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Proposed Structuring of Preliminary Design and Equipment Testing for an Early EMP Posture

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Abstract

The Navy is currently working towards developing organized procedures and documentation requirements to analyze the EMP survivability of a ship and its equipment in the early stages of the ship design process. At this time, a number of standardized equipment-level and platform-level inspection and test procedures already exist which could be structured in such a way that an organized and streamlined hardening analysis could be performed. The new approach could be used to more effectively identify improvements to ship EMP hardening and equipment hardening treatments. With this proposed approach, the total ship system could be evaluated against its specified EMP test requirements early enough in the design and construction stages for corrections to be implemented in the most cost effective manner. Further, the approach proposed can enhance the trade-off between more rigorous ship hardening or improved hardening of the equipment.

Introduction

Systems engineering principles were applied to an existing area of concern in order to evaluate, streamline, and standardize the early ship topside Electromagnetic Pulse (EMP) design process. The primary objective of this effort was to develop an overall generic EMP platform-level evaluation structure that incorporated all available supporting documentation and requirements. Specifically, the effort was directed at incorporating previous requirements documents, visual surveys, EMP assessments, and box, system, and/or platform-level EMP test results with a structured and simplified process that could be used when necessary in an iterative process to predict EMP hardness of ships and ship's equipment at various stages prior to formal testing. The key to this effort was to identify the correct information and techniques necessary to support hardening predictions at whatever stage they became available.

As depicted in Figure 1, evidence exists that EMP generated threats can access sensitive electrical connections through an opening in a ship bulkhead. Historically, EMP design guidelines and requirements have been followed by the ship builder with the expectation that correct installation of the shielding would provide sufficient EMP protection. Equipment to be placed on the ship would be somehow additionally hardened or otherwise protected as necessary from EMP threats on an equipment-by-equipment basis at some later date. Standards are currently being developed specifically for ship design [1], [2]. Visual inspections during and after the construction phase are used to verify that the design guidelines are satisfied.

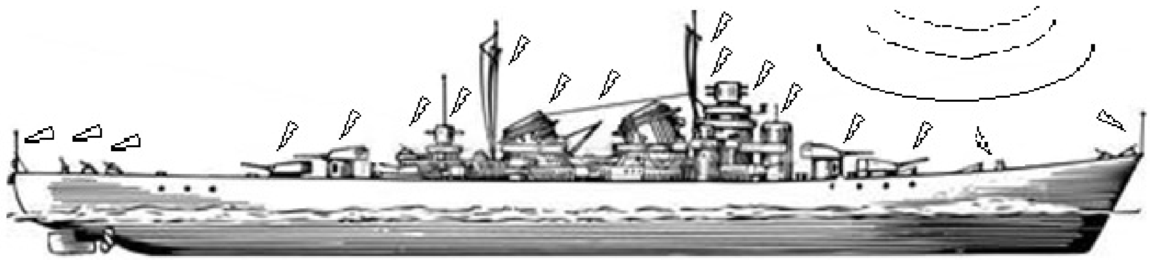

Figure 1 - EMP Penetration

EMP shipboard equipment assessments to determine damage thresholds have also existed at levels ranging from rough guess to minutely detailed mathematically complicated predictions. Computer programs are available to examine coupling capabilities and component failure thresholds. Box-level test procedures and guidelines have been developed [3], [4] are in place to analyze a number of susceptibility characteristics for the equipment being installed on a ship.

With all these various parts to the puzzle in place or available, a structure is needed to tie everything together such that it can be applied from ship acquisition through on-board installation of new equipment, and finally to the pre- trial evaluations in preparation for formal EMPRESS II testing. First let us examine where the first application of design guidance might be the least expensive and most useful, the acquisition process.

Ship Acquisition Process

OPNAV Instruction 9010.300B describes the development of Naval ship characteristics for ship acquisition. In this instruction, details of the process for the orderly development of ship characteristics during the acquisition process are described. Figure 2 shows the principal structure of this acquisition process.

Concept Exploration			Demonstration & Validation	Full Scale Development		Production
USN Ship	Mission Need	Feasibility Studies	Preliminary Design	Contract Design	Lead Ship Design & Cost	Following Ships
			PDR	CDR		

Figure 3 – Stages of the Ship Acquisition Process

Note that during the contract design phase, sufficient lead time exists, simple changes could be implemented without significantly affecting overall costs.

What process or analysis techniques are available, what informational requirements are necessary to support the analysis efforts, and what results could provide useful guidance during the time period covered by the contract design and/or construction phases? Available ship design information during the design phase includes mast or antenna height, cable shielding methods and characteristics, wire-way trunk and waveguide requirements [5], and grounding methods. Some widely used and matured computer-aided EMP coupling analysis programs are also available, both proprietary and as commercial products.

Another piece of information necessary to perform a preliminary analysis, and one which is not always available is expected equipment susceptibility characteristics. However, some useful information is available regardless of the type of equipment to be installed. Here again, as with installation guidelines, there are susceptibility requirements and test documents that can be applied against any potential equipment deployed. MIL-STD 461C contains EMP hardening requirements that will provide useful guidance in allowing the estimation of potential EMP problems well before the ship is actually built.

Streamlining the Magnitude of the Problem

Due to the interactive nature of the problem, streamlining an iterative EMP assessment effort that begins early in the ship design process and carries through construction is a difficult goal to achieve. The following tasks were identified to accomplish this objective.

1. Identify the informational requirements for a higher level of confidence and more effective assessment process including problem and shortfall identification.
2. Prepare a format and structure for the analysis in support of documentation requirements.
3. Review related activities and coordinate activities with other outside organizations to insure community or related requirements are not in conflict.
4. Prepare informational requirements for document development and submission to review organizations.

The estimate of a potential EMP problem on a ship platform is not precise since each system will have a multitude of cable routings and their associated input circuits will have a large variation of actual susceptibility thresholds. Accurate EMP assessments are usually approached at a micro level not a macro level. Prior industry thinking on this issue has resulted in dismissing the usefulness of "rough" EMP predictions at early stages in the design. However, early in the design process it really does not matter since all we are trying to identify at this point are major problems. In addition, as computer-aided processing capabilities become more refined, including the Navy's database of system level coupling effects for Navy combat system equipment, so called "rough" predictions become better and better.

Let us hypothesize that a rough EMP estimate is possible. If the equipment to be installed has a requirements specification that must be met, then some susceptibility prediction is possible. A safety margin could then be used to assign a preference for additional ship hardening measures if necessary. Another streamlining measure could be to only assess a worst case single cable pin for each ship antenna or point of entry (POE). A closer look is necessary.

The Early Prediction Process

What we have early in the design program is the simple flow diagram shown in Figure 3. The process allows an assessor to make optimum use of various data sources and commercially available software prediction programs for a "rough" estimate of expected pin threat for a representative sampling of cables. The question here is "Will the analysis data prediction that can be generated at this point be useful?"

To answer the question of usefulness, we need to address where probable predictive data would help modify the emerging ship design. Let us say, for example, that a paper design exists for a ship. Each of the openings or external electrical cables of a ship is a potential point-of-entry (POE) for an EMP threat to enter the victim system. No previous ship with a similar design had ever been EMP tested with EMPRESS II, and all electronic systems on the ship were new.

Depending upon the cable configuration used with a particular susceptible shipboard system, the threat signal at the circuit level will be some combination of the voltages and currents developed across the POE's along the signal path from the external system component to the susceptible internal circuit. A worst-case threat is estimated if the assumption is made that all the coupled threats (including cross coupling or "back door" coupling) are in phase.

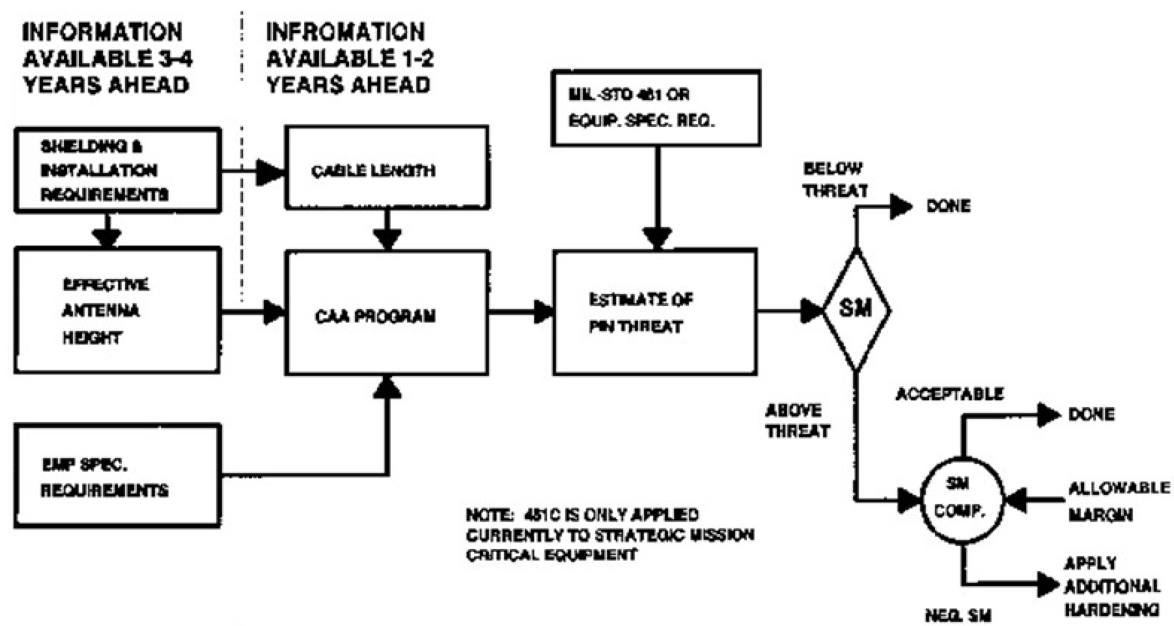

Figure 3 - Flow Diagram of Early Design Documents

Since we knew the height of the mast, and also where a particular antenna type will be located during the ship design, we use a typical software EMP coupling program [6] to calculate the expected pin level threat from the MIL-STD field strength burst. We can also assume that, provided the guidelines of design specifications, including MIL-STD 1310E [7] and MIL-STD 16400 [8] are followed, we will have a minimum of 40 dB additional attenuation provided by the shielded cabling from the antenna POE. The new equipment must be tested to the MIL-STD 461C RS05 radiated levels and CS10 and 11 pin threat levels. Therefore, by comparing the calculated threat level to the to-be-tested threat level, we can easily determine if the potential for a susceptibility problem exists. Namely, if there is a negative safety margin, a susceptibility problem is possible.

Developing an Iterative Strategy

The most useful assessment process would be one that was able to utilize data from whatever sources were available at any given time and also one that could incorporate new information for ultimate upgrading of the susceptibility prediction. Such a process would need to be hierarchical in nature so that some newer input data would be "worth more" to the prediction then other previous or related data. In other words, system-level testing would be worth more than box-level testing which would be worth more than computer predictions. Some structured hierarchal approach is also necessary to take into account previous data and incorporate requirements documents into the process. The information from each source document feeds into an overall document we have called the EMP Control Plan at this time.

In assigning a value to each data source, if the same system was tested in a similar configuration at a previous EMPRESS II test, the value of this data would be worth more than the results of previous lower-level analysis or test results. Mid- level test results and system-level test results have similar data value and need further explaining.

Mid-level testing relates to several test techniques designed to augment hardening evaluations on less-than-full systems and in preparation for Empress II testing. They are designed to verify safe operation of equipment when exposed to full threat and are not intended as qualification testing. Five test types have been identified [9], with a rough description of each presented below.

- RS05 is considered a mid-level test when performed on less than a full system or box. It is intended to determine the system/equipment susceptibility to upset and/or damage at 50 KV/m threat.

- RS-W01 is a free-field continuous wave (FFCW) low-level swept CW test. This is currently a developmental
- R&D test procedure intended to verify hardening treatments on ships.

- CS-W01 is a QA type test which determines grounding effectiveness of installed topside hardening. Known as the Pulse Current Injection (PCI) test technique, the test injects a 10 amp 2 MHz damped cosine waveform through a current probe into the cable. A ship builder can verify that he has satisfactorily met his cable installation and design requirements by PCI testing. The limitation of this test is that it does not evaluate back door coupling nor does it generate the full threat pulse. It does, however, allow for threat extrapolation based on shielding attenuation of the actual platform.

- CS-W02 is a direct drive test which uses a predicted synthesized waveform for determining the vulnerability of a system or equipment.

- CS-W03 is a modified MIL-STD 461 CS11 test which determines equipment vulnerability to 10 amp cable coupling. The test consists of injecting the damped cosine bulk current at three fixed frequencies.

- CS-W04 is similar to CS-W03 but drives the cable to upset with a repetitive waveform injection at increasing amplitude.

System-level testing is EMP testing on full systems, but less than full platforms, using EMPRESS I, TEM cell, or parallel plate type testing such as depicted in Figure 4 and 5. In this case, the system to be tested is installed in a representative configuration between the plates or near the Pulsar (EMPRESS I) and pulsed with the specified EMP field strength.

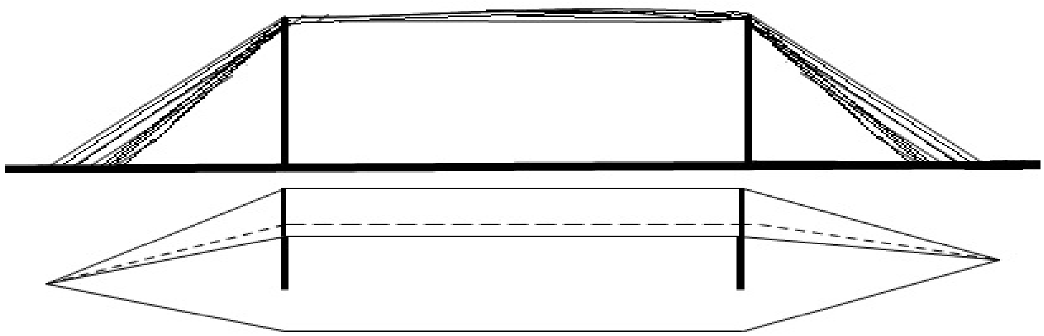

Figure 4 – Typical Bounded Wave Simulator

The parallel plate line is a bounded wave type simulator capable of generating fields to approximately 1 GHz. The main advantages of a parallel plate line are simple structure, well-defined radiating characteristics, and predictable behavior as a load to the pulse generator. The advantage of a TEM cell is that the intense field remains completely within the boundaries of the apparatus.

The parallel plate transmission line is essentially a strip line consisting of two rectangular sheets of conductive material, usually of equal length but one often wider than the other, and separated. The sheets are driven and terminated at their respective narrow ends. A TEM mode field is created between the two plates as shown in Figure 5. While this test method does look at system hardening at full threat, there will still normally be differences, sometimes significant, related to cross-coupling from other systems when the tested system is actually installed on a platform. A disadvantage of this test is that the field is not contained between the plates as in the bounded simulator as shown in the figure.

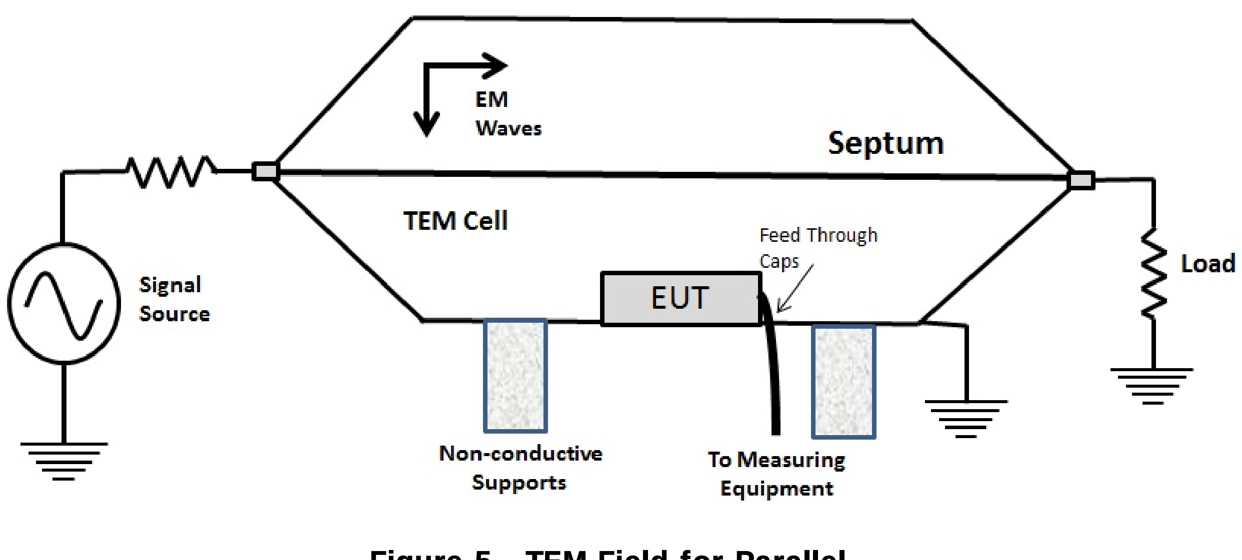

Figure 5 - TEM Field for Parallel Plate Transmission Line

MIL-STD 461, while currently undergoing review, is a well-established test standard for Navy equipment. Although some equipment may not meet the RS05, CS10 or CS11 EMP test limitations specified, it is still a very useful document for box-level susceptibility verification. It is also the earliest available test document in many instances, and its test limits are certainly useful when early paper design assessments are performed.

System analytical studies are basically equipment or system- level assessments or predictions of potential susceptibility problems. As previously indicated, an assessment can be as detailed or as simple as necessary depending on the sensitivity of the information required.

The Assessment Process

Box-level EMI Design Control Plans are "living" design documents that start out with theoretical predictions or assessments that are slowly replaced with actual design data and R&D test results as the design nears completion. Could a similar approach be applied at the macro level to a ship platform? A simple assessment process (theoretical) applicable early in the design phase has been discussed. The final issue remains of how to inexpensively make the assessment process iterative such that earlier assessment data can be replaced by better assessment data as the design progresses.

What data is necessary for an assessment and where does it come from? Figure 6 shows the technical input requirements necessary for a formal EMP assessment. We have already discussed what input data might be available from a paperwork design. A document exists, the EMP Ship Survey and Exposed Cable Data Report [10], commonly referred to as the Penetration Report, that supports a number of data fields including cable length and location, penetration treatment, and cable manufacturing specifications (characteristic impedance and transfer impedance).

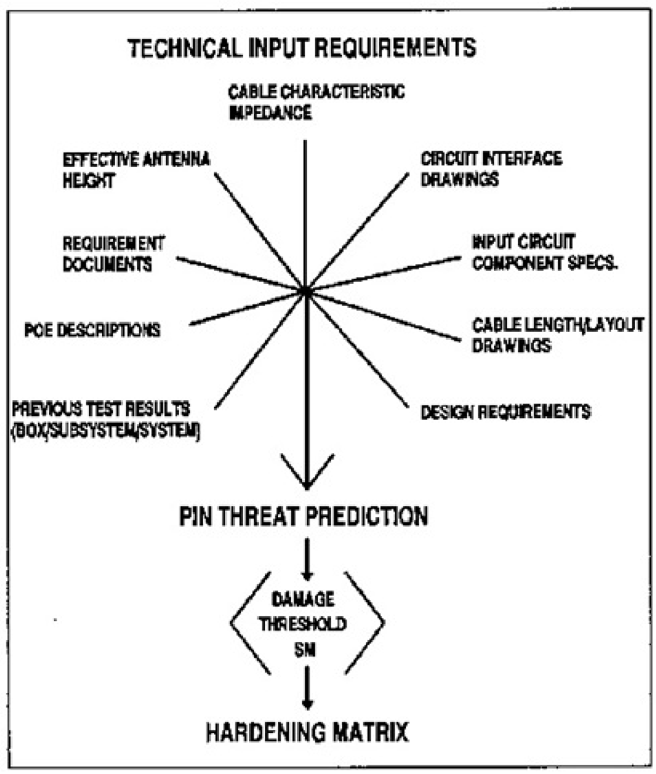

Figure 6 - Formal EMP Hardening Prediction Assessment Data

Previous test data from systems installed on similar ships may or may not be available. In addition, circuit interface drawings and pin threat projections are probably not available initially, but will certainly become available at some point during the system design and platform integration process. Therefore, each of the necessary data inputs exists or will become available as the design progresses.

Streamlining the Useful Equipment Data

Current early design assessment techniques are often overly detailed and costly simply because the assessor does not know where a problem might show up unless he actually looks. Formal assessments of installed equipment on operational ships are expensive for the same reason. The suggested streamlined assessment technique is not intended to replace formal assessments, but it is intended to provide a viable prediction alternative to formal assessments at a time period when the full formal assessment is not necessary.

An important distinction should be made regarding the cost of early design and operational ship assessments. As more detailed equipment design data and information becomes available, the danger with continuing to use an assessment approach is expensive overkill. By more detailed design information, the author means actual interface circuit schematics and/or actual input device information. Overkill can therefore be minimized by narrowing the focus of an assessment approach to some predetermined application at specific points in the design or build program.

Narrowing the focus of an effort involves reducing what would otherwise be needed. Since there are limitations to the usefulness of early assessments, a scope reduction is possible. To achieve the objective, some attempt at streamlining and filtering out repetitive or less useful information must be applied to the overall problem. A straightforward inexpensive technique for assessing EMP susceptibility was previously described. An application of the approach is suggested herein which will greatly decrease the magnitude of the assessment problem.

Several techniques are useful for streamlining. In many cases, a number of input pins exist on a particular connector interface, and these interfaces are not upgraded when a new system is designed. This is done so a new system can easily replace an older installed system. In addition, often the same line driver or receiver circuit is used for a number of interface signal lines. Therefore, there is already a built-in reduction mechanism for many cables; similar connectors and line driver/receiver combinations.

The next reduction technique concentrates on evaluating only the most sensitive circuit in a cable bundle based on some predetermined guidelines. Since upgrades to pre-existing equipment would likely have similar interfaces, a quick review of previous assessments or test reports would reveal what could be considered as one of, or in fact, the single most sensitive circuit in a particular cable bundle. This circuit input would be the one pin evaluated in the early assessment. Other similar cable runs with similar, though not necessarily exact, interface circuits would not be evaluated. It is important to note here that choosing a particular sensitive circuit, while maybe not the most sensitive circuit, will provide sufficient information for a useful hardness assessment at this stage of the design process.

As a final method of reduction, only a representative sampling of cables from each to-be-deployed system would be evaluated. In this manner, even an assessment for a platform with many systems could be streamlined into a manageable and inexpensive program. Documentation requirements for this approach could be formatted and presented in methods outlined in a Data Item Description (DID).

Assessment Flexibility

There is an inherent flexibility to using an upgradable and hierarchal approach for equipment EMP assessments. The major advantage is that, as each successive new source of information is uncovered based on new test or evaluation results, the previous assessment can be upgraded. In other words, the structured hardening evaluation becomes a "living document" which tracks the ship and its EMP hardening upgrades from conceptual design through final platform-level EMPRESS II testing.

Conclusions

There currently exists the documents and data sources necessary to perform preliminary EMP hardening assessments early in the design, and also the structure and techniques necessary to upgrade the assessment predictions as the new ship design and construction progresses. The suggested structure and techniques are both iterative, and hierarchical in their usefulness to the overall EMP susceptibility requirement. The incorporation of a systems approach can provide cost savings by reducing uncertainty and re- work later in a ship acquisition and test program.

Acknowledgements

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Footnotes

[1] (SPAWAR SPEC. under development)
[2] **Recommended Element Hardening Evaluation, Verification, & Instrumentation Guidelines** (DRAFT Stage), NSWC.
[3] **Suggested Electronic Equipment Standards for Nuclear Weapons Environments**, NSWC TR 87-192, 15 January 1988.
[4] **Ship General Specification**, Section 407 & 408.
[5] **Electromagnetic Pulse (EMP) Protection for Navy Ships, Materials and Methods for**, NAVSEA Technical Report No. 407-TR- 0001, 22 September 1987.
[6] Two such programs are MACE (Jaycore) and NEC II (Numerical Electromagnetic Code, Lawrence Livermore, Jan 81)
[7] MIL-STD 1310E (NAVY), **Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility and Safety**, 8 Feb 1979.
[8] MIL-STD 16400, **EMP Protection for US Navy Ships**, Materials & Methods for, NAVSEA TR 407-TR-0001, 22 Sep 1987.
[9] (see Ref. 2) [10] Ingalls Shipbuilding, **POE Baseline IV Configured Ship Sampling**