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Report to the Chairman, Subcommittee on Projection Forces and Regional Defense, Committee on Armed Services, U.S. Senate

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SUBMARINE COMBAT SYSTEM

Technical Challenges Confronting Navy's Seawolf AN/BSY-2 Development

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The Honorable Edward M. Kennedy
Chairman, Subcommittee on Projection Forces
and Regional Defense
Committee on Armed Services
United States Senate

Dear Mr. Chairman:

During a December 1988 briefing and in subsequent discussions with your office, we agreed to identify areas that will need continued management oversight by the Department of the Navy in its efforts to develop the AN/BSY-2 combat system (BSY-2) for the new SSN-21 Seawolf attack submarine. BSY-2 is an advanced computer system designed to detect, classify, track, and launch weapons at enemy subsurface, surface, and land targets. In response to the Soviet submarine threat, BSY-2 is designed to (1) enable the submarine to detect and locate targets faster, (2) allow operators to perform multiple tasks and address multiple targets concurrently, and (3) ultimately reduce the time between detecting a threat and launching weapons.

In March 1988, the Navy contracted with the General Electric Company for full-scale development of BSY-2 and production of the first three systems. Delivery of the first BSY-2 system is required by November 1993 to meet the scheduled delivery of the first SSN-21 submarine in May 1995. Total development and procurement costs for 28 planned BSY-2 combat computer systems are estimated to be $9.1 billion.

Development of the BSY-2 system is one of the largest computer software development efforts ever undertaken for a submarine. The Navy faces significant challenges to meet the performance requirements within the tight time frames and budget established. We have identified several areas to date where the Navy's early and continuing management attention should be focused if the Navy is going to successfully meet these challenges. These areas include (1) developing and integrating a massive amount of software, most of which is planned to be written in a relatively new computer language for which there is a shortage of experienced programmers; (2) designing a system with sufficient reliability to ensure mission needs are met; (3) developing, refining, and testing a model to accurately predict system performance; (4) ensuring there is sufficient time for the government to witness software testing and to resolve identified problems; and (5) ensuring that independent verification and validation assessments are performed on the software development effort.

Since the BSY-2 program is early in the planning stages of design and development, the system's performance cannot yet be evaluated. However, generally there's a greater opportunity to avoid increases in program costs and schedule slippage and to ensure that the system meets performance requirements if problems associated with system design, development, integration, test, and evaluation are addressed early in the life cycle of the project. We believe the BSY-2 contractor and the Department of the Navy have an early opportunity to focus management attention on these areas and take appropriate actions to mitigate potential cost, schedule, and performance problems.

Can the Navy Maintain Its Software Development Schedule?

The contractor's software development plan estimates that the combat system will require up to 900 software personnel to develop and integrate[1] about 3.6 million lines of code written predominately in the Ada programming language. This is a massive software development effort for which few experienced Ada programmers exist and no consistent training program has been developed by the contractor. Attempting to develop this amount of code without adequately trained, experienced programmers could affect the development schedule by reducing the level of programmer performance, increasing the number of coding errors, or both. These areas will require continuing attention by the Navy.

Responsibility for developing the software will be shared by seven development organizations under the direction of the prime contractor: four within the prime contractor's company and three subcontractors. The contractor is planning to reduce the development risk inherent in the size of the system by partitioning the system into 113 work packages, called building blocks, each containing up to 75,000 lines of code.[2] Even though the contractor is planning to partition code development, integrating 113 separately developed building blocks, averaging 30,000 lines each, will be a complex and time-consuming undertaking.

[1]The term integrate means incorporating many software modules written by different programming teams so that together they constitute an effective system.

[2]The Navy's statement of work allows building blocks to be even larger than 75,000 lines "if explicitly approved by the government." The software development plan states that the contractor plans to limit building blocks size to 30,000 lines of code, on the average.

The software development effort is further complicated because most of the software, approximately 2.2 million lines, is to be developed in the Ada programming language. Ada has not been used extensively and the existing pool of experienced programmers is small. While most of the contractor's software development organizations have experience in developing large-scale combat systems, they have little experience using the Ada language.

According to the Ada Adoption Handbook,[3] expertise in writing Ada is important. The handbook states that Ada development contractors should have a proven record of providing quality Ada programs within cost, on schedule, of high quality, and within the application domain. According to the handbook, a contractor attempting to do a large Ada development without Ada experience presents a risk.

Officials from two of the software development organizations responsible for developing large amounts of software stated they do not have extensive Ada experience. For example, one development organization has responsibility for developing approximately 770,000 lines of Ada code; however, only a few staff members have experience using the Ada language. Similarly, another development organization, responsible for developing approximately 355,500 lines of Ada code, has no past experience in Ada.

Further, software development officials recognize there is a small pool of experienced Ada programmers currently available in industry, and are thus not imposing strict hiring requirements for experienced Ada programmers. According to the October 1988 version of the Software Development Plan, only one of the seven development organizations, responsible for 407,000 lines of code, is specifically requiring programmers to have prior Ada experience.

The Ada Adoption Handbook also states that the contractor should, among other things, develop and execute a long-term, phased training plan that includes all levels of staff and software engineering principles. The handbook stresses the importance of the prime contractor's office levying training requirements on all development organizations to help ensure consistency in methodology, standards, and approach across the entire development effort. According to the handbook, the amount of

[3]The Ada Adoption Handbook was published in May 1987 by the Software Engineering Institute, a federally funded research and development center sponsored by the Department of Defense under contract to Carnegie-Mellon University.

training necessary is dependent on a programmer's background. In some cases, becoming a truly productive Ada programmer can involve 4 to 6 months of experience.

The prime contractor has not required consistent training programs for the seven development organizations, and is essentially leaving each of the development organizations to train their programmers as they see fit. For example, one organization planned to provide programmers with 2 weeks of training in-house, while a second organization plans to hire a training vendor to provide 4 weeks of training for staff, with the length of training time dependent on the person's development role. Under this program, mid-level programmers would receive about 19 days of training, while lower-level staff would receive about 12 days of training. A third organization has not decided what type of training to provide its staff. As of January 1989, with software development scheduled to begin as early as October 1989, some of the software development organizations had not finalized their training plans and the Navy does not have adequate assurance that sufficient and consistent training will be provided to BSY-2 programmers.

Does the System's Design Provide Sufficient Reliability?

The Navy needs to be assured that the system will meet the specified performance requirements. We noted that the contractor plans to provide system reliability for the weapons cluster by designing 100 percent redundancy in this cluster, and designing the other clusters with less than 100 percent redundancy. At this early stage of development, Navy does not fully understand the impact of providing various levels of redundancy on mission capability. Before committing to a final design, currently scheduled for August 1989, it is important that the Navy evaluate and document how the system with its various redundancy and priority levels will meet required mission capabilities.

According to contractor officials, the current BSY-2 system design consists of approximately 200 processors,[4] assigned to perform various functions within the combat system. The system design calls for processors performing related functions to be grouped together in four clusters: (1) acoustics, (2) command and decision, (3) weapons, and (4) display.

[4] A processor is the part of the computer that interprets and executes instructions. A processor, in this report, refers to the Motorola 68030 enhanced 32-bit microprocessor.

According to Navy officials, the contract specifies requirements for the system's availability and reliability. It does not specify how the contractor is to satisfy these requirements, such as the level of redundancy or back-up, for individual processors or groups of processors. As such, the contractor is developing a system design that provides a designated back-up spare for each of the four processors in the weapons cluster so that, if any processor fails, it will be electronically replaced with its spare. This means all processors in the cluster have 100 percent redundancy. However, the same level of redundancy is not being provided for the other three clusters.

Contractor officials said that the system design for the three clusters that will not have 100 percent redundancy employs a variety of operational procedures to provide back-up support if one or more processors in a cluster should fail. As these clusters are currently being designed, a failure in one or more of the processors in the cluster would result in one of three outcomes. First, two or three spare processors are available for the three clusters and could be electronically substituted for a failed processor or processors. Second, other processors in the affected cluster might be available to be used as spares, if their specific function was not being performed at the time. Third, if all available processors are in use and some of them begin to fail, the system will lose some operational capability.

Once operational capability is lost, a prioritized list of functions to be performed is planned to be used. This list ensures that minimum defensive functions, called "self-protect" functions, can be maintained at all times. These defensive functions would protect the submarine from damage by hostile forces, but would not provide the submarine with the full capability it would need to perform its attack mission.

Finally, if a cluster begins to lose operational capability, additional spare processors carried aboard the submarine could be manually connected into the system. Although additional spare processors will be available, they would not be interconnected with the system, and may take more time than available in a threat situation to manually replace a failed processor.[5]

[5]The precise time frame to manually replace a processor is classified information.

Will the Design Model Provide Accurate Analysis of System Performance?

A model that accurately represents a system and its behavior under the full range of operational conditions is important in order to provide assurance that a proposed design will be capable of meeting contract requirements before substantial resources are invested. Estimates show that the cost of correcting software mistakes escalates as a program progresses, costing 10 to 100 times as much to correct the same error in operational software as in preliminary design.

Because of the complexity of the BSY-2 combat system design and its use of multiple processors, it is crucial that accurate simulation and modelling be done early in the design phase and continued throughout development. According to contractor officials, early analyses are being conducted with a limited and incomplete set of assumptions that do not incorporate parameters, such as the time needed to reconfigure the system in the event of processor failure, the time required for a processor to perform its particular function, or the amount of data that the system will have to process.

Further, when the simulation was run, the values of certain critical parameters, such as message sizes and the time for an operator to respond to messages from the system, were not varied. As a result, little is known about how the system will behave under realistic, operational conditions. Only after a complete, realistic, and accurate set of simulations have been completed and analyzed can the adequacy of system performance against requirements be determined. Contractor officials have stated that more extensive simulations will be conducted and a complete model developed in the future.

Is the Testing Schedule Reasonable and Procedures Adequate?

For the BSY-2 effort, the Navy expressed its intentions to maintain early government visibility over the contractor's building block testing efforts and to ensure retesting is performed when significant code changes are made. According to Navy officials, this visibility was intended to ensure that problems are identified and fixed as early in development as possible, when corrections are more cheaply and quickly made, as opposed to later, after hundreds of thousands of lines of code have been integrated and changes are often difficult and expensive to make. Retesting after changes are made to tested software is intended to verify that the changes do not adversely impact other portions of the system.

Each development organization is tasked to develop certain software subcomponents, integrate them into building blocks, and then test groups of building blocks to demonstrate the performance of various functions. The prime contractor will integrate all the building blocks and begin testing groups of functions. Each building block is planned to undergo government-witnessed testing prior to its integration at the contractor's program office.

This integration and test period is scheduled to span 5 years, from 1989 to 1994.[6] However, during the period from April 1993 to June 1994 the Navy is planning to conduct one-third of the government-witnessed tests, resolve all problems identified during these tests, and successfully integrate the building blocks into the complete system. Leaving this amount of work for the final 14 months allows the Navy little flexibility to resolve problems discovered in the testing without adversely affecting system delivery.

A risk may also exist with regard to retesting building blocks after changes have been made. The Navy included a requirement in its statement of work that if five percent or more of a building block is changed after government-witnessed testing, the entire building block must be retested. Navy officials informed us that this five percent threshold is intended to ensure that significant changes are retested. The officials stated that they used their subjective judgment in choosing five percent of a building block as the amount of code change at which to begin requiring retesting of the entire building block. However, changes of less than five percent of the code in building blocks of up to 75,000 lines of code could still amount to almost 3,750 lines without mandating retesting of the entire building block.

Contractor officials stated they would perform some retesting on changes under the five percent threshold, but it is unclear how and to what degree the contractor's retest efforts would ensure that changes did not affect other parts of the software. Given this situation, the Navy may not have adequate assurance that developed software will be stable. Because of the critical nature of this system, the risk of unstable software is unacceptable.[7]

[6]The contractor plans to provide the first BSY-2 system by November 1993, but this first system will not possess full capabilities. Additional software needed to increase the system's performance to full operational capability is planned to be tested and integrated beginning in April 1993 and delivered in June 1994, just prior to the final system design certification test.

[7]Unstable software is a term applied to software that is unpredictable, that may or may not perform as expected or may not produce consistent results when run against a known set of operating conditions.

Are Adequate Independent Verification and Validation Tasks Planned?

Independent verification and validation (IV&V) is comprised of specific activities conducted throughout software development by an organization not responsible for developing system software. Verification tasks are intended to verify the accuracy of the specifications, requirements, and design, while validation tasks are later performed to test the software products to measure performance and ensure compliance with requirements. An independent verification and validation process is important to reduce risk in software development. The other military services have published official guidance on the use of independent verification and validation to improve the reliability, performance, and integrity of software being developed and to reduce system life-cycle costs.

The Navy has designated an in-house organization—the Naval Underwater Systems Center—to perform IV&V tasks. This organization has assisted the Navy's BSY-2 program office in managing the contractor's system development, such as reviewing contract deliverable documents for contract compliance. The center has also performed other program tasks, such as developing specifications from the top-level requirements. As such, we question whether this organization has an appropriate level of independence and whether a risk may exist that substantial, technical IV&V tasks may not be effectively performed.

At this point in the program's development, the Navy's plan is not complete and lacks the level of detail required to implement an independent verification and validation program. The Naval Underwater Systems Center has yet to develop a complete IV&V plan, even though the development phase is already 12 months old and a major design review is scheduled for May 1989. Considering the magnitude of the BSY-2 development, both in terms of development effort required and significance to the Navy, effective planning for and implementation of IV&V procedures could be an appropriate step toward reducing development risk.

Observations

The Navy faces several technical challenges in developing BSY-2 that, if addressed early and completely, could significantly reduce risk. Technical issues exist in the areas of the system design for reliability and modelling for system performance, which could either result in degraded capabilities or impaired system performance. In particular, the lack of spare processors could, under some conditions, degrade the attack mission of the submarine.

In the software development and testing areas, additional steps could be taken to minimize the possibility that errors will not be discovered until later in the project, when it will be costly to identify and correct them. Emphasizing Ada training for the nearly 900 software personnel needed to develop BSY-2 and coordinating consistent training among the development organizations could prove cost-effective in reducing the risk of significant errors later.

Finally, effective use of IV&V can be a useful risk reduction tool. Ensuring that IV&V tasks are effectively performed on the BSY-2 project could well be worth the investment by identifying potential weaknesses in development efforts and resolving them early on in development.

The development schedule provides little flexibility for BSY-2 program delays. Despite the stringent schedule, the importance of resolving these issues before system development is too far along cannot be overstated. Further, an appropriate time to deal with these issues is now, in the design and development phase, rather than later in development when correction could cause large cost overruns or schedule delays.

Appendix I describes our assignment objectives, scope, and methodology. While we did not obtain official agency comments on a draft of this report, we discussed the contents of this report with Navy officials, and incorporated their views where applicable. BSY-2 program officials generally agreed with the technical issues we raised, and said they would focus management attention on them. With regard to the Naval Underwater Systems Center's ability to perform independent verification and validation duties, the officials felt that the center was capable of performing these duties if properly tasked and supervised. Our work, conducted between August 1988 and February 1989, was performed in accordance with generally accepted government auditing standards.

As arranged with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution of it until 30 days from the date of this letter. At that time, we will send copies of this report to the Chairmen, Senate and House Committees on Appropriations and the House Committee on Armed Services. We will also send copies to other interested parties and make copies available upon request.

This report was prepared under the direction of Samuel W. Bowlin, Director for Defense and Aeronautics Mission Systems. Other major contributors are listed in appendix II.

Sincerely yours,

Ralph V. Carlone

Ralph V. Carlone
Assistant Comptroller General

Objectives, Scope, and Methodology

In response to a request from the Chairman, Subcommittee on Projection Forces and Regional Defense, Senate Armed Services Committee, and in subsequent discussions with the Chairman's office, we agreed to identify technical challenges confronting the Department of the Navy in its efforts to develop the AN/BSY-2 combat system (BSY-2) for the new SSN-21 Seawolf attack submarine. Our work focused on four technical areas: system design, software development, testing and integration, and use of independent verification and validation. We performed our work between August 1988 and February 1989 at Navy, contractor, and subcontractor offices having responsibility under the BSY-2 program. We worked primarily at the Naval Underwater Systems Center in Newport, Rhode Island; the Naval Sea Systems Command's BSY-2 Program Office, in Arlington, Virginia; and the General Electric Corporation in Syracuse, New York.

We interviewed numerous Navy, contractor, and subcontractor officials responsible for BSY-2 design and development, and analyzed relevant BSY-2 documents, including the BSY-2 contract, technical data and preliminary design documents, the System Design Document, the Software Development Plan, the Master Test and Evaluation Plan, and various Navy and Defense policies and regulations. We also interviewed other military department officials, vendor representatives, and private experts knowledgeable in the technical aspects associated with BSY-2 and with the Ada programming language.

To obtain background information on the BSY-2 program, we analyzed relevant Defense and GAO reports and BSY-2 contract documents. For information about current plans and the design for BSY-2, we interviewed prime contractor management officials responsible for systems engineering, software development, and testing and integration.

To obtain information on the Ada programming language, we interviewed various Ada experts; Ada training vendors; officials at Carnegie-Mellon University's Software Engineering Institute in Pittsburgh, Pennsylvania; and Defense's Ada Joint Program Office in Arlington, Virginia. We analyzed vendors' Ada training plans, the Ada Adoption Handbook, and prior reports on Ada.

We discussed the use of independent verification and validation and relevant Defense regulations with Defense officials, independent verification and validation contractors, and the Naval Underwater Systems Center.

While we did not obtain official agency comments on a draft of this report, we discussed the contents of this report with Navy officials, and have included their comments where appropriate. We conducted our review in accordance with generally accepted government auditing standards.

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