pipe Size
NR	NAVSEA 08 Naval Reactors
NRRO	Naval Reactors Representative Office
NSWC	Naval Surface Warfare Center
NUWC	Naval Underwater Warfare Center
OMI	Operations Maintenance Instruction
OPF	Orbiter Processing Facility
OPNAV	Office of Chief of Naval Operations
OQE	Objective Quality Evidence
ORD	Operational Requirements Document
P/L	Payload
PAR	Pre-flight Assessment Review
PAT	Process Action Team
PDR	Preliminary Design Review
PE	Procedures Evaluation
PEO	Program Executive Officer
PFMEA	Process Failure Modes and Effects Analysis
PM	Program Manager
PMAG	Program Management Assistance Group
PMMT	Pre-launch Mission Management Team
PNS	Portsmouth Naval Ship Yard
PQA	Procurement Quality Assurance
PR	Procedures Review
PRA	Probabilistic Risk Assessment
PRCB	Program Requirements Control Board
PV	Process Verification
PVI	Product Verification Inspection
QA	Quality Assurance
QALI	Quality Assurance Letter of Inspection
QDR	Quality Deficiency Report
QPM	Quality Performance Manual
RCM	Reliability-Centered Maintenance
REC	Re-entry Control
RFI	Ready For Issue
RTLS	Return to Launch Site
SAIL	Shuttle Avionics Integration Laboratory
SAP	Ship Alteration Proposal
SAR	Ship Alteration Record
SCA	Shuttle Carrier Aircraft
SCN	Ship Construction, New
SHAPEC	Ship Availability Planning and Engineering Center
SHIPALT	Ship Alteration
SIMA	Shore Intermediate Maintenance Activity
SIT	System Integration Team
SLI	Space Launch Initiative
SOF	Special Operations Forces

SOM	SUPSHIP Operations Manual
SOSG	Supervisor of Shipbuilding, Groton
SOSN	Supervisor of Shipbuilding, Newport News
SOW	Statement of Work
SRB	Solid Rocket Booster
SRC	Submarine Rescue Chamber
SRD	Selected Record Drawing
SS	SUBSAFE
SS Manual	NAVSEA 0924-062-0010 Rev C
SSBN	Submarine Ship, Ballistic, Nuclear
SSC	Stennis Space Center
SSGN	Submarine Ship, Guided, Nuclear
SSIC	SUBSAFE Improvement Committee
SSME	Space Shuttle Main Engine
SSN	Submarine Ship, Nuclear (Fast Attack)
SSPD	SUBSAFE Program Director
SSWG	SUBSAFE Working Group
STS	Space Transportation System (Space Shuttle)
SUBMEPP	Submarine Maintenance Engineering, Planning and Procurement
SUBSAFE	Submarine Safety
SUPSHIP	Supervisor of Shipbuilding, Conversion and Repair
TAG	Technical Advisory Group
TAL	Trans-Atlantic Landing
TCDT	Terminal Countdown Demonstration Test
TDP	Technical Data Package
TECH	Technical
TGI	Task Group Instruction
TRS	Training Record System
TWD	Task Work Document
TYCO	Type Commander (COMSUBLANT and COMSUBPAC)
UMR	Unsatisfactory Material Reporting
URO	Unrestricted Operations
UTRS	Uniform Technical Requirements System
VAB	Vehicle Assembly Building
WAD	Work Authorization Document
WAF	Work Authorization Form
WBS	Work Breakdown Structure
WNY	Washington Navy Yard
WSESRB	NAVSEA Weapons System Explosive Safety Review Board