DIRECTORATE OF ANALYSIS

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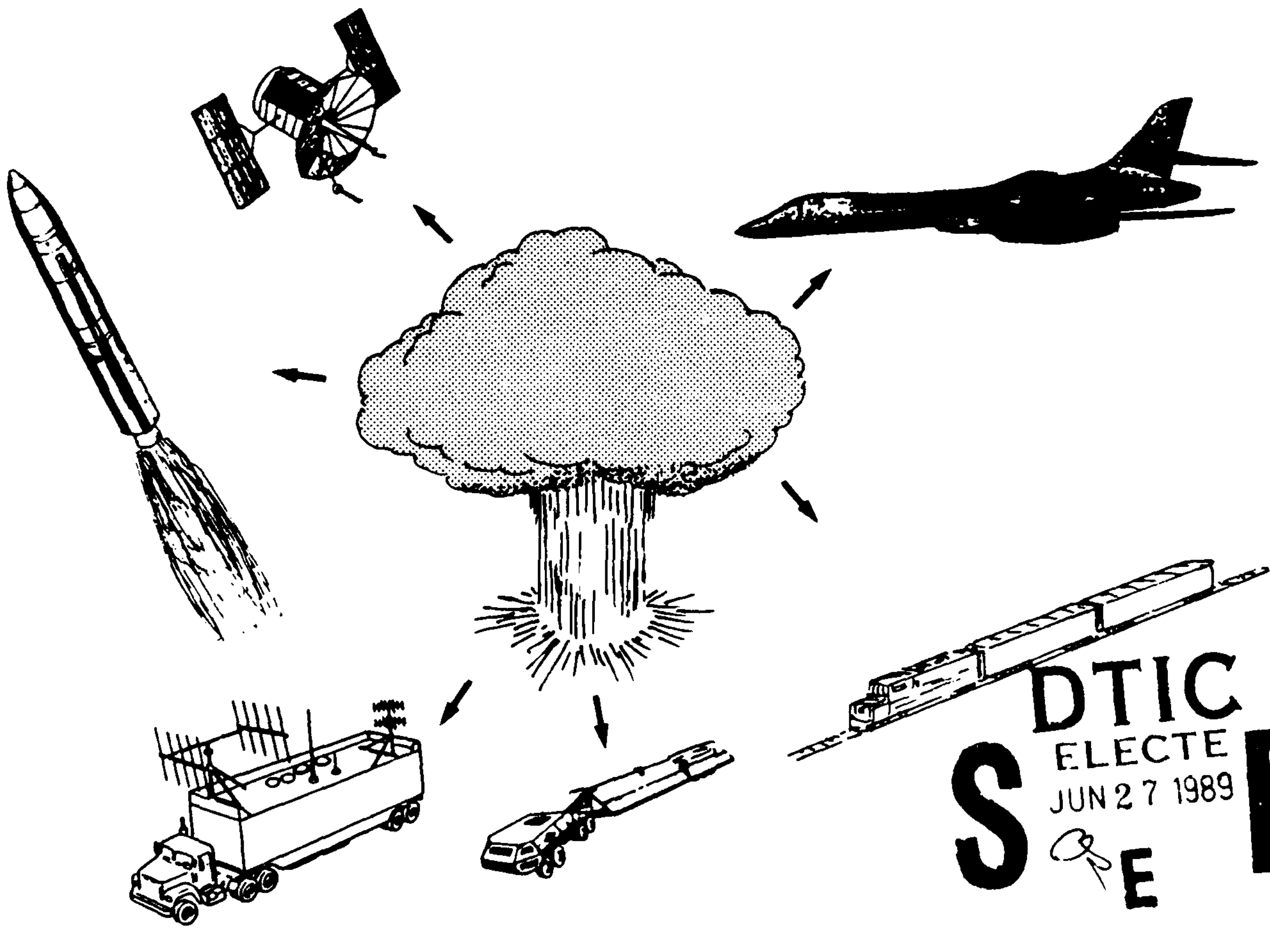
INTRODUCTION TO THE OPERATIONAL NUCLEAR SURVIVABILITY ASSESSMENT PROCESS



TECHNICAL PAPER 13.0 APRIL 88 OPR: AFOTEC/OAS

PREFACE TO THE ANALYSIS DIRECTORATE

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Donald M. Douglas, Col, USAF
Director of Analysis

This series of technical papers will only be as good as you, the ops effectiveness analysts, make it. Certainly each paper can be improved, and there may be additional subject areas of general interest. I solicit your feedback and constructive criticism. All the papers can be rapidly edited and redistributed, so if you have thoughts please contact me.

Mike Stolle, GM-15
OA Technical Advisor

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ACRONYMS AND ABBREVIATIONS

AF	Air Force
AFCSA	Air Force Center for Studies and Analysis
AF/IN	Air Force Intelligence Office
AFOTEC	Air Force Operational Test and Evaluation Center
AFOTEC/LG	Air Force Operational Test and Evaluation Center Logistics Directorate
AFR	Air Force Regulation
ASAT	Antisatellite
cal/cm^2	Calories per centimeter squared
CDR	Critical Design Review
CQ+I	Critical Questions and Issues
DCP	Decision Coordinating Paper
DNA	Defense Nuclear Agency
DoDD	Department of Defense Directive
DT&E	Development Test and Evaluation
EAM	Emergency Action Message
EMP	Electromagnetic Pulse
ESA	Electrical Surge Arrestor
FSED	Full Scale Engineering Development
FT	Feet
GAIT	Ground/Airborne Integrated Terminals
GTP	General Test Plan
HCI	Hardness Critical Item
HEMP	High Altitude Electromagnetic Pulse
HM	Hardness Maintenance
HM/HS	Hardness Maintenance and Hardness Surveillance
HS	Hardness Surveillance
ICBM	Intercontinental Ballistic Missile
IEMP	Internal Electromagnetic Pulse
IOC	Initial Operational Capability
kT	Kiloton
LCF	Launch Control Facility
LF	Launch Facility
LRU	Line Replaceable Unit
MCE	Mission Critical Element
MCF	Mission Critical Function

ACRONYMS AND ABBREVIATIONS

MCF/E	Mission Critical Function and Equipment
MILSTAR	Military, Strategic, Tactical and Relay
MT	Megaton
N/A	Not Applicable
NAM	Nuclear Assessment Methodology
NAP	Nuclear Assessment Plan
NCGS	Nuclear Criteria Group Secretariat
n/cm^2	Neutrons per centimeter squared
NEP	Nuclear Event Protection
NH&S	Nuclear Hardness and Survivability
OT&E	Operational Test and Evaluation
PMD	Program Management Directive
psi	Pounds per square inch
rads(Si)/sec	Absorbed dose of ionizing radiation per second equal to an energy of 100 ergs per gram of silicon
RV	Reentry Vehicle
SATCOM	Satellite Communication
SGEMP	System Generated Electromagnetic Pulse
SORD	System Operational Requirements Document
SOW	Statement of Work
SPO	System Program Office
SRA	System Requirements Analysis
SRAM	Short-Range Attack Missile
SREMP	Source Region Electromagnetic Pulse
TEMP	Test and Evaluation Master Plan
TO	Technical Order
TREE	Transient Radiation Effects on Electronics

INTRODUCTION TO THE
OPERATIONAL NUCLEAR SURVIVABILITY ASSESSMENT PROCESS

1.0 INTRODUCTION

The objective of this document is to introduce the AFOTEC project analyst to the process of conducting an operational assessment of weapon system performance in the nuclear threat environment. A Nuclear Assessment Methodology (NAM) has been developed and implemented by AFOTEC to assess weapon system operational effectiveness. The goal of the operational nuclear survivability process is to assess the weapon system performance characteristics and employment techniques that are impacted by operation in the nuclear threat environment. The focus of this document is how this methodology is implemented for various types of weapon systems from both a technical and management perspective. The intent is to provide the project analyst: (1) a basis for effectively managing operational test and evaluation ~~(OT&E)~~ nuclear survivability assessments and (2) a top level understanding of the technical requirements.

This section presents a brief discussion of the AFOTEC role in the acquisition process of major Air Force systems and presents an overview of the OT&E NAM. Subsequent sections will describe in more detail how the methodology is implemented and the types of results the project analyst may expect from an assessment. ~~In addition,~~ a brief description of nuclear effects is provided to familiarize the project analyst with the terminology and environments related to nuclear weapons.

1.1 AFOTEC's ROLE

The role of AFOTEC in the acquisition process is to conduct independent and objective evaluations of the system's operational effectiveness and suitability. AFOTEC brings the operational perspective by assembling a team with the appropriate operational experience and technical credentials. In a combined development, test and evaluation (DT&E) and OT&E program, AFOTEC may observe DT&E tests, participate in combined DT&E/OT&E tests, and conduct separate OT&E activities through analysis and test.

The inclusion of nuclear survivability in the OT&E process is a relatively new development in the acquisition of major Air Force systems. AFOTEC developed an assessment approach based on the use of combined DT&E/OT&E data and activities to ensure efficient use of available test and analysis resources. This led to the AFOTEC NAM -- the methodology emphasizes assessment of the performance impacts of exposure to a nuclear environment, as opposed to an independent validation of DT&E results. In this process AFOTEC uses its influence to ensure DT&E/OT&E testing is conducted under as operationally realistic conditions as possible and that sufficient data is collected to permit an assessment of operational impacts.

1.2 OVERVIEW OF THE NUCLEAR ASSESSMENT METHODOLOGY

The NAM process, depicted in Figure 1-1, was developed as a structured way of reducing the problem to the issues most vital to system performance which can be assessed given the program's DT&E/OT&E data expectations. The NAM process consists of two phases, Nuclear Assessment Plan (NAP) Development and Nuclear Assessment Plan Implementation. The overall process begins with a review of the following documents to familiarize the project analyst with top level program requirements and issues:

(1) Decision Coordinating Paper (CDP)
(2) System Operational Requirements Document (SORD)
(3) Program Management Directive (PMD)
(4) Test and Evaluation Master Plan (TEMP)
(5) Survivability Plan
(6) DT&E/OT&E Test Plans

These documents provide the fundamental background to begin the NAM process.

The NAM begins with Development of the NAP. An understanding of how the system operates to complete its mission, the operational nuclear environments experienced by the system and the system resistance to those environments are key to NAP Development and form the foundation for NAP Implementation. System functional data is normally obtained from the system developer, i.e., design specifications, and from the using command, i.e., the SORD. These documents are reviewed to identify those system functions critical to mission performance and the equipment associated with each function.

The susceptibility of the system is based on the type of nuclear environments the system will experience during its mission. These environments are determined from user provided operational scenarios and the operational concept.

Most systems are designed with nuclear effects hardness features which drive the system vulnerability to the nuclear environments. System hardness data is acquired from the developer for equipment which performs the critical functions and used to determine vulnerability.

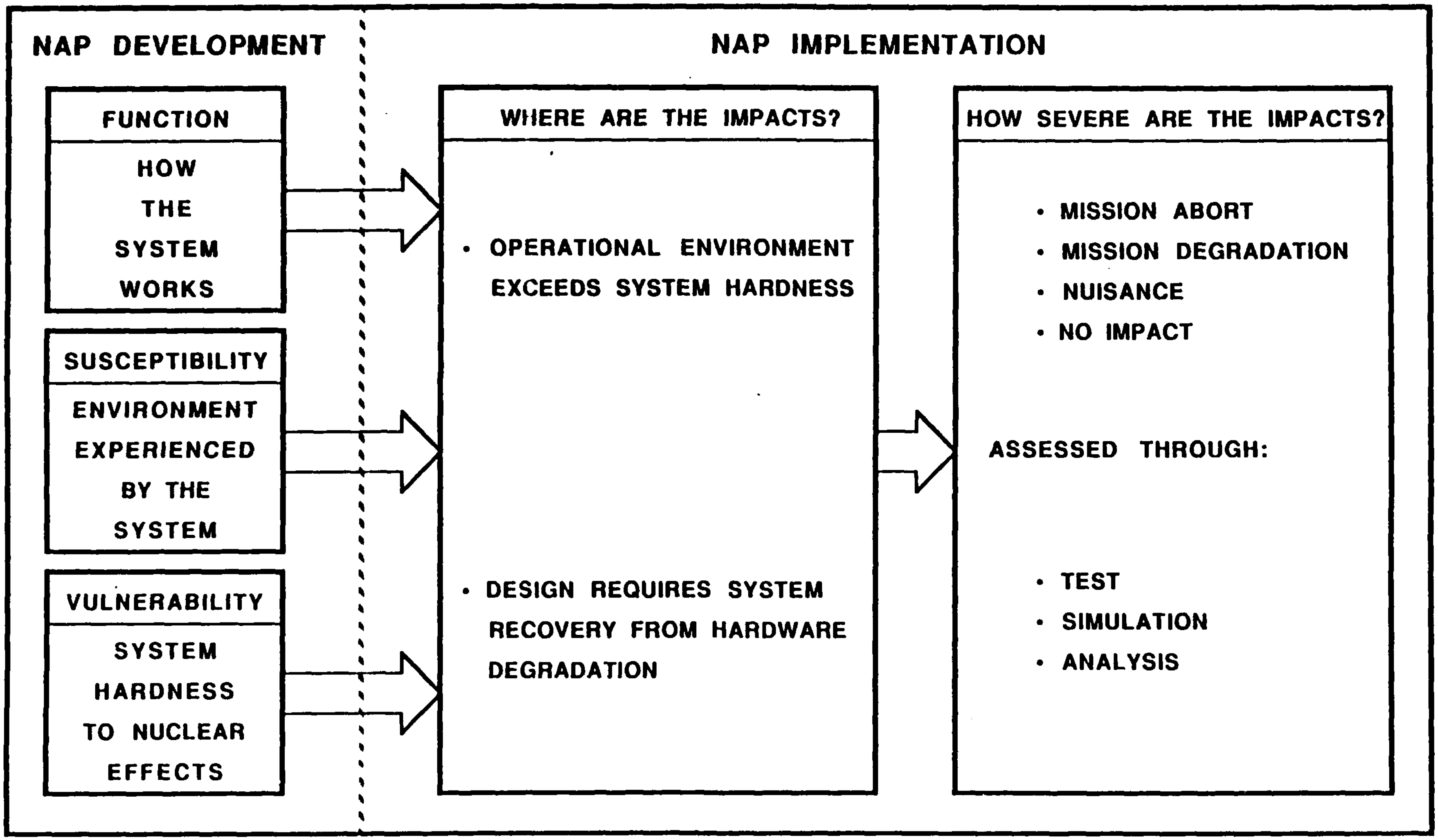

Figure 1-1. Nuclear Assessment Process

These three areas (functions, susceptibility and vulnerability) are assessed during NAP development to focus the OT&E towards identifying performance penalties due to system operation in the nuclear threat environment. During NAP Implementation, the test and analysis data are assembled and investigated to identify mission impacts due to operation in the nuclear environments. There are two conditions which generally lead to mission impacts:

(1) The operational nuclear environment exceeds system hardness levels.

(2) System design requires recovery from nuclear environment induced equipment degradation and resultant functional degradation.

The severity of the mission impacts, which can vary from a mission abort to no impact, are assessed by a combination of test and analysis. The planned development test and evaluation (DT&E) nuclear hardness and survivability (NH&S) program provides system hardness and vulnerability data. The user provided, and AFOTEC refined, scenarios provide the susceptibility data. Combined DT&E/OT&E tests as well as dedicated OT&E tests at the system level are used to identify mission impact severity as the system is used to perform its operational functions. The major tasks the project analyst will perform during NAP Implementation are integrating test requirements, executing tests, and identifying mission impacts. The NAP Development and Implementation tasks are defined in more detail in Section 2.0.

1.3 OVERVIEW OF NUCLEAR EFFECTS

It is important for the project analyst to understand the basics of nuclear effects as they play a key part in the system level OT&E assessment process. A knowledge of nuclear effects is required to narrow the scope of the assessment as discussed in NAP development subsections 2.2.1.2 and 2.2.1.3.

Table 1-1 summarizes the nuclear weapon environments and the effects these environments may have on various systems and system elements. A nuclear detonation can generate eight nuclear environments, as listed in Table 1-1, to which a system may be susceptible. The type of systems which are susceptible to the different nuclear environments are marked in the table. The susceptible systems may contain components which are vulnerable to the nuclear environment effects. The function of these components in the system may be degraded resulting in potential mission impacts. The listing of nuclear weapons characteristics in Table 1-1 is obviously not exhaustive,

Table 1-1. Nuclear Environment Effects

NUCLEAR ENVIRONMENTS	SYSTEMS: GROUND SYSTEMS*	SYSTEMS: AIRCRAFT	SYSTEMS: SATELLITES	SYSTEMS: MISSILES IN-FLIGHT	COMPONENT TYPES: ELECTRICAL	COMPONENT TYPES: MECHANICAL	COMPONENT TYPES: HUMAN	EFFECTS ON COMPONENTS	POTENTIAL MISSION IMPACTS
NUCLEAR RADIATION · NEUTRONS · GAMMA	●	●	●	●	●	●	●	· DISPLACEMENT · IONIZATION · NUCLEAR HEATING · EXCITATION · IEMP · TREE	· SYSTEM FAILURE DUE TO LOSS OF COMMUNICATION/PROCESSING EQUIPMENT · SYSTEM FUNCTIONAL DELAY DUE TO TRANSIENT UPSET OF COMMUNICATION/PROCESSING EQUIPMENT
EMP -SREMP -HEMP	●	●	●	●	●			· CONNECTOR SOLDER MELT · SPURIOUS CURRENTS · INDUCED VOLTAGES · MAGNETIC FIELDS	· SYSTEM FAILURE DUE TO LOSS OF COMMUNICATION/PROCESSING EQUIPMENT OR POWER SYSTEMS · SYSTEM FUNCTIONAL DELAY DUE TO TRANSIENT UPSET OF COMMUNICATION/PROCESSING EQUIPMENT
X-RAYS			●	●	●	●	●	· SURFACE REMOVAL · SPALLATION · DEBONDING · X-RAY HEATING · BLOW-OFF IMPULSE · THERMOMECHANICAL STRESS · SGEMP · TREE	· SYSTEM FAILURE DUE TO LOSS OF COMMUNICATION/PROCESSING EQUIPMENT · SYSTEM FUNCTIONAL DELAY DUE TO TRANSIENT UPSET OF COMMUNICATION/PROCESSING EQUIPMENT
THERMAL RADIATION	●	●	●	●	●	●	●	· HEATING · ABLATION	· SYSTEM FAILURE DUE TO STRUCTURAL DAMAGE OR LOSS OF COMMUNICATION/PROCESSING EQUIPMENT
AIRBLAST	●	●			●	●	●	· OVERPRESSURE · GUST · IMPULSE	· SYSTEM FAILURE DUE TO STRUCTURAL DAMAGE OR LOSS OF COMMUNICATION/PROCESSING EQUIPMENT
DEBRIS	●	●			●	●	●	· EROSION · HEATING · PENETRATION · INGESTION	· SYSTEM FAILURE DUE TO STRUCTURAL DAMAGE OR LOSS OF COMMUNICATION/PROCESSING EQUIPMENT OR ENVIRONMENTAL/POWER SYSTEMS
GROUND SHOCK	●				●	●	●	· GROUND MOTION · CRATERING	· SYSTEM FAILURE DUE TO STRUCTURAL DAMAGE OR ELECTRICAL DISCONNECTIONS · SYSTEM FUNCTIONAL DELAY DUE TO TEMPORARY DISABLEMENT OF CREW
SCINTILLATION/ ABSORPTION	●		●					N/A	· COMMUNICATION PROPAGATION PATH DISTURBANCES RESULTING IN SIGNAL LOSS FOR PERIODS OF TIME

* GROUND SYSTEMS INCLUDE: (1) MOBILE OR STATIONARY COMMUNICATIONS STATIONS AND (2) MOBILE OR STATIONARY LAUNCH FACILITIES (WITH MISSILE LAUNCH THROUGH ZERO PHASE OF FLIGHT).

but provides a checklist of effects the project analyst should be aware of when managing an OT&E assessment. A more detailed description is provided in Appendix A.

To become more familiar with the terminology and technology associated with nuclear weapons, the reader should refer to Appendix A. In most assessments, the project analyst will rely on the technical expertise of the support contractor in evaluating applicable nuclear environments and potential effects on the system.

2.0 NUCLEAR ASSESSMENT METHODOLOGY (NAM)

2.1 INTRODUCTION

Over the past several years AFOTEC has developed, implemented, and updated the NAM. The NAM can be applied to both strategic and tactical systems and is unique in its ability to bring the operational perspective to the highly technical and DT&E dominated field of nuclear survivability.

The first major assessment of this kind performed by AFOTEC was the evaluation of the Peacekeeper Intercontinental Ballistic Missile (ICBM) system based in existing Minuteman silos. The lessons learned from the program have been used to improve the methodology and have been applied to such systems as the MILSTAR terminal, the SRAM II missile, the Nuclear Detection System Ground/Airborne Integrated Terminals (GAIT), and to a limited extent, the B1-B bomber. The AFOTEC project analyst should use the documents generated in these and other programs as references to learn both the basics of the NAM and gain an understanding of how the process can be managed successfully. A list of these documents is contained in the bibliography.

The methodology is essential for the development of a NAP as well as successfully implementing the NAP to identify mission impacts due to system operation in the nuclear environments. Because of the many technical complexities involved in the overall process, AFOTEC uses a technical support contractor for assistance. The contractor support is orchestrated by the project analyst and assistance in executing the NAP is obtained from the AFOTEC test team. The project analyst, contractor, and test team must work together to successfully implement the NAM. These and other important factors are addressed in the detailed discussion of NAM implementation provided below.

2.2 NUCLEAR ASSESSMENT METHODOLOGY IMPLEMENTATION

Table 2-1 shows the tasks required in a simplified NAM. The NAM essentially consists of two phases: (1) development of the NAP and (2) implementation of the NAP to assess the system. There are specific tasks required to be performed during each phase to achieve the assessment objectives. It should be noted, however, that the assessment process is highly concurrent in that some implementation as well as planning tasks may need to be performed early to coincide with the combined DT&E/OT&E program schedules. For example, certain test requirements may need to be identified earlier than NAP preparation to meet program schedules and later refined or updated. In addition, operational scenarios which should be defined during NAP development may be refined during implementation due to changes in threat or operational concepts. The NAM has proven flexible and can accommodate major changes in user requirements or developer test schedules that occur during most acquisition schedules.

Table 2-1. Nuclear Assessment Methodology

PHASE I: NAP DEVELOPMENT

TASKS

- Mission Definition
- Operational Scenarios
- Initial Dominant Nuclear Environments Definition
- Mission Critical Function/Mission Critical Equipment Identification
- Potentially Degradable MCF/MCE Identification
- Candidate Mission Impacts Identification for Further Analysis
- Data Opportunity and Deficiency Identification
- Program Plan Preparation for NAP Implementation
- Nuclear Assessment Plan Preparation

PHASE II: NAP IMPLEMENTATION AND ASSESSMENT

TASKS

- Operational Scenario Refinement
- Operational/Nuclear Environments Refinement
- Test Requirements Identification and Integration
- Data Shortfall Identification and Resolution
- Test and Analysis Execution
- Test Monitoring/Participation
- Mission Impact Assessments
- HM/HS Reporting

The project analyst and support contractor tasks required to implement the two NAM phases are described in the following subsections. The support contractor should keep the project analyst informed of current task status by providing informal task reports (not official contract deliverables) as major portions are completed.

2.2.1 NAP Development

The basis for NAP development includes the results of: (1) mission definition, (2) operational scenario development and the initial estimation of dominant nuclear environments, (3) potentially degradable mission critical function (MCF) and mission critical equipment (MCE) identification, (4) data opportunity and deficiency identification, (5) candidate mission impacts, and (6) program plan development. The NAP objectives, subobjectives, and measures of effectiveness are derived from the critical issues and assessment objectives defined in the OT&E Test Plan developed by AFOTEC for the system. The NAP development process (Phase I) is shown in flow format in Figure 2-1. Each NAP development task is depicted as a block in the flow and is described in subsections to follow.

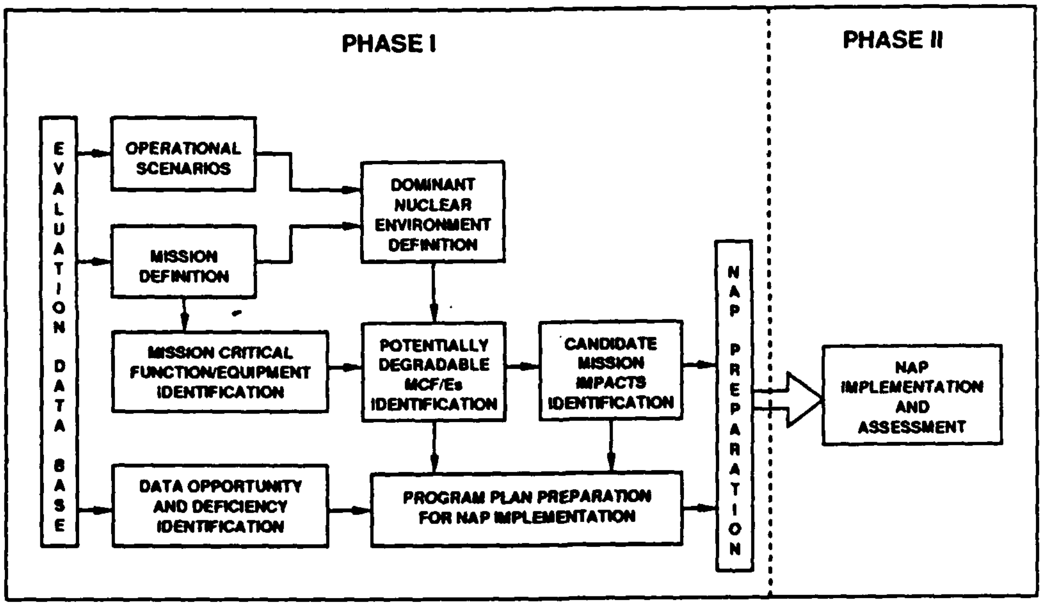

Figure 2-1. Developing the NAP

2.2.1.1 Mission Definition

Each weapon system, whether strategic or tactical, has a unique mission or set of missions associated with it. Mission definition is important for mission critical function identification, operational scenario development, and, later on, development of measures of effectiveness defined in the NAP. The using command will have defined the mission specifically in their SORD and this is one of the first sources the analyst should review to aid in mission definition. The mission definition should contain the objectives and timeline of the mission, details of the functions the system must perform to accomplish its mission, the timing of those functions, and the location and configuration of the system at the time the functions are performed.

The AFOTEC project analyst must associate an operational mission scenario with the basic mission definition to permit inclusion of performance requirements such as timeline, accuracy and endurance. The system responsiveness will be influenced by whether it is associated with strategic warning, tactical warning or both. Strategic warning is usually referred to in terms of hours or days while tactical warning can be minutes. The warning time and mission response definition provide the analyst the data needed to develop a mission timeline. This timeline is needed to identify mission critical functions and operational scenarios as well as to determine response time related measures of effectiveness.

To clarify a "mission definition," it is beneficial to construct an example. The Peacekeeper ICBM has a time-on-target mission with a required accuracy and a defined range once the message to launch is transmitted by higher authority. Therefore, there are four major mission requirements that must be met to achieve this goal: (1) the message to launch has to be successfully received at the launch control facility, (2) the missile must be targeted and launched from the silo within a certain launch reaction time, (3) the missile must function properly to provide the required flight range, and (4) the missile must function properly such that the target is impacted with the required accuracy. The timeline that is associated with these mission requirements is shown in Figure 2-2. Breaking the timeline into mission phases, as demonstrated in Figure 2-2, aids the project analyst in identifying mission critical functions and defining operational threat scenarios.

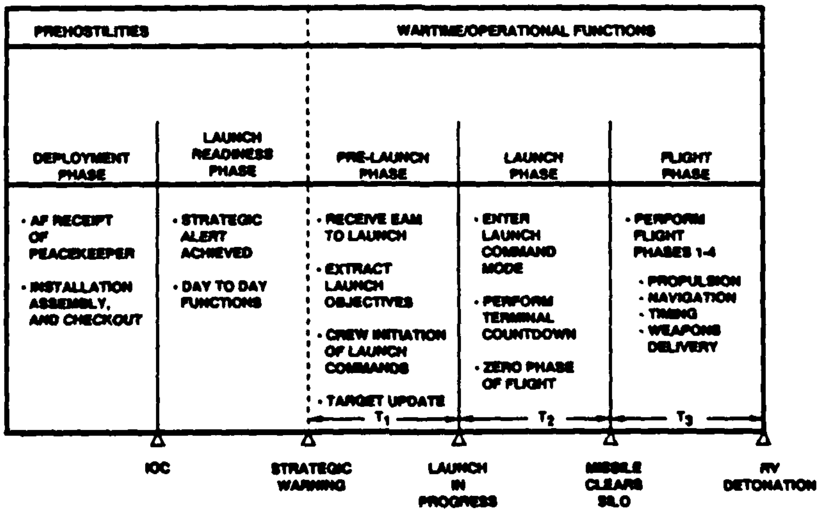

Figure 2-2. Peacekeeper Operational Timeline Example

2.2.1.2 Operational Scenarios

In the context of the NAM, operational scenario is a rather loose term used as a basis for development of the nuclear threats against the system. There are two aspects to operational scenario development -- how the system is intended to be used i.e., its mission and user requirements, and the nuclear attacks against the system which are likely. To assist the project analyst in operational scenario development, AFOTEC has prepared Technical Paper 11.0, Developing Operational Threat Scenarios (April 1987).

Figure 2-3 below presents a sample operational scenario for a satellite communication (SATCOM) system. This sample operational scenario shows the aggregate of all potential nuclear effects on the SATCOM system, i.e., scintillation and a nuclear antisatellite (ASAT) attack would not be expected to occur at the same time. Once all possible system threats are established, it must be determined in which mission phase they are valid. The AFOTEC project analyst in conjunction with the support contractor should establish a complete operational scenario such as the one depicted in Figure 2-3 for the system being assessed. Beginning with a detailed operational scenario which includes all possible threats to the system allows the analyst to decide which threats are reasonable for the system, based on mission phase, how much effort the contractor should devote to each, and how to best integrate the threat environment survivability into the combined DT&E/OT&E test efforts.

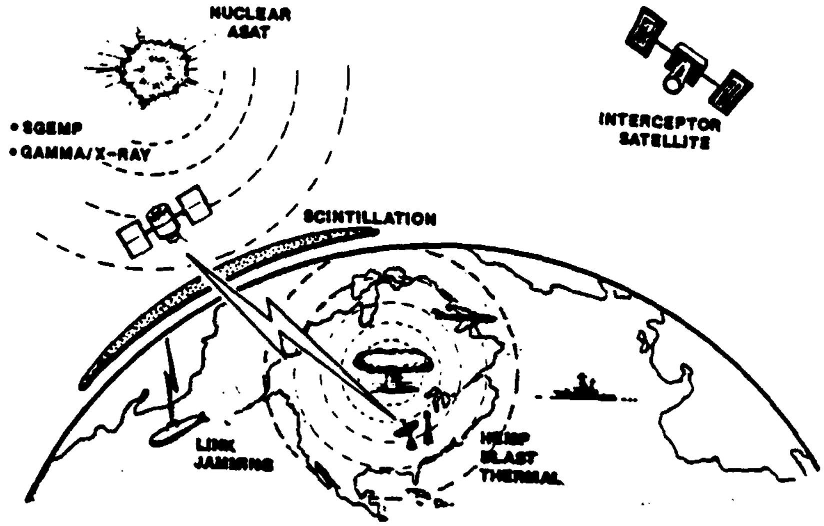

Figure 2-3. Operational Scenario Example

AFOTEC is not responsible for the actual generation of scenarios; rather, resources are used from various Air Force agencies to aid in scenario development. The primary sources AFOTEC has at its disposal are the Nuclear Criteria Group Secretariat (NCGS), the using command, the Air Force Center for Studies and Analysis (AFCSA) and the Air Force Intelligence office (AF/IN). The information from these agencies is used to define the most realistic scenarios to develop the NAP.

2.2.1.3 Initial Dominant Nuclear Environments Definition

An initial set of dominant nuclear environments are determined once the operational scenarios are defined during NAP development. The technical support contractor evaluates the mission operational timeline and threat scenarios to determine which environment(s) will affect the mission functions performed during each mission phase. These are termed the dominant environments and may vary with estimated weapon yield as well as mission scenario. Figure 2-4 provides an example of dominant environment dependency on threat weapon yield. For a given range, the anticipated weapon yield will determine which nuclear environment dominates. In example A, a small yield (100 kT) at a given range may produce a dominant environment of nuclear radiation which could potentially degrade system functions. However, for a larger yield (1 MT) at the same range, the blast environment could dominate as shown in example B. The nuclear radiation environment would still exist, but now the dominant kill mechanism for the system is overpressure.

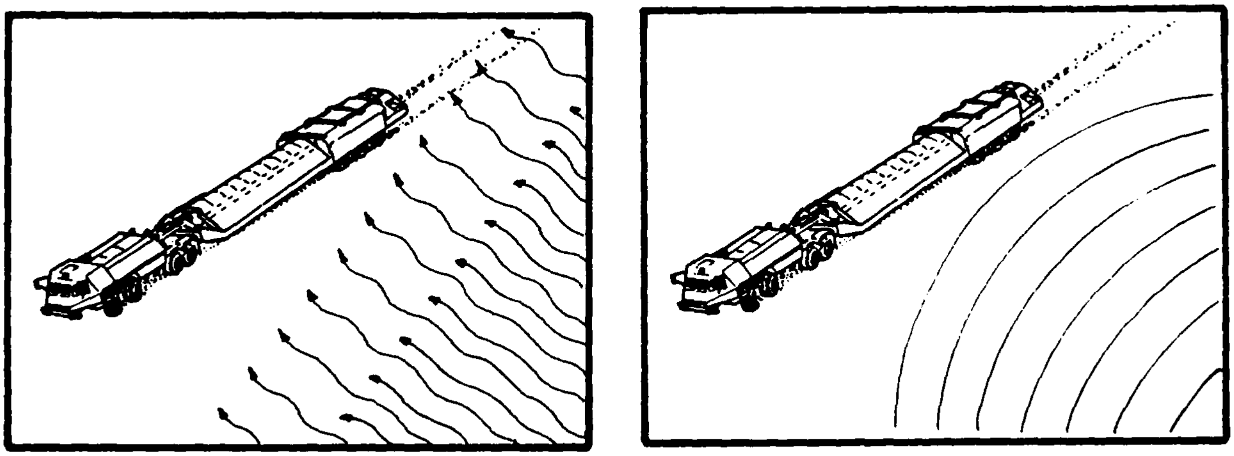

Figure 2-4. Dominant Environments Based on Weapon Yields

For an example of dominant environment dependency on mission phase, we use the previous Peacekeeper example. Assuming a direct attack on the silos as our operational scenario, for instance, ground shock may be the dominant environment effect on the system prior to launch. It will not affect the missile once in-flight. Therefore, ground shock will be a dominant nuclear environment to assess against ground system functions but not for missile flight functions. This is an example of a dominant environment related to the pre-launch phase of the mission.

The technical capabilities of the support contractor in the nuclear effects area will be needed to assess the interactions between mission phase and potential system threat to determine which nuclear environments will dominate the functional response of the system. Establishing a set of dominant nuclear environments scopes the assessment and focuses it towards critical operational issues. Nuclear environments which do not dominate system response during a particular mission phase are discarded from further evaluation effort. The set of dominant environments may be refined as NAP implementation progresses.

2.2.1.4 Mission Critical Function/Mission Critical Equipment Identification

One of the most important management tasks for the AFOTEC project analyst is identification of MCFs. The technical support contractor is normally used to complete this task due to the time investment that is required. MCFs are functions which the system must perform to meet the mission goals. An example of an MCF is the ability of the weapon system to receive communications from higher authority. It is important that the project analyst understand how these functions work together at the system level to complete the mission. A functional understanding of the system aids the analyst during NAP development to identify the key evaluation areas and to define OT&E test requirements for both combined DT&E/OT&E tests and unique OT&E tests.

The mission definition, system requirements and operational timeline, as previously discussed, are the basis for MCF identification. There are several sources available to the supporting contractor in developing the MCFs. The using command will most likely have a preliminary list of MCFs and this should be requested by the project analyst for support contractor review early in the NAP development process. Depending on the system, there may also be a requirement for the System Program Office (SPO) to perform a System Requirements Analysis (SRA) to aid in design of system elements. The SRA output defines specific functions the system elements must perform to complete the mission. A subset of this SRA list relating to operational functions can be used by the support contractor as an initial MCF list. There are functions inherent in the system which are not critical or required during launch or flight (such as test functions or non-essential communication links). These should become obvious to the support contractor during the SRA review.

Another important resource is the knowledge of Air Force personnel who have operated similar systems or who have been involved in similar system OT&E programs. Interviews of such personnel to understand the functional requirements should be set up by the AFOTEC project analyst. This is very useful especially for systems which include many crew interface requirements. These people provide unique operational data which may not be available from the SRA. The fact that they actually used similar systems can help the project analyst to identify potential areas where there may be data deficiencies or a lack of adequate test and analysis emphasis.

Once a set of functions is identified the support contractor must assess each to determine whether or not it is addressable during NAP implementation. This is based on two factors: (1) addressable mission phases and (2) assessment scope. For instance, in the Peacekeeper evaluation, the mission phase functions performed prior to launch message transmittal were not to be assessed in a nuclear environment. These functions included maintenance, maintenance tests, etc. The missile was assumed to be launch-ready at the time of attack and performance of maintenance actions during attack was considered unrealistic.

In many cases the set of mission critical functions becomes very large (over 600 in Peacekeeper) and unmanagable. A technique developed during previous assessments is to separate the functions into functional groups. These functional groups represent major blocks of MCFs. An advantage of developing a set of functional groups is that they form a top level structure for the MCFs which helps the project analyst in defining NAP assessment objectives and tasks.

Table 2-2 shows the functional groups developed for Peacekeeper. The reader should note how these groups correlate to the Peacekeeper mission requirements defined earlier and are ordered concurrent to the operational timeline shown in Figure 2-2.

Table 2-2. Peacekeeper Functional Groups

1)	EAM Transmitted to LCF Interface
2)	EAM Received, Processed, and Authenticated at LCF
3)	Launch Commands Manually Initiated at LCF
4)	Launch Commands Processed
5)	Terminal Countdown
6)	Zero Phase of Flight
7)	LF Status Monitoring and Reporting
8)	First Phase of Flight
9)	Second Phase of Flight
10)	Third Phase of Flight
11)	Fourth Phase of Flight
12)	Reentry Phase of Flight

To exemplify further the functional group concept, let's take the functional group "Zero Phase of Flight" and break it down into a set of MCFs. There are six functions which form this group including:

(1) Perform zero phase of flight guidance and control
(2) Provide navigation
(3) Provide ordnance power
(4) Perform canister separation
(5) Provide zero phase equipment release
(6) Separate umbilical from missile and retract

All of these functions are mission critical in that they must be performed to complete the missile zero phase of flight, i.e., missile ejection from the silo. These functions were all assessed during the Peacekeeper program.

During MCF development, the system equipment, i.e., MCE, which perform each function are also identified by the support contractor. The MCE consist of hardware elements such as computers, software elements such as mission programs, and the crews. The MCEs are identified to aid the contractor in determining potentially degradable functions (discussed in the next subsection) and during functional degradation validation performed during NAP implementation.

Thorough understanding of MCFs by the project analyst is important throughout the program when test and analysis requirements are being defined by the SPO and during OT&E test requirements integration. For instance, during the Peacekeeper program, AFOTEC operational inputs into the Critical Design Review (CDR) process and nuclear hardness and survivability (NH&S) analyses were well received because they reflected a thorough knowledge of operational requirements rather than hardware design specifications. Because of this acquired knowledge of critical mission functions AFOTEC was able to contribute early in the process and identify data and potential system deficiencies. This type of AFOTEC involvement aids the system developers in alleviating potential deficiencies early in the design where it is most cost effective and should ultimately produce a better system.

2.2.1.5 Potentially Degradable MCFs/MCEs Identification

The project analyst must not only understand how the MCFs work together to complete a successful mission but also understand how the nuclear environments may interact with the system and potentially result in functional performance degradations. Based on the initial set of dominant nuclear environments, the project analyst must have the technical support contractor analyze how these environments may degrade functional performance. Potentially degradable MCFs and MCEs are identified by analyzing the effects of the dominant nuclear environments on the system elements and translating these effects to potential functional degradations. In addition, the potential mission impacts are also identified. This analysis should be performed concurrently with MCF identification to reduce resource investments and result in a more efficient assessment process.

Table 2-3 provides an example of identifying potential MCF degradations. A computer element, the launch control system controller (LCSC), can be affected by EMP, nuclear radiation, and ground shock -- the dominant nuclear environments which may impact the particular mission phase during which the LCSC functions. Since the LCSC is an electrical as well as mechanical element both electrical (EMP, radiation) and mechanical (ground shock) nuclear environments can impact its performance. (A concrete structure on the other hand would not be affected by the electrical environments but could be structurally degraded by the mechanical environments). This illustrates the

Table 2-3. Functional Degradation Example

ELEMENT NAME	NUCLEAR ENVIRONMENTS	POTENTIAL ELEMENT DEGRADATION	POTENTIAL FUNCTION DEGRADATION	CANDIDATE MISSION IMPACT
LAUNCH CONTROL SYSTEM CONTROLLER (LAUNCH CONTROL PROGRAM)	EMP	COMPONENT DAMAGE, SOFTWARE/MEMORY UPSET, SPURIOUS CURRENTS	FAILURE OR DELAY TO ENTER LAUNCH-IN-PROGRESS MODE AND TERMINAL COUNTDOWN.	LAUNCH TIME INITIALIZATION DELAYED OR FAILED RESULTING IN TIME ON TARGET ERRORS IN FLIGHT PHASE, OR ABORTED LAUNCH
	GROUND SHOCK	STRUCTURAL DAMAGE, COMPONENT DAMAGE, ELECTRICAL DISCON-NECTIONS		
	GAMMAS, NEUTRONS	NUCLEAR HEATING, IEMP, TREE		

fact that each MCE must be analyzed to determine which types of nuclear environments could affect its performance. Degradations to the system element itself, i.e, upset, component damage, heating, are translated to potential MCF degradations as shown in Table 2-3. Contractor nuclear effects expertise is needed during this portion of the process to translate from the effects of nuclear environments on MCEs to potentially degradable functions and resultant mission impacts.

The value of postulating functional degradations and mission impacts early in the evaluation is two-fold. One, it prepares the project analyst to effectively defend the need for various pieces of data from the DT&E NH&S test activities to use in OT&E analysis of potential mission impacts. Second, the data is essential to understanding the integration of the results of several tests and analyses performed during the implementation phase into system level mission impact statements -- the ultimate goal of the nuclear survivability OT&E program.

2.2.1.6 Candidate Mission Impacts Identification for Further Analysis

Candidate mission impacts are estimated by the technical support contractor from the potentially degradable functions and system mission requirements. As shown previously in the Table 2-3 example, mission impacts resulting from the functional degradations could include a complete mission failure or a delay in the execution of mission requirements. An indepth understanding of mission functions and how they operate together is required to estimate candidate mission impacts. The MCE identification process allows the support contractor to gain this understanding and provides the basis for mission impact estimation. As potential MCF degradations are identified, potential system level mission impacts should also be postulated.

2.2.1.7 Data Opportunity and Deficiency Identification

Data opportunities must be identified early during NAP development and taken advantage of throughout development and implementation. Data opportunities include additional test events, additional analyses, data from past programs, etc. The project analyst is not limited to opportunities provided just within AFOTEC or the SPO. Work performed by other agencies should also be explored to determine data opportunities relevant to the assessment. For example, during the Peacekeeper program, AFOTEC identified unique capabilities of a contractor working for the Defense Nuclear Agency (DNA), which were needed for the Peacekeeper OT&E. An agreement was made between AFOTEC and DNA that the DNA contractor would perform OT&E

modeling work through DNA funding. AFOTEC was able to acquire the work without spending additional resources or requiring a request for proposal. In addition, the data supplied was found to be useful for follow-on programs.

It is necessary for the project analyst, with inputs from the support contractor, to identify data deficiencies early in the program and continue to do so throughout the program. These deficiencies are quite important as they may identify a shortfall in the testing or analysis which could ultimately result in a system performance deficiency. Data deficiency identification starts as early as the initial TEMP reviews. The combined DT&E/OT&E TEMP should include a set of tests which will eventually satisfy all OT&E nuclear survivability test objectives. There may be deficiencies in the test program that could result in lack of relevant OT&E nuclear survivability data. These deficiencies can be resolved by: (1) integrating additional OT&E test events, (2) integrating additional OT&E test requirements into existing DT&E/OT&E tests or (3) identifying data opportunities outside of the combined program as discussed previously. It may also be reasonable to incorporate additional requirements in planned DT&E analyses efforts. This approach must be considered carefully as it is usually not adequate to meet OT&E objectives due to the lack of operational realism and large uncertainties associated with analyses.

Data opportunity deficiency identification is an iterative process and extends throughout the program. As part of NAP implementation, resolution of data deficiencies is further discussed in subsection 2.2.2.4.

2.2.1.8 Program Plan Preparation for NAP Implementation

The project analyst should develop a top-level program plan for NAP implementation. This plan will describe how the NAP will be implemented, the resources required, and include schedules for all planned NH&S activities. The NAP implementation discussion should include major activities relevant to OT&E that will provide data for the assessment and present guidelines for aiding the technical support contractor in test requirements integration, test performance, and further planning. The program resources address both funding and manpower requirements in terms of level-of-effort. The areas which should be covered include Headquarters support, technical contractor support, and test team support. Any additional support which may be required from other Air Force agencies should also be included. To aid the project analyst in managing NAP implementation a detailed schedule should be prepared which includes major program acquisition milestones, DT&E and OT&E test events, DT&E analysis schedules, and, if known, major OT&E deliverables that may be required during the course of the program.

2.2.1.9 Nuclear Assessment Plan Preparation

The purpose of a NAP is to define and document the measures and methods required to meet the OT&E critical assessment objectives for the program and is a product of the activities described in the preceding paragraphs. The NAP is a detailed plan usually written by the support contractor which incorporates operational scenarios, dominant environment determination, mission critical functions, assessment objectives and the tasks to ultimately fulfill the requirement to estimate mission impacts due to system operation in the nuclear environments.

An example of a typical NAP outline is shown in Table 2-4. The NAP should be a usable document, i.e., it provides enough information such that it becomes the primary assessment resource during implementation. The content of each major section of the NAP is described in detail in Appendix B. How the NAP tasks are implemented is discussed in the following section.

Table 2-4. NAP Outline

1.0 INTRODUCTION

- Purpose of NAP
- Evaluation Scope
- System Overview
- Program Goals

2.0 OT&E CONCEPT

- Operational Scenarios and Mission
- OT&E CQ&Is
- OT&E Assessment Objectives
- OT&E Measures of Effectiveness

3.0 METHOD OF ACCOMPLISHMENT

- Dominant Environments Analysis
- Operational Environment Estimation
- Test Requirements Identification and Integration
- Data Shortfall Identification and Resolution
- Utilization of DT&E Data for Functional Degradation Validation
- Test Monitoring Impact Estimates
- Mission Impact Estimates
- Task Results Reporting

4.0 NAP IMPLEMENTATION MANAGEMENT AND SCHEDULE

- Program Management and Schedule
- Roles and Responsibilities
- Evaluation Schedule

Appendix A - Operational Effectiveness and Suitability

Appendix B - Operational Scenarios/Dominant Environments (Classified)

Appendix C - System Nuclear Hardening Description

Appendix D - Mission Critical Functions/Mission Critical Equipment

Appendix E - Data Requirements/Test Requirements

2.2.2 NAP Implementation and Assessment

The majority of the program resources are devoted to NAP implementation, using the NAP as the assessment guideline and following the NAP implementation program plan previously developed. The NAP implementation tasks, highlighted in Table 2-1 below, are discussed in detail in the following paragraphs.

Table 2-1. Nuclear Assessment Methodology

PHASE I: NAP DEVELOPMENT

TASKS

- Mission Definition
- Operational Scenarios
- Initial Dominant Nuclear Environments Definition
- Mission Critical Function/Mission Critical Equipment Identification
- Potentially Degradable MCF/MCE Identification
- Candidate Mission Impacts Identification for Further Analysis
- Data Opportunity and Deficiency Identification
- Program Plan Preparation for NAP Implementation
- Nuclear Assessment Plan Preparation

PHASE II: NAP IMPLEMENTATION AND ASSESSMENT

TASKS

- **Operational Scenario Refinement**
- **Operational/Nuclear Environments Refinement**
- **Test Requirements Identification and Integration**
- **Data Shortfall Identification and Resolution**
- **Test and Analysis Execution**
- **Test Monitoring/Participation**
- **Mission Impact Assessments**
- **HM/HS Reporting**

2.2.2.1 Operational Scenario Refinement

During NAP implementation, it may be necessary for the support contractor to refine the operational scenarios. Scenario refinement is usually based on revised or new threat data provided by AF/IN, the user and/or the NCGS. Computer model results, not available during NAP development, may also result in a change in operational scenario. For example, during the Peacekeeper NAP implementation it was found through modeling that a high altitude pin attack on the weapon system was not viable due to the threat resources required to effectively impact system performance. The ultimate result of excluding a pin attack was that nuclear radiation was excluded as a dominant nuclear environment for the missile during the in-flight mission phase.

In addition, as new threat data became available from the NCGS, the threat scenario also changed for the Peacekeeper ground system. As these examples show, it is necessary for the project analyst to maintain monitoring of AF/IN, the NCGS, the user, etc., to accommodate any changes in threat during NAP implementation. These changes will affect the dominance and operational environments analyses performed by the contractor.

2.2.2.2 Operational/Nuclear Environments Refinement

The goal of any OT&E program is to focus the bulk of assessment resources on key areas without inadvertently missing a major impact. Determining the nuclear environments which "dominate" each mission phase is a technique useful in focusing the assessment and preventing unnecessary tasks. During NAP development, the technical support contractor defined dominant nuclear environments by mission phase in order to postulate potentially degradable functions. During NAP implementation, the mission phase dominant environments may have to be refined even further by the contractor, as discussed below.

There are two factors which are considered during refinement of the dominant nuclear environments: (1) the operational environment in terms of range-to-effect based on system susceptibility and (2) system vulnerability to the environments. Estimation of the operational environments based on refined system susceptibility range-to-effect calculations. The range-to-effect calculations in conjunction with system vulnerability data will determine the dominant environments. The concept of range-to-effect is useful to the project analyst and technical contractor in determining operational environments if a well defined system failure level to at least one environment is known. This is clarified in the example below.

If it is known that a complete structural failure of our system is caused by an overpressure level of 10 psi we can then assess ranges from our system to a nuclear detonation to determine the collateral nuclear environments. Figure 2-5 demonstrates this concept. At a range of 2500 feet for a 100 kT weapon yield a 10 psi overpressure environment is generated. Therefore, at 2500 feet for 100 kT the overpressure environment dominates all other environments (ground shock, EMP, nuclear radiation) and a mission failure will result. If we extend the range beyond 2500 feet, overpressure is no longer a failure mechanism and the levels of the nuclear environments must be estimated to determine which environments dominate.

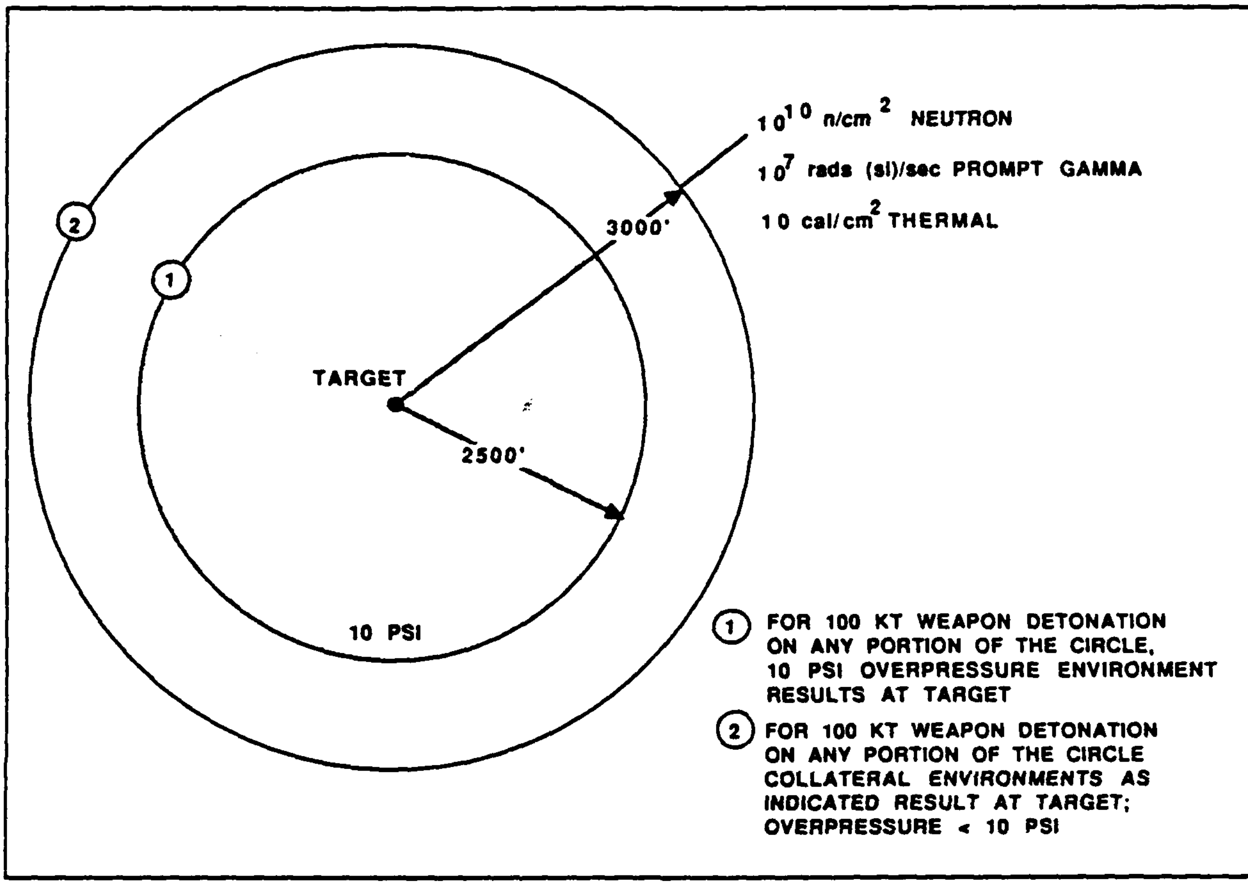

Figure 2-5. Range-to-Effect Concept Example

At a range of 3000 feet let's assume we have calculated collateral environments as given in Figure 2-5. We do not know which environment(s) dominate until we consider the system vulnerability. Vulnerability refers to how resistant the system is to the environment of interest. For the sake of our example, let us assume that the collateral environments are 10^{10} neutrons/cm^2 and 10^7 rads(Si)/sec. Both environments exceed the specification environment, however, the DT&E NH&S data for various subsystems showed that the system could successfully operate through 10^{10} neutrons/cm^2 but failed at 10^7 rads(Si)/sec. Therefore, the prompt gamma environment dominates and is the primary failure mechanism to be assessed. The example shows how the overall system vulnerability is based on the vulnerability of the functional elements which compose the system.

As an aside, AFOTEC assumes that the system meets specification unless data becomes available from DT&E NH&S tests and analyses which indicate otherwise. The goal is not to verify the system meets specification but to assess mission performance in the operational nuclear threat environment.

The range-to-effect technique described above is primarily used for stationary systems with a known failure level to a specific environment such as overpressure. This technique does not work as well to determine dominant environments for mobile systems. In this case, system modeling may be required to determine which attack scenarios generate which types of environments. The modeling allows the analyst to examine movement limitations, movement timelines, etc. which influence an attack scenario.

There are existing computer codes and analytical methods used in past programs to estimate the operational nuclear environments based on range-to-effect. The NAP will list basic codes and methods available and guide the analyst as to how they are used to acquire the desired results. The support contractor is usually responsible for the operational environments calculations and should have the codes and methods defined in the NAP. Since each system assessment is unique, the methods used may vary.

2.2.2.3 Test Requirements Identification and Integration

From the system's general test plan (GTP), the technical support contractor must first match candidate DT&E and OT&E tests to specific NAP evaluation objectives. Each objective and correlated test event are then reviewed to determine a preliminary set of OT&E test requirements. At this point, a test requirements matrix is developed which correlates assessment objectives, OT&E test requirements, test events, expected data, and test requirement integration schedules. This type of matrix is helpful to the project analyst and contractor performing the test requirements integration tasks. It summarizes the program data relevant for each test into a single document which can be used to keep track of test requirements integration status. Most of the test requirements are based on MCFs and dominant nuclear environments and this direct link enables the AFOTEC project analyst to effectively defend the OT&E requirements when dealing with upper management or the DT&E organizations.

Once the OT&E test requirements are identified they must be integrated into the combined DT&E/OT&E test program. Test requirements integration can be very time consuming depending on: (1) the level of acceptance by the test community, and (2) the level of test requirements detail required by the test community. Test requirements are integrated at test plan working group meetings. It is important the AFOTEC project analyst, the technical support contractor, and/or the AFOTEC test team attend the test planning meetings on a consistent basis when test requirements are being integrated. Without this consistency, AFOTEC risks OT&E requirements being minimized or deleted.

2.2.2.4 Data Shortfall Identification and Resolution

During NAP implementation, the support contractor must continually monitor the program results and planned tests and analyses to identify data shortfalls that may materialize due to budget cuts, test consolidation, etc. This is a highly iterative process and the project analyst must be kept informed of any deficiencies found. Some shortfalls can be identified early on and alleviated through integration of additional OT&E test and/or analysis requirements into remaining DT&E NH&S activities. Others do not become obvious until after a test is completed. In every case, the project analyst must decide the importance of the data shortfall in terms of assessment results.

Some data shortfalls cause minimal impact to the assessment results and will not be resolved. Others are so significant that the assessment results will be incomplete or not as accurate as required. In these cases the data shortfall must be resolved and this usually requires implementing one of three options: (1) integration of additional OT&E objectives into a planned test, (2) performing a new dedicated OT&E test, or (3) resolution through analysis. Each shortfall will have unique factors which drive which of these options should be used.

The preferred option is integrating additional test requirements into planned system level tests, whether they are DT&E or OT&E tests. This approach is usually the most cost effective for the system developer but proves to be the most difficult for the AFOTEC project analyst to manage in terms of test requirements integration and discussed in the last subsection. Data resolution through analysis results is many times less acceptable than test results due to inherent uncertainties in analytical techniques.

To clarify the data shortfall identification and resolution importance an example is provided below. This example addresses an actual test event during the Peacekeeper program which resolved two major data shortfalls.

Example: Peacekeeper Command and Control Test

The Peacekeeper weapon system currently consists of the Peacekeeper ICBM based in existing Minuteman silos. The Peacekeeper ground system configuration consists of a launch control facility (LCF) where launch commands are initiated by a two person launch crew and the launch facility (LF), or silo, which contains the missile and operational ground equipment critical for launch. The launch commands are transmitted from the LCF to the LF over a buried cable communication system.

Two major data shortfalls were identified during the Peacekeeper program pertaining to functional degradations due to the Source Region EMP (SREMP) and the prompt gamma nuclear radiation environments (see Appendix A for nuclear environment definitions). The SREMP data shortfall was identified during OT&E test requirements integration into a combined DT&E/OT&E NH&S test. This test, the LF EMP Electrical Surge Arrestor (ESA) vault test, was intended to determine the level of SREMP induced electrical current, voltage, and magnetic field penetrated through the ESA vault to MCE. The ESA vault is intended to provide LF protection against electrical surges due to EMP, lightning, power grid fluctuations, etc. Downstream MCE was simulated by resistors rather than operationally configured hardware. This created a major OT&E data shortfall, i.e., the impact on functional performance of the MCE due to the transmitted SREMP induced currents into the LF.

The second data shortfall pertained to designed functions in the missile and operational ground MCE called Nuclear Event Protection (NEP) functions. These functions were designed to prevent system performance degradations induced by the prompt gamma radiation environment. Three NEP functions were designed into missile electronics and two in operational support equipment processors.

During development the SPO only tested the NEP functions separately and at the subsystem level. There was no testing of the NEP functions at the integrated system level. This was a significant data shortfall operationally because all five NEP functions would perform simultaneously during a prompt gamma event resulting in an unknown system response.

Upon review of the planned Peacekeeper test program, it became apparent there were no candidate NH&S tests adequate to resolve the two data shortfalls. However, there was a dedicated OT&E system level test, the Peacekeeper command and control test, planned which could resolve the data shortfalls if the NH&S requirements were integrated. AFOTEC's project analyst decided to integrate test objectives into the command and control test to resolve the two nuclear assessment data shortfalls with the help of the support contractor and the AFOTEC test team. It took about 16 months to integrate the requirements, develop SREMP simulation and NEP activation techniques, perform detailed test planning, and execute the test.

There were major hurdles to overcome during the integration process. First, AFOTEC had to present a case at the working level for the requirements. This meant detailed justification for the requirements, how the requirements could technically be met, and how these additional requirements would impact test schedules. The system functional knowledge gained through MCF identification played an important role in acceptance of the objectives by the test community. AFOTEC's support contractor investigated several techniques to use to simulate the effects of the SREMP environment at the LF MCE and to activate the NEP functions simultaneously. The contractor eventually built test hardware to accomplish these objectives. The test was performed at an operationally configured LCF and LF at Vandenberg AFB, California and completed in June 1987. The results fully resolved the data shortfalls. Because this was a system level test performed in an operationally realistic configuration, mission performance was directly observed. Thus, there was no functional analysis or system analysis required to define mission impacts. The results of the test are included in Reference 1.

2.2.2.5 Test and Analysis Execution

AFOTEC uses many resources to assess the system nuclear survivability. These include: (1) DT&E NH&S test and analysis data, (2) combined DT&E/OT&E NH&S test data, (3) dedicated OT&E test and analysis data, and (4) system level functional analyses and simulations. The DT&E organization or SPO usually has an ongoing program to test and analyze subsystems to specification or failure levels. This data provides failure or degradation levels due to the nuclear environments for the various MCE which perform the mission critical functions. The AFOTEC technical support contractor uses this data to compare the failure levels to the operational environments to validate the previously postulated functional degradations.

If a failure level is below the operational nuclear environment then a functional degradation is expected to occur, i.e, it is valid. If a failure level is above an operational environment then a functional degradation is not expected to occur. This is the idea behind validated functional degradations. When the functional degradations are valid the support contractor must then perform a mission impact analysis as discussed below. Again, contractor technical knowledge of nuclear effects is required during this portion of the process.

2.2.2.6 Test Monitoring/Participation

During implementation, a major activity performed by the project analyst, contractor, and test team is test monitoring and participation. The NAP will define which test events require monitoring and participation. Most combined DT&E/OT&E NH&S tests are monitored by AFOTEC support contractor personnel on-site to acquire and analyze data. On-site monitoring is required to ensure previously integrated OT&E requirements are met and to identify any data shortfalls which may be alleviated during the test. This monitoring activity benefits the OT&E because it allows constant interaction with the test community, resulting in establishment of productive working relationships and in more efficient data reduction and analysis.

Some programs include dedicated OT&E tests funded by the SPO. The Peacekeeper command and control test, discussed previously, was an example of such a test. These tests are actually conducted by AFOTEC with support from SPO personnel. Since AFOTEC is conducting the test, there is usually more flexibility during test execution in terms of adding requirements. The project analyst should consider taking advantage of such tests early in the assessment for integration of nuclear effects simulations, such as was done during the Peacekeeper command and control test.

2.2.2.7 Mission Impact Assessments

To arrive at mission impact results, the preferred method is test. System level tests are best for OT&E because they provide direct observation of mission impacts at the system level if performed in an operationally realistic manner. However, there are usually few, if any, system level NH&S tests for the nuclear environments of interest due to configuration, logistics, and cost limitations.

Integrating nuclear effects simulations into non-NH&S system level tests, i.e., surrogate testing, is a realistic alternative to meet OT&E objectives. The surrogate test is a replication of the operational nuclear environment or the effects of the environment, during a system level test which allows direct observation of mission impacts. This is a valuable tool the project analyst can use to assess mission impacts and resolve data deficiencies.

To clarify the idea of surrogate test, let us assume that the EMP environment causes an upset condition in our aircraft Inertial Navigation System (INS). This upset causes a small drift in the INS which results in erroneous data output to the central computer. In a surrogate test at the system level we can either replicate the EMP induced signal which caused the upset or replicate the effect of the upset, i.e., create the drift condition in the INS. During the test the INS output, the response of the central computer and the resultant system performance will be observed to identify a mission impact due to the INS drift.

In addition to system level surrogate tests, mission impact analyses can also be performed to obtain results. Mission impact analysis is simply the process the technical support contractor uses to derive mission impacts from the system functional and vulnerability analyses and test data as compared to the dominant threat effects.

The actual techniques used to derive mission impacts are program dependent with test preferred over analysis. However, no matter which techniques are used, every mission impact result that AFOTEC presents must be supported by a substantial data base due to the high visibility of the results.

2.2.2.8 HM/HS Reporting

The objective of an operational suitability assessment should be met by the system's HM/HS program developed by the SPO. The HM/HS program must be monitored by the AFOTEC project analyst to ensure that it adequately addresses both the user HM/HS requirements and satisfies NAP objectives by preserving nuclear hardness through the system life cycle. Deficiencies or shortfalls in the HM/HS program are identified by the analyst and recommendations are made based on impacts to mission accomplishment. Test and analysis requirements are integrated into the DT&E/OT&E program as applicable. The role of HM/HS in an OT&E assessment is discussed in detail in Section 3.0.

3.0 OPERATIONAL SUITABILITY

Operational suitability as stated in Air Force Regulation (AFR) 80-14 is the degree to which a system can be satisfactorily placed in field use. Consideration is given to availability, compatibility, transportability, interoperability, reliability, wartime usage rates, maintainability, safety, human factors, logistics supportability and training requirements. These are weapon system support considerations which are not included in an operational effectiveness assessment performed by AFOTEC.

Also encompassed in the operational suitability requirements are nuclear hardness maintenance (HM) and nuclear hardness surveillance (HS). Figure 3-1 shows in flow format the importance of HM/HS in system development. As can be seen in the figure, nuclear HM/HS has a direct input into the decision of whether a system will reach full scale engineering development (FSED). HM/HS is defined as an OT&E objective when AFOTEC conducts a nuclear survivability OT&E program for a weapon system. HM and HS are defined below (extracted from Ref. 2).

<u>Hardness Maintenance (HM)</u>: Procedures implemented during the operational phase to preserve the nuclear hardness of the system and/or hardness feature(s). HM includes activities, controls, and precautions to prevent hardness degradation due to operations, logistics support, normal maintenance actions, natural environments, and product improvement (preventive HM). HM also includes procedures to detect and correct hardness degradations and failures (corrective HM).

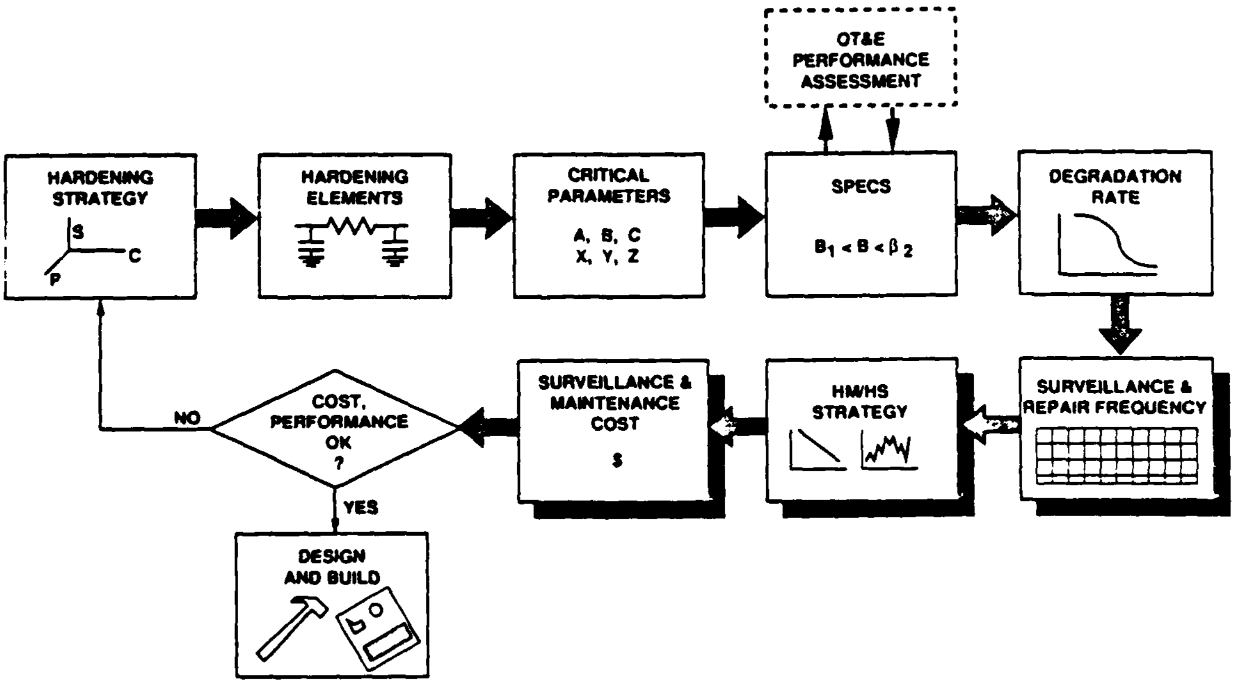

Figure 3-1. Role of HM/HS in System Development

Hardness Surveillance (HS): Special procedures, processes, inspections, tests, analyses implemented during the operational phase on a scheduled basis to measure the nuclear hardness of the system and/or hardness feature(s) in order to make decisions relative to operational deployment of the system and relative to the effectiveness of the hardness maintenance program.

The bulk of the HM/HS OT&E assessment is usually performed by the AFOTEC Logistics Directorate (AFOTEC/LG). The AFOTEC/LG writes an HM/HS assessment plan which is based on the complexity of the HM/HS program, user emphasis, and the OT&E test approach for the system written by the project analyst. An example of an HM/HS assessment plan is provided in Figure 3-2 for the Small ICBM weapon system. The criteria for acceptability, measures of effectiveness, and related tasks are presented.

The project analyst must be familiar with the HM/HS assessment plan and coordinate HM/HS activities with AFOTEC/LG. The OT&E assessment goal of the project analyst is to determine whether the user is provided with an HM/HS program that provides the equipment, training, procedures, and data required to ensure the fielded system's nuclear hardness does not degrade below acceptable levels. Nuclear HM/HS should address, as applicable, electromagnetic pulse (EMP), transient radiation effects on electronics (TREE), crew radiation dose, blast, and thermal hardening provisions. The OT&E HM/HS assessment must be tailored to the constraints of the system supported and specific user requirements. AFR 80-38 and Department of Defense Directive (DoDD) 4245.4 are good references to aid the project analyst in identification of program specific HM/HS OT&E requirements.

The HM/HS assessment is usually performed in three phases: (a) review of early HM/HS concepts and approach planning, (b) detailed test planning, and (c) test conduct and reporting. As early as possible in the system NH&S program, AFOTEC reviews maintenance and HM/HS concepts available to identify user requirements and any operational deficiencies. The final user HM/HS plan is usually not available until system initial operational capability (IOC) or sometimes even later.

The results of this review are used by AFOTEC/LG to develop the OT&E HM/HS assessment approach. Generally, a HM/HS program will require specialized equipment, training, and procedures to maintain and periodically verify hardness of line replaceable units (LRUs), subsystems, and/or systems. Provisions may also be made for specific maintenance coding of HM/HS procedures and

Criteria for Acceptability

MOE: HM/HS Planning Documents.
- Identify & track HM/HS deficiencies. Is "deficiency" associated with HM/HS program or is it a hardness degradation?
- Relationship of HM/HS to purpose of hardening.
- Is "hardness" defined relative to the design specification or the SOW.
- Knowledge of hardness status -- both system and features.
- Ability to make resource allocation decisions.

MOE: Tech Data.
- Work unit codes.
- HCIs marked properly.
- Does visual inspection include yes/no criteria?
- Proper tools & equipment specified.
- "What to do" instructions for HCIs defined.

MOE: Support Equipment.
- Proper tools & equipment specified.
- Test points accessible.
- Test data are interpretable.
- Test data are repeatable.
- Tests can be accomplished by skills identified.
- Permits detection & location of degradations.
- Permits knowledge of hardness status.
- Permits decisions to be made - e.g., what & when to fix.

MOE: Supply Support.
- Adequate (how is "adequate" judged) spares of HCIs.
- Permit proper substitution of HCIs.
- Spare test equipment.

MOE: Impact on Maintenance.
- No adverse impact on maintenance repair times.
- Do not damage equipment.
- Do not cause unsafe practices.

MOE: HS Techniques.
- Are there enough techniques to satisfy the hardness goals of knowing the hardness status?
- Are all required resources needed to perform a technique identified?
- Does the technique permit knowledge of hardness status?
- Does the technique yield results from which decisions can be made?

MOE: Gathering Hardness Related Data.
- Identification of <u>what</u> data to gather.
- Identification of how to recognize hardness degradation modes, ratios, causes.
- Work unit codes to collect this data.
- Identification of infrastructure/technology that is not available. E.G., part to part variations.

Figure 3-2. Small ICBM HM/HS Assessment Plan the capability to extract/sort these data as inputs to a computer model which outputs a system hardness assessment.

A separate HM/HS test objective in the OT&E test approach may be warranted by the project analyst if HM/HS is a high-interest item or if the program is complex. HM/HS may also be addressed under a nuclear survivability effectiveness objective or component parts of HM/HS, e.g., training, support equipment, etc., may be addressed under a logistics support objective. In all cases, the suitability analyst assigned to the Test Support Group will be responsible for HM/HS issues.

Detailed test planning requires the project analyst to revise and add detail to the test approach plan based on evolving HM/HS plans for the system, delivery schedules for HM/HS support equipment, training availability, etc. Details required for technical order (T.O.) review, training assessment, etc., should be included in the test plan, as appropriate. Provisions should be made to include HM procedures in planned maintenance demonstrations (M-demos), if feasible. An additional effort that may occur during this phase is the incorporation of OT&E test requirements into system-level EMP test(s) during NAP planning. An example of this is the B-1B NAP (Ref. 3) which includes three survivability objectives based on planned EMP testing. The OT&E goal for such tests is to ensure the test is operationally realistic and test objectives will meet AFOTEC/user requirements for HM/HS. The AFOTEC test team should be actively involved in the planning process as they normally execute the test activities.

Test team conduct and reporting of HM/HS will be done as prescribed in the test plan. Key elements to be addressed should include usability of support equipment, accessibility of test points, ability to interpret test results and, if applicable, provision of hardness critical item visual inspection acceptance/rejection criteria.

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APPENDIX A

NUCLEAR WEAPON EFFECTS

APPENDIX A

This appendix provides a brief description of nuclear weapon environments and the potential effects on weapon systems. Eight environments are associated with a nuclear detonation:

1. Nuclear Radiation
2. Electromagnetic Pulse (EMP)
3. X-Ray
4. Thermal Radiation
5. Airblast
6. Debris
7. Ground Shock
8. Scintillation/Absorption

Table 1-1 summarized these event environments and the potential impact of each environment on various systems and system elements. System elements to be evaluated for nuclear effects are divided into three categories: hardware, software, and human. Actual degradations caused by nuclear environments occur in hardware (electrical or mechanical) and human elements. However, nuclear environments are not uniformly damaging to all system elements, i.e., electrical, mechanical and human elements are not necessarily affected the same way by the same nuclear environment. The software (or computer processing) functional degradations are the result of the nuclear effects on hardware elements.

Supporting discussions on each environment are presented in subsections to follow. This discussion of nuclear environments and weapon effects is presented in a top level manner to familiarize the analyst with basic nuclear phenomena. A list of documents which provide a detailed study of nuclear effects is included in the reference section. Probably the most widely known, unclassified reference is Glasstone and Dolan, The Effects of Nuclear Weapons, 1977. This is an excellent primer for the AFOTEC project analyst.

A.1 NUCLEAR RADIATION

A nuclear weapon detonation releases two types of nuclear radiation of concern -- neutrons and gamma rays. The neutron environment is specified as neutron fluence, in number of neutrons per unit area (n/cm^2). Neutrons interact with materials to produce three effects: (1) displacement, (2) ionization, and (3) nuclear heating. Chemical changes in materials due to displacement damage or ionization is referred to as radiolysis. Neutrons may cause degradations in exposed cable systems by nuclear heating and insulator radiolysis effects degrading dielectric properties. Electrical systems and computer memory will also be affected by nuclear heating and transient radiation from the neutron environment. Neutron effects on electronic system components are part of the TREE (transient radiation effects on electronics) environment, which may cause software upset.

The gamma ray environment is usually specified in terms of a dose rate and a cumulative (or total) dose. The dose rate is the amount of ionizing gamma radiation that is received by a material per unit time, specified as rads/sec. The cumulative dose is the total quantity of ionizing radiation that is received by a material expressed in rads. Gamma rays affect materials in one of four ways: (1) ionization, (2) excitation, (3) nuclear heating, and (4) generation of internal EMP (IEMP). Absorbed gamma radiation could generate IEMP producing transient currents and voltages on cables and within sensitive electrical equipment. The induced currents and voltages can cause computer software and memory upsets, component damage, and processing function degradation. Humans are first affected by total dose radiation at a much lower level than electronics (about 100 rads[Si]).

A.2 ELECTROMAGNETIC PULSE

There are four primary sources of nuclear weapon generated EMP that can affect systems:

1. Exoatmospheric or high altitude burst (high altitude EMP-HEMP)
2. Atmospheric or surface burst less than 100 kft from the surface (source region EMP-SREMP)
3. IEMP generated from gamma radiation
4. System generated EMP (SGEMP) from X-rays

IEMP and SGEMP are discussed in the appropriate radiation sections. HEMP and SREMP are dominant destruction mechanisms for ground-based systems. HEMP can radiate over a large area affecting all types of systems. SREMP can cause damage to hardened structures exposed to large yields or, in some instances, to battlefield systems exposed to very small yields. SREMP is not considered for in-flight systems because of the low altitude burst point, i.e., overpressure from airblast would be the dominant destructive mechanism at this altitude.

HEMP and SREMP can both affect system electrical systems. Wire solder connections can melt from high energy coupled to cable systems. Spurious currents, coupled through penetrations such as antennas, can be propagated to interface circuits and damage or upset semiconductor components. Damage of electronic components causes either failure or permanently degraded performance of the component. Upset results in erroneous data, loss of data transmission, or logic state change in digital circuitry effecting an unacceptable degradation of mission performance. Other mechanisms for SREMP penetration to electrical systems are magnetic field saturation through structural metals and generation of interior wall surface currents.

Note that the EMP environment only affects electrical system elements. The electromagnetic fields or EMP-induced transients do not have sufficient energy to damage or degrade any mechanical system elements or humans. The EMP environment is usually measured in kV/M.

A.3 X-RAY RADIATION

Satellites, missiles, and other systems in space are exposed to relatively high levels of X-ray radiation from exoatmospheric bursts. At that altitude, the X-rays propagate for long distances because the air is thin. X-rays do not affect ground systems or aircraft since X-ray radiation is absorbed by the air at lower altitudes and will not propagate more than a few feet from the burst point. The X-ray environment is usually measured in fluence which is the amount of X-ray energy received per unit in cal/cm^2.

Nine effects on system components are associated with X-rays:

1. Surface removal
2. Spallation
3. Debonding
4. X-ray heating
5. Blow-off impulse
6. Thermomechanical stress
7. Radiolysis
8. SGEMP
9. TREE

The X-rays interact with the system structure to produce extremely rapid and localized heating. This can cause bending, vibration, surface spalling, and related mechanical effects. The vulnerability of space systems to thermal shock from X-rays is usually considered a primary kill mechanism. The X-rays also knock electrons out of materials, setting up a current which produces SGEMP that can damage electronic parts. Finally, the X-ray radiation can damage electronic parts directly by altering the semiconductor material characteristics - part of the TREE environment.

A.4 THERMAL RADIATION

For surface, near surface or air bursts less than 100 kft, the X-ray radiation emitted is absorbed within a few feet of the burst point heating the atmosphere to a high temperature. This absorption creates the thermal pulse or fireball. Thermal radiation is measured in terms of fluence, cal/cm^2.

Two effects are associated with the thermal environment: heating and ablation. An example is ablation and charring of radomes. A system exposed to thermal radiation will experience surface heating that can cause structural damage and electrical disconnections. Surface heating can also cause interior temperature rise in electronic boxes which may cause component burnout or alteration of electrical parameters affecting their functional performance. The thermal environment can also affect the crew of a system with vulnerabilities including burns and flash blindness.

A.5 AIRBLAST

The shock wave released by the nuclear explosion is termed an airblast and causes a sudden, short duration increase in air pressure. Airblast is manifested in two forms: peak overpressure and gust (dynamic overpressure). Airblast is considered a main air burst damage mechanism for most ground systems and aircraft because it exerts a mechanical force (impulse) on the system which can cause structural damage or displacement and electrical disconnections. Aircraft are particularly vulnerable to gust effects. Due to lack of air to propagate airblast shock waves at altitudes above 100 kft, satellites, missiles in-flight and other space systems are not considered vulnerable to the airblast environment. Airblast is normally measured in pounds per square inch (psi).

A.6 DEBRIS

A strong updraft with inflowing winds, called afterwinds, is produced in the immediate vicinity of a surface, near surface or low airburst. These afterwinds cause varying amounts of dust and pebbles to be sucked up from the earth's surface into the radioactive cloud. The debris environment is specified by three parameters for the dust/pebble components: (1) bulk density, (2) maximum particle size, and (3) particle size distribution.

The suspended particulates provide an extremely abrasive atmosphere and are a concern for external surfaces of ground systems and aircraft. Three effects are associated with the debris environment: heating, erosion, and penetration. Environmental control systems (for equipment and crews) and motors can be damaged by ingestion of the debris environment. The debris environment is not a concern for space systems including satellites and missiles in-flight above 100 kft.

A.7 GROUND SHOCK

The strength of a ground shock is proportional to the amount of energy coupled directly into the ground at a detonation point or the forces induced by a propagating airblast. For surface and near surface bursts, another environment related to ground shock, cratering, is generated. Surface bursts create craters and subsequent ground shock by pushing the earth materials outward at the point of detonation. For a near surface burst, the crater is formed when the fireball reaches the earth's surface pushing mass outwards. The ground shock emanates from the crater.

Ground shock only affects ground systems and is the predominant destruction mechanism for buried ground elements. Critical equipment can experience structural damage and internal component damage due to ground motion. However, the ground shock does not necessarily have to physically destroy the hardware element to have an effect. A ground shock can be effective in displacing internal hardware components such as circuit boards and wires, creating electrical disconnections without actually damaging the entire piece of hardware. Cables can be severed due to ground motions or craters formed, resulting in loss of communications or data transmission. Ground motions can also be effective in degrading human performance of system functions.

A.8 SCINTILLATION/ABSORPTION

Exoatmospheric nuclear detonations create large doses of X-rays, gamma rays, neutrons and trapped energetic electrons which cause disturbances in the ionosphere. These disturbances can cause scintillation or absorption of any radio signals being transmitted through the ionosphere by satellites. The effects can disrupt satellite communications over thousands of square miles from the point of burst and last several hours.

Scintillation is the fluctuations in amplitude, phase and angle of arrival for radio signals propagating through the ionosphere. Two significant effects of scintillation on signal transmission are signal fading and signal degradation in the form of message word errors. Ground terminal satellite communications in the ultra high frequency band (and possibly the high frequency and extremely high frequency bands) are potentially vulnerable to scintillation. Transmitted signals may also be absorbed so severely that a communications "blackout" results for a substantial time period. There is no radio frequency band that is completely immune to possible blackout effects.

APPENDIX B

NUCLFAR ASSESSMENT PLAN DESCRIPTION

APPENDIX B

This appendix describes in detail each major section of the NAP as outlined in Table 2-4 below. The NAP structure is designed towards early results and usefulness to the project analyst. The NAP should be a document which is continually referred to for technical guidance during implementation.

Table 2-4. NAP Outline

1.0 INTRODUCTION

- Purpose of NAP
- Evaluation Scope
- System Overview
- Program Goals

2.0 OT&E CONCEPT

- Operational Scenarios and Mission
- OT&E CQ&Is
- OT&E Assessment Objectives
- OT&E Measures of Effectiveness

3.0 METHOD OF ACCOMPLISHMENT

- Dominant Environments Analysis
- Operational Environment Estimation
- Test Requirements Identification and Integration
- Data Shortfall Identification and Resolution
- Utilization of DT&E Data for Functional Degradation Validation
- Test Monitoring Impact Estimates
- Mission Impact Estimates
- Task Results Reporting

4.0 NAP IMPLEMENTATION MANAGEMENT AND SCHEDULE

- Program Management and Schedule
- Roles and Responsibilities
- Evaluation Schedule

Appendix A - Operational Effectiveness and Suitability

Appendix B - Operational Scenarios/Dominant Environments (Classified)

Appendix C - System Nuclear Hardening Description

Appendix D - Mission Critical Functions/Mission Critical Equipment

Appendix E - Data Requirements/Test Requirements

1.0 INTRODUCTION

This section describes the purpose and content of the NAP document. The assessment scope is defined taking into account any test constraints imposed on the system and OT&E resources. (For example, the assessment of the Peacekeeper in existing silos was constrained in that examination of probability of survival and investigation of retained, unmodified Minuteman equipment and functions were prohibited.)

A brief description of the system, its intended mission requirements and functional requirements are included. The top-level assessment goals are described such that the analyst acquires a "big-picture" view of the overall program, i.e., the current status of the program and the type of assessment results to be achieved. Appendices are included that contain the MCFs which are to be assessed. The operational scenarios and operational concept are also included in the appendices to provide a top level understanding of the performance aspects which could be impacted by operating the system in the nuclear environments.

2.0 OT&E CONCEPT

The purpose of this section is to emphasize the overall OT&E concept to be incorporated into the evaluation. The operational scenarios and mission requirements upon which the assessment is based are described. The results achieved during NAP Development for scenario identification and mission requirements definition will be presented to provide the analyst the background required to perform NAP implementation tasks.

The critical questions and issues identified in the OT&E test plan are presented and NAP assessment objectives are derived from these. The OT&E philosophy towards assessments, i.e., only test to user requirements, will be reflected in the objectives and NAP implementation tasks. Concurrently, the OT&E measures of effectiveness will be presented such that they directly represent well defined, quantifiable user requirements. The scenarios, mission requirements, critical questions and issues, assessment objectives, and measures of effectiveness result from performance of the NAP development phase and the OT&E Test Plan.

3.0 METHOD OF ACCOMPLISHMENT

This section of the NAP defines the tasks required to meet the overall assessment objectives in conjunction with more detailed information provided in appendices (see Table 2-4). The techniques used to accomplish the assessment should be defined in as much detail as possible to aid the project analyst, technical contractor, and test team during implementation. A high degree of detail also allows utilization of past program experience and prevents unnecessary replication of results during the implementation phase.

There are numerous assessment tasks to be accomplished during NAP implementation, as was shown in Table 2-4. Most tasks are performed concurrently due to the varied activities in process during the DT&E NH&S program. The techniques used to perform the dominant nuclear environments analysis will be defined in detail in the NAP, including: (1) how the analysis is performed, (2) data requirements to perform the analysis, and (3) resources, in terms of past program data, computer models, etc. available to the support contractor. Since each OT&E program is different, unique constraints, if any, will be defined.

The techniques needed to perform the operational environment(s) estimation will be defined. The operational environments are estimated based on mission phase, operational scenarios and dominant environments. Computer codes and analysis techniques, used successfully on past programs, will be provided in the NAP and any new or unique techniques will be included if appropriate for the system assessed.

OT&E test requirements are normally identified throughout the program beginning as early as the initial TEMP review. The NAP will include, as a minimum, a detailed test requirements matrix which correlates specific test objectives, test requirements and candidate test events to the OT&E assessment objectives and critical issues. Major test requirements and more significant test events will be defined in more detail to provide the project analyst, technical contractor and test team the needed information to successfully integrate requirements. The tasks and techniques necessary to integrate OT&E test requirements into combined DT&E/OT&E tests should be defined. Test requirements integration into combined tests can be an arduous task for the analyst and contractor. Techniques used during past programs should be defined to aid in accomplishing this task. A test requirements integration schedule should be included with the requirements matrix to efficiently plan resources and level-of-effort required to integrate OT&E test requirements.

As the program progresses and the support contractor becomes more involved in test working groups, analysis working groups, etc., OT&E data shortfalls will be identified. The NAP will include guidelines for the contractor and analyst which will aid in data shortfall resolution. Past program experience, i.e., lessons learned, will be used to construct these guidelines. This is a very important aspect of any OT&E program.

The techniques to be used by the technical support contractor to validate functional degradations will be described in detail. The DT&E NH&S data, in conjunction with operational environment estimates and system level tests, are used to validate functional degradations. The DT&E NH&S program is intended to determine MCE failures or degradations due to nuclear environment effects. If the operational environment exceeds the level at which MCE failures or degradations occur then the functional degradation postulated early in the NAP development phase is valid and mission impacts need to be assessed. This section in the NAP will also provide sources of data for the contractor to accomplish this task.

Most NH&S programs will include several test events. AFOTEC, as discussed previously, will integrate OT&E test requirements into many of these tests and become involved in test performance. In some cases, the project analyst will only require the test data or final test report; in other cases the support contractor and/or test team will participate in the test through monitoring or actual test execution. The test program will be laid out in the NAP such that the AFOTEC role is clearly defined for each test. In addition, the NAP will include the type of data each test is expected to provide and define how this data is used in the system level assessment.

The overall objective of the OT&E assessment is to estimate mission impacts due to the effects of the nuclear environments. The NAP will define the various techniques available to the contractor used to perform the mission impact assessment. These techniques include system level test, functional analysis, and simulation and modeling. Since each program is unique, the techniques actually used can vary. For example, the B-1B OT&E program only addressed the high altitude EMP nuclear environment. A system level test was performed in which OT&E test requirements were integrated. The test data and subsequent analysis were the primary techniques used to estimate mission impacts. In the Peacekeeper program, on the other hand, both system level tests and functional analysis were used to estimate mission impacts. In addition to unique program factors which drive the mission impact analysis, changes in program scope, threats, etc. may also result in utilization of different techniques. This should be noted in the NAP.

Over the course of NAP implementation, several reports are required in which task results are presented. The contractor is responsible for submitting task results reports periodically throughout the contract period of performance to the AFOTEC project analyst. Briefings may also be required by the contractor, project analyst, and test team which present results to upper management. In addition, AFOTEC is responsible for preparing an Interim OT&E Test Report and a Final OT&E Test Report which present OT&E results. The requirements for results reporting depend on the type of program and thus will be defined in the NAP. The NAP will include a description of various reporting responsibilities for the project analyst, technical contractor, and, if relevant, the test team.

4.0 NAP IMPLEMENTATION, MANAGEMENT AND SCHEDULE

To aid the project analyst, contractor, and test team in accomplishing the assessment, a section will be included in the NAP which provides management guidelines and assessment schedules. The roles and responsibilities for each party involved in the OT&E will be defined. This discussion will define how these various personnel will work together to accomplish the assessment during the implementation phase. Program management tasks and responsibilities will be included to aid the project analyst and contractor Program Manager in effectively managing with programmatic and technical areas.

Finally, a detailed evaluation schedule will be provided. This schedule will present test events, analysis schedules, task completion schedules, and reporting milestones. This schedule should be detailed enough to aid the project analyst, contractor, and test team to efficiently manage the technical evaluation and should be a constant resource for program tracking.

Appendices

A set of appendices will be included in the NAP which provide detailed information for the analyst to successfully accomplish NAP implementation. The appendices shown in Table 2-4 are examples of appendices included in NAPs developed for past programs. The program NAP is not limited to these and should include as much information as required to supplement the NAP implementation tasks.

Example NAP

A typical example of a NAP is provided in Reference 3. the B-1B Nuclear Assessment Plan.