Report of the
Defense Science Board Task Force
on

Nuclear Weapon Effects Test, Evaluation, and Simulation

April 2005

Office of the Under Secretary of Defense
For Acquisition, Technology, and Logistics
Washington, D.C. 20301-3140

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
WASHINGTON, DC 20301-3140

DEFENSE SCIENCE BOARD

11 May 2005

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE (ACQUISITION, TECHNOLOGY & LOGISTICS)

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on Nuclear Weapon Effects Test, Evaluation and Simulation

I am pleased to forward the final report of the DSB Task Force on Nuclear Weapon Effects Test, Evaluation and Simulation. This Task Force was begun in January 2004 to identify near and far term nuclear weapon effects test and simulation needs and produce a roadmap of capabilities to guide simulation technology development.

The Task Force found that there remains a base of Department of Defense personnel and facilities to accomplish nuclear weapon effects test and evaluation, but that capability has eroded significantly in the past 15 years. The Task Force goes on to make several recommendations. These recommendations include outlining specific actions to ensure nuclear survivability is a considered need for operational forces. The Task Force also recommends a coordinated Department of Defense / Department of Energy program for supporting, sharing, and using the expertise, codes and test facilities of the two departments.

I endorse the findings and recommendations of the Task Force and encourage you to review the report.

William Schneider, Jr.
DSB Chairman

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DEFENSE SCIENCE BOARD

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on Nuclear Weapon Effects Test, Evaluation, and Simulation

The DSB Task Force on Nuclear Weapon Effects Test, Evaluation, and Simulation has completed its work and a final report is attached. The Task Force was established to identify nuclear weapons effects test and simulation needs of Department of Defense (DoD) in current and emerging threat environments and to produce a roadmap of capabilities to guide the development of future simulators and simulation technology.

The Task Force assessed opponent capabilities and DoD processes for establishing and enforcing survivability goals with consideration of the following factors: the emergence of terrorism as a major threat to the U.S. homeland and deployed forces abroad; the asymmetric attractiveness of the use of nuclear weapons to offset U.S. conventional superiority; and the growing evidence of proliferation of nuclear-capable states. In conjunction with these factors, the Task Force also evaluated the evolution of DoD and Department of Energy (DOE) modeling, simulation, and above-ground testing capabilities since the cessation of underground testing to understand the ability to qualify hardened systems. The Task Force concluded that a small and limited base of DoD personnel and facilities to accomplish nuclear weapon effects test and evaluation remain, but capabilities have significantly eroded over the past 15 years. Of greater concern is that both the requirements process for new systems and the experimentation and exercise programs with fielded systems largely ignore nuclear survivability as a factor in operations. Based upon these findings, each of the Task Force's recommendations is intended to ensure that nuclear survivability is a considered need for our nation's operational forces. The Task Force also recommends a coordinated DoD/DOE program to support, share and use the expertise, codes, and test facilities of the two Departments.

The Task Force firmly believes that the recommendations contained in this report will aid the U.S. in assuring the nuclear survivability of its critical national security systems. The Task Force urges the senior leaders of DoD to implement the recommendations at the earliest opportunity.

Miriam John

Dr. Miriam John
Task Force Chair

Jay Davis

Dr. Jay Davis
Task Force Vice-Chair

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EXECUTIVE SUMMARY

The Defense Science Board (DSB) Task Force on Nuclear Weapon Effects (NWE) Test, Evaluation and Simulation was undertaken with the overall goal of providing a comprehensive evaluation of current and future Department of Defense (DoD) processes for assuring successful operation in nuclear environments. As directed by the Terms of Reference, we have assessed opponent capabilities and DoD processes for establishing and enforcing hardness goals. These assessments have considered the emergence of terrorism as a major threat to the U.S. homeland and deployed forces abroad, the asymmetric attractiveness of the use of nuclear weapons to offset U.S. conventional superiority, and the growing evidence of proliferation of nuclear-capable states. We have also evaluated the evolution of DoD and Department of Energy (DOE) modeling, simulation, and above-ground testing capabilities since the cessation of underground testing to understand our ability to qualify hardened systems. The results of this Task Force were developed independent of, but are highly consistent with, the findings and recommendations of the Congressionally mandated Electromagnetic Pulse (EMP) Commission.[1]

Principal findings of this Task Force are:

- Despite the reduction of the threat of strategic nuclear exchange, it is becoming more, not less, likely that U.S. forces will have to operate in a nuclear environment in regional operations. This is driven by the proliferation of nuclear weapon capabilities and the attractiveness of nuclear weapons as an offset to U.S. conventional superiority and as a counter to U.S. preemptive doctrine.

- It is essential that U.S. forces retain the capability to conduct conventional operations after limited nuclear use by opponents.

- Trends in acquisition and conventional military operations over the past 15 years have created a set of factors that should make decision makers concerned about the survivability of critical warfighting elements in a nuclear environment. These include the shift to commercial-off-the-shelf (COTS) based electronics, aging of key systems, the growing reliance on historically "soft" C4ISR[2] assets, the general neglect of nuclear hardening as a requirement, and the general neglect of nuclear environments as a factor in gaming and exercises. The bottom

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[1] *Report of the Commission to Assess the Threat to the United States of Electromagnetic Pulse (EMP) Attack*, July 2004.

[2] Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance

line is that commanders and planners cannot be assured that today's weapons platforms, command and control (C2), intelligence, surveillance and reconnaissance (ISR), and associated support systems will be available should a nuclear detonation occur.

- Across Service and Joint systems, there are highly uneven approaches to assessing the need for nuclear survivability and assuring the proper processes in either acquisition or concept of operations (CONOPs) development to ensure successful operations in nuclear environments.

- The shift in acquisition from threat-based requirements to capabilities-based development supporting Joint operations offers an opportunity to develop and apply uniform survivability tools and assurance processes across a range of systems and operations. These elements must be developed and applied through scenarios that test warplans in circumstances of operational nuclear use.

- The deployment of Missile Defense Agency (MDA) systems presents both technical and procurement challenges that are unlike those of previous experience, but could serve as a flagship with respect to addressing nuclear hardening in the context of an evolutionary acquisition strategy.

- There remains a base of DoD personnel and facilities to accomplish many nuclear weapon effects test and evaluation needs, but it is fragile and has eroded significantly in the past 15 years.

- DOE components of nuclear weapons must also be survivable in nuclear environments. The integrated DOE system for assuring nuclear warhead hardening in the absence of underground testing, using modeling and simulation as well as testing with simulators, has been more robust and become more technically advanced than the DoD equivalent over the past decade. This is a result of not only of DOE's explicit support for nuclear survivability, but also investment in advanced codes and computers and large parallel investments in radiation, pulsed power and fusion science and technology. Many of these new capabilities and advances at DOE are of direct benefit to, or can be leveraged by, DoD.[3]

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[3] See Appendix L for a summary of Congressional actions of concern affecting DOE that occurred during review of this report.

The following recommendations are based on the principle that the Department of Defense/Office of the Secretary of Defense, the Joint Staff, and the Services need to accept that the ability to assure the nuclear survivability of critical national security systems is an inherent governmental responsibility. The capabilities to support this endeavor – in particular, advanced code development and simulator infrastructure maintenance and improvements – cannot be met by the private sector. The principal recommendations of this Task Force can be summarized as follows:

1) In order to reinstate nuclear survivability as a considered need:

    a) The Deputy Secretary of Defense (DEPSECDEF) should assure that the Department promptly and carefully considers the recommendations of the EMP Commission and this Task Force, prioritizes corrective actions, and provides appropriate funding, with the authorities of the Assistant to the Secretary of Defense (National Center for Biodefense) [ATSD(NCB)] reaffirmed to assure follow through;

    b) The Office of the Joint Chiefs of Staff/Joint Requirements and Integration (OJCS/J8) should ensure that nuclear threats and survivability assessments are addressed through the reference scenarios of the Joint Capabilities Integration and Development System (JCIDS) process;

    c) Waivers to survivability requirements for new or modified systems should be granted only by agreement of the Undersecretary of Defense for Acquisition, Technology and Logistics (USD/AT&L) and the Vice Chairman, Joint Chiefs of Staff (VJCS) in the context of Joint operations; and

    d) The DEPSECDEF should direct the Services to assess the hardness of critical current operational components and the impact on overall operations should they fail to operate in a nuclear environment. Where serious issues are identified, operational and/or hardening fixes should be developed, approved by ATSD(NCB) and implemented. The Defense Threat Reduction Agency (DTRA) should serve as the principal technical resource to aid the Services in such efforts.

2) ATSD(NCB) should direct DTRA to serve as the DoD lead to establish a coordinated DoD/DOE program in which expertise, codes and test facilities are optimally supported, shared and used.

    a) Such a coordinated program should include investment plans and business models that support the needs of both departments to conduct research and development (R&D), to support agency and Service users, and to provide contractor/supplier access to the facilities.

b) An immediate need is agreement between DoD and DOE on the long term plan to assure continued availability of a prompt neutron source.

c) The two departments should also ensure the operation of a sufficient suite of EMP simulators, as also recommended by the EMP Commission, to meet the needs of both conventional and nuclear warfighting systems.

d) Agreements between the two departments should be institutionalized through amendments to the recently signed Memorandum of Understanding between DTRA and the National Nuclear Security Administration (NNSA).[4]

3) MDA should convene a group of experts from across the community (DoD and its contractors, NNSA and its labs) to sort through the options for assessing and qualifying its system to the HAENS[5] standard in the context of its evolutionary development process.

a) Existing simulators coupled with the advances in modeling being made through DOE's Radiation Effects Science and Advanced Simulation and Computing (ASC) programs appear sufficient to meet MDA's needs, so that further investment in the DECADE facility is not warranted.

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[4] See Appendix C for the text of the current MOU.

[5] High Altitude, Exo-atomspheric Nuclear Survivability

CHAPTER 1

INTRODUCTION

1.1 The Changing Threat Environment

For the most part, our Nation's current capability to address NWE testing, evaluation, and simulation is a legacy from the Cold War. The U.S. was focused on an adversary with the capability to launch a massive nuclear attack and possessing a substantial numerical superiority of conventional ground troops. Our nuclear weapons were viewed as a deterrent against the massive attack as well as a hedge against conventional attack. It was clear that many of our military systems might be required to survive and operate reliably in a hostile nuclear environment. The evaluation and definition of the necessary survivability levels were therefore a rigorous part of the DoD acquisition process, and many of the resulting components and systems were usually built around "radiation hard" technologies and methods developed specifically for government use and at government expense. Experimental validation of the survivability of these hardened systems was achieved by a series of exposures to radiation simulators at as near threat level as possible. The "final exam" came with threat level exposure in an underground nuclear explosion. Computational modeling was used as an adjunct to the exposure experiments but was severely limited by computational horsepower in its ability to model the complex shapes and materials of actual components and experiments.

Although the number of stockpiled nuclear weapons (by all parties) was quite large during the Cold War, the number of nuclear nation states was small and all possessed rigorous systems of C2 over their nuclear arsenals. This helped to add a degree of stability and predictability throughout this period in the nation's history.

The Cold War ended more than a decade ago and much has changed since the collapse of the Soviet Union in ways that significantly alter the manner in which we must go about the business of determining operational capabilities and judging the need for nuclear survivability across the spectrum of warfighting systems, both strategic and non-strategic. Foreign nuclear activities worldwide are not negligible and it is clear that the future will not be nuclear-free.

Although the U.S. no longer appears to face the immediate threat of a massive nuclear exchange, we now live in a much more complex and unpredictable nuclear world. There has been unprecedented proliferation of nuclear technology, nuclear weapons, and potential delivery platforms. The U.S. now faces smaller but more numerous adversaries that possess or may acquire nuclear weapons in a geopolitical environment where alliances can, and do, change rapidly. While C2 of nuclear weapons remains strong in the U.S. and in other major nuclear powers, proliferation and weak nuclear states are creating a much higher probability of loss of control of a nuclear weapon. A nuclear weapon in the hands of a rogue nation or a terrorist group is a real possibility.

Current concerns range from the terrestrial use of a nuclear device for gaining an asymmetric advantage in a conventional conflict to the detonation of a nuclear device at high altitude to produce an EMP for the purpose of disrupting electronic systems and impacting infrastructures required to support operations in both military and civilian sectors. This latter use would almost certainly enhance the earth's radiation belts with fission electrons in a manner that would reduce satellite lifetimes with significant consequences for the reconnaissance, communications, navigation and commercial space communities.[6] Detonation at lower altitudes would probably not have so widespread an effect, but could be tailored to disable "soft" military systems in a more localized theater of operations.

The nuclear threat environment has therefore become more diffuse, uncertain, and difficult to characterize, but it has not gone away. Over the past decade, the U.S. has built up a competent and highly capable conventional force which surpasses that of our potential adversaries. The acquisition of nuclear weapons as a hedge against overwhelming conventional force superiority is now more important to our adversaries than it is to the U.S. The view of nuclear weapons as a potential war-fighting tool is more prevalent in many nations and groups than it is in the U.S. Tactical use of a nuclear weapon on the battlefield is a growing possibility. **The U.S. must retain the ability to conduct both conventional <u>and</u> nuclear operations after nuclear use by others.** Critical space systems and missile defense must operate in a nuclear environment and our strategic systems must continue to be survivable to nuclear effects. Moreover, our conventional systems must be subjected to a hard look at how survivable they would be in a battlefield nuclear environment – a factor not seriously considered for some time. This may require hardening, redundancy, operational changes, rapid reconstitution, or combinations thereof to achieve an effective survivability strategy.

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[6] *Report of the Commission to Assess the Threat to the United States of Electromangentic Pulse (EMP) Attack,* July 2004.

1.2 Key Trends in U.S. Capabilities

An important trend has resulted from the cessation of underground nuclear testing. The rapid growth of computational capabilities has driven a major shift in the approach to the testing and validation of nuclear effects and survivability. No longer do we have the luxury of the full-scale test to validate a given design in a "real" threat environment. The validity must be inferred from a combination of intelligent design rules, above-ground simulator experiments, and sophisticated computer models. Computer modeling in conjunction with simulator experiments is maturing to become the cornerstone of nuclear effects evaluation. This shift in approach is especially important as we attempt to evaluate nuclear effects on large, complex, highly interconnected systems where experimental testing is not feasible.

A feature of the recent, rapid evolution of our defense technology is the growing dependence on COTS components, particularly electronics hardware and computer software. While such commercial equipment provides tremendous capability at reduced cost, the components are typically not radiation hardened because there is little commercial incentive to make them so. It is a unique government responsibility to develop and maintain the test and validation technologies and skills necessary to produce military systems that will operate reliably and predictably in a nuclear environment. This is particularly important as the acquisition process moves to spiral or evolutionary development in which major block changes are planned from the onset, but nuclear hardening is often deferred to later phases. The radiation effect design and evaluation technologies must be in place to support the planned evolution, but it is critical that the basic design concepts are consistent with hardening the subsequent hardware iterations unless DoD is prepared to accept much higher costs for redesigned systems – or continue to accept yet another spiral of "soft" capability.

1.3 Definitions and Organization of the Report

In the context of this fundamentally different future, this DSB Task Force was established to conduct a comprehensive assessment of DoD needs for a nuclear weapon effects enterprise, including test facilities, modeling and simulation capabilities, and a healthy base of expertise in relevant areas, to assure responsible NWE hardening and validation of systems in current and emerging threat environments. In its broadest usage, NWE includes effect on our assets (survivability, vulnerability) and the assets of others (lethality, collateral effects); but in this report, we focus on the effects on our assets. Nuclear survivability of a military system is the ability of that system to perform its intended functions with no more than acceptable degradation during or after exposure to specified natural, intrinsic, diagnostic, hostile, and/or fratricide radiation and nuclear environments. The principal environmental context considered in this report is hostile environments.

The report addresses the current and emerging threat environment over the next decade (Chapter 2) and discusses how that threat translates into capabilities (and attendant requirements) (Chapter 3). A particularly important issue that underpins nuclear effects evaluation deals with our understanding of weapon outputs, a topic treated as a focus subject in Chapter 4. Current approaches and methods intrinsic to the hardening and validation process are addressed in Chapter 5; whereas the future strategy and associated business models for the NWE testing and validation enterprise are addressed in Chapter 6. Finally, recommendations for revitalizing and sustaining a national capability are delineated in Chapter 7. Several appendices are also included to provide relevant details supporting principal report themes.

CHAPTER 2

THE CURRENT AND EMERGING NUCLEAR THREAT AND OPERATING ENVIRONMENTS

2.1 Trends in Adversary Capabilities as a Context for Analysis

Nowhere has the end of the Cold War had a more profound effect on national security policy than in the area of nuclear weapons. Dramatic changes continue to occur in the source and nature of the nuclear threat to the U.S. and as discussed in Chapter 1, the future world will not be nuclear-free. Although nuclear weapons will have much less impact in political and military calculations than at the height of the Cold War, it appears that they will have a significant, albeit different, role in the years ahead. Importantly, the attitude of many other countries regarding nuclear weapons is evolving in a manner quite different from ours, with selected nations viewing nuclear weapons as a legitimate, asymmetric war fighting tool.[7] This Task Force believes that the U.S. is, unavoidably, entering a future in which the probability of nuclear weapon use by others is higher than during the Cold War. The U.S. must create resources agile enough to confront the nuclear challenges of the next 15 years. Considerations must include three categories of nuclear threats: peer nuclear nations, emerging nuclear nations, and terrorists.

Peer states, specifically Russia and China, continue to advance their nuclear weapons capabilities. In addition to stockpile safety and reliability issues, Russian investment includes work on new designs and testing protocols over a range of applications.[8] For example, President Putin recently announced the development of a new class of nuclear weapons designed to penetrate our developing National Missile Defense System. China has launched the first in a new class of ballistic missile submarines that will carry intercontinental missiles capable of hitting targets in the U.S. without ever leaving protected waters of the Chinese coast.

Although the U.S. cannot ignore the possibility for strategic engagements between peers, the unclassified literature underscores the increasing importance of nuclear use by Russia (and others) in non-strategic engagements as an offset to

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[7] National Intelligence Council, *Global Trends 2015: A Dialogue About the Future with Nongovernmental Experts*, December 2000

[8] Remarks of Defense Minister Ivanov: *Russian Views of Nuclear Weapons as a Basis for Global Stability,* Moscow Interfax (in English), July 2004.

conventional strength of neighboring adversaries.[9] Even if the U.S. is not involved in the initial stages of regional conflicts, the potential exists to be subsequently drawn in to aid our allies. Strategies, doctrine, and new low yield weaponry are maturing to make nuclear environments a recognized operational reality for other countries in a range of engagements. The U.S. must be prepared for a world in which at least some existing and future nuclear powers perceive an advantage in improving, expanding, and brandishing their nuclear arsenals.

With respect to emerging nuclear states, the roster of nuclear-capable nations during the next decade or two is likely to lengthen, not shorten. The attitudes of these nations regarding nuclear weapons vary widely, as do their views of the U.S.; neither is static. Views regarding the role of nuclear weapons by current regimes in North Korea and Pakistan, both of which aggressively threaten provocation, proliferation and use for diplomatic and military purposes, contrast with India's views, which are largely deterrence based.[10] The role of Pakistani scientists in the proliferation of nuclear know-how and technologies cannot be ignored, for they serve as seed for the worldwide global nuclear community of the next decade. Moreover, rogue states, such as North Korea and Iran, may also be developing the capability to pose a nuclear threat to the U.S. and its military forces, which may be unpredictable and difficult to deter.[11]

Terrorist groups pose an even more complex problem. These groups have no state identity, may have only one or a few weapons, and are motivated to attack the U.S. without regard for their own safety. There are a growing number of militant Islamic groups in addition to al-Qaeda that continue to advertise their intent to strike the U.S.[9]. In addition, other non-Islamic terrorist and insurgent groups, such as the Revolutionary Armed Forces of Columbia (FARC), may evolve to become a threat to the U.S. and its allies. Moreover, other non-traditional emerging threats from non-state actors, such as anti-globalization activists and organized crime, may complicate the U.S. counterterrorism mission as well as frustrate other political, economic, and technological goals.[10] Interest in terrorist groups acquiring a nuclear weapon is not new. While the capability for terrorist organizations to prosecute a nuclear EMP attack

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[9] Moscow Nezavisimoye Voyennoye Obozreniye (in Russian), Weekly independent military newspaper published by Boris Berezovskiy-financed Nezavisimaya Gaseta.

[10] *N Korea Wants Nukes to Reduce Cost on Military*, Reuters, July 9. 2003; Paul Bracken, Fire *in the East: The Rise of Asian Military Power and the Second Nuclear Age*, New York Harper Collins, 1999

[11] National Intelligence Council, *Global Trends 2015: A dialogue About the Future with Nongovernmental Experts,* December 2000.

[9] National Commission on Terrorism, *Countering the Threat of International Terrorism,* June 2000.

[10] National Intelligence Council, *Annual Report to Congress on the Safety and Security of Russian Nuclear Facilities and Military Forces*, February 2002.

against U.S. military forces cannot be ruled out, the scenarios of greater concern for terrorist usage of a nuclear weapon involve terrestrial detonations (producing blast, shock, thermal, and fallout effects), likely in urban areas with civilian populations and facilities as the target.

2.2 Projection of Capabilities and Scenarios of Potential Nuclear Use Against the U.S.

The scenarios of concern over the next decade or two may be correlated with the actors discussed in the previous section. A profile of these concerns and their ranking by the Task Force as High, Medium, or Low is shown in Figure 2.1 below. Using the categories outlined above, several additional issues should be noted regarding potential scenarios involving nuclear weapons. These are discussed below.

Scenario / *Concerns*	Strategic Exchange	Non-Strategic Exchange	Terrorist Use
High			Red
Medium		Green	
Low	Blue		

Figure 2.1 Scenario concerns and potential future use of nuclear weapons

Scenario

1. Large-scale strategic exchange of nuclear arsenals (Cold War scenario)
2. Limited, non-strategic (tactical) nuclear use by peers or N^{th} tier powers
3. Use by terrorists

Concerns regarding the use of nuclear weapons in the next 15-20 years

1. High (red)
2. Medium (green)
3. Low (blue)

Strategic Exchanges

It is not difficult to imagine future political situations that would prompt marked increases in tensions between three major nuclear powers, on a pair-wise basis. U.S. – China relations could erode over Taiwan; U.S – Russian relations could sour over conflicts between Russia and U.S. allies and friends; Russia-China relations might turn hostile over border conflicts; other regional issues might escalate in a manner that ensnares the U.S. In the extreme, any of these might result in a strategic exchange, although these circumstances are perceived as quite remote by the leadership of involved countries.[11] Although the arsenals of the U.S. and Russia will likely continue to be reduced, it must be remembered that such trends are easily reversed. The Cold War clearly demonstrated that with will and resolve, a technologically advanced nation can develop and produce *thousands* of nuclear weapons, involving hundreds of megatons of yield in just a few years. The striking slope of these build-ups is shown in Figure 2.2 below.[12]

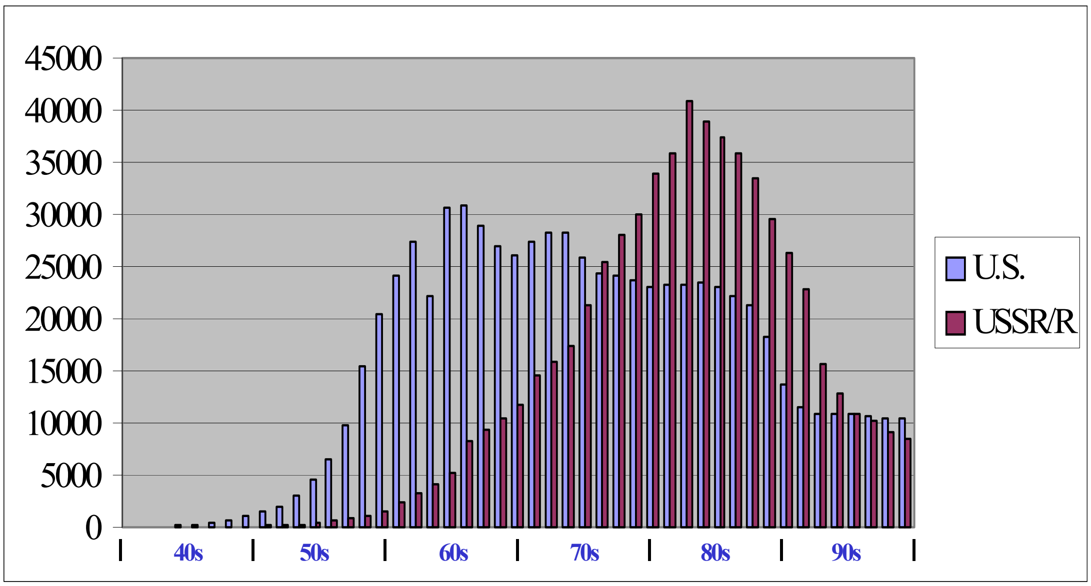

Figure 2.2 Stockpile Development Profile---Numbers of Weapons by Decade

Although not a driving future contingency, this potential underscores the prudence of assuring that our small backbone of legacy strategic systems are viable and not allowed to erode.

Non-Strategic Exchanges

Many nuclear nations, including major players and aspirants, particularly those with limitations in their conventional forces, view nuclear weapons as an equalizer to overwhelming conventional superiority. Public statements, military writing and field

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[11] Central Intelligence Agency, Unclassified Responses to Questions for the Record, in Senate Committee on Intelligence, United States Senate, *Current and Projected National Security Threats to the United States*, February 11, 2003.

[12] Michael Light, 100 Suns, Alfred A. Knopf, New York 2003.

exercises in Russia, for example, underscore the operational value of nuclear weapons to the Russian military in a range of non-strategic conflicts. In fact,

> *"…nuclear weapons are now the main and a relatively cheap means of deterrence, and during an emergency period the main weapon for conducting combat operations to ensure the territorial integrity of Russia and it allies*."[13]

The potential exists for the U.S. to be drawn into such a conflict in which its troops and systems would be exposed to a nuclear environment including both ionizing and electromagnetic radiation. Within this context, U.S. forces would be particularly vulnerable at times when forces are massed, e.g., a Navy Carrier Battle Group, a deployed Air Force Wing of aircraft, and/or Army or Marine divisions during debarkation and forward-movement operations. Adversaries would seek to gain significantly in terms of anti-access and overall asymmetric advantage. The Task Force has seen these circumstances exercised on a limited basis in war games such as the Carlyle Barracks War Games and encourage a much more frequent use of a limited number of nuclear weapons in operational planning scenario assessments, scripted gaming activities, and in field experiments involving operational resources. This scenario usage is discussed further in Chapter 3.

Terrorist Attacks

> *"For five centuries only a state could destroy another state…We are entering a period, however, when very small numbers of persons, operating with enormous power of modern computers, biogenetics, air transport, and even nuclear weapons, can deal lethal blows to any society*." [14]

Today, and unfortunately well into the future, non-state actors appear motivated to inflict massive damage on the United States. Official reports are unambiguous, for example, about al Qaeda's intent to acquire and use chemical, biological, radiological, and nuclear weapons to cause mass casualties in the western world and among those that support the west.[15] However,

> *"…If al Qaeda and Usama bin Laden were to disappear tomorrow, the United States would still face potential terrorists threats from a growing number of groups opposed to*

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[13] Moscow Nezavisimoye Voyennoye Obozreniye, 2004 (weekly independent military newspaper published by boris Berezovskiy- finanaced Nezavisimaya Gaeseta).

[14] Phillip Bobbitt, *The Shield of Achilles*, Alfred A Knopf, New York, 2002

[15] Central Intelligence Agency's Directorate of Intelligence, *Terrorist CBRN: Materials and Effects*, May 2003

perceived American hegemony. Moreover, new terrorist threats can suddenly emerge from isolated conspiracies or obscure cults with no previous history of violence."[16]

To the extent that recent events characterize the future, terrorist groups are likely to target icons of American society with a goal of human casualty. Attacks are likely to be directed toward civilian targets in urban areas where heat, blast and fallout are the dominant problems. Almost none of our civilian systems are designed to operate in a nuclear environment. Additionally, terrorist groups might attempt to detonate a nuclear device at high altitude to generate an EMP (see discussion in Section 2.3). It is unlikely that these groups would have access to a specifically designed EMP weapon; but even crudely designed nuclear devices can produce significant impacts on electronic and communications systems. Again, while terrorist capabilities to conduct an EMP attack cannot be ruled out, the terrorist use of most concern involves a ground detonation of a nuclear device.

2.3 Special Cases

Missile Defense

Nuclear environments may result from missile defense intercepts occurring within either a strategic or non-strategic context, if a nuclear weapon is delivered by an adversary missile. Within today's context, this could occur if the threat missile employs a nuclear-armed re-entry vehicle that is salvage fused, i.e., designed to detonate if impacted by a kinetic interceptor of the type being developed by the United States. These environments would be produced at high altitude and likely result in global effects, including both EMP and enhanced space-radiation environments. These effects could be produced over the open ocean in the case of a mid-course intercept of some threats over the Pacific, or over the country that launched the missile.[17] In the latter case, U.S. forces deployed in the theater could also be subject to EMP and other collateral effects of the engagement.

The above circumstances underscore the importance of developing missile defense kill vehicles that can operate in a nuclear environment produced either by direct attack by an adversary or by the explosion resulting from intercepting an incoming nuclear warhead. The operational requirements attending these engagement scenarios are discussed in detail in the Ballistic Missile Defense System (BMDS) HAENS

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[16] National Council on Terrorism, *Countering the Threat of International Terrorism*, June 7, 2000

[17] *Foreign Missile Developments and Ballistic Missile Threats Through 2015*, *Unclassified Summary of National Intelligence Estimate*, National Intelligence Council, December 2001

standard. This nuclear environment standard was created by the MDA as a basis for system hardness considerations to be addressed with each cycle of system acquisition. Issues related to this standard and its impact on U.S. nuclear weapons effects testing and simulation needs are discussed in subsequent chapters of this report. The description of the MDA system concept and acquisition strategy is described in more detail in Appendix D.

High-Altitude EMP Attacks

An intense pulse of electromagnetic energy is produced (as is an enhanced space-radiation environment) when a nuclear weapon is detonated above approximately 40 km altitude. The scope of this phenomena and its potential use by a number of nuclear players, as well as its consequences for electronics systems were the subject of a Congressional Commission that recently finished a two-year effort to characterize this effect and its implications, particularly on the U.S. infrastructure. Refer to the Commission's report,[18] which is partially quoted below:

> *"The high-altitude nuclear weapon-generated electromagnetic pulse (EMP) is one of a small number of threats that has the potential to hold our society*
>
> *seriously at risk and might result in significant degradation of our military forces.*
>
> *Briefly, a single nuclear weapon exploded at high altitude above the United States will interact with the Earth's atmosphere, ionosphere, and magnetic field to produce an electromagnetic pulse (EMP) radiating down to the Earth and additionally create electrical currents in the Earth. EMP effects are both direct and indirect. The former are due to electromagnetic "shocking" of electronics and stressing of electrical systems, and the latter arise from the damage that "shocked"—upset, damaged, and destroyed—electronics controls then inflict on the systems in which they are embedded. The indirect effects can be even more severe than the direct effects.*
>
> *The electromagnetic fields produced by weapons designed and deployed with the intent to produce EMP have a high likelihood of damaging electrical power systems, electronics, and information systems upon which the U.S. military and American society depends. Their effects on dependent systems and infrastructures could be sufficient to qualify as catastrophic to the Nation.*
>
> *China and Russia have also considered limited nuclear attack options that, unlike their Cold War plan, employ EMP as the primary or sole means of attack. Indeed, as recently as May 1999, during the NATO bombing of the former Yugoslavia, high-*

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[18] *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack*, Volume 1: Executive Summary, July 22, 2004

ranking members of the Russian Duma, meeting with a U.S. congressional delegation to discuss the Balkans conflict, raised the specter of a Russian EMP attack that would paralyze the United States. This emphasis on non-strategic use of nuclear weapons is in addition to the more traditional strategic employments, which, although reduced in priority, have certainly not been eradicated.

This type of detonation is likely to damage key weapon systems and support capabilities, including satellite navigation systems, intelligence and targeting systems, and many other militarily significant platforms. Battlefield impacts will be significant, particularly if our small, technically superior but electronically dependent force is transformed into a small, impaired and vulnerable force."

2.4 Survivability Concerns

Several factors have combined to produce the potential for a "perfect storm" with regard to nuclear survivability risks. These factors include the following:

DoD has moved from requirements-based acquisition to a capabilities-based protocol. This has left nuclear survivability an implicit rather than explicit issue to be addressed by program offices, contractors and review boards, largely as they see fit;

The decade or more following the Cold War produced a diffuse threat spectrum marked by uncertainty, until galvanized by the events of 9/11. During this period, the DoD nuclear weapon effects enterprise eroded markedly in testing and test facilities, in research, and in the health of the workforce;

Both acquisition policy and strategy during the past decade have encouraged commercial best practices as the key principle of evolutionary acquisition. This has lead to a proliferation of commercial-of-the-shelf (COTS) technology mixed with non-COTS technologies in military systems. Little to no attention has been given to performance of these systems in nuclear environments.

Moreover, the digital electronics industry, particularly the telecommunication industry, has revolutionized the way the world lives. Most classes of emerging digital technologies are being designed to respond to increasingly lower signal levels. These trends result in greater challenges for the radiation hardening community in attempting to assure the nuclear survivability of such sensitive components.

Finally, and as a counterpoint to the above issue, a significant number of in-place military systems are decades old. Little is known about the way hardened technologies, systems, and protocols change with age, both with and without an aggressive hardness assurance program. Moreover, the past decade or more has seen erosion in attention to these programs in general.

At odds with these factors is the assessment of the Task Force that in future threat environments, nuclear survivability will become more important to a range of military systems beyond (but including) the traditional strategic systems. Moreover, the nuclear environment issues are different than during the Cold War. Figure 2.3 illustrates how particular elements of a nuclear environment should be prioritized, given the scenario concerns shown previously in Figure 2.1. The first six environment components relate to nuclear detonations at high altitude, whereas the last three are intrinsically low altitude detonation concerns. Consistent with Figure 2.1, the color-coding indicates the scenario concerns for the next decade or two. In Chapter 5, each of the environments is discussed and related to nuclear hardening protocols and the test facilities and simulation tools needed to validate system and component hardness levels.

Scenario / Nuclear Environment Component	Strategic Exchange	Non-strategic Exchange	Terrorist Use
X-rays (High Fluence)	•		
Prompt Gamma-Rays	•		
Prompt Neutrons	•		
X-rays (Low Fluence)	•	•	
Fission Decay Products (Trapped Electrons, etc.)	•	•	
EMP	•	•	
Blast/shock	•	•	•
Thermal	•	•	•
Fall out	•	•	•

Figure 2.3 Scenarios and dominant nuclear environment concerns

The need for nuclear survivability must be assessed intentionally and rigorously for each system that enters the acquisition process. The elements of the new triad, particularly the defensive and the C4ISR components (including space systems), warrant attention at technology block changes and upgrade points, as well as a continuing hardness maintenance and assurance program. A periodic scorecard or checklist process that requires the Services and Commands to test operational resources to certify and validate hardening could inject discipline into the process. Since non-strategic resources may also be required to operate in nuclear environments, these systems should also be subjected to the scorecard audit process initially and annually.

CHAPTER 3

TRANSLATING THREAT TO REQUIREMENTS

The contributors to the "perfect storm" of nuclear survivability risks are growing in size and potential impact on U.S. warfighting capabilities, affecting not only future forces being developed through the DoD requirements and acquisition processes, but also today's in-place forces and support systems.

The intensity level of this "storm" relates directly to the evolving threat and the growing likelihood that a nuclear weapon will be used to gain asymmetric leverage against conventionally superior U.S. forces. A significant portion of the storm relates to the ongoing erosion of any nuclear survivability discipline within DoD in both the requirements and surveillance processes. The fact that few of today's decision makers appear interested in understanding the seriousness of this threat only multiplies the potential intensity of the storm and its impacts on U.S. forces.

The dangers associated with not acknowledging the potential for the "perfect storm" and its attendant risks make crucial the need to better accommodate nuclear survivability in DoD's requirements process. This translation of threat-to-requirements should focus on two important areas: integration into the evolutionary acquisition strategy for future forces, and development of a methodology for assessing survivability of in-place forces.

3.1 Current Service, Agency, and System Practices[19]

U. S. Army

The Army has taken nuclear survivability seriously for new development programs for decades. Although somewhat out of date, the Army directives provide excellent guidance on the process for determining survivability requirements. The U.S. Army Nuclear and Chemical Agency (USANCA) has responsibility for reviewing the specifications for all new Army systems and for recommending the nuclear survivability requirements for those systems. USANCA also advises the program offices on how to achieve and verify that the system meets these specifications. For a system to receive a waiver of these requirements, the waiver must be approved by the Deputy Chief of Staff G-3/5/7 of the Army. The program office knows what the

[19] See Appendices E, F, and G for a more expansive description of practices in the Army, Navy, and Air Force, respectively.

requirements are, what to do to prove that they meet the requirements, and how to do it – or how to make the case as to why the need for hardening is unimportant. Once fielded, however, systems are not periodically checked to assure that hardness levels have been maintained.

Late in the course of this study, the Task Force learned that the Army is considering the move of USANCA from the Army Training and Doctrine Command (TRADOC) to the Chemical Corps. The Task Force believes that this would be a serious mistake and lead to the erosion of the Army's current exemplary process among all the Services.

U. S. Navy

The directives and instructions regarding nuclear survivability in the Navy are out of date. As an example, the waiver process called out in the Navy instructions references Department of Defense Directive (DoDD) 4245.4, "Acquisition of Nuclear Survivable Systems" which was canceled in the early 1990s without replacement. The organization that is called out as the waiver authority for nuclear survivability, PMS-423, was dissolved in 1993.

In spite of this, critical systems within the Navy continue to maintain nuclear survivability requirements. The Strategic Systems Program Office (SSPO) has maintained clear hardening requirements for the Submarine-Launched Ballistic Missile (SLBM) portion of the nuclear deterrent. As these systems are upgraded, the nuclear hardening requirements are maintained. They have an effective program to analyze, test, and verify that the system still meets the requirements.

Navy systems other than the strategic systems are less clearly focused on survivability and hardening. Surface combatants continue to have nuclear survivability requirements levied (although at lower levels than previously required). However, nuclear survivability validation is performed primarily through engineering analysis rather than testing. The Standard Missile-3 upper tier defense has hardening requirements from the MDA HAENS standard. However, the Standard Missile-2 lower tier defense Block IV has no hardening. For naval aircraft, several specific platforms such as the E-6Bs have requirements levied on them because of their missions. Otherwise, Navy air platforms do not have to address nuclear survivability requirements.

U. S. Air Force

The information provided to the Task Force concerning the process for addressing nuclear survivability requirements reflected, with some exceptions, a general decline in attention paid to nuclear survivability requirements. After the demise of the Nuclear Criteria Group Secretariat in 1994, it is not obvious who is responsible for establishing and implementing nuclear survivability requirements. Air Force Air and Space Operations (AF/XOS)[12] is the designated advocate for nuclear issues. However, AF/XOS only acts in an advisory capacity. In general, the Air Force directives and instructions are out of date. The organization assigned the responsibility for this area, the Secretary of the Air Force, Acquisition (SAF/AQQS), no longer exists.

As is the case with the Navy, the Air Force strategic platforms continue to assess nuclear survivability. These platforms include the Minuteman III Intercontinental Ballistic Missile (ICBM), the B-52 and B-2A strategic bombers, and the Air-Launched Cruise Missile (ALCM) and Advanced Cruise Missile (ACM). Assessments appear to be conducted on an aperiodic, as opposed to routine, basis and do not include testing. The ICBM community maintains a hardness surveillance program and took care to address hardening in the recent upgrade to the Minuteman III. In addition, some of the enduring command and control and communications systems have continuing nuclear survivability requirements. The National Space Systems Office (NSSO) of the USAF is currently establishing a policy concerning nuclear survivability for space assets although the Task Force was unable to get any insight into the effort.

Among conventional weapon platforms or support hardware, there is almost universal silence concerning any requirement to operate in or after a nuclear environment.

Missile Defense Agency (MDA)

MDA is required to engage and negate incoming targets that may include nuclear warheads. Consequently, the BMDS has nuclear hardening requirements. As mentioned in Chapter 2, these requirements are defined in the HAENS. The HAENS standard is a three level standard that provides a yardstick for evaluation of BMDS capability against nuclear weapon threats, both now and in the future. MDA is following the evolutionary acquisition strategy mentioned earlier and described more fully in Appendix D, with the goal of progressive improvements in capability as the system matures. Survivability is one of the attributes to be included in a later block

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[12] Formerly the Directorate of Nuclear and Counterproliferation (AF/XON), which has been recently dissolved.

change to the system. The MDA Director is the approving authority for system survivability requirements.

Command and Control (C2)

The primary focus of DoD's transformational C2 improvements is implementation of a network-centric, collaborative architecture. This architecture will be capable of incorporating sophisticated and fused intelligence inputs as well as enabling rapid, collaborative and adaptive planning and will provide military and civilian leaders superior decision capability. The C2 architecture will ride on the bandwidth-expanded Global Information Grid (GIG), the Transformational Communications Architecture, and Net-Centric Enterprise Systems (NCES).

Survivability of specific C2 systems as well as complementary space- and ground-based communications and ISR assets is vital for the U.S. to maintain its superiority against any potential adversary. However, dual problems of growing system vulnerabilities (stemming from inattention to hardening requirements and surveillance, use of COTS electronics, etc.) and an evolved, ever-more-likely nuclear threat combine to raise the threat to survivability to a high level of concern. The growing potential for U.S. forces to lose some or all of its C2 agility and advantage on a future battlefield is unacceptable. These are critical problems requiring high-level attention in the requirements process.

Intelligence, Surveillance and Reconnaissance (ISR)

Similar to C2, transformational ISR systems will depend upon a diverse, robust and tiered-sensor architecture to tie fused intelligence information into the network-based C2 system. This tiered-sensor array will include space-based and penetrating airborne platforms, close-in airborne sensors, and ground-based sensors. The transformational vision for ISR includes responsive, persistent and agile surveillance and reconnaissance platforms feeding into a process for netted, collaborative, real-time signal-level sensor exploitation. Responsive, agile ISR coupled with netted, collaborative C2 will increase U.S. advantage and leverage on the battlefield – particularly in terms of allowing us to operate inside the decision loop of the adversary.

Survivability challenges similar to those facing C2 systems are evident for transformational ISR platforms and supporting systems. "Current surveillance and reconnaissance systems lack hardness against nuclear effects, including electromagnetic pulse (EMP)."[20] DoD decision makers must address the tough questions and difficult trade-offs involving nuclear survivability requirements for future ISR systems.

3.2 Transitioning from Requirements to Capabilities-Based Acquisition

Evolutionary Strategy

In the current reality of asymmetric and evolving threats, DoD has recognized that the methods used for determining military system requirements to support U.S. warfighting goals is in need of change. In May 2003, the DoD Instruction 5000.2, "Operation of the Defense Acquisition System," introduced the evolutionary acquisition strategy:

> *"Evolutionary acquisition is the preferred DoD strategy for rapid acquisition of mature technology for the user. An evolutionary approach delivers capability in increments, recognizing, up front, the need for future capability improvements. The objective is to balance needs and available capability with resources, and to put capability into the hands of the user quickly. The success of the strategy depends on consistent and continuous definition of requirements and the maturation of technologies that lead to disciplined development and production of systems that provide increasing capability towards a materiel concept."*

Two approaches are defined for implementing the evolutionary acquisition strategy:

1) **Spiral Development.** In this process, a desired capability is identified, but the end-state requirements are not known at program initiation. Those requirements are refined through demonstration and risk management, there is continuous user feedback, and each increment provides the user the best possible capability. The requirements for future increments depend on feedback from users and technology maturation.
2) **Incremental Development.** In this process, a desired capability is identified, an end-state requirement is known, and that requirement is met over time by developing several increments, each dependent on available mature technology.

Assuring Joint Capabilities

The Chairman of the Joint Chiefs of Staff is assigned the responsibility to provide advice regarding military capability needs for defense acquisition programs. The

[20] *Future Strategic Strike,* Defense Science Board report, November 2003.

process through which the Chairman provides this advice is described in Chairman of the Joint Chiefs of Staff Instruction 3170.01C, "Joint Capabilities Integration and Development System" (JCIDS), dated 24 June 2003. In conjunction with representatives of other DoD communities, the Chairman is to formulate broad, time-phased, operational goals and is directed to consider affordability, technology maturity, and responsiveness in the process. Figure 3.1 is a flow diagram of the JCIDS process.

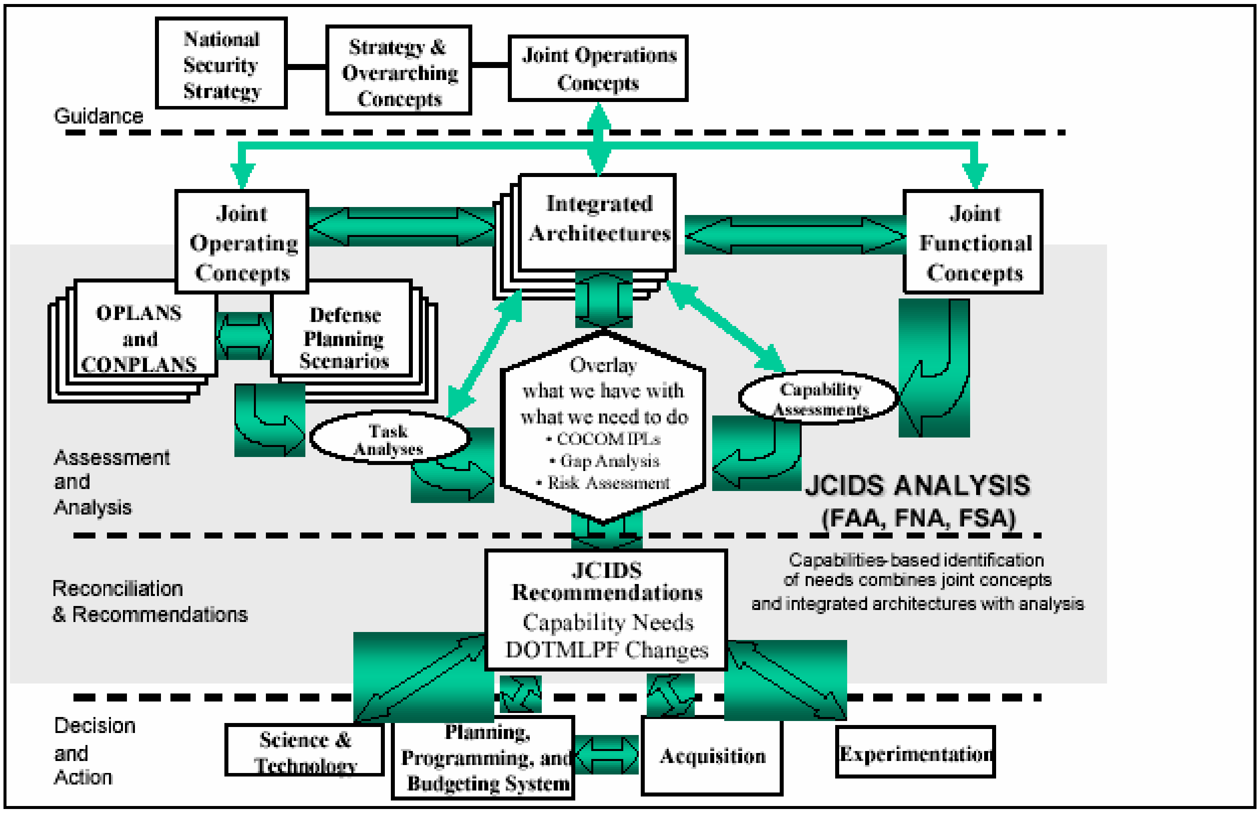

Figure 3.1 The JCIDS Process

3.3 Nuclear Survivability – A Reduced Priority in the Joint Process?

DoD Directive 5000.1, "The Defense Acquisition System", dated May 12, 2003, focuses on a total systems approach, and in doing so, relegates survivability to one of the competing characteristics to be considered in the process of making acquisition decisions:

> *"The PM [Program Manager] shall be the single point of accountability for accomplishing program objectives for total life-cycle systems management, including sustainment. The PM shall apply human systems integration to optimize total system*

performance (hardware, software, and human), operational effectiveness, and suitability, survivability, safety, and affordability. PMs shall consider supportability, life cycle costs, performance, and schedule comparable in making program decisions. Planning for Operation and Support and the estimation of total ownership costs shall begin as early as possible. Supportability, a key component of performance, shall be considered throughout the system life cycle."

While the JCIDS process is intended to introduce a streamlined and agile process for generating requirements within DoD, this capabilities-based approach removes nuclear survivability from its former status as an explicit requirement to be addressed and places it in the trade space. Any stated need for building nuclear hardness into a system is likely to be a non-winner in most trade space competitions. This is true in part because of the widespread perception throughout DoD that nuclear use is an unlikely event and that nuclear hardening is expensive. Although the consequences of a nuclear detonation would be catastrophic, its assumed low likelihood – assessed against the low relative costs of COTS equipment and perceived high costs of hardening – stacks the competitive deck against nuclear hardness requirements.

To be more specific, a capabilities-based acquisition process will gravitate toward the development of various complementary or competing capabilities in order to reduce the risk of technological surprise. In addition, resource constraints require that the relative worth of various capabilities be rank-ordered in some manner. Such a rank ordering of capabilities will usually involve a cost/benefit trade that includes the relative probability that a capability will be required, the effect on U.S. interests if the capability does not exist, and the relative cost to develop and deploy the capability. Given the mechanics of this new process, nuclear survivability will not be competitive.

The evolutionary strategy can aggravate the problem by allowing the option to defer hardening to a later stage or spiral in acquisition even where nuclear hardening is a clear requirement, as in the case of missile defense systems. Yet history and recent studies tell us that nuclear survivability is best incorporated into a system during the initial design (see Chapter 5, Sections 5.1 and 5.2 for a discussion of design for hardening). If nuclear survivability is not addressed in the initial design, the cost of incorporating such features downstream into an existing design will likely be much more expensive, if possible at all.

3.4 Nuclear Survivability for In-Place Forces

From 1990 to the present, widespread avoidance of nuclear survivability issues put many in-place systems and platforms in high-risk (possibly vulnerable) categories.

Some, fielded with hardened components, are in question because of little or no surveillance and/or testing. Others were simply built and fielded with COTS-based electronics in an era of inattention or lack of concern about hardening requirements.

Added to the current situation is a low-level of understanding of the impact on operations of unhardened platforms and supporting systems. Wargames and exercises do not routinely include the use of a nuclear weapon such that operational workarounds and/or mitigation actions are not being developed in parallel with conventional concepts of operation.

Consider the example of an adversary EMP attack. Any potential for U.S. units in a large geographical area to experience significantly degraded electronics would be unacceptable. A series of questions puts the issue in perspective. What would be the impact on a U.S. Marine Corps (USMC) or an Army division debarking at a Middle Eastern or Korean port and/or airfield (C2, computer-driven equipment, weapons systems, etc.)? What impacts would a carrier battle group (weapons platforms, avionics, ship systems, etc.) experience in the Straits of Taiwan? What vulnerabilities does a forward-deployed Air Force wing have with regard to EMP (platforms, C2, avionics, ground and test equipment, etc.)? The crucial issue here is that commanders and planners cannot be assured that current weapons platforms, C2, ISR and associated support systems will be available should a nuclear detonation occur. We simply do not know!

CHAPTER 4
WEAPON OUTPUT CALCULATIONS

4.1 The Red Book

In order to link information about current and emerging threats to design efforts for hardness or to the assessment of operational workarounds to assure operations in a nuclear environment, estimates of the temporal and spatial aspects of the radiation environments produced by threat devices are needed. For many years, publication of these estimates has been the responsibility of DTRA and its predecessor organizations (Defense Nuclear Agency and Defense Special Weapons Agency) through its Nuclear Warhead Output Modeling Program. The Defense Nuclear Agency) publication 6500H – known more commonly as the "Red Book" – was first published in 1981 and has been updated periodically since then, with the latest revision scheduled for completion in late 2004. The program also produces a parallel document, the "Blue Book," that provides output radiation characteristics of U.S. devices.

The Red Book is intended to provide bounds on hostile environments. Nuclear weapon models described in the handbook represent generic weapon technologies that may be used to obtain rough estimates of yield and radiation output for given weapon system configurations and to allow tradeoffs among warhead mass, dimensions, special nuclear material (SNM), and various weapon technologies. Information on model definition, yield/mass and dimension/mass ratios, fission fraction vs. yield, interstage time vs. yield, SNM cost vs. yield, and radiation output (X-rays, neutrons, and gamma-rays) are included. One-dimensional calculations have been the source of handbook information prior to the latest revision of the Red Book. Validation of the results has been based on the limited underground test data generated for this purpose up to the cessation of underground testing.

Promising advances, enabled by DOE's Advanced Simulation and Computing (ASC) program, are currently being made in computational transport algorithm development that will extend our ability to calculate the output of devices of critical interest to the nation and help mitigate the limited test data set. The latest version of the Red Book will introduce 2-D results and be more comprehensive in addressing a broader array of potential threats. Its content is expanded to four volumes:

- Volume I - Foreign Strategic Nuclear Weapons
- Volume II - Foreign Tactical Systems and Improvised Nuclear Devices
- Volume III - Foreign Proliferant Weapon Systems

- Volume IV - Advanced Foreign Nuclear Weapons

Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL) have complementary roles in providing input to the Red Book. Peer review is an integral part of the program. Validation and verification is being augmented to include code-to-code comparisons in addition to checks against simulator and existing underground test data. The customers of the Red Book are the Services and supporting contractors, and DOE/NNSA and its laboratories. Current principal users include STRATCOM, Navy SSP, and the Air Force.

4.2 Uncertainties in the Calculations

The majority of the outputs for all weapon models are known to within a level of ~20%. However, the effects of nuclear outputs on some military systems can be driven by the details of the upper and lower 1% of the spectrum. Uncertainties in those regions can vary by factors of two to three and, in some important cases, can vary by an order of magnitude (i.e., the upper 1% as calculated may actually be the upper 10%). It is important to systematically study the uncertainties in output calculations across the full range of weapon types, perform experiments to validate the models and reduce the uncertainties where they are extreme, and make certain that the Red Book appropriately bounds the remaining uncertainties.

Some plans exist to address the issue. Uncertainty quantification for X-ray output of a specified weapon system will be delivered in Fiscal Year (FY) 2005. The Science and Engineering Campaigns of DOE's Stockpile Stewardship Program will support development and validation of improved weapon output models. Nuclear weapon effects simulators such as pulsed-power accelerators (ZR) and the pulsed reactors, as well as high energy density physics laser facilities such as National Ignition Facility (NIF) and Omega (University of Rochester), will be used for development and validation of these models.

4.3 Variabilities in the Calculations

There are differences between *uncertainty* in weapon outputs and *variability* in weapon outputs–and both have hardening consequences that are often mixed up or ignored. In this Chapter we have highlighted some fundamental issues associated with uncertainties in output estimates that may relate to material opacities, scattering cross-sections, radiation transport details and other phenomenon, even for idealized isotropic output models. These uncertainties are important since they help to establish an upper limit to the threat environments used for vulnerability and hardening analyses and testing.

In reality, there is a potentially large "lumpiness" or spatial variability in the prompt radiation output at any given point, particularly for high-altitude detonations, that results from mass absorption shadowing. The flux or fluence of prompt gammas, neutrons and X-rays is by no means isotropic about the burst point of a high-altitude detonation. Clumps of materials (thrusters, gas bottles, propellant tanks, firing units, etc., for example) surround a warhead in a non- symmetric fashion and make radiation output estimation inherently three-dimensional. In realistic situations, some warhead components will shield the prompt radiations from other components, creating a large shadow cone in a preferential direction. For example, the STARFISH test warhead was inverted prior to the high-altitude test over Johnston Island in 1962 because of concerns that some masses within the design would cause an undesirable shadowing of prompt gamma rays and mask selected nuclear effects that were to be tested. In another example, a nuclear driven kinetic kill warhead (that destroys a reentry vehicle with steel pellets) will have a very low yield-to-mass ratio, which will greatly suppress the X-ray output. The Russians reported on their 1962 high-altitude testing of such a device at an International Conference on Electromagnetic Effects in 1994 held in Bordeaux, France. The impact of shadowing by the heavy metals on prompt radiation outputs is an ideal problem to be addressed within the ASC program. Both DOE Laboratories should evaluate the impact of such weapon system design variabilities on hardness testing, in addition to the impact of weapon output uncertainties.

4.4 Programmatic Observations

The DTRA Red and Blue Book program is expected to be funded at ~$1M/yr through FY07. The supporting DOE campaigns contribute an additional ~$3M in related model development activities, but the FY05 program in nuclear weapons effects at DOE is targeted to be reduced by ~2/3 of its FY04 funding of $27M by Congress, because it is viewed as being unresponsive to changes in the threat environment. The Task Force came to some important observations about this area, which serves as the lynch pin between threat and mission assurance:

> Adversary weapon output calculations have historically been a modestly funded effort compared to calculations of U.S. weapons outputs; as such, the transition to 2- and 3-D calculations has lagged. The shift to higher fidelity is revealing uncertainties in the estimates that prior 1-D calculations did not.

Pinning down these uncertainties and providing the highest fidelity possible for the full spectrum of radiation effects for both red and blue systems should be a priority for the DOE program. For red systems, we need to understand the drivers for design and certification of critical U.S. systems. For blue systems, we need to fully understand the collateral effects as we move to limited strike planning scenarios.

CHAPTER 5

HARDENING SYSTEMS AND ASSESSING PERFORMANCE – PAST AND PRESENT

Systems that are expected to operate in a nuclear environment within the atmosphere may be subject to thermal, blast, and shock effects, as well as EMP, neutron and gamma (γ) radiation. Systems that operate in space may be subject to all types of ionizing radiation, including neutrons and radioactive debris decay products and low earth orbiting systems may be exposed to a dispersed EMP. In this chapter, we first address the overall problem of formulating hardening design strategies and how the hardening design process and design assessment should proceed. The environments and the means for modeling and simulating them are discussed in the following sections. The chapter concludes with a description of the current DoD and DOE business models for radiation hardening.

5.1 Design Strategies

For most military systems with radiation hardness requirements, a protocol of well understood design rules, parts screening, and testing in high fidelity radiation environments is sufficient to assure adequate performance. *These methods are straightforward and generally do not add more than a few percent to the cost of developing and building the system if incorporated early in the design process.*

The challenge is much greater for those few systems with high-level requirements. In these cases, it is essential that rigorous design measures be considered for assuring survival. These can include: the use of radiation hardened parts; radiation shielding; the use of special radiation absorbing materials that minimize shock generation; rigorous electrical shielding and grounding schemes; avoiding materials with exceptionally high neutron capture cross sections; specialized techniques for laying out, coating, and potting electrical assemblies; and accounting for the performance degradation from radiation exposure of parts and components in the overall system design. The dilemma is that these techniques can add complexity, weight, and procurement cost to the system.

There is always a tradeoff between using best “rad-hard” design practices and the desire to maximize nominal system performance and minimize costs. However, failure to follow best rad-hard design practices can turn a straightforward protocol for assessing performance in radiation environments into a much more difficult and costly process for assessing performance. Furthermore, options for fixing vulnerabilities that are uncovered late in the design process are much more constrained and can force a redesign or compromise in performance.

A positive trend, especially over the last decade, has been the growing use of sophisticated computational tools in system design as they become available. This approach should be encouraged since it improves our ability to design systems with lower performance margins above the system requirements. and mitigates the tradeoffs necessary to design hardened systems. It also provides information to make informed design choices that can ameliorate difficulties in assessing system performance, as discussed in the next section.

5.2 The Hardening Process and Design Assessment

The difficulty and cost of assessing system performance can be impacted dramatically by the approach taken in designing the system. For systems with high-level requirements, it is essential to consider hardening and assessment issues at the beginning of the design process.

The nuclear hardening and validation process is conceptually simple and has been done well many times in the past. It generally proceeds as follows:

- The design specification describes the range of radiation environments that may be encountered by the system, including details concerning energy spectrum and time history.
- Radiation transport calculations determine the radiation environment at each subsystem or component, based on a preliminary design and appropriate assumptions about the orientation of the system to a nuclear burst.
- This is an iterative process, since the radiation environment at one component will be modified by nearby components. Shielding is often used to protect components that are particularly sensitive to prompt x rays, at the cost of added weight and volume.
- For electronic systems, the need to test candidate parts depends on the radiation levels in the design specification. In some cases, extensive screening is done early in the design to provide response data for parts that may be useful in the design. As circuits are designed, these data are used to predict their response to

radiation. These are then combined into a model of how the subassembly or system will respond.

- If there is a large margin between the predicted response and one that would cause a failure, testing at the subassembly or system level may not be necessary. Otherwise, testing is done in radiation environments that simulate the threat requirements to verify the accuracy of the circuit models and to assure the survival of the system.

- When testing reveals vulnerability in the system, the models are used to analyze the problem and modify the design. This continues until the design meets the system requirements.

A similar process is followed to assess other types of responses, such as mechanical shocks generated in the system, currents generated in cables, or heating of materials. The testing needs depend on the margin between predicted responses and failure thresholds, accounting for uncertainties in the modeling.

Methods for assessing the performance of systems in radiation environments vary widely, depending on the type of system and the radiation levels of interest. For the preponderance of military systems, the requirements are relatively modest and performance can be assessed in a straightforward fashion. Especially for systems that do not operate in space or at high altitude, the neutron, γ, and EMP environments can be simulated in the laboratory with high fidelity. Performance is often assessed directly with full system tests at existing facilities. Space systems with prompt requirements must be addressed with more care because of the potential degradation that they might suffer in a full system exposure test. In those cases, a combination of subsystem testing and wide design margins help assure survivability.

Assessing the performance of space-based systems which do not have prompt radiation requirements is also straightforward, although again, full system tests are rarely done. The main concerns are long-term degradation of electronic parts from total ionizing dose slowly accumulated during the mission and single-event upset of digital electronics from proton or heavy ion strikes. Parts are screened by testing them with Co^{60} sources for total dose and with ion accelerators for single-event upset. By choosing parts that meet the performance and lifetime needs of the system, designers can assure survival in the space radiation environment without doing full system tests.

For a small number of systems having the highest level requirements, including prompt X-ray requirements, performance assessment can be extremely challenging.

Examples include strategic nuclear weapons and their ballistic missile delivery systems, National Missile Defense systems, and a small number of satellites. In many cases, some of the X-ray environments of interest cannot be generated in the laboratory. In past years, underground nuclear effects tests were used to assess performance. Today, we must rely on modeling and simulation, backed up with a rigorous experimental validation protocol, to assess system performance when we cannot do appropriate system tests. Each new or refurbished system generally requires a focused research program to develop confidence in the assessment methods.

5.3 Nuclear Weapon Effects Simulators

There is a wide range of radiation facilities operating in the U.S. to reproduce various radiation environments and stimulate effects caused by radiation. This variety is driven by the diversity of radiation environments that military and space systems may have to survive. The direct output of a nuclear burst consists of neutrons, γ rays, and X- rays, and there are facilities designed to simulate each component of these prompt environments, as well as radioactive debris producing delayed radiation environments of consequence. In addition, the direct radiation may interact with the ambient environment to produce an EMP, produce a blast wave in the atmosphere, or generate a modified neutron and γ ray environment. Moreover, the radioactive Beta-decay of fission debris can pump up the space radiation belts and produce an enhanced trapped electron environment. There are facilities that attempt to simulate each of these environments. The radiation may interact with a system to generate a severe shock, induce vibrations in the system, or produce an electromagnetic pulse within the system called system-generated electromagnetic pulse (SGEMP) or internal electromagnetic pulse (IEMP), depending upon the production mechanisms. There are facilities that can stimulate these effects in test articles. Finally, there are facilities that can simulate other radiation environments, such as the normal space radiation environment, or the radiation produced by radioactive materials within a system.

Prompt γ Simulators

Sandia National Laboratories operates the High-Energy Radiation Megavolt Electron Source (HERMES) pulsed-power facility to simulate prompt γ environments at extreme dose rates (well above 10^{12} rad/s over substantial volumes). This is more than adequate for testing systems with high fidelity in the most extreme γ environments. HERMES is a unique capability.

Since most systems do not have to survive the extreme environments produced at HERMES, there are a number of smaller γ-ray facilities that are used to test systems at lower levels. These include the PulseRad 1150 at Titan International, Sphinx at Sandia National Laboratories, Relativistic Electron Beam Accelerator (REBA) at White Sands Missile Range, and machines at Little Mountain and at Boeing. Like HERMES, they generate bremsstrahlung by hitting a target with an electron beam. In addition, electronic parts are often tested at electron linear accelerators (LINACs). These are available at a number of facilities, such as White Sands Missile Range, Naval Surface Warfare Center (Crane), Boeing, Little Mountain, Rensselaer Polytechnic Institute, and Idaho State University. LINACs produce a short burst of electrons with sufficiently high energy that they will pass through a small part without stopping, thus simulating the ionizing dose produced in a prompt γ environment. Institutions that operate the smaller γ-ray machines and LINACs make cost/benefit decisions based upon the convenience of having local test capability and the scope of the programs they support. Market forces will determine how many of these machines continue to operate.

Prompt Neutron Simulators

Until recently, prompt neutron and sustained γ environments have been simulated at three fast-burst reactors: the Sandia Pulsed Reactor III (SPR III) at Sandia National Laboratories, the Army Pulsed Reactor Facility (APRF) at Aberdeen, and Molly-G, or the Fast Burst Reactor (FBR) at White Sands Missile Range. SPR III is unique in that it has a relatively large central cavity (17-cm diameter) in which articles can be tested at high levels. Unmodified environments produced by these reactors are characterized by hard neutron energy spectra and short pulse durations (40-76 μs). These reactors are versatile facilities because materials placed in and around them can be used to tailor the neutron spectra, modify the neutron to γ ratio, and broaden the pulse to more than a millisecond. Because these reactors have metal cores consisting of highly enriched uranium, the steadily increasing standards for their security have dramatically increased their cost of operation. As a result, Aberdeen ceased operation at the end of 2003. Operation of SPR III was suspended in 2000, and the core was placed in secure storage. Sandia plans to resume operation in 2005 to support qualification of the W76-1 electronics, but the Secretary of Energy has announced that operation at Sandia will terminate no later than the end of 2006. At present, White Sands has the only operational fast-burst reactor.

While fast-burst reactors have been the only means of creating these environments to date, other concepts have been proposed that do not require highly enriched uranium (HEU). The most promising that the Task Force learned about is a hybrid utilizing an electron accelerator and a sub-prompt critical reactor assembly consisting of low enriched uranium (LEU). A large pulsed-power electron accelerator generates the initial burst of neutrons. The electron beam hits a metal target, typically tungsten, to produce bremsstrahlung radiation. Subsequently, (γ,n) reactions in the reactor assembly provide a pulse of neutrons. The initial pulse is multiplied by a factor of several hundred by the reactor assembly as the neutron flux decays exponentially. The resulting neutron environments are equivalent to those provided by existing fast-burst reactors. The concept provides increased experimental flexibility without the security and safety burden of HEU materials. While this concept appears technically sound, it would take the construction of a major new facility to provide such a capability.

Some devices and some military systems are potentially susceptible to neutron and γ combined effects. The simple configurations and large exposure cells typical of fast burst reactors make them a suitable venue for experiments in combined environments by co-locating a γ source in the reactor cell.

X-ray Simulators

X-ray environments are the most challenging to simulate in the laboratory. Historically, underground nuclear effects tests were done principally to study X-ray effects. Existing X-ray facilities only partially compensate for the loss of underground testing, and opportunities for improving the capabilities of X-ray facilities are both limited and costly. Recent investments in advanced modeling and simulation tools have focused on X-ray effects to provide an alternate means of assessing the performance of systems in severe environments that cannot be produced in the laboratory.

X-rays are only of concern for systems that operate in space or at high altitude, since X- rays are rapidly absorbed in the atmosphere. In addition, the X-ray environment within a system is a strong function of location and orientation of the system with respect to the nuclear burst. A nuclear weapon generates X-rays with a spectrum similar to a blackbody radiator, over a wide range of energies. It is common to characterize regions of the nuclear spectrum according to where they dominate damage mechanisms within the system:

- The lowest energy X-rays of concern, *cold* X-rays, are stopped in the first, outermost layer of a system, where they can generate severe shocks in the absorbing material. Differential, rapid heating also can cause large vibrations of the system structure. Most of the total X-ray energy emitted in a nuclear burst will be in the cold X-ray portion of the spectrum.

- The more penetrating *warm* X-rays will mostly pass through the outer layer and dominate energy deposition in internal components. They can also generate large currents in cables. X-ray shields around sensitive components will stop most warm X-rays.

- The most energetic *hot* X-rays will penetrate internal shields. Even though only a tiny fraction of the X-rays created in a nuclear burst are in the hot portion of the spectrum, their penetrating power makes them a threat to upset or destroy sensitive electronic systems.

The cold, warm, and hot descriptors are not defined by precise energy bands, but depend on the output of adversary weapons of concern and on the design of a particular blue system.

There are a number of pulsed power facilities that generate X-ray environments. The major facilities are operated by Sandia National Laboratories (Saturn and Z) for DOE and DTRA (Decade, Pithon, and Double Eagle). There are two important physical mechanisms used to generate X-rays at these facilities. Bremsstrahlung sources use intense electron beams to hit a target made from a material with a high atomic number, generally tantalum. The X-ray energy spectrum created from bremsstrahlung production is broad, with an endpoint determined by the energy of the incident electrons. Since the bremsstrahlung production cross section rises with energy, these sources are most efficient for simulating the hot portion of the threat spectrum.

While there are differences in terms of the achievable X-ray intensity, spectra, and pulse width that are important for specific applications, all of these facilities except Z have a significant capability to simulate hot X-ray environments of interest. When operated at relatively low voltages (around 300 keV or less), they can approximately simulate the warm X-ray spectrum for some applications. However, bremsstrahlung production is so inefficient at these energies that the resulting X-ray environment is frequently several orders of magnitude below threat conditions.

For cold X-rays, imploding plasma z-pinches are used to generate X-rays from k-shell line radiation. Different materials are used in the implosion to make X-ray sources at various energies. However, the pulsed-power current needed to drive an efficient implosion rises rapidly as the k-shell energy of the material increases. Decade, Double Eagle, and Saturn have useful sources up to 3 keV. The Z facility has a unique capability to create useful sources up to about 8 keV, and this will be extended slightly when an upgrade (ZR) is completed. In general, these facilities are able to test material samples and small items at interesting levels. For systems with the highest level requirements, we are not able to do cold X-ray testing of entire systems at threat conditions.

After four decades of pulsed-power development, opportunities for improving our capability to simulate cold and warm X-ray environments using these methods are limited. Relatively modest incremental improvements are gained with great difficulty and considerable cost. A dramatically better test capability requires a breakthrough, such as achieving high-yield inertial confinement fusion (ICF) in the laboratory. Even this is not straightforward, since the ratio of X-rays to neutrons in an ICF capsule is expected to be orders of magnitude lower than in a typical thermonuclear weapon, and the pulse width will be orders of magnitude shorter. Scattering schemes to stretch the pulse and improve the X-ray to neutron ratio require at least several hundred MJ of capsule yield to generate interesting environments. Shielding the DoD test object from the blast and debris of an ICF explosion that is not characteristic of the real threat while passing the X-rays characteristic of the threat environment is a technical challenge, but at the high energies typical of Z-pinch sources, doable.

Modified Neutron/Gamma Simulators

The Annular Core Research Reactor (ACRR) is operated by Sandia National Laboratories to simulate a broad range of modified neutron and γ environments. ACRR is a pool reactor that is capable of both pulsed and steady-state operation. In pulsed mode, it generates large neutron fluences in pulses of several ms duration. The neutron energy spectra are much softer than those created by free-field metal fast-burst reactors, with significant thermal and epithermal components. ACRR also simulates a broad range of sustained γ environments, delivering total doses up to several MRad in pulsed mode. ACRR is a unique facility for simulating an important set of radiation environments. ACRR also provides neutron radiography for imaging low atomic number materials.

EMP Simulators

Since EMP is a propagating electromagnetic wave, the impact on a system can, at least in principle, be calculated with a computational model of the system. The practical difficulty is creating the model of a (typically) highly complex system. The more tractable approach is to partition the system into electromagnetically shielded boxes and limit electromagnetic currents and voltages between boxes by designed-in protection. Most large systems require the calculated protection and survival of the system to be validated through testing. Systems are tested using current injection at openings to simulate calculated voltages and currents that would result from an electromagnetic pulse. They can also be tested using free field or bounded wave simulators to simulate the electromagnetic pulse itself.

Free field EMP simulators are currently available at Patuxent River Naval Air Station and at White Sands Test Range. While these facilities can test most systems, they cannot test large systems to the most stringent environments. In particular, a capability does not exist to test ships or airplanes.

Building a full scale facility presents two problems. First, facilities for large test objects are both expensive and technically challenging, and have in the past required high levels of expertise to make them operate successfully. There are only two top level technical designers of EMP facilities left in the country, and they are at or past retirement age. Second, the last two facilities built or partially built (Empress II for irradiating ships and vertically polarized electromagnetic pulse simulator [VEMPS II] to test large Army equipment) were both stopped because of environmental concerns about the effects of radiated electric fields. Any new facility will have to consider both environmental issues and the availability of qualified designers to be successful.

Impulse Simulators

Magnetic Flyer Plates and Light Initiated High Explosive (LIHE) are both methods of simulating the large impulse that X-rays from a nuclear event would introduce into a structure. These are only used for strategic systems where the requirement for nuclear survivability is such that the X-ray environment could cause major structural deformation or damage to the structure.

Flyer plates are the best match for the impulse on the outside of the structure but they are limited in the complexity of the structures that can be matched. There is a DTRA flyer plate facility in Albuquerque. It was in mothballs but resurrected and operated to validate the response of models for the W76 reentry body refurbishment. It is now being put back in mothballs until needed again.

Light initiated explosive tests utilize a thin layer of explosive sprayed on the outside of the structure to be tested. The explosive is initiated simultaneously over the entire surface with a pulse of ultraviolet (UV) light. The spraying technique allows very complex geometries to be tested. This provides a good simulation of shocks transmitted to the internal components of a missile or a reentry system. Sandia is currently reviving its LIHE facility to test the refurbished W76 warhead.

Blast Simulators

The Large Blast and Thermal Simulator (LBTS) built and operated by DTRA at the White Sands test range has the capability to test the shock, overpressure and thermal environment at ground level on systems up to and including those the size of battle tanks.

The system was built approximately ten years ago. It uses compressed nitrogen as a driving fluid for the air blast and aluminum powder and oxygen for the thermal simulator. Supplementing the system with air compressors in lieu of nitrogen would reduce the cost of a test by 50% and would upgrade LBTS test capabilities. The thermal capability of the simulator is currently not operational. Restoring this capability would require repairs and safety upgrades. Operations beyond FY04 are not supported in the current DTRA plan.

Sandia has a six-foot diameter blast tube. It was shut down in the early 90's, but it has been returned to operation to support the W76 refurbishment.

5.4 Modeling and Simulation

The role of modeling and simulation has grown significantly over the last decade to support design of replacement components for the nuclear stockpile and assessments of their performance in radiation environments. This role will continue to expand over the next decade, creating many opportunities for applying new capabilities to a broad range of defense systems. Computational tools are used to translate system requirements to radiation environments at the subsystem or component level, to design for survivability, to define appropriate test environments for system assessment, and to assess performance in radiation environments that cannot be produced in the laboratory. In general, uncertainties in calculations are mitigated by adding margin to the design, so calculations that have higher fidelity and are more rigorously validated with experiments can reduce the cost of developing rad-hard systems. Better simulation helps identify problems in the design phase when they are much easier to address than when vulnerabilities are revealed downstream in system testing.

The first step is to calculate the radiation output of the nuclear devices of concern. While many of the environments can be calculated with a high degree of certainty, there are some troubling areas, as discussed in Chapter 4.

Given an estimate of the adversary weapon output, the next step is to determine radiation environments at a component. Most systems are geometrically complex, and self-shielding within a system can be important. High-fidelity computations can reveal sneak paths for radiation through a system and greatly assist the optimization of shielding. If the system is on the ground or at low altitude, the radiation from a nuclear detonation will be modified drastically by interactions with the air and the ground. Most or all of the X-rays may be absorbed, but neutron interactions will spread out the neutron pulse to the system in time and shift the neutron spectrum to lower energies. Neutron interactions in the air, the ground, and the system itself will generate gamma rays that, in some cases, can dominate the ionizing dose in a component. Motion of the system can significantly shift the thermal and epithermal portion of the neutron spectrum. Frequently, these calculations define a set of radiation environments to be simulated at existing radiation facilities for assessing the performance of a system in nuclear environments.

The burden on modeling and simulation is more severe when a system must survive radiation environments that cannot be simulated adequately in laboratory facilities. Then the full complexity of radiation interaction with the system and its response must be simulated computationally. Radiation can cause damage in many different ways. Energy deposition from neutrons or X-rays will rapidly heat materials, causing deformation, decomposition, spallation, delamination, degradation of material properties, and the generation of intense shocks. Neutrons will cause displacement damage, activation, heating, and charged particle production in materials. X-rays and γ-rays will generate charge deposition and photocurrents that can upset or burn out electrical systems and cause dielectric breakdown in insulators. While impressive progress is being made in each of these areas, we are far from having a comprehensive, validated capability to simulate these phenomena. Each new assessment project is likely to identify gaps in capability that warrant further research.

DTRA has maintained a suite of legacy computer codes for modeling radiation effects. These are mostly one-dimensional codes that can approximate the response of complex systems, but often with large uncertainties. Within the Advanced Strategic Computing Program, DOE has sponsored the development of more sophisticated three-dimensional tools to support the assessment of replacement components in nuclear weapons. These tools could be applied usefully to other military systems that must be capable of surviving severe radiation environments. The DoD could take advantage of these capabilities with a relatively modest incremental investment.

5.5 Surveillance

After a system's hardening design is validated by a rigorous protocol of simulation, testing, and analysis, it can be produced and fielded. However, its production and operational maintenance and support plan should include nuclear hardness assurance and surveillance elements. Such plans have been successfully implemented in the past, particularly for strategic nuclear weapon delivery systems and warheads (e.g., the Navy Trident Weapon System and Air Force MM III). During a production run, a few systems are randomly selected and subjected to specific environmental tests, including radiation, to make sure hardness requirements are being met for each production lot. Additional parts testing at the component level and inspections are also used for hardness assurance.

Once fielded, hardened systems need to be monitored via a surveillance and maintenance program. Ongoing maintenance and repair, component wearout and replacement, and even normal aging can impact the hardness of a system. There are examples of 20-year old electronics parts that met all performance specifications for operation in normal environments, but failed to meet the hardness requirements exhibited when they were new. The Task Force found that the Services have been neglecting this surveillance and maintenance activity. As an example, Air Force XOS and its predecessor organizations had, in the past, received routine nuclear survivability management status reports on the various Air Force strategic systems having nuclear hardness requirements. However, the generation of these reports has dwindled and, since 1999, has become a non-routine event. There is therefore good reason to believe that many systems deployed with nuclear hardness designs are no longer able to meet their requirements or have smaller design margins than when first deployed. The Task Force found no evidence of surveillance testing of non-strategic systems with hardness requirements and little for strategic systems.

5.6 Underground Nuclear Effects Testing

The last underground nuclear effects test was Hunter's Trophy in 1992. Until the moratorium on nuclear testing, underground tests (UGT) were important in assessing the performance of systems in extreme radiation environments. The test fidelity of underground experiments was not perfect. The experimental program was limited by cost, an infrequent test schedule, competition for space in the test alcoves, and the practical difficulties of working in the tunnel complex. Many radiation effects issues could be studied more efficiently at above-ground radiation facilities. Nevertheless, underground testing provided some radiation environments of importance that still cannot be matched in today's radiation facilities.

The unique role of UGTs was to generate extreme X-ray environments, especially in the cold and warm portion of the energy spectrum. The nuclear devices used on underground effects tests were designed to optimize X-ray environments for the proposed experiments, as far as was practical. Some experiments were conducted in an evacuated pipe with a direct line of sight to the nuclear device. Other experiments used a modified X-ray environment produced by scattering X-rays in a specially designed scatter station. The scatter station increased the temporal pulse width, reduced the intensity of neutrons and γ-rays relative to X-rays, and changed the X-ray energy spectrum. In both cases, filters were used to further modify the X-ray energy spectrum. While there were practical limits on how much the X-ray spectrum and pulse width could be modified, the X-ray fluence was essentially unlimited. Existing above-ground simulators produce less total X-ray fluence by orders of magnitude than what was available at the experiemental stations in underground tests.

Despite having unlimited fluence, there were important differences between threat environments and what could be achieved in underground simulations of those environments. Mining costs were a large fraction of the considerable expense of underground effects tests, so the nuclear device was designed to have the smallest practical total yield, orders of magnitude less than typical strategic nuclear weapons. This forced inevitable tradeoffs in the desired radiation output of the device. Even in scatter stations, the X-ray pulse width was generally not as long as desired. For many experiments, the X-ray energy spectrum was far from ideal, even after extensive modification with scatter stations and filters. Because experiments were located so much closer to the device than what would likely be the case in a warfighting scenario, the neutron pulse width was much shorter and arrived with a much smaller time delay after the X-ray pulse than in a threat environment. In fact, the neutron environment was so different from typical threat environments that neutron experiments were rarely done on UGTs. It was far more typical that neutrons were an unwelcome background that needed to be mitigated to perform a successful X-ray experiment. Neutron effects were almost always studied at nuclear reactors, even when UGTs were available. γ-ray effects could be studied more efficiently with pulsed power accelerators and reactors.

The principal impact of the moratorium on nuclear testing has been the loss of extreme X-ray environments. Above-ground simulators are able to adequately simulate only the hot X-ray environment relevant to heavily shielded components. While it is sometimes suggested that we lost the ability to do experiments in combined environments, this is a misconception: UGTs did not provide a high fidelity simulation of combined environments, and UGTs were not used to study synergistic effects caused by exposure to multiple radiation environments.

5.7 Current Business Models

DOE Program[13]

The nuclear survivability of the U.S. nuclear stockpile is the focus of the DOE/NNSA NWE program. An NWE program element for developing improved understanding of the relationships between warhead design features, outputs, and lethality and collateral effects has been scoped but has not been implemented. Only the survivability elements of the NNSA program are addressed in this report.

The NNSA NWE Program develops and sustains capabilities to support the nuclear survivability of the enduring and evolving stockpile, its certification and life extension, without relying on underground tests, through research and development, radiation hardening, modeling and validation, and aboveground testing. It develops validated computational tools to evaluate threat nuclear weapon radiation environments and system radiation responses, develops radiation-hardened technologies, and improves radiation sources and diagnostics.

NNSA NWE tools and technologies are provided through major program elements of the Stockpile Stewardship Program, the goal of which is to maintain and enhance the safety, security, and reliability of the nation's nuclear weapons stockpile to counter the threats of the 21st century. Survivability is an element of reliability. Science and Engineering Campaigns, in collaboration with Directed Stockpile Work (DSW), ASC, Readiness in Technical Base and Facilities (RTBF), DoD, support Stockpile Life Extension Programs (SLEPs), Limited-life Component (LLC) replacements, and stockpile modifications.

The Manager of the Nuclear Survivability and Effectiveness Program at NNSA Headquarters (who is also the manager of the Nuclear Survivability Activity within the Engineering Campaign) and science and technology (S&T) program directors at the NNSA national laboratories, together with the Manager, Radiation Effects Sciences Program at Sandia National Laboratories, and the Outputs and Survivability Program leaders at LLNL and LANL, are the primary NNSA proponents and champions for nuclear survivability technology development and stewardship. Laboratory and NNSA DSW program directors rely on developed and validated tools and technologies to qualify systems to their negotiated nuclear survivability requirements and are among

[13] See Appendix H for a more complete description of the DOE program.

the strongest proponents when needed for their programs. At Sandia, Radiation Effects Sciences is among its suite of critical capabilities.

The ASC Campaign develops, verifies, and validates NWE simulation codes using experimental data generated by the Science and Engineering Campaigns. The Engineering Campaign, through the Nuclear Survivability Activity also supports the development and initial implementation of radiation hardened microsystems. RTBF sustains the simulators and microelectronics infrastructure so that, when combined with investments and utilization by the campaigns and DSW, they remain technically and economically viable. Upgrades and new capabilities are developed with operating funds when practical, or with construction funds when appropriate. Utilization by DoD of the NNSA NWE simulators is through Work for Others agreements on a cost reimbursable and non-interference with DOE programs basis. This access is relatively unencumbered in most cases. For some assets, such as Z (or ZR) or NIF (when it becomes operational at useful levels), long-term agreements need to be negotiated at a high level to provide significant access outside the DOE community. Access by DoD to the advanced scientific computing resources of the NNSA weapons laboratories on the same basis is possible, but problematical because of heavy utilization by the Stockpile Stewardship Program. Appendix H offers two charts that summarize the status of DOE effects simulators and the ASC codes at this point.

The campaigns and ASC generally perform R&D and establish nuclear survivability technologies. DSW invests in research and tools development and improvement when needed for system-specific applications and problems.

Issues and Trends Impacting NNSA NWE Programs[14]

The most challenging issue facing the NNSA nuclear survivability program is the absence of a clearly articulated policy supported and enforced at the highest levels regarding the purposes of our nuclear stockpile. A substantial nuclear survivability program is clearly an imperative if, in addition to deterring the use of WMD by regional, state, or sub-state aggressors, its purposes are to counter the threat of emergence of a peer, or near peer adversary, and to hold at risk high value targets that might be defended by nuclear interceptors in the first third of the 21st century.

Report language accompanying the House Energy and Water Appropriations Bill for 2005 explicitly questions "the continued high level of funding requested in the

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[14] See Appendix L for results of Congressional and NNSA budget planning actions that occurred while this report was in review.

Nuclear Survivability campaign to assess the ability of the weapons in the stockpile to continue to function as designed during a massive nuclear exchange." It further states "In the post-Cold War world with no new weapon production ongoing, this activity is a waste of scarce resources." These statements reflect a misunderstanding of the rationale for the nuclear survivability of our stockpile. Nuclear survivability enhances the credibility of the U.S. nuclear deterrent, hedges against the emergence of a peer, or near-peer adversary, enables the penetration of point nuclear defenses of high-value targets, reduces incentives for nuclear proliferation, and deters the use of weapons of mass destruction. As discussed throughout this report, new nuclear survivability challenges exist in the present security environment - new weapons production is ongoing in other nations, our stockpile is being refurbished with new technologies and materials susceptible to nuclear effects, and aging of the stockpile introduces new challenges to reliability, including nuclear survivability.

Mindful of the current and emerging threat environment, both the Navy SSPO and the Air Force Ballistic Missile Office have revalidated their survivability requirements with the NNSA laboratories as active participants. Some Stockpile-to-Target-Sequence requirements have been significantly altered in these re-evaluations.

An additional challenge is that gaps in stockpile refurbishment schedules make it difficult to defend nuclear survivability budgets for radiation effects research and development required to develop improved rad-hard design methods and tools in order to anticipate and solve problems before crises arise, and for hardness assurance verification of the enduring stockpile.

The impact of either challenge is potentially to drive the currently viable NNSA NWE program to a sub-critical state in which neither the expertise nor the infrastructure is capable of sustaining nuclear survivability. The Task Force believes that this will undermine the credibility of our deterrent, provide increased potential returns on investment to the proliferant, and greatly increase the time needed to respond to new nuclear threat environments.[15]

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[15] To elaborate, strategic systems, which are currently hardened to survive severe environments, will be compromised when components are replaced. When components reach the end of their functional life, they are generally redesigned because the parts and materials used originally are no longer available. A typical electronics part will only be on the market for about 18 months when it will be replaced with the next generation device. Even items like epoxies and potting materials undergo an evolution. If the new component is not designed to meet strategic radiation requirements, it will compromise the entire system. Abandoning hardness requirements and qualification of strategic systems will be the first time in the nuclear age that the U.S. will not be guaranteed to hold at risk the vital assets of a potential nuclear-armed adversary.

DoD Requirements

There is no clear guidance from DoD on the battle scenario or requirements for operating on a battlefield that has experienced a nuclear event; many in authority do not believe that a nuclear event will ever affect their system. The development and procurement system is not well integrated to force assessment of operations in nuclear environments. Because the design and manufacturing of DoD systems is awarded on a competitive basis, it is generally not economically viable for any single system contractor to maintain all of the disciplines and test facilities needed to validate the nuclear survivability of all types of systems. The tools (models and test facilities) for nuclear hardened design and verification are generally developed and maintained by DTRA for the use of DoD program offices and system developers.

Under current DoD procurement philosophy, nuclear hardening is part of the trade space allowed to the program office (as discussed in Chapter 3, Section 3.3). Nuclear survivability or the level of nuclear survivability may be traded away to maintain program cost or schedule, even if it compromises the ability of the system to operate if there is a nuclear event. Moreover, systems are never audited to see if they will operate in a battlefield after a nuclear event.

DTRA Nuclear Weapon Effects Technology Program

The DTRA NWE program is divided into five business areas. The following four areas are relevant for the test and simulation focus of this report:

1) **Radiation Hardened Microelectronics.** This program develops and demonstrates radiation-hard, high performance prototype microelectronics to support the availability of radiation-hardened microelectronics and photonics for DoD missions in both private sector and government organizations. This program has two complementary components: a core program that develops and demonstrates enabling technologies; and an Accelerated Technology Development Program whose objective is to establish the capability to fabricate radiation hardened 0.15-micron Complementary Metal Oxide Semiconductor (CMOS) technology at two domestic radiation hardened semiconductor suppliers, BAE Systems and Honeywell Defense and Space Electronic Systems (DSES).

2) **Simulation Technology.** The Simulation Technology area develops technology and facilities to simulate nuclear environments in the laboratory. The program develops technologies to improve the intensity, fidelity reliability, reproducibility, and cost effectiveness of existing and future simulation facilities. It also develops test-beds and response databases for prompt radiation and thermal effects for the

defeat of biological agents; and develops concepts, plans, and risk reduction strategies for affordable next-generation radiation simulators with improved intensity and fidelity.

3) **Assessments Technology.** The Assessments Technology area develops design protocols, hardware, and software that enhance the ability of mission essential systems to survive a nuclear attack and to operate after a nuclear attack. It defines the engineering standards for hardening, develops testable design protocols, and develops effective nuclear threat mitigation technologies. The Assessments Technology area also develops the science and technology base for predictive nuclear effects assessment and maintains a core expertise in nuclear weapons effects methodologies. With the emergence of non-nuclear weapons that present a similar electromagnetic threat (high-power microwave or ultra-wideband weapons), this area includes a parallel development effort to predict and mitigate their effects.

4) **Environments.** The Environments area provides fast running tools to enhance lethality, promote survivability, and enable assessment of strategic and tactical systems. This area validates existing codes, modifies current codes for end use, develops new codes, and sponsors work to fill gaps between our ability to predict nuclear weapon effects environments and the warfighter's needs for fast and reliable results.

DTRA Program Execution

Since there are few mandatory nuclear survivability requirements from DoD, DTRA currently assigns low priority to nuclear weapons effects technology programs.[16] Furthermore, the agency has said that DTRA 6.2 R&D money should be spent on R&D with "long term" goals rather than assisting in the hardening and validation of military systems. The agency position is that efforts to develop specific capabilities to harden and validate military systems should be reimbursed by the program offices.

This low priority has led to reduced funding. Capability has only been maintained by industry consolidation. The only significant test capability is at the West Coast Facility operated by Titan Corporation for DTRA at a current cost ~$8.3M/year. Titan also maintains most of the DoD nuclear hardening modeling capability. Up until the draft findings of this Task Force, DTRA was spending a large fraction of its simulation R&D budget ($2.4M) on the DECADE facility at Arnold Engineering

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[16] A principal exception is hardened microelectronics.

Development Center (AEDC). Lack of sufficient funding for a dedicated workforce and technical difficulty is leading DTRA to reassess that investment.

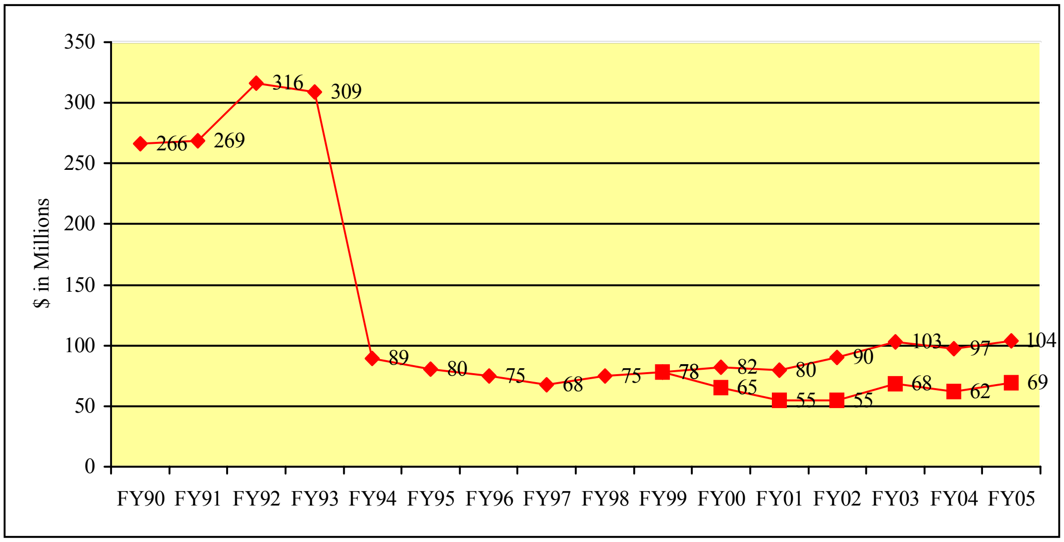

Figure 5.1 Nuclear Weapon Effects S&T Budget Trend (Approximated)

Figure 5.1 illustrates the dramatic budget drop in the program in FY94. The two funding lines shown starting in FY00 represent the total funding the program (top line) and for the program less the fenced rad-hard microelectronics program (bottom line). To the agency's credit, the problem has been recognized and a plan developed to redress critical gaps that are emerging. A summary is provided in Appendix I.

CHAPTER 6

HARDENING SYSTEMS AND ASSESSING PERFORMANCE – THE FUTURE

6.1 Evolving Design Strategies

It is expected that the process of designing nuclear hard systems in the future can still be accomplished using the mature hardening design strategies that had evolved by the end of the Cold War. Once the system CONOPS and threat environments have been defined and uncertainties in the actual nuclear environments have been reflected in the desired system capabilities, several options are available to the system engineers to help develop the best hardening strategy.

First, however, a broad system architecture review should be undertaken to make sure that there are no inherent, fundamental obstacles to arriving at a hardened overall system design. These obstacles could include the inability to verify that the design meets its requirements via a rational combination of simulation, testing, and analyses. Next, shielding at the system, box, or component level can be traded against weight and cost penalties. Use of hardened electronic parts is clearly an attractive option if such parts can be made cost effectively to meet performance requirements. Alternatively circumvention and recovery (C&R) schemes can be implemented wherein a nuclear event detector will be used to alert a system to shut down vulnerable subsystems, store critical data in non-volatile memory, and begin planning to restart its most vulnerable subsystems when it is safe to do so. In this way, components can be protected from some effects of prompt ionizing radiation and large current surges. The design and development can then proceed along the same lines as discussed in Chapter 5, Section 5.2.

6.2 Future Radiation Hardened Technology Challenges

The ability to design radiation hardened systems depends on a set of special technologies, particularly for systems that have the highest level requirements. The most significant of these technologies is rad-hard microelectronics, which are manufactured by a small and rapidly declining set of niche vendors. Most commercial electronic systems can be upset or destroyed by exposure to modest radiation environments. Special manufacturing techniques can reduce the sensitivity of electronic parts to radiation by orders of magnitude.

Since the early development of microelectronics was driven by applications in military and space technologies, there is a long history of studying radiation effects in electronics and developing special rad-hard parts. There are significant technological and business challenges to maintaining these technologies. The technological challenge is the rapid evolution of commercial electronics, where 18 months is a typical product cycle. The radiation response of electronic parts changes as feature sizes decrease and manufacturing techniques evolve. Because the hardening techniques have to build upon commercially available technologies, there is a constant race to adapt hardening processes to the evolving commercial environment. The business challenge is that the market for rad-hard parts is a vanishingly small fraction of the overall commercial market for microelectronics. It is essential that the government continue to monitor and invest in the technical and manufacturing base for rad-hard parts, without which it will be impossible to design and build rad-hard systems. The one-time, USD(AT&L) Accelerated Technology Development Initiative to close the performance gap between commercial and rad hard parts was inaugurated in FY02 and ends in FY05. This successful effort, which has been managed by DTRA, will meet DoD's near term requirements through ~2012 and lays the foundation to reduce future industrial reliance on DoD for foundry recapitalization. The Department's long term needs will be met only through continuation of its core S&T investments to develop rad hard solutions as new commercial technologies emerge. Senior level attention to the DoD's corporate strategy for rad hard microelectronics, such as that provided by the Radiation Hardened Microelectronics Oversight Council currently chaired by the DDR&E, is essential for future success.

There are other special technologies that are important for certain systems and new ones will emerge as military capabilities evolve. One of the challenges faced by MDA is the need for survivable optical components. A multi-layer coating on a mirror may be damaged by X-ray exposure, vibration in the system can impair identification of a target, and material blown off of baffles onto the mirror can obscure a scene. These issues will have to be studied in detail to develop mitigation strategies. In the future, micro-electromechanical systems (MEMS) may be incorporated in many military systems including nuclear weapons, and we may face new challenges in making these resistant to radiation. Another challenge is developing non-volatile rad-hard memories, which would be useful in many systems. Research programs in radiation effects and scientific expertise must be robust enough to tackle new hardening challenges as they arise.

6.3 Future Requirements for Nuclear Weapons Effects Simulators

Radiation facilities will continue to be important for testing components and systems, research in radiation effects, and validation of computational models. While the total number of operational facilities will depend on the number and scope of rad-hard systems being developed, there is a core set of radiation facilities that must be maintained. This core set includes:

At least one facility to provide prompt neutron environments. These environments have historically been generated by fast-burst reactors. Existing facilities are at risk because of escalating costs for protecting HEU. DoD and DOE should work together to insure the availability of at least one of the two remaining facilities until an alternative capability can be developed.

A facility to simulate modified neutron and γ environments. Currently, ACRR at Sandia National Laboratories has unique capabilities in this area.

Facilities to simulate X-ray environments. Currently, the major facilities are operated by DTRA (Decade, Double Eagle, Pithon) and Sandia National Laboratories (Saturn, Z, and Z is undergoing a significant upgrade to ZR). There is enough work at these facilities to support both DOE and DTRA facilities. However, the capabilities at Decade and the DTRA West Coast Facilities (Double Eagle, Pithon) are largely redundant and are not heavily utilized.

Prompt γ simulator. The HERMES facility operated by Sandia National Laboratories has unique capability that supports systems with the highest levels of radiation requirements. There are many smaller prompt γ simulators, which should continue to operate based on local cost/benefit considerations.

EMP simulators. DoD and DOE should maintain facilities to support their missions. These may be mothballed as long as the capability to restore operation when needed is maintained. The need for full scale facilities should be addressed soon while the leading experts are still available to contribute and educate successors.

Impulse simulators. Both flyer plate facilities and LIHE facilities have been important in studying impulse generated by extreme X-ray deposition. DoD and DOE should maintain facilities to support their missions. These may be mothballed as long as the capability to restore operation when needed is maintained.

Blast simulator. DoD and DOE should maintain the capability to support their missions. This is another area where facilities may be mothballed for extended periods.

The DOE continues to build ever larger pulsed-power accelerators (ZR) to support multiple programs. While it would be difficult to justify this investment strictly from the standpoint of radiation effects, the radiation effects community should take full advantage of this evolving capability. Similarly, NIF may provide some unique experimental capabilities, and these should be pursued once the facility is operational.

In the far future, a high-yield ICF capsule could generate X-ray environments similar to what was available in underground nuclear effects tests. While this would not be a panacea for nuclear hardening, since an ICF facility would face fidelity issues similar to those on UGTs, high-yield ICF would be a breakthrough technology that would be important for a small number of systems with the highest-level radiation requirements.

6.4 Improved Modeling and Simulation

In the future, advanced computational tools will impact every aspect of rad-hard design, performance evaluation, and system surveillance. The same computer-aided design (CAD) description of a system that is produced in the engineering design phase will provide the input for assessing performance in radiation environments. Radiation hardening will be integrated into the design process from the beginning.

Realizing this future will require increased cooperation and coordination between the DOE and DoD. The advanced computational capabilities that DOE is developing in the Advanced Strategic Computing Program will address nuclear stockpile issues, but there are a number of DoD issues, such as the optics for MDA's system, that are not being considered in this effort. By teaming with DOE, DTRA can build on the DOE investment to incorporate additional capabilities into the DOE suite of codes. DTRA can do this with a modest incremental investment.

6.5 Surveillance

More rigorous protocols for assessing the hardness of systems as they evolve and age should be implemented in the future. Recent experiments have demonstrated that the radiation response of electronic components can change dramatically as they age. Depending on the design margin, this could cause the failure of a system that originally met its radiation requirements when new. Another issue is the possible degradation of EMP shielding as systems are used in the field and modified with periodic upgrades.

6.6 A New Business Model

The time has passed when DoD and DOE needed largely parallel programs supporting dedicated facilities and expertise. It is now important that DoD and DOE work together to make available critical capabilities and to provide access to facilities and expertise. The goal should be a single "national enterprise" shared by the two departments.

For large-scale radiation simulators, it is very difficult to sustain operation under a business model that relies on full funding from customers. While there may be periods of time when these facilities are very busy, inevitably there will be gaps in test programs that result in periods of underutilization. It is vital that the critical capabilities be sustained during these periods. This is not to say that facilities with extremely sparse utilization or long periods of inactivity are not candidates for mothball or shutdown, but DOE and DoD should ensure that critical, unique capabilities are maintained. Even more important, the two agencies need to ensure that the expert personnel are continually challenged with a combination of direct support to the design and surveillance communities, and ongoing R&D to improve fundamental understanding and the modeling tool set that goes with that understanding.

DTRA appears to be uncomfortable embracing routine operation of facilities as an important mission when it cannot tie this operation to its research program. DoD should endorse this critical role for DTRA. This will make it easier for DTRA to consolidate a set of simulators at its West Coast Facility to support routine testing across the broad range of DoD systems.

Test facilities operated by the military services also play a vital role. This is particularly true of the fast-burst reactor at White Sands Missile Range, which will be the only operational capability after 2007.

In its Stockpile Stewardship Program, DOE invested heavily in programs that support nuclear survivability. This created unique capabilities at their experimental facilities, a radically improved set of computational capabilities, and considerable scientific expertise at their laboratories. DoD, through DTRA, should work with DOE to facilitate utilization of this important national resource.

CHAPTER 7

RECOMMENDATIONS

7.1 Summary of the Findings

The findings of the Task Force as discussed throughout the preceding chapters can be summarized as follows:

a) The nuclear threat is evolving, and in troublesome ways that should lead DoD leadership to expect that the military will be forced to operate in a nuclear environment at some point in the foreseeable future.

b) With respect to vulnerabilities, have we created the elements of the "perfect storm"? The lax attitude to hardening requirements, the increasing reliance on COTS components, the move to net centric operations, and other contributing factors should raise concerns.

c) Weapon output calculations can and should be higher fidelity based on advances in DOE codes.

d) Survivability requirements for all but a part of the nuclear strategic force have been routinely waived or ignored.

e) Expertise for assessing survivability has atrophied considerably in the DoD, but remains robust at the DOE laboratories.[17] Simulator capabilities have largely been maintained although large scale EMP facilities are no longer available and the remaining fast neutron sources are in danger of disappearing.

f) The MDA system presents new and unique challenges because of its evolutionary acquisition strategy and the need to harden or protect the optical components of the interceptor.

g) The belief that hardening adds considerable cost is not uniformly true if hardening is addressed early in design. Design practices are well understood and supported by easy-to-use design tools.

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[17] This is a true statement as of the time the report went into review. Subsequent FY05 Congressional budget decisions and out-year projections will dramatically reduce support for the DOE program.

h) For those “soft” systems already fielded, a number of operational alternatives can offer workarounds or mitigation to effects, but they must be developed and tested with high fidelity simulations supporting games and exercises.

7.2 Recommendations: Assuring Capabilities

The Task Force recommendations are based on the principle that DoD/OSD, the Joint Staff, and the Services need to accept that the ability to assure the nuclear survivability of critical national security systems is an inherent governmental responsibility. The needs to support this endeavor – in particular, advanced code development and simulator infrastructure maintenance and improvements – cannot be met by the private sector.

1) In order to assure capabilities, the Task Force recommends that:

    a) DEPSECDEF assure that the Department promptly and carefully considers the recommendations of the EMP Commission and this Task Force, prioritizes corrective actions, and provides appropriate funding. The recommendations are largely coincident, with this Task Force broadening those of the EMP Commission to include the full spectrum of NWE issues.

    b) In parallel, DEPSECDEF should reaffirm the authorities of ATSD(NCB) granted in Directive 5134.8, section 3, for ensuring that those recommendations are addressed and routinely audited.

    c) ATSD(NCB) should require of DOE a more complete characterization of weapon outputs, to include uncertainties in the calculations, for both adversary and U.S. systems, to enable survivability and effects based planning, respectively.

2) For the tech base:

    a) DoD and DOE/NNSA should formally coordinate and collaborate in their nuclear weapons effects program under the oversight of their Nuclear Weapons Council. The goal should be to assure that adequate capabilities are developed, sustained, continuously improved, and utilized to meet the needs of both departments. The specific terms of the Joint program should be encoded as an addendum to the recently signed Memorandum of Understanding on Nuclear Weapons Effects Technology between DTRA and DOE/NNSA.

b) Such a coordinated program should include investment plans and business models that support the needs of both departments to conduct R&D, to continuously improve "Red Book" output calculations, to support agency and Service users, and to provide contractor/supplier access to the facilities.

c) DTRA should immediately provide resources and expand its core staff to include expertise capable of guiding contractor simulator and simulation efforts, including importing DOE/NNSA modeling tools as appropriate and of advising DoD developers and planners of approaches to understanding vulnerabilities and survivability options based on both DoD and DOE capabilities.

3) For new system acquisition or existing system upgrades:

a) J8 should ensure that nuclear threats and survivability assessments are addressed through the reference scenarios of the JCIDS process. DoD directives and instructions will probably need to be revised to include survivability as a required key performance parameter.

b) Waivers to survivability requirements should be granted only by agreement of USD/AT&L and VJCS in the context of Joint operations, based on the recommendation of ATSD(NCB) and J8. This too may require a new DoD directive to grant these authorities.

c) USD/AT&L should provide support to DTRA to develop the tools to characterize nuclear environment and assess system response to support military utility assessments.

4) For currently fielded systems:

a) DEPSECDEF should task the Services to identify and assess the hardness of critical current operational components.

b) VJCS should direct JFCOM and the Services to introduce nuclear events into exercises and games, using the results of the assessments performed on critical operational components, in order to help define critical Joint capabilities whose vulnerabilities might create significant operational impacts. We note that the same tools that DTRA develops for new system survivability assessments should be used here as well to assure consistency in assessments between fielded and new systems.

c) Where serious issues are identified, the CoCOMs and Services should be required to develop and implement operational and/or hardening fixes and/or workarounds.

5) For both new and fielded systems:

a) DTRA, in keeping with its mission as a combat support agency, should step up to the technical advisor and support role for the Services and Combatant Commands (CoCOMs).

7.3 Recommendations: Simulators and Simulation

1) With respect to qualifying MDA's system:

a) Because we were able to develop potential alternatives for MDA survivability validation during the course the study, the Task Force did not see a compelling case for the proposed Central Test and Evaluation Investment Program (CTEIP) upgrade to Decade. Therefore, we concur with canceling the CTEIP upgrade to Decade, and we recommend that DTRA consolidate its X-ray facilities at a single location, preferably the West Coast Facility where the last critical mass of expertise exists to support DoD. DTRA should have sufficient capability there and with the DOE to continue to conduct its R&D program.

b) MDA should expand the HAENS Standard Verification Working Group to include national expertise from DTRA and DOE for develop a viable assessment and qualification approach. Simultaneously, MDA should plan for the necessary resources to support implementation of the approach in the context of its evolutionary development process. The Task Force believes that existing simulators combined with the state-of-the-art codes from DOE's ASC program will provide most of the needed capabilities. New modeling tools may need to be developed to help in the assessment of specific interceptor components.

2) As a part of the coordinated program between DOE and DoD:

a) The first step should be agreement on the need for and assurance of a pulsed fast neutron source. For the near term, the two departments should develop and implement a strategy for maintaining at least one operational capability. For the longer term, the two departments should commit to building a capability that removes the security burden of current simulators, which rely on special nuclear materials.

b) The next step should be to define the minimum necessary set of X-ray, EMP, gamma, and neutron effects simulators to meet the needs of both conventional and nuclear forces. This definition should be integrated with the ever more robust modeling tools expected to be continuously evolved from DOE's ASC program.

7.4 Deferring the Roadmap

The terms of reference for this study indicate that the Task Force is to propose a roadmap for implementation of its recommendations. On the advice of USD/AT&L, the Task Force deferring that task as a follow-on based on DoD's required response to Congress regarding the recommendations of the EMP Commission. The Task Force urges that its recommendations also be integrated into the response.

Appendix A: Terms of Reference

ACQUISITION, TECHNOLOGY AND LOGISTICS

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

JAN 21 2004

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference -- Defense Science Board Task Force on Nuclear Weapon Effects Test, Evaluation and Simulation

You are requested to form a Defense Science Board Task Force on Nuclear Weapon Effects Test, Evaluation, and Simulation.

The test and evaluation community lacks a comprehensive view of Department of Defense (DoD) requirements for Nuclear Weapon Effects (NWE) testing for current and future weapon systems that must operate in current and emerging threat environments. While the Department has developed or improved a number of NWE simulation capabilities since the cessation of nuclear underground testing, there is currently no comprehensive DoD evaluation or assessment of the current and future requirements for NWE testing and simulation. The Task Force should develop a comprehensive understanding of DoD needs and specific requirements for NWE test, evaluation and simulation capabilities.

Tasks to be to be completed:

- Review Intelligence Community, DoD and National Nuclear Security Agency estimates of present and future nuclear weapon outputs (to include thermal, radiation and EMP) for all weapons that are used to define the operational threat.

- Review nuclear threat environments as used across DoD Services and Agencies and assess whether they are being defined and applied to develop credible consistent hardness requirements.

  Assess the current NWE predictive capability to confidently predict the response of nuclear and conventional weapon systems and C4 systems to credible nuclear environments that might be encountered over the next 15 years.

  Assess the extent to which alternatives to testing, i.e., improving code predictive ability and building in hardness, can be used to offset the need for simulation capability.

- Identify both near-term and far-term NWE test and simulation needs responsive to DoD requirements for nuclear systems, strategic and conventional weapon systems belonging to the new Triad as defined in the Nuclear Posture Review, missile defense systems, and C4I systems required to operate in hostile nuclear environments. In particular, this should address the need to simulate multiple components of the threat environment simultaneously, i.e., combined effects.

Assess the current NWE simulation and system survivability evaluation capabilities of the DoD, the Department of Energy, and the commercial sector. Goals of this assessment should include identification of redundant capabilities and capability shortfalls, in terms of environments produced, the ability to model the environments, simulation fidelity, alternative simulation technologies, systems response and the capacity to meet test workloads consistent with Nuclear Posture Review and Quadrennial Defense Review guidance.

- Produce a comprehensive roadmap of NWE test, evaluation and simulation capabilities that will guide future simulator/simulation technology developments, test planning, investment decisions, model development, facility sustainment planning and responsibilities, and realignment/closure alternatives. The roadmap should describe a time-phased approach to achieving the required NWE test capabilities end-state.

Preliminary Task Force results are desired by June 1, 2004, in order to support planning and programming leading to the FY06 -FY11 POM. A final report is requested by October 1, 2004.

The Study will be co-sponsored by me as the Acting Under Secretary of Defense (Acquisition, Technology, and Logistics), Assistant to the Secretary of Defense (Nuclear, Chemical and Biological Defense Programs) and the Director, Operational Test and Evaluation. Dr. Miriam John will serve as chairperson of the Task Force. Dr. Jay Davis will serve as vice chairperson of the Task Force. Mr. Derrick Hinton, DOT&E/S&TR, and Dr. Andrew Cox, ATSD(NCB) will serve as Co-Executive Secretaries and CDR David Waugh, USN, will serve as the Defense Science Board Secretariat representative.

The Task Force will operate in accordance with the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DOD Directive 5105.4, the "DoD Federal Advisory Committee Management Program," It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of Section 208 of Title 18, U.S. Code, nor will it cause any member to be placed in the position of acting as a procurement official.

Michael W. Wynne
Acting

Appendix B: Task Force Participants

<u>Task Force Chairs</u>

- Dr. Mim John, Chair, Sandia National Laboratories
- Dr. Jay Davis, Vice Chair, Private Consultant

<u>Task Force Members</u>

- Dr. Bob Barker, Private Consultant
- Dr. John Crawford, Sandia National Laboratories
- Dr. Bryan Gabbard, Defense Group Inc.
- Dr. Jim Lee, Sandia National Laboratories
- MG Tom Neary, USAF (Ret.), SAIC
- Mr. Roy Setterlund, Draper Laboratory
- Dr. Gordon Soper, Defense Group Inc.
- Dr. Charles Stallings, Private Consultant

<u>Executive Secretaries</u>

- Dr. Andrew (Butch) Cox, ATSD(NCB)
- Mr. Derrick Hinton, DOT&E

<u>Government Advisors</u>

- LtCol Doug Amon, MDA
- Dr. Ted Luera, DOE/NNSA
- Mr. James McComb, MDA
- Jim Miller, AF/XOS
- Ms. Joan Pierre, DTRA
- LCDR Rome Ruiz, Navy Nuclear Affairs
- Dr. Ralph Schneider, DOE/NNSA

<u>DSB Secretariat</u>

- CDR David Waugh, USN

<u>Support</u>

- Ms. Michelle Ashley, SAIC
- Mr. R. C. Webb, SAIC
- Dr. Bruce Wilson, Northrop Grumman

Appendix C: DTRA/ NNSA Memorandum of Understanding

MEMORANDUM OF UNDERSTANDING
IN
NUCLEAR WEAPON EFFECTS TECHNOLOGY
BETWEEN
THE NATIONAL NUCLEAR SECURITY ADMINISTRATION DEFENSE PROGRAMS
AND
THE DEFENSE THREAT REDUCTION AGENCY

1. Purpose: This memorandum of understanding (MOU) establishes a basis for cooperation between the Defense Threat Reduction Agency (DTRA) and National Nuclear Security Administration Defense Programs (NNSA/DP) in nuclear weapon effects (NWE) technology development, planning, stewardship, and application. The purpose of this cooperation is to ensure that the complementary roles of the two organizations efficiently meet the NWE technology needs of the Nation by identifying and filling gaps and by eliminating unnecessary duplication of efforts.

2. Authority: This MOU is authorized and was developed under the provisions of:

   a. Department of Defense Directive 5105.62, Defense Threat Reduction Agency, 30 September 1998.

   b. DoD Instruction 4000.19, Interservice and Intragovernmental Support, 9 August 1992.

   c. Atomic Energy Act, as amended, 42 U.S.C. Sec. 2011, *et seq.*

   d. Energy Organization Act of 1977, as amended, 42 U.S.C. Sec. 5801, *et seq.*

   e. National Defense Authorization Act for FY2000, Public Law 106-65, *et seq.*

3. Scope: The scope of this MOU is limited to coordination and cooperation in nuclear weapons effects technologies research, development, validation, and application. This scope includes experimental and computational simulation and protection (hardening) technologies. It addresses short and long-term nuclear weapon effects on U.S. military assets and intentional and potential unintentional effects on the assets of others. This MOU applies only to NNSA/DP and DTRA.

4. Background:

   a. Accurate predictions of NWE lethality, collateral damage, and other consequences of execution are essential to guide national command authority in assessments of deterrence needs, nuclear capabilities, and war planning to respond to a spectrum of threats to U.S. national security. Validated NWE experimental and computational simulation tools are required for confidence in these predictions.

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b. Nuclear survivability in this context addresses NWE on U.S. military assets. Nuclear survivability prediction, simulation and testing capabilities, and protection technologies are essential to assure survivability of military systems and nuclear warheads in nuclear environments.

c. DTRA and NNSA/DP are both stakeholders in the accuracy and completeness of NWE tools and availability of protection technologies, but from different perspectives, DTRA from the perspective of the warfighter and NNSA/DP from the perspective of warhead designer and steward.

5. Policy: NNSA/DP and DoD/DTRA agree to cooperate in the development, application, and stewardship of weapon output calculations, nuclear weapon effects (NWE) experimental and computational tools, and protection (survivability) technologies.

6. Agreements and Responsibilities:

a. DTRA and NNSA/DP will continue to conduct their NWE programs to efficiently meet their individual mission requirements.

b. Cooperation under this MOU will be facilitated by:

(1) transparency, through frequent, periodic exchange of programmatic and technical information addressing codes, simulators, and protection technologies between organizations; and

(2) management visibility through annual self-assessments and annual reporting of NWE program status to senior management by each organization.

c. Three levels of joint NNSA-DTRA oversight will monitor cooperative efforts to ensure that program efficiencies and effectiveness are achieved and maintained in meeting current and future national NWE objectives.

(1) Level 1 - The NNSA/DP Program Manager, Nuclear Survivability and Effectiveness, and the DTRA Chief, Nuclear Technology Division, will monitor technical and programmatic exchanges, review the annual self-assessments of both organizations, and meet regularly to identify and resolve issues.

(2) Level 2 - The Assistant Deputy Administrator for Research, Development, and Simulation, NNSA/DP, and the Director, Technology Directorate, DTRA, will maintain overarching oversight of NWE capabilities and programs. They shall review both NNSA and DTRA NWE programs at least yearly and address unresolved issues.

(3) The Deputy Administrator for Defense Programs and the Director, DTRA, will maintain executive oversight of NWE capabilities and interactions between the two agencies.

d. Subsequent agreements, subordinate to this MOU, will be developed as needed to facilitate cooperation or resolve issues. Both parties recognize that budget restrictions may impact the ability of each partner to meet responsibilities under specific agreements.

7. Funding and Reimbursement: This MOU contains no funding or reimbursement requirements between the parties.

a. This MOU is not a binding contract but is a memorandum that states the parties' basic understandings of the tasks and methods for performing the tasks described herein. This MOU is neither a fiscal nor funds obligation document. All commitments made in this MOU are subject to the availability of appropriated funds and each agency's budget priorities. Nothing in this MOU authorizes or is intended to obligate the parties to expend, exchange, or reimburse funds, services, or supplies, or transfer or receive anything of value, or to enter into any contract, assistance agreement, interagency agreement, or other financial obligation.

b. The details of the levels of support to be furnished to one organization by the other with respect to funding will be developed in specific interagency agreements or other agreements, subject to the availability of funds. Each subsequent agreement or arrangement involving the transfer of funds, services, or property between the parties to this MOU must comply with all applicable statutes and regulations, including those statutes and regulations applicable to procurement activities.

c. NNSA and DTRA will provide mutual support in interactions with the Office of Management and Budget and assist each other in providing information to the Congress regarding collaborative NWE programs conducted pursuant to this MOU.

d. This MOU in no way restricts either of the parties from participating in any activity with other public or private agencies, organizations or individuals.

e. This MOU does not direct or apply to any person outside NNSA and DTRA. It is strictly for internal management purposes for each of the parties. This MOU is not legally enforceable and shall not be construed to create any legal obligation on the part of either party. This MOU shall not be construed to provide a private right, benefit, or cause of action for or by any person or entity enforceable by law or equity against NNSA or DTRA, their officers, or employees, or any other person.

8. Administration: Administration of and compliance with the provisions of this MOU are the responsibility of the Director, DTRA and Deputy Administrator, NNSA/DP. Each will appoint a representative to act as the Agency/Administration POC for routine administration

and management of this MOU. Additionally, each party may appoint a POC for functional/ operational matters.

a. For DTRA, this MOU will be administered and managed by the Support Agreements Program Manager, Analysis and Support Branch, Program Integration and Support Office, Business Directorate. The POC for operational issues will be the Chief, Nuclear Technology Division, Technology Development Directorate.

b. For NNSA/DP, this MOU will be administered and managed by the Office of Defense Science, NNSA/Defense Programs, or its successor.

9. Conflict Resolution: Conflicts which cannot be resolved at the Agency/Administration level will be referred through each party's chain of command for resolution.

10. Information Release:

a. The information in this MOU is jointly owned by the parties hereto; therefore, requests for release of information from or concerning this MOU, under the Freedom of Information Act (FOIA), must be coordinated through the FOIA Officer of each party.

b. Public or news media requests for information regarding this MOU and related research, development, validation, and application of NWE technologies should be referred to the Public Affairs (PA) offices of DTRA and NNSA/DP. These PA offices will coordinate the response, as appropriate

11. Reviews and Revisions:

a. This MOU may be revised at any time by mutual agreement of the parties.

b. The parties will review this MOU every two years to determine the need for revision.

12. Effective Date and Termination:

a. This MOU will become effective on the date of the last signature, and will remain in effect until terminated by mutual agreement of the parties or unilateral action of one of the parties.

b. Unilateral termination of this MOU requires a written 180-day advance notice of termination to the non-terminating party.

Trudy H. Clark
TRUDY H. CLARK
Maj Gen, USAF
Acting Director
Defense Threat Reduction Agency

27 July 04
Date signed

Everet Beckner
EVERET H. BECKNER
Deputy Administrator
for Defense Programs
National Nuclear Security Administration

JUL - 2 2004
Date signed

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Appendix D: Missile Defense Agency (MDA)

The MDA Acquisition Strategy

Since the BMDS is required to engage and negate nuclear weapons, the BMDS must be able to survive and operate in the environments produced by the detonation of a nuclear weapon regardless of whether that detonation was intentional or inadvertent. MDA has established the BMDS High Altitude Exo-Atmospheric Nuclear Survivability (HAENS) Standard that provides the basis for design and verification / validation of the BMDS Element Nuclear Survivability and Operation in the Nuclear Environments (OPINE) Capabilities. The HAENS standard is a three level standard that provides a yardstick for evaluation of BMDS capability against nuclear weapon threats.

The BMDS HAENS Standard relates the nuclear hardening and environmental levels that the BMDS must survive and operate in to effectively counter the evolving threat. The BMDS HAENS standard identifies all of the critical nuclear environments produced by a nuclear detonation in the BMDS battle space (e.g. HEMP, Prompt Radiation, Persistent Radiation, Disturbed Ionosphere, Optical backgrounds, Radar and RF Communication link parameters). BMDS System and Element effectiveness against a certain threat will be judged against the corresponding Level for that threat in the HAENS Standard.

MDA has embraced the new Evolutionary Acquisition approach which is DoD's preferred strategy for rapid acquisition of mature technology for the user. An evolutionary approach delivers capability in increments, recognizing, up front, the need for future capability improvements.

The MDA Capability-Based Acquisition Process includes spiral development and incremental development. In the Spiral Development process, a desired capability is identified, but the end-state requirements are not known at program initiation. Those requirements are refined through demonstration and risk management; there is continuous user feedback; and each increment provides the user the best possible capability. The requirements for future increments depend on feedback from users and technology maturation. In the Incremental Development a desired capability is identified, an end-state requirement is known, and that requirement is met over time by development of several increments, each dependent on available mature technology.

The Representative Test and Evaluation Approach for Qualification in Nuclear environments is based on analysis, test, and evaluation activities that will be necessary to verify/valuate the MDA contractor claims of capability against the threat.

The MDA approach is based on the DTRA Testable Hardware Protocols, Testable Hardware Toolkit, Hardware-In-The-Loop, and other DoD domain experience verifying and validating survivability. MDA needs to expand their survivability approach to include recent advancement made by the DOE Advanced Simulation and Computing (ASC) initiative. To demonstrate that the appropriate MDA Nuclear Survivability Level is achieved will require varying amounts of radiation testing to include testing at the piece part, module, circuit board/optical component, subsystem, and system level testing. The tests required will depend on the MDA Nuclear Survivability Level I, II, or III that is necessary to verify that the contractor has achieved the threat capability claimed. Gaps in simulator capability need to be bridged using Modeling and Simulation via a collaborative effort with the DOE ASC program. The modeling and simulation activity needs to be anchored by carefully planned benchmark tests.

BMDS hardening approach will involve a combination of radiation hardened and COTS electronic piece parts that will require burnout and upset screening to X-ray and gamma ray, total dose and dose rate, and neutron Single Event Upset (SEU) environments. The specific MDA Level to which an element is hardened will determine the amount of testing. For level I a minimum amount of testing will be necessary whereas for levels II and III a complete set of radiation testing will be necessary to include piece part and component, subsystem and system (i.e., EKV system level) tests in the hot and cold X-ray, the neutron, the debris betas and the debris gamma environments. To fully verify OPINE the sensor subsystem and the EKV tests will have to be performed in both single environments and in multiple environments properly spaced in time. For the Exo-EKV and LEO satellites, a cyro-test chamber will be required to simulate the space environment will be needed with IR background and targets.

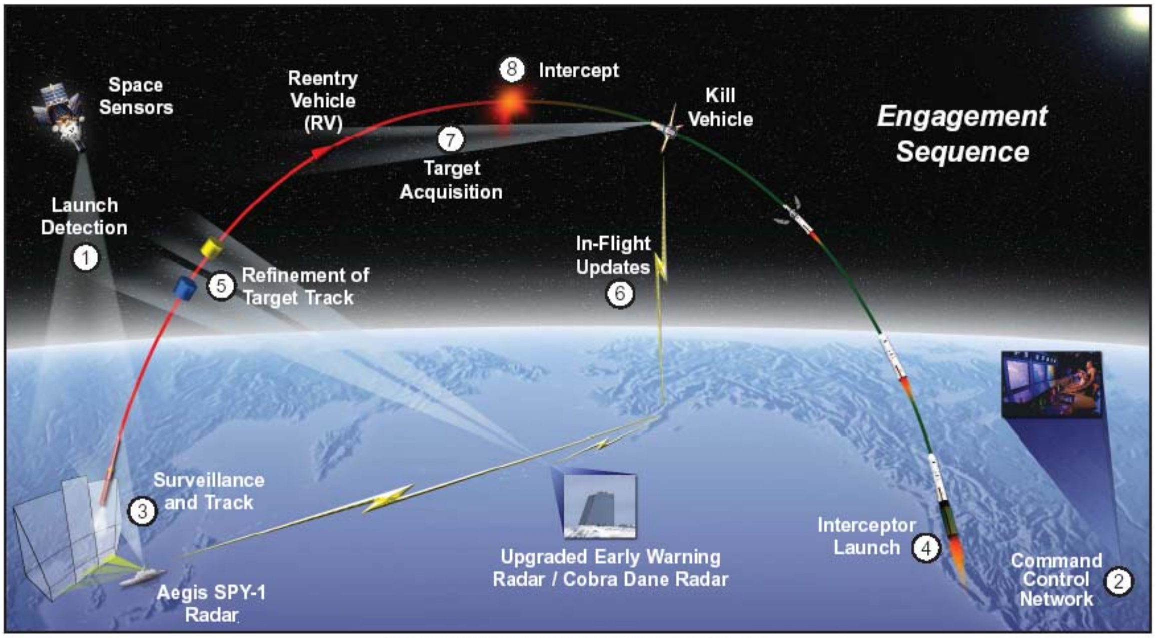
<u>BMDS System Description</u>

To counter the threat of ballistic missiles carrying Weapons of Mass Destruction (WMD), the Department of Defense established the Missile Defense Agency (MDA) to manage and integrate all missile defense programs and technologies into one Ballistic Missile Defense System (BMDS). Our top Missile Defense priorities are:

• To defend the United States, deployed forces, allies, and friends
• To employ a BMDS that layers of defenses to intercept ballistic missiles in all phases of their flight — boost, midcourse, and terminal — against all ranges of threats — short, medium, intermediate, and long
• To enable early fielding for elements of the BMDS
• To develop and test technologies and, if necessary, use prototype and test assets to provide early capability.

The BMDS program is structured in two-year "blocks," with fielding opportunities occurring throughout the blocks. The first period, Block 2004, represents calendar years 2004-2005. Block 2006 represents 2006-2007, and so on. The work done in each block will build upon the capabilities and development of previous blocks. Over time, this block approach will yield a fully integrated and layered BMDS, capable of defeating ballistic missiles of all ranges and in all phases of flights.

• Block 2004 Objective: Field an initial capability to provide a modest defense of the United States
• Block 2006 Objective: Increase the depth and breadth of our initial capability by adding interceptors, adding "deployable" radars, and integrating these systems to maximize their performance
• Block 2008 Objective: Enhance our ability to protect our deployed forces and coalition partners, and add an initial capability to defeat the threats in the boost phase.



How Missile Defense will Defend the United States

Engagement Sequences

MDA has developed an "engagement sequence" concept to demonstrate and measure how the components of the BMDS work together. An engagement sequence is a unique combination of detect-control-engage functions performed by BMDS components (e.g., sensors, weapons, and command control equipment) used to engage a threat ballistic missile. The engagement sequence defines the specific detection sensor, fire control radar, and weapon to be used, and is an innovative product of our efforts to create an integrated system, as opposed to a collection of diverse units. MDA's testing program verifies the engagement sequences. These sequences, in turn, allow MDA to test the flexibility and interoperability of the system. Engagement sequence testing measures the effectiveness of data interchange between components, such as a sensor and the kill vehicle. A notional engagement sequence with the initial missile defense capability against a long-range ballistic missile is described with reference to the *Engagement Sequence* graphic above:

(1) The Defense Support Program constellation of satellites monitors the entire globe. These satellites use infrared sensors to detect the heat generated during a missile launch.
(2) The U.S. National Military Command and Control Network receives an alert of the possible launch of a long-range ballistic missile. The alert would be sent to several Department of Defense locations, including the Combatant Commands (COCOMS). Upon receiving the alert from the COCOMS, the BMDS directs its land- and sea-based sensors to search for the long-range missile flying along a predicted trajectory.
(3) Forward-deployed U.S. Navy Aegis destroyers receive the launch notification and, using the upgraded SPY-1 radar, begin searching possible trajectory sectors for a ballistic missile. Upon detection, the tracking information is transmitted through the BMDS Data Network to the Ground-Based Midcourse Defense (GMD) system. An intercept course is calculated based on such tracking data.
(4) A Ground-Based Interceptor (GBI) is launched.
(5) The Upgraded Early Warning Radar (UEWR) is alerted as the hostile missile approaches the radar's area of coverage. Once the hostile missile has completed its boost phase, the booster separates and a reentry vehicle (RV) containing a weapon — chemical, biological, nuclear, or conventional — is deployed,

possibly with countermeasures (e.g., decoys). Using improvements in track accuracy, the UEWR identifies and begins to track the cluster containing the RV.
(6) UEWR tracking data is used to provide interceptor course corrections. These corrections are transmitted to the interceptor missile so that it steers to the proper point in space where it releases its "kill vehicle."
(7) The kill vehicle, a 155-pound system of advanced sensors and state-of-the-art components, uses the information it has received from the command and control network to get into the proper position. Once there, the kill vehicle uses its onboard sensors to locate and acquire the target cluster and discriminate the RV from any accompanying decoys.
(8) The kill vehicle adjusts its trajectory using small rocket motors to collide with the RV payload at a closing speed of more than 15,000 miles per hour. The force of the impact pulverizes the RV using only the kinetic force of the collision. This is called "hit-to-kill" technology.

MDA is laying the foundation of our nation's missile defenses with the initial fielding of the BMDS. This initial set of capabilities is designed to meet the near-term ballistic missile threat to our homeland, deployed forces, allies, and friends. Extensive realistic testing is planned to take place for many years. MDA's development program will provide improvements and upgrades to existing technology and will ensure that the missile defense system on alert is the most effective, reliable, and capable system, now and in the future, contributing greatly to homeland defense, public safety, and our overall national security. For the first time, the BMDS will be able to execute multiple engagement opportunities, a true test of an integrated, layered defense. In the future, based on lessons learned in the BMDS Test Bed, more advanced capabilities will be fielded in successive blocks. The ABL and our Kinetic Energy Interceptor program would allow us to exploit the advantages of a boost-phase intercept. THAAD would add an additional intercept opportunity in the terminal phase and would provide a greater area of coverage than existing terminal point defenses. Forward-deployed radars would provide additional layers of sensor capability and more effective tracking of hostile missiles. Over time, MDA's acquisition approach will yield a fully integrated and layered BMDS capable of defeating ballistic missiles of all ranges in all phases of flight.

<u>New -EKV Sensor Unique Conditions</u>

- The MDA Ballistic Missile Defense System (BMDS) has unique hardening and Operate in the Nuclear Environment (OPINE) requirements while the KV design constraints do not allow the normal radiation shielding to the gamma limit. After the EKV separation and the shroud is blown away the sensor including the telescope, mirrors, focal plane array and associated electronics are exposed to the full suite of nuclear environments that result when a nuclear explosions occurs. Because kill vehicles operate above the bulk of the atmosphere, there is little or no air mass shielding between the kill vehicle and the nuclear detonation.

- The sensor must identity, discriminate, and home in on RV with numerous decoys while flying through the nuclear debris from prior explosions from previous nuclear detonation. Nuclear detonations can result from salvage fusing, inadvertent yield at intercept (not "one point safe"), or deliberate detonation of a nuclear warhead in the BMDS battle space.

- The KV must survive the prompt X-ray, gamma and neutron radiation and must operate through the debris gamma and beta environment. Optical sensors are susceptible to gamma and beta induced noise spikes at radiation levels that are far below the levels that are of concern for digital electronics. The senor gain is so high that the radiation induced noise is amplified and interpreted as a valid signal. Senor operability requires a combination of hardware and software to detect, reject spurious radiation induced noise, and discriminate the target from penetration aides including chaff, balloons, light weight replicas, and other decoys.

- The combined effects of both the prompt radiation, thermal flash, and the delayed radiation debris (gammas and betas) while the neutrons arrive from multiple are single event upsetting, mirrors deforming, battles flaking off particulates, and the thermal flash are exacerbating the signal to noise at the same time the sensor is discriminate the targets from various decoys.

- Exo-atmospheric nuclear detonations deposit tremendous amounts of energy into the ionosphere causing disruption of radar and RF communications systems via blackout, redout, and scintillation.

<u>Issues for Assuring Survivability with Simulators</u>

X-Ray Gap. Gaps exist in the Cold and Warm X-Ray environment. It is difficult to accurately simulate the fluence, temporal, and spectral fidelity in these regimes using above ground simulators (Z-Pinch plasma radiation and bremsstrahlung sources). This gap can be partially bridged using modeling & simulation and benchmark tests conducted with nuclear radiation simulators.

Example 1: MBS provides a critical capability in the warm x-ray regime. Even though the fluence from MBS is several orders of magnitude below threat levels, it is used to measure SGEMP drive currents that are scaled up to threat levels in higher level system models. Sub-fluence testing in the warm bremsstrahlung mode finds flaws and defects in the as built design that cannot be found using as built drawings and computer models and simulation.

Example 2: Z-pinch Plasma radiation sources provide high fluence line spectra that are used to simulate the cold blackbody component of the weapon x-ray spectrum. Although, the fluence is approximately correct the spectral fidelity can drive artificial effects while potentially missing real effects.

SGEMP Gap. Extensive work by DTRA and DOE has developed the testable hardware design philosophy for SGEMP that relies on 4◎ gamma limit radiation shields. However, open cavity SGEMP associated with homing optical sensors is not as well understood. The optical sensors on the MDA homing sensor kill vehicles are the first of a kind that require this phenomenology to be better understood. However, it is likely that homing sensors may become common on future weapon system of all kinds.

Neutron Gap. Fast Burst Reactor (FBR) is critical. Security concerns are driving cost. Recommend maintaining a single FBR at WSMR. Linear accelerator driven 14 MeV neutron sources are also required, but these are typically small scale laboratory test sources. Thermal reactors also provide a useful tool for evaluating nuclear reactions that are driven by 1/v thermal cross-sections.

Heavy Ion Gap. Heavy Ion Test Capability for Cosmic Ray Testing. The Berkley cyclotron is at risk of closure. It is important to keep at least one cyclotron that is capable of heavy ion testing. Texas A&M, University of Michigan cyclotrons can fill this role.

Neutron Single Event Upset Gap. Modern electronics has shown an enhanced response to neutron radiation following prompt radiation exposure. There is a need for maintaining combined effects testing at the electronics piece part and circuit level. Data indicates that there can be both total dose and dose rate driven synergies depending on the specific design of the specific part. Recommend combined effects capability be co-located with the WSMR FBR.

Combined Effects Gap. The timeline of radiation insult to a system can result in synergistic effects. As an example, prompt radiation lasts for several nanoseconds, neutron arrival follows several milliseconds later, lasting for seconds, and persistent fallout, delayed gamma, and trapped beta environments that last for hours to months after a nuclear detonation. Synergistic effects are difficult to predict a priori. However, Hardware-In-The-Loop testing can often be used to find and mitigate these effects. In many cases, HWIL testing can use software driven interrupts to simulate nuclear radiation events. It appears to be appropriate to perform combined effects testing at the circuit and subsystem level and bridge the remaining gap with Modeling and Simulation.

System of Systems Gap. System of Systems verification should be based on modeling and simulation anchored by element and subsystem V&V data. Engagement Planner with nuclear battle planning algorithms consistent with the fielded hardware capability is essential.

Appendix E: U.S. Army Survivability Procedures

<u>FACTS:</u>

DODI 5000.2 states, "…the PM shall address personnel survivability issues including protection against fratricide, detection, and instantaneous, cumulative, and residual nuclear, biological, and chemical effects."

CJCS Manual 3170.01A, 12 Mar 04, pages E-A-5 and F-A-5, paragraph 14, Other System Attributes, states that Combat Developers (CBTDEVs) should address "conventional and initial nuclear weapons effects and nuclear, biological, and chemical contamination (NBCC) survivability."

AR 15-41, *Nuclear and Chemical Survivability Committee (NCSC)*, 20 Feb 92, the Army G-3 serves as the approval or disapproval authority for proposed modifications or waivers to nuclear and NBC contamination survivability criteria. Establishes a Secretariat that provides the Committee with technical support and advice in the review of nuclear and NBC contamination survivability requirements, and requests for modification or waiver of nuclear and NBC contamination survivability criteria.

AR 70-1, *Army Acquisition Policy*, 31 Dec 03, states that "the DCS, G-3 will approve or disapprove all waiver requests for nuclear, biological, and chemical (NBC) contamination survivability."

AR 70-75, *Survivability of Army Personnel and Materiel*, 10 Jan 95. The Materiel Developer (MATDEV) will ensure appropriate survivability requirements are included in the testing and evaluation master plan, the quality assurance plan, the integrated logistics support plan, and the life-cycle survivability maintenance plan. The Director USANCA will establish preliminary nuclear effects and NBC contamination survivability criteria for requirements contained in the MNS which specify nuclear and NBC contamination survivability. (See AR 10–6). The Director USANCA will establish final nuclear effects and NBC contamination survivability criteria for requirements contained in ORDs which specify nuclear and NBC contamination survivability. The Director USANCA will assist CBTDEVs with the application of nuclear effects and NBC contamination survivability criteria for systems and assist in the evaluation of system survivability shortfalls. The Director USANCA will provide a director and two members to the Nuclear and Chemical Survivability Committee Secretariat (NCSCS) and administrative support to both the NCSC and the NCSCS. The Director USANCA will monitor the Army's nuclear and NBC contamination survivability programs.

New TRADOC's Guide for Development of Army Initial Capabilities Documents (ICDs), 22 Oct 03, Paragraph 5.2, page 14, "In most cases, a statement should be included that the capability may have to operate in an electromagnetic pulse (EMP) and nuclear, biological and chemical (NBC) environment. Even if an EMP/NBC environment will not affect the system, NBC must be mentioned. This will ensure the capability is designed and tested to ensure operability by soldiers wearing mission oriented protective posture (MOPP) gear."

New TRADOC's Capabilities Development Document (CDD) Writing Guide, 10 Mar 04, contains the same projected threat verbiage as in the ICD and adds:
14.6. <u>Initial nuclear weapons effects</u>. State if the system is mission critical. ("The system is (is not) mission critical").
If it is mission critical, further define the initial nuclear survivability criteria (see below).

- If the system is mission critical, as a minimum, you must include the statement "System will survive the Initial Nuclear Weapon Effects of High-Altitude Electromagnetic Pulse (HEMP)."
- During a nuclear event, system electronics can be upset. As such, if HEMP is required, you must also identify one of the following: "System upset is acceptable during a nuclear event and may be rebooted or power cycled to bring the system back to operational configuration within XX minutes." or "System upset is not acceptable during a nuclear event and must operate through the event."
- If the system is mission critical and if system is a front line combat system, CDD must contain the words: "System must also withstand the initial nuclear weapon effects of blast, thermal radiation, and initial nuclear radiation to the same level where a sufficient percentage of operators remain combat effective long enough to execute the mission."
- This suggested wording above provides for minimum requirements to allow mission critical systems to conduct their mission in a nuclear environment. (see AR 70-75)
- For additional information or assistance, contact U.S. Army Nuclear and Chemical Agency or consult TRADOC Pam 71-9.

14.7. Nuclear, biological, and chemical contamination (NBCC) survivability

State if the system is mission critical. ("The system is (is not) mission critical". This must match the statement in 14.6).

If it is mission critical, further define the NBCC survivability criteria (see below).

- If the system is mission critical, as a minimum, you must include the statement: "System must survive the effects of NBC contamination, must be compatible for use by soldiers in Mission Oriented Protective Posture (MOPP) 4, and must be able to conduct its mission while contaminated for 72 hours without failure due to contamination."
- If the system is mission critical, which requires survivability, you must also address decontamination. As such, you must include the words: "Operators, using on-board equipment, must be able to conduct Immediate Decontamination within 15 minutes, Operational Decontamination using on-board or crew-served equipment within 6 hours, and Thorough Decontamination when mission allows reconstitution." If in the event system does not need to be decontaminated, for example, a fire and forget sensor, the CDD needs to state: "System (or component) does not need to be decontaminated." Be sure to provide rationale that will justify not needing decontamination.
- This suggested wording above provides for minimum requirements to allow mission critical systems to conduct their mission in an NBC contaminated environment. (see AR 70-75)
- For additional information or assistance, contact U.S. Army Nuclear and Chemical Agency or consult TRADOC Pam 71-9.

New TRADOC's Capability Production Document (CPD) Writing Guide, 10 Mar 04, contains the same threat environment statement as in the ICD and the same paragraph 14.6 and 14.7 as the CDD.

DISCUSSION:

The methodology for ensuring NBC survivability, both nuclear survivability and NBC contamination survivability, begins with equipment characterization. Characterization includes identifying the equipment configuration, topology, operational requirements, and location of the equipment relative to the forward line of own troops. The CBTDEV establishes the equipment characterization in the requirements documents. These documents are sent out for worldwide staffing before seeking TRADOC approval. Once approved by TRADOC the final draft is sent to DAMO-RQ for Army staffing and approval.

The equipment purpose is then used to establish whether or not the equipment supports one or more critical missions. If it does, the equipment must be nuclear and NBC contamination survivable. Nuclear survivability is further broken down into High-Altitude Electromagnetic Pulse (HEMP) and initial nuclear weapon effects (INWE) survivability. All mission critical systems must survive HEMP. Additionally, front line combat systems must also survive the INWE of blast, thermal radiation, and initial nuclear radiation.

The next question to address is whether equipment hardening is the preferred way to meet that survivability requirement, or if it can be addressed by tactics, techniques and procedures that address mitigation, redundancy and resupply. If the CBTDEV determines that hardening/mitigation is the preferred way to meet that survivability requirement, they must establish the threat spectrum. On the regional battlefield, specific threat yields less than 500 kT are expected.

Assuming the CBTDEV determines hardening is the answer, USANCA will issue the Materiel Developer (MATDEV) HEMP criteria from Volume II, QSTAG 244, *Nuclear Hardening Criteria for Military Equipment*, and QSTAG 1031, *Consistent Sets of Nuclear Hardening Criteria for Classes of Equipment*, to address the HEMP requirement. Likewise, USANCA will issue criteria to the MATDEV for hardness, decontaminability, and compatability derived from QSTAG 747, *NBC Contamination Survivability Criteria for Military Equipment*, to meet the NBC contamination survivability requirement.

If INWE survivability and human operators are required, USANCA issues nuclear survivability criteria to the MATDEV based upon the balanced-hardening methodology described in QSTAG 244. Using this methodology, criteria levels have already been specified in QSTAG 1031 for each of five equipment classes associated with troops. In this case, the balanced-hardening procedure is based on the inherent survivability of human operators documented in a database of human susceptibilities to each type of nuclear weapon effect.

It should be noted that some first-generation unmanned equipment, notably mobile, ground-based equipment, could be operated by nearby troops. In this case, nearby is defined as operators being less than 0.5 km from the unmanned equipment. Using this definition, the equipment should be balanced to man’s survivability levels as described in QSTAG 244. Thus, first-generation unmanned platforms and systems could have nuclear hardening criteria similar to manned legacy equipment.

If human operators are <u>not</u> required and equipment is not operated near troops, USANCA issues hardening criteria to the MATDEV based on QSTAG 2041, *A Rationale for Establishing Nuclear Hardening Criteria for Unmanned Operational Platforms and Systems*. In this case, hardening is based upon isodamage curves of equipment susceptibility; curves that are not based on human vulnerability but on system design limits. One must not infer that this form of hardening sets nuclear hardening criteria at the failure levels of the equipment; instead, it means equipment hardening is based upon several major considerations: the anticipated range of battlefield nuclear threats, the role the unmanned equipment will play on the nuclear battlefield, the equipment physical configuration and topology, the electronics sensitivity, and the amount of risk commanders are willing to take.

The MATDEV must then design the equipment to meet the criteria with technical assistance provided by ARL/SLAD. Experience has shown that appropriate nuclear hardening techniques, if incorporated in early system design, added about 1-2% to the overall system cost of manned legacy equipment. The least expensive procedure to nuclear harden equipment is to design it in during the original system design.

Protection techniques and even certification of nuclear survivability must be explicitly identified in the Test and Evaluation Master Plan. This document is managed by the Test and Evaluation Management Agency with input from Material Developers, CBTDEVs, Developmental Test Command (DTC), and Army Evaluation Command (AEC).

NBC survivability can only be validated through breadboard and brassboard testing and analysis of subsystems and systems during the early phases of the equipment life cycle, through quality assurance testing on the assembly line, and by validation tests of prototype equipment. Implicit in this step is the need for test validation. The highest confidence method to assure adequacy is via some system-level or component-level test to the NBC survivability hardening criteria performed by DTC.

The final determination on whether or not the equipment meets the criteria rests with AEC. If the equipment does not meet the criteria, the MATDEV can go to HQDA through USANCA and ask for a waiver. The waiver request does not negate the requirement for the equipment to survive. This request begins with the level the equipment achieved during testing. The MATDEV then addresses the costs associated with modifying the equipment to meet the criteria. The CBTDEV then discusses how tactics, techniques and procedures can address mitigation, redundancy and resupply to reduce the risk assumed by not hardening the equipment to the specified levels. This waiver request is forwarded to a panel of experts, the NCSCS. The NCSCS forwards their recommendation to a panel of general officers, the NCSC. The NCSC then forwards their recommendation the Army G-3, who makes the final decision.

This might seem like we have reached the goal of procuring survivable equipment, but it is only the beginning. The MATDEV must develop a complete hardness maintenance, assurance, and surveillance program over the entire equipment life cycle. This can be achieved by executing simple, scheduled inspections for gross physical damage and circuit upset/damage, and shielding integrity and penetration control tests to ensure barrier control.

SUMMARY:

There exists DoD and JCS regulatory guidance on NBC survivability. The services write and implement their own survivability regulations to provide further guidance and assign responsibilities. The Army decided to regulate the survivability program in the following ways:

1) Write the appropriate regulations for the survivability program.
2) CBTDEV make a determination if equipment is mission critical and requires hardening.
    a. CBTDEV can meet the survivability requirement via operational tactic, techniques, and procedures (TTP), which are analyzed to determine if nuclear and NBC contamination survivability can be met by mitigation, redundancy, or resupply.
3) If it is mission critical and requires hardening, then the equipment must be designed to be nuclear and NBC contamination survivable.
    a. Nuclear survivability: All mission critical equipment must survive HEMP; additionally, front line combat systems must survive INWE.
    b. NBC contamination survivability: All mission critical equipment must demonstrate that they can survive hardness, decontaminability, and compatability criteria.
4) Publish nuclear and NBC contamination survivability criteria.

5) MATDEV designs equipment with respect to published nuclear and NBC contamination survivability criteria.
6) Verify equipment nuclear and NBC contamination survivability through the testing and/or analysis of the design/prototype equipment. Independent evaluation of test and/or analysis determines equipment nuclear and NBC contamination survivability.
7) Inability to appropriately meet criteria via nuclear and NBC contamination survivability tests causes the results to be submitted to USANCA to initiate the waiver process review using the NCSCS, NCSC, and final DCS G-3 process described in AR15-41.
8) MATDEV ensures that a life-cycle up survivability maintenance plan is developed and implemented.

Appendix F: U.S. Navy Survivability Procedures

Conventional Systems

The Defense Science Board (DSB) requested a short summary of the Navy's DSB presentation provided by LCDR Rome Ruiz on 17 March 2004. The purpose of the brief was to provide Navy's responses to questions from the DSB Task Force to the Chief of Naval Operations concerning Navy's nuclear survivability requirements process for its major systems and how systems are validated to ensure requirements are met. The following summary is provided.

References

(a) DODD 4245.4, "Acquisition of Nuclear Survivable Systems," (cancelled)
(b) DODD 3150.3, "Survivability and Security of Non-Strategic Nuclear Forces," (cancelled)
(c) DODD 3150.3, "Nuclear Force Security and Survivability," 16 August 1994
(d) OPNAVINST 9070.1, "Survivability Policy for Surface Ships," 23 September 1988
(e) OPNAVINST 3401.3A, "Nuclear Survivability of Navy and Marine Corp Systems," 05 January 1989
(f) NAVSEAINST C3401, "Nuclear Survivability Criteria for Surface Ship Classes," 26 April 1990
(g) CJCSINST 3170.01 (Series), "Joint Capabilities Integration and Development System"
(h) SECNAVINST 5000.2 (Series), "Implementation of Operation of the Defense Acquisition System and Joint Capabilities Integration and Development System"
(i) MDA-STD-001, "BMDS High Altitude/Exoatmospheric Nuclear Survivability Standard"

Background

In 1988, references (a) and (b) updated DoD policy on the acquisition/requirements of nuclear survivable systems and established procedures consistent with the DoD 5000 series that directs defense acquisition processes. However, with the end of the cold war coupled with an ostensibly decreasing nuclear threat, references (a) and (b) were cancelled without an equivalent DoD level directive or instruction mandating nuclear survivability for tactical systems. Although reference (c) was issued in 1994 as an update to reference (b), it provided no requirements guidance and further de-emphasized nuclear survivability requirements for tactical systems.

Given that references (a) and (b) were the underlining guidance for references (d) through (f), all Navy guidance mandating non-nuclear, conventional hardening requirements for the full spectrum of nuclear effects became, by default, obsolete. However, Navy never officially cancelled or updated references (d) through (f) and likewise continues to use these references as baseline guidance for nuclear survivability policy and criteria.

Platform Requirements and Capabilities

Ships. Per reference (d), ships are grouped into three general survivability levels for protection requirements:

- Level III (highest) for aircraft carriers and battle force surface combatants, i.e. cruisers and destroyers

- Level II (moderate) for frigates, amphibs, and certain replenishment ships
- Level I (low) for patrol combatants, mine warfare and auxiliary ships

Reference (f) establishes nuclear survivability criteria for all surface ships:

- Level III balanced limits for blast, thermal, HEMP, and TREE requirements
- Level II balanced limits for increased standoff ranges for blast, thermal, and HEMP without TREE (for large yield weapons)
- Level I only requires HEMP

There have been revisions to these requirements:

- A CNO memo dated 12 January 1989, which reduced nuclear protection levels for destroyers and cruisers to Level II.
- NAVSEA 05P memo dated 20 March 2003, which recommended reduction of nuclear protection levels for aircraft carriers to Level II. This was accepted by OPNAV N78 and included in revised CVN 21 ORD. It is being implemented on all carrier alterations and modifications.

Aircraft. There are currently no identified NAVAIR requirements for placing the full spectrum of nuclear weapons effects requirements on NAVAIR platforms. However, VH/VXX platforms, as well as E-6B's, have the full spectrum of nuclear weapons effects requirements levied on them that are derived from and based on platform ORDs and system threat assessment reports (STAR).

Infrastructure. There is no identified requirement or guiding instruction for placing the full spectrum of nuclear weapons effects requirements on navy ashore infrastructure. However, there are two critical C3I navy facilities that have hardening requirements for EMP only:

- NCTAMS PAC Honolulu
- NAVCOMSTA Puget Sound

The best-known guidance on shore infrastructure nuclear survivability is a series of eight Army Corp of Engineers documents that are twenty years old.

Missiles. In accordance with reference (i), the SM-3 missile (upper tier defense) has nuclear hardening requirements. However, Navy has no hardened lower tier BMD missile to protect fleet assets since OSD cancelled the hardened SM-2 block IVA program in December 2001.

Nuclear Survivability Validation

In accordance with reference (e), NAVSEA ensures that nuclear survivability requirements are validated at the appropriate points of system development. Furthermore, per reference (f), nuclear survivability measures will be validated by tests. Validation by engineering analysis is allowed where testing is not feasible or warranted as determined by the technical authority of NAVSEA (previously PMS 423). However, given NAVSEA has no capability, for example, to validate an entire ship for EMP vulnerabilities, NAVSEA has no choice but to accept engineering analysis (EMP whole ship test capability, EMPRESS II, was decommissioned in 1994).

Managing Nuclear Survivability Requirements

Navy recognized that there were shortcomings to the general management and documentation instructions during Navy's requirements and acquisition process.

Consequently, in accordance with references (g) and (h), the Navy embraced and adapted the Joint Capabilities Integration and Development System (JCIDS) process for the vetting of its warfighting requirements. Navy is an active participant in the Joint Capability Boards and Integrating Concept(s) working groups in order to ensure our requirements documentation is processed and validated through the JCIDS construct.

Additionally, Navy recently adopted a Navy Capabilities Board (NCB) Charter that formalizes new and mature program reviews to ensure top leadership has an opportunity to view the programs in context of their performance, adherence to objectives, and future capability. Specifically, the NCB is an instrument of the Chief of Naval Operations and Secretary of the Navy to review, validate, and approve all Navy originated JCIDS documents. The NCB serves as a forum where Navy leadership can debate the merits of program contents, for example, nuclear survivability/hardening requirements, and leverage cost versus capability while considering risks and threats.

Navy will continue to use references (d) through (f) as baseline guidance for nuclear survivability policy and criteria since reference (h) does not specifically reference or mandate nuclear survivability requirements. However, an overarching goal of the NCB will be to ensure nuclear survivability and hardening capabilities for all non-nuclear, conventional capabilities are considered prior to embarking on major acquisition programs and changes thereto.

Strategic Systems Program (SSP)

The Defense Science Board (DSB) requested the following information as a result of an SSP Presentation provided by LCDR Mark Galvin to the DSB on 17 March 2004. The purpose of the brief was to provide SSP's responses to questions from the DSB Task Force to the Chief of Naval Operations concerning Nuclear Weapons Effects Test, Evaluation, and Simulation. The SSP response focused on nuclear survivability and only addresses the Strategic Weapons System (SWS).

1. SSP's Mission Statement. "The Strategic Systems Programs team is dedicated to serving our nation by providing credible and affordable sea-based deterrent missile systems."

2. The requirements for Major Systems begins with an Initial Capabilities Document (replaced Mission Need Statement(MNS)). The Trident II (D5) SWS development was tasked by the 2 February 1981 Secretary of Defense Decision Memorandum (SDDM), which endorsed a Submarine Launched Ballistic Missile (SLBM) Modernization Report. By direction of the Secretary of Defense's direction, the SDDM served as the MNS. The SLBM Modernization Report presented high level requirements for increased capability over the Trident I (C4) SWS, specifying the development of Trident II (D5) SWS including the Mk5/W88 reentry body.

3. Nuclear survivability is a significant driver for credibility and affordability, key objectives of SSP's mission. To be credible, the system must be able to operate in hostile environments, fratricide environments and natural space environments. To be affordable, the cost to achieve a credible level of nuclear survivability must be proportional to the value of the deterrent.

4. Nuclear survivability is an integral aspect of a credible deterrence. In order for the deterrence to remain effective, current as well as anticipated future threats must be assessed. Over the next several

decades, formidable threats are expected to invest significant resources resulting in multiple opportunities to counter our deterrent systems. For example, existing tactical nuclear warheads can be mated to interceptors. The approach to selecting radiation environments must be insensitive to what cannot be known, i.e., the future threat. Technology-driven requirements, with intelligence-based threat inputs, allows for the maximum weapon system flexibility at a reasonable cost.

5. Reentry body requirements originate through Military Characteristics (MCs), which describe the military capability to be achieved. The Stockpile to Target Sequence (STS) describes the normal and credible abnormal environments the weapon will encounter and specifies nuclear survivability requirements. Both the MCs and the STS are reviewed, approved, and promulgated by the Nuclear Weapons Council.

6. The missile and guidance nuclear survivability are defined by the Weapon Specification (WS) for boost phase hostile environments. The WS, developed by the missile and guidance communities and approved by the Director (SSP), is based on intelligence analysis of potential nuclear threats prior to reentry body deployment and includes the natural radiation environment. Reasonable technology assumptions constrain the Nuclear Weapons Models (NWMs) and engagement scenarios used in the threat analysis.

7. Strategic nuclear threat requirements generation starts with the NWMs provided in the DTRA "Red Book". The Red Book defines the radiation output characteristics of all technologically feasible nuclear weapons. This information is reformatted in a Threat Summary for Navy usage. Engagement scenarios are then generated for interaction with enemy threats based upon the Navy Fleet Ballistic Missile (FBM) mission. The Defense Intelligence Agency (DIA) provides information for interceptor and engagement assumptions. Analysis using all feasible and reasonable threats over the range of likely scenarios results in a set of predicted radiation environments described in terms of x-ray, gamma and neutron spectra. The severity of these environments is then evaluated against U.S. technology capability. The envelope of these levels is summarized in the Trident nuclear specification of Radiation Requirements, which may also be constrained by our ability to test or otherwise demonstrate "Compliance" with the Radiation Requirements. The Radiation Requirements Document also defines peak flux and dose rates for each component of the environment, and provides number of nuclear events and relative size and altitude distribution of those events. This approach assures that the FBM System is survivable against all field-able threats over its lifetime.

8. The current Red Book was published in 1980. Since then, there have been tremendous improvements in computing power, allowing us to analytically investigate and define threat weapon outputs with greater resolution in time, space, and energy. Furthermore, based on development and use of radiation specifications derived from the 1980 NWMs, we better understand which weapon model output components and parameters are important, and hence, need to be refined for future specification development and application. The Red Book is currently under revision now and is expected to be completed and released over the next couple of years. Two of the four volumes have been completed. One of the volumes still in progress provides the key threat weapon models that drive the SLBM system requirements. Preliminary versions of the new models have been examined to determine the major significance of any changes, relative to 1980 NWM.

9. SSP is, in fact, sponsoring development of a new radiation requirements specification in preparation for the D5 Life Extension Program. This re-examination involves both the nuclear weapon models and the threat operational scenarios. In addition, specification development must consider Nuclear Hardening & Survivability (NH&S) capabilities of the critical instrument and component technologies

needed to build the system to achieve performance requirements. It is not reasonable to set the radiation hardness requirements to levels that are unachievable using the best available technologies needed to meet mission objectives. Lastly, the specification must also consider the existing and projected radiation test capabilities that will be available to verify system compliance to that hardness specification. The D5 SWS and many of its key subsystems went through rigorous hardness testing, using a variety of Above Ground Test (AGT) facilities, and Under Ground Tests (UGTs) with the final UGT serving as an "Admiral's Test." The D5 system included 12 UGT's. Given the loss of UGTs, future systems must develop an alternate methodology based on AGT capability and advanced modeling and simulation.

10. The acquisition process used for nuclear weapons is based upon the DoD Procedures for Joint DoD-DOE Nuclear Weapons Life-Cycle Activities (DoD Instruction 5030.55 dated January 25, 2001) and the Joint DoD-DOE Nuclear Weapon Life-Cycle Activities (DoD Directive 3150.1 dated August 26, 2002). The acquisition process used for the non-nuclear subsystems is the DoD 5000 series. Both acquisition efforts are mapped together to achieve initial operating capability.

11. Requirements flow down to the contractor as contractual requirements; MCs and STS for reentry and WS for remainder of the SWS. The Compliance Plan, prepared by the contractor, shows how MCs, STS, and WS requirements will be met, through one-to-one mapping of requirements to method of verification (testing, simulation, analysis). The Compliance Plan is approved and monitored by Project Officers Group (MCs and STS) and Program Office (WS).

12. Nuclear Survivability Testing is combination of existing UGT data, AGTs, and analysis. An Integrated Test Plan describes tests to be conducted at component, board, package, subsystem, and system levels. It also maps the test objectives to the Compliance Plan to ensure that all testable requirements are tested in a suitable environment. The Integrated Test Plan is prepared by contractor and approved by Project Officers Group (reentry) or Program Office (missile and guidance). The Compliance Plan specifies analyses (or test/analysis combination) to be conducted for nuclear survivability requirements that cannot be tested to the design level.

Other Board Questions Related to Nuclear Survivability

1. How many major programs have nuclear survivability requirements? The SWS has nuclear survivability requirements
2. At what point in the acquisition process was it decided to levy the requirements? Nuclear survivability requirements have been a part of the Strategic Weapons System since its inception.
3. Who made the decision to levy the requirements? Nuclear Weapons Council
4. How many systems have applied for a waiver to nuclear survivability requirements? The SWS has never applied for a waiver to nuclear survivability requirements.
5. How many were granted waivers? N/A for the SWS
6. On what grounds were the waivers granted? N/A for the SWS
7. By whom were the waivers granted? N/A for the SWS

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Appendix G: U.S. Air Force Survivability Procedures

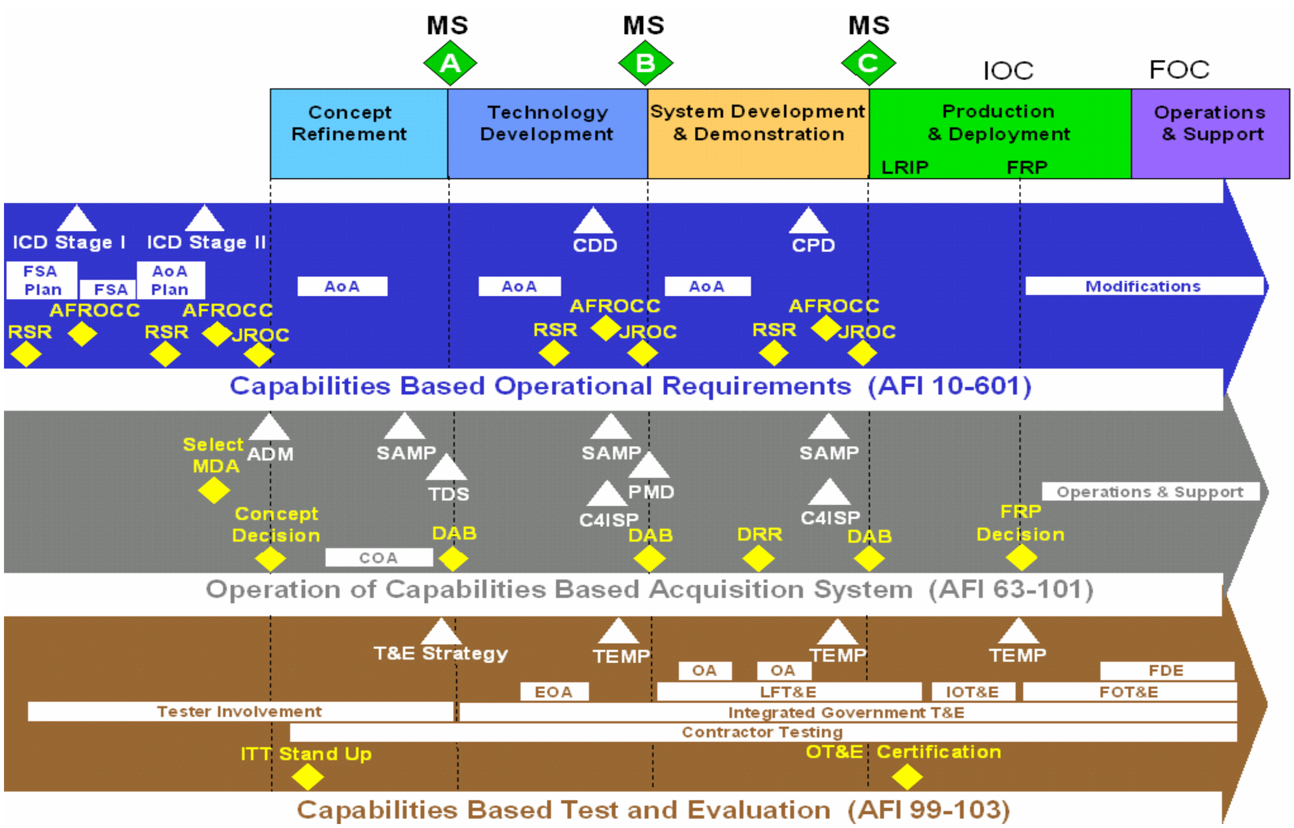
U.S. Air Force Survivability Requirements

Prior to 1994 nuclear survivability requirements were derived from threat, fratricide, and targeting data. The Air Force Nuclear Criteria Group (AFNCG), an assemblage of General Officers, approved the requirements levied upon major Air Force systems. The actual analysis of the data and planned operational requisites of the system under consideration was accomplished by the AFNCG Secretariat through Working Groups. These Working Groups were comprised of technical officers who made engineering judgments on a variety of offensive/defensive scenarios for each system then developed a composite nuclear environment. The scenarios considered both the weapon system and operational concepts in order to have the most cost-effective solution (hardening requirements vs. change in operational concept). Recommendations for system nuclear survivability/hardening specifications were then forwarded to the AFNCG for approval. The specifications were completed prior to Milestone II of the acquisition process, were included in the program management directive as a high-level system requirement, and were difficult to change. Other Services also relied upon AFNCG to either cross-check their own results or to use the same values if the systems were similar.

These nuclear 'criteria' were thus imposed upon the System Program Office (SPO) and 'user' as requirements. The SPO then designed and developed the system to meet these requirements. Testing was performed on piece-parts, components, sub-systems, and in some cases the entire system to verify the hardening criteria and therefore survivability in the nuclear environment. The then Defense Nuclear Agency oversaw much of this testing at government managed, government contractor, and underground nuclear test facilities. Once the system was produced and in the field annual Nuclear Survivability Management Status Reports were produced and sent to the Secretary of the Air Force, Acquisition (SAF/AQQS). These reports covered the maintenance of the baseline system, upgrades, and retrofits for all aspects of nuclear hardness and operational survivability in a nuclear environment. In 1990 there were 61 systems (aircraft, missiles, satellites, and ground stations) evaluated and reported on. When necessary, some of the system components or sub-systems were subjected to additional testing to verify that new or retrofitted units were just as hard as the initial units.

With the fall of the Iron Curtain, reorganizations within the Air Force, and a new acquisition process within the Department of Defense (DoD), nuclear survivability requirements and reporting changed. The legacy Air Force strategic nuclear weapons systems (ICBMs, B-52s, B-2s, ALCM, ACM, missile fields, and the nuclear weapons) continued to impose the original requirements and evaluate nuclear hardness, however testing waned and design analysis evaluation was relied upon. In FY96 the Air Force Program Element funding cite was zeroed. This fund cite was for research, development, testing, and evaluation to assess the survivability and vulnerability of Air Force projected and operational systems that may be required to operate in nuclear weapons environments. On the contrary, other Air Force systems were not as rigorous with respect to nuclear survivability.

The new DoD acquisition process is 'capabilities based' and not 'requirements based.' This is a top-down process to develop a concept of operations through a Joint Service environment. It brings operational considerations and assets from other Services into the national security strategy to provide the Combat Command the resources they need. If a desired capability is not available then a capability gap is identified and one of the Services pursues it. The Air Force prioritizes these capability gaps and the highest priorities are developed pursuant to funding levels. Therefore, the Joint Capabilities Integration and Development System plays an important role in the initial stages of the acquisition process. Through this process, requirements are reviewed and approved by the Air Force Requirements for Operational Capabilities Council (AFROCC), the Joint Requirements Oversight Council (JROC), and the Defense Acquisition Board. The Air Force through SAF/AQ instituted a Single Process Initiative (SPI) as the response to this acquisition reform. It is designed to reduce costs associated with doing business with the Government. It provides for a streamlined contract change process to allow industry to use best practices, performance requirements/specifications, and commercial processes, specifications, and standards. SPI allows block contract changes to implement common processes and replace or eliminate military standards and specifications and business requirements when they do not add value. SPI also allows contractors to reduce costs by adopting new acquisition reform initiatives on existing contracts. The overall Air Force Acquisition process is shown graphically below:



Nuclear survivability is important for the Combat Commander who expects to operate in a nuclear battlefield. However most Combat Commanders apparently do not expect to this to be the case, but they do believe that chemical, biological, and radiological threats will be faced. As a result most of the Initial Capabilities Documents, Analysis of Alternatives, Capability Development Documents, and Capability Production Documents do not address nuclear weapon environment survivability but do include chemical, biological, and radiological requirements. A recent survey of Air Force systems in the Information Retrieval Support System (IRSS) showed 16 systems had nuclear weapon hardness requirements in their System Operational Requirements Documents, Mission Needs Statements, Statement of Needs, and Operational Requirements Documents while 33 systems had chemical, biological, and radiological survivable requirements and the rest (approximately 100) were silent on the entire subject. Of the 16 systems, only 3 were not directly related to the legacy strategic nuclear weapons systems. Combat Commanders using non-strategic and non-nuclear systems (tactical) are more concerned with day-to-day operational needs and likely battlefield situations that do not include the possibility of nuclear war. Likewise, many of the space assets are expected to operate in a non-nuclear weapons environment and only include the natural radiation environment requirements. The Air Staff office responsible for Strategic Security coordinates on all documents in the IRSS and recommends if nuclear, chemical, biological, or radiological survivability should be taken into account. However as seen in the graphic above, these documents and recommendations are reviewed by the AFROCC and later by the JROC. Apparently these reviewers also are more concerned with day-to-day operational needs and likely battlefield situations that do not include the possibility of nuclear war.

Terms

NOTE: The purpose of this glossary is to help the reader understand the terms listed as used in this publication. It is not intended to encompass all terms. See pertinent Joint and Air Force specific publications for standardized terms and definitions for DoD and Air Force use.

Acquisition Category (ACAT)--Categories established to facilitate decentralized decision-making and execution, and compliance with statutorily imposed requirements. The categories determine the level of review, decision authority, and applicable procedures. DoDI 5000.2, reference b, provides the specific definition for each acquisition category.

Acquisition Program Baseline (APB)—Each program's APB is developed and updated by the program manager and will govern the activity in the phase succeeding the milestone for which it was developed.

Advanced Concept Technology Demonstration (ACTD)--One of three technology transition mechanisms; the other two are ACTDs and experiments. ACTDs are used to determine the military utility of proven technology and to develop the concept of operations that will optimize effectiveness. ACTDs are not themselves acquisition programs, but are designed to provide a residual, usable capability upon completion, and/or transition into acquisition programs.

Advanced Technology Demonstration (ATD)--One method of technology transition. ATDs are used to demonstrate the maturity and potential of advanced technologies for enhanced military operational capability or cost effectiveness, and reduce technical risks and uncertainties at the relatively low costs of informal processes.

Analysis of Alternatives (AoA)--The evaluation of the operational effectiveness and estimated costs of alternative systems to meet a mission capability. The analysis assesses the advantages and disadvantages of alternatives being considered to satisfy capabilities, including the sensitivity of each alternative to possible changes in key assumptions or variables.

Architecture--The structure of components, their relationships, and the principles and guidelines governing their design and evolution over time.

Attribute--A testable or measurable characteristic that describes an aspect of a system or capability.

Capability--The ability to execute a specified course of action. It is defined by an operational user and expressed in broad operational terms in the format of an initial capabilities document or a DOTMLPF change recommendation. In the case of material proposals, the definition will progressively evolve to DOTMLPF performance attributes identified in the CDD and the CPD.

Capability Development Document (CDD)--A document that captures the information necessary to develop a proposed program(s), normally using an evolutionary acquisition strategy. The CDD outlines an affordable increment of militarily useful, logistically supportable, and technically mature capability.

Capability Gaps-- Those synergistic resources (DOTMLPF) that are unavailable but potentially attainable to the operational user for effective task execution.

Capability Production Document (CPD)--A document that addresses the production elements specific to a single increment of an acquisition program.

Capstone Requirements Document (CRD)--A document that contains capabilities based operational requirements that facilitates the development of CDDs and CPDs by providing a common framework and operational concept to guide their development.

Command, Control, Communications, Computers & Intelligence Support Plan (C4ISP)-- The acquisition authority develops the C4ISP during system development. The C4ISP development and review process provides a mechanism to identify and resolve implementation issues related to C4I support and information technology system (including National Security Systems [NSS]) interface requirements. The C4ISP identifies needs, dependencies, and interfaces focusing attention on interoperability, supportability, and sufficiency concerns.

Concept of Operations (CONOPS)--A high-level concept whose purpose is to describe a problem that combatant commanders may face, objectives to solve problem, desired effects, capabilities needed to achieve effects, and sequenced actions that describe the employment concept.

Course of Action (COA)--The COA is a planning and decision process that culminates in a MAJCOM decision. The COA includes a series of alternative program choices developed by the MDA or his designate, presented to a MAJCOM commander and that once a specific COA is selected, becomes a formal agreement between the MDA and the operator (MAJCOM Commander) that clearly articulates the performance, schedule, and cost expectations of the program. The COA provides the basis for the Technology Development Strategy during the Technology Development Phase. The COA becomes the basis for the SAMP.
Defense Acquisition Board (DAB)--The Department of Defense corporate body for system acquisition providing advice and assistance to the Secretary of Defense normally chaired by the Under Secretary of Defense (Acquisition, Technology, and Logistics).

DD Form 250--The DD Form 250 (Material Inspection and Receiving Report) is a multipurpose report used to: (1) provide evidence of acceptance at origin/destination; (2) provide evidence of Government contract quality assurance at origin/destination; (3) supply packing list(s); (4) document shipping/receiving; (6) as a contractor invoice; and (7) commercial invoice support.

Distributed Mission Operations (DMO)--An Air Force readiness initiative to allow operators to train as they would expect to fight; in large horizontally and vertically integrated Joint Composite Force packages. DMO will fill gaps in training by providing operators the ability to train with current and emerging weapons systems, tactics, techniques and procedures that cannot be supported through existing ranges, airspace or simulations. DMO will enable operators to maintain primary combat readiness at home or deployed; and conduct mission rehearsal in a realistic operational environment.

DoD Components--The DoD components consist of the Office of the Secretary of Defense, the Military Departments, the Chairman of the Joint Chiefs of Staff, the combatant commands, the Office of the Inspector General of the Department of Defense, the Defense Agencies, DoD Field Activities, and all other organizational entities within the Department of Defense.

Effects-Based Operations (EBO)--Military actions and operations designed to produce distinctive and desired effects through the application of appropriate movement, supply, attack, defense, and maneuvers. Effects-based operations focus on functional, systemic, and psychological effects well beyond the immediate physical result of a tactical or operational event. Furthermore, it is equally concerned with military actions and operations that trigger additional effects beyond those desired.

Experiments--Experiments test candidate technologies alone and as components in new systems and are a critical part of the development of a new technology. Experiments facilitate the transition of a device from operation in the laboratory to operation as a component or system in the field.

Evolutionary Acquisition (EA)--DoD's preferred strategy for rapid acquisition of mature technology for the user. An evolutionary approach delivers capability in increments, recognizing up-front the need for future capability improvements.

Family-of-Systems (FoS)--A set or arrangement of independent systems that can be arranged or interconnected in various ways to provide different capabilities. The mix of systems can be tailored to provide desired capabilities, dependent on the situation.

Functional Area Analysis (FAA)--An FAA identifies the operational tasks, conditions and standards needed to achieve military objectives. It uses the national strategies, Joint Operating Concepts (JOC), Joint Functional Concepts (JFC), Integrated Architectures (as available), Air Force CONOPS, and the Universal Joint Task List (UJTL) as input. Its output is the tasks to be reviewed in the follow-on functional needs analysis. The FAA includes cross-capability and cross-system analysis in identifying operational tasks, conditions and standards. The FAA should be conducted as a collaborative effort.

Functional Capabilities Board (FCB)--A permanently established body that is responsible for the organization, analysis, and prioritization of joint warfighting capabilities within an assigned functional area.

Functional Needs Analysis (FNA)--The sponsor leads the FNA. It assesses the ability of the current and programmed joint capabilities to accomplish the tasks that the FAA identified, under the full range of operating conditions and to the designated standards. Using the tasks identified in the FAA as primary input, the FNA produces as output a list of capability gaps or shortcomings that require solutions, and indicates the time frame in which those solutions are needed.

Full Operational Capability (FOC)--The full attainment of the capability to effectively employ a weapon system, item of equipment, or system of approved specific characteristics, which is manned and operated by a trained, equipped, and supported military unit or force. FOC is not necessarily a date; it defines the criteria necessary to declare full operational capability.

Full-Rate Production--Production of economic quantities following stabilization of the system design and prove-out of the production process.

Gatekeeper--That individual who makes the initial joint potential designation of JCIDS proposals. This individual will also make a determination of the lead and supporting FCBs and JWCA teams for capability proposals. The Gatekeeper is supported in these functions by USJFCOM, DJ-6, DJ-7, and the JWCA team leads. DDJWCA serves as the Gatekeeper.
Human Systems Integration--Part of the acquisition, and design process that includes such elements as manpower, personnel, training, environmental issues, safety, health, human factors, and personnel survivability for incorporation into the total human weapon system for the life-cycle of the system.

Implementing Command--The command (usually Air Force Materiel Command or Air Force Space Command) providing the majority of personnel in direct support of the program manager responsible for development, production, and sustainment activities.

Increment--A militarily useful and supportable operational capability that can be effectively developed, produced or acquired, deployed, and sustained. Each increment of capability will have its own set of threshold and objective values set by the user.

Information Assurance (IA)--Information operations and technology that protects and defends information and information systems by ensuring their availability, integrity, authentication, confidentiality, and non-repudiation and includes restoration through protection, detection, and reaction capabilities.

Information Exchange Requirements (IER)-- Requirements that define the interoperability KPP threshold and objective values documented in CDDs, CPDs and CRDs. The IERs should reflect both the information needs required by the system under consideration and the needs of other supported systems. The IERs should cover all communication and computing requirements for command, control and intelligence of the proposed system (See CJCS 3170.01 Instruction & Manual & CJCSI 6212.01).

Initial Capabilities Document (ICD)--Documents the need for a materiel solution to a specific capability gap derived from an initial analysis of alternatives executed by the operational user and, as required, an independent analysis of alternatives. It defines the capability gap in terms of the functional area, the relevant range of military operations, desired effects, and time. In order to capture capabilities based planning along with capabilities development, the Air Force develops ICDs in two distinct stages. ICD Stage I covers capabilities based planning and ICD Stage II covers capabilities based operational requirements development.

Information & Resource Support System (IRSS)--IRSS is a web-based Air Force-wide system, which facilitates and integrates operational requirements definition, coordination, and management activities of the warfighting commands, HQ USAF, MAJCOMs and other AF agencies. IRSS supports AFCIS development and coordination, AF CONOPS capabilities based planning, speeds up the development and processing of AF requirements documents and provides the much-needed links between planning and programming. IRSS provides a unique capability to tie Planning to Requirements across the AF Enterprise - long a goal of senior leadership.

Initial Operational Capability (IOC)--That first attainment of the capability to employ effectively a weapon, item of equipment, or system of approved specific characteristics with the appropriate number, type, and mix of trained and equipped personnel necessary to operate, maintain, and support the system. It is normally defined in the CPD. *NOTE:* IOC will be event-driven and not tied to a specific future date.

Integrated Architectures--An architecture consisting of multiple views or perspectives (operational view, systems view, and technical view) that facilitates integration and promotes interoperability across family of systems and systems of systems and compatibility among related architectures.

Interoperability--The ability of systems, units or forces to provide data, information, materiel and services to and accept the same from other systems, units or forces and to use the data, information, materiel and services so exchanged to enable them to operate effectively together. NSS and ITS interoperability includes both the technical exchange of information and the end-to-end operational effectiveness of that exchanged information as required for mission accomplishment.

Joint Capabilities Board (JCB)--The JCB functions to assist the JROC in carrying out its duties and responsibilities. The JCB reviews and, if appropriate, endorses all JCIDS and DOTMLPF proposals prior to their submission to the JROC. The JCB is chaired by the Joint Staff, J-8, Director of Force Structure, Resources, and Assessment. It is comprised of Flag Officer/General Officer representatives of the Services.

Joint Functional Concept (JFC)--An articulation of how a future Joint Force Commander will integrate a set of related military tasks to attain capabilities required across the range of military operations. Although broadly described within the Joint Operations Concepts, they derive specific context from the Joint Operating Concepts and promote common attributes in sufficient detail to conduct experimentation and measure effectiveness.

Joint Operating Concept (JOC)--An articulation of how a future Joint Force Commander will plan, prepare, deploy, employ, and sustain a joint force against potential adversaries' capabilities or crisis situations specified within the range of military operations. Joint Operating Concepts guide the development and integration of Joint Function Concepts (JFCs) to provide joint capabilities. They articulate the measurable detail needed to conduct experimentation and allow decision makers to compare alternatives.

Joint Operations Concepts (JOpsC)--A concept that describes how the Joint Force intends to operate 15 to 20 years from now. It provides the operational context for the transformation of the Armed Forces of the United States by linking strategic guidance with the integrated application of Joint Force capabilities.

Joint Potential Designator (JPD)-- designation assigned by DDJWCA to specify JCIDS validation, approval, and interoperability expectations.

a. "JROC Interest" designation will apply to all ACAT I/IA programs and programs designated as JROC Interest. This designation may also apply to intelligence capabilities that support DoD and national intelligence requirements. These documents will be staffed through the JROC for validation and approval. All CRDs will be designated as JROC Interest.

b. "Joint Impact" designation will apply to ACAT II-and-below programs where the concepts and/or systems associated with the document affect the joint force such that an expanded review is appropriate in order to ensure that the most appropriate and effective solution is developed for the joint warfighter. This designation will also apply to those intelligence capabilities supporting both national intelligence and DoD when they were not designated as JROC Interest. A Functional Capabilities Board (detailed below) will validate Joint Impact proposals, returning them to the sponsor for approval and acquisition activity.

c. "Joint Integration" designation will apply to ACAT II and below programs where the concepts and/or systems associated with the document do not significantly affect the joint force and an expanded review is not required, but C4 interoperability, intelligence, or munitions certification is required. Once the required certification(s) are completed, Joint Integration proposals are validated and approved by the sponsoring component.

d. "Independent" designation will apply to ACAT II and below programs where the concepts and/or systems associated with the document do not significantly affect the joint force, an expanded review is not required, and no certifications are required. Once designated, these documents are returned to the sponsoring component for validation and approval.

Joint Requirements Oversight Council Memorandum (JROCM)--Official JROC correspondence generally directed to an audience(s) external to the JROC -- usually decisional in nature.

Joint Requirements Oversight Council Staff Memorandum (JROCSM)--Official JROC correspondence generally used for internal staffing and tasking, usually predecisional in nature and not releasable outside of JROC circles.

Joint Warfighting Capability Assessment-- The JWCA leads/teams provide the analytical underpinning for the development and refinement of issues that support JROC priorities. This includes participation in the requirements generation process, development of JROC guidance, operational concepts, architectures, programmatic assessments and alternative programmatic recommendations. As such, JWCA efforts are governed exclusively by the JROC. Additional guidance on JWCAs is located in CJCSI 3137.01.

Key Performance Parameters (KPP)--Those attributes or characteristics considered most essential for an effective military capability.

Lead Command--The command that serves as operators' interface with the PM for a system as defined by AFPD 10-9, not to be confused with that MAJCOM designated by HQ USAF/XOR as OPR for authoring a capabilities based operational requirements document.

Low-Rate Initial Production (LRIP)--Production of the system in the minimum quantity necessary (1) to provide production-configured or representative articles for operational tests pursuant to §2399; (2) to establish an initial production base for the system; and (3) to permit an orderly increase in the production rate for the system sufficient to lead to full-rate production upon the successful completion of operational testing.

Materiel Solution--A defense acquisition program (nondevelopmental, modification of existing systems, or new program) that satisfies identified operator capabilities.

Milestones--Major decision points that separate the phases of an acquisition program.
Milestone Decision Authority (MDA)--The individual designated, in accordance with criteria established by the USD(AT&L), by the ASD(C3I) for Automated Information System acquisition programs or by the USecAF(Space) for space programs to approve entry of an acquisition program into the next phase.

Militarily Useful Capability--A capability that achieves military objectives through operational availability for and dependable, effective performance of mission functions, interoperable with related systems and processes, transportable and sustainable when and where needed, and at costs known to be affordable over the long term.

Modification--An alteration to a configuration item applicable to aircraft, missiles, support equipment, ground stations software (imbedded), trainers, etc. As a minimum, the alteration changes the form, fit, function or interface of the item. A weapon system is defined as a combination of elements that function together to produce the capabilities required to fulfill a mission need, including hardware, equipment, software, and all Integrated Logistics Support elements, but excluding construction or other improvements to real property.

Objective-- The desired operational goal associated with a performance attribute, beyond which any gain in utility does not warrant additional expenditure. The objective value is an operationally significant increment above the threshold. An objective value may be the same as the threshold when an operationally significant increment above the threshold is not significant or useful.

Operating Command--Those commands operating a system, subsystem, or item of equipment.

Operator --An operational command or agency that employs acquired systems for the benefit of users. Operators may also be users.

Operational Requirements--A system capability or characteristic required to accomplish approved capability needs. Operational (including supportability) requirements are typically performance attributes, but they may also be derived from cost and schedule. For each parameter, an objective and threshold value must also be established.

Operational Test and Evaluation (OT&E)--Testing and evaluation conducted in as realistic an operational environment as possible to estimate the prospective system's operational effectiveness and operational suitability. In addition, OT&E provides information on organization, personnel requirements, doctrine, and tactics. Within the Air Force, OT&E is conducted by the Air Force Operational Test and Evaluation Center, AFOTEC.

Operational View (OV)--A view that describes the joint capabilities that the user seeks and how to employ them. The OVs also identify the operational nodes, the critical information needed to support the piece of the process associated with the nodes, and the organizational relationships.
Performance Attributes--Attributes so significant they must be verified by testing or analysis. Whenever possible, attributes should be stated in terms that reflect the capabilities necessary to operate in the full range of military operations and the environment intended for the system, family of systems (FoS), or system of systems (SoS). These statements will guide the acquisition community in making tradeoff decisions between the threshold and objective values of the stated attributes. Operational testing will assess the ability of the system(s) to meet the production threshold values.

Procurement--Procurement appropriations fund those acquisition programs that have been approved for production (to include low rate initial production (LRIP) of acquisition objective quantities), and all costs integral and necessary to deliver a useful end item intended for operational use or inventory upon delivery.

Program Executive Officer (PEO)--A military or civilian official who has primary responsibility for directing several MDAPs and for assigned major system and non-major system acquisition programs. A PEO has no other command or staff responsibilities within the Component, and only reports to and receives guidance and direction from the DoD Component Acquisition Executive (this sentence does not apply to the PEO/Space).

Program Management Directive (PMD)--The official Air Force document used to direct acquisition or modification responsibilities to appropriate Air Force MAJCOMs and FOAs for the development, acquisition, modification or sustainment of a specific weapon system, subsystem, or piece of equipment. It is used throughout the acquisition cycle to terminate, initiate, or direct research for development, for production, or modifications for which sufficient resources have been identified. States program unique requirements, goals, and objectives, especially those to be met at acquisition milestone B or later, or other program review.

Program Manager (PM)--As used in this instruction applies collectively to System Program Director, Product Group Manager, Single Manager, or acquisition program manager. The PM is the designated individual with responsibility for and authority to accomplish program objectives for development, production, and sustainment to meet the user's operational needs. The PM shall be accountable for credible cost, schedule, and performance reporting to the MDA.

Rapid Response Process (RRP)--An expedited process for documenting and staffing urgent, time-sensitive requirements. It is used to document deficiencies that arise during combat or crisis operations where there is a threat of loss of life or imminent loss of life is apparent. The process is fully described in AFI 63-114, *Rapid Response Process*.

Sponsor--The DoD component responsible for all common documentation, periodic reporting, and funding actions required to support the capabilities and acquisition process.

System-of-Systems (SoS)--A set or arrangement of interdependent systems that are related or connected to provide a given capability. The loss of any part of the system will degrade the performance or capabilities of the whole.

Systems View (SV)--A view that identifies the kinds of systems, how to organize them, and the integration needed to achieve the desired operational capability. It will also characterize available technology and systems functionality.

Technical View (TV)--A view that describes how to tie the systems together in engineering terms. It consists of standards that define and clarify the individual systems technology and integration requirements.

Test and Evaluation Master Plan (TEMP)--The TEMP correlates and integrates T&E with the overall acquisition program strategy, schedule, and other program documentation, and defines the critical path for completing test and evaluation. The TEMP will place the most emphasis on the next phase of system development rather than provide a historical account of program progress. Update the TEMP prior to major milestones, program baseline changes, and when there have been significant changes to the program.

Threshold--A minimum acceptable operational value below which the utility of the system becomes questionable.

Trade-Space--Selection among alternatives with the intent of obtaining the optimal, achievable system configuration. Often a decision is made to opt for less of one parameter in order to achieve a more favorable overall system result.
User--An operational command or agency that receives or will receive benefit from the acquired system. Combatant commanders and their Service component commands are the users. There may be more than one user for a system. Because the Service component commands are required to organize, equip, and train forces for the combatant commanders, they are seen as users for systems. The Chiefs of the Services and heads of other DoD components are validation and approval authorities and are not viewed as users.

Validation--The review of documentation by an operational authority other than the user to confirm the operational capability. Validation is a precursor to approval.

Document Coordination

A2.1. Document Coordination and Approval. AF/XOR has delegated tasking authority to AF/XORD for HQ USAF and Secretariat review on all ICDs (Stage I and II), CDDs, CPDs, and CRDs. Normally each MAJCOM/Agency is given one opportunity to review and comment on a capabilities based operational requirements document. The AFROCC reviews and validates all Air Force ICDs (Stage I and II), CDD, CPD, and CRDs. This review is the final opportunity to comment on these documents. Documents are validated and approved per Table 2.1. Use of the Information and Resource Support System (IRSS) is mandatory once IRSS is declared FOC. Current staffing flowcharts and guidance for the staffing process is located on the AF/XORD web site at: https://www.afreqs.hq.af.mil/.

A2.2. Review for Comment Phase. Each MAJCOM/Agency responsible for reviewing ICD Stage I and operational requirements documents establishes a single office with responsibility for receiving documents for comment, distributing the document within their organization, and consolidating and returning comments. A listing of applicable agencies and offices to be included in this review is located on the AF/XORD web site at: https://www.afreqs.hq.af.mil/.

A2.2.1. Air Force Review. Normally, ICDs (Stage I and II), CDDs, CPDs, and CRDs are submitted for simultaneous MAJCOM and HQ USAF review. After developing the document, the lead MAJCOM/Agency distributes it for Air Force-wide review. The sponsor (Lead MAJCOM/Agency) provides a copy of the document along with a transmittal memo to AF/XORD to start the HQ USAF review. AF/XORD designates an HQ USAF SME to accomplish the staffing of the document within the HQ USAF, Secretariat, and ANG. The HQ USAF and Lead MAJCOM/Agency SMEs send the document out for review based on the Document Distribution List maintained on the AF/XORD web site. AF/XOR has delegated the authority to AF/XORD to staff the document to the appropriate level. The intent is to obtain an O-6 level review to support the AF Flag review at the AFROCC. However, organizations may elevate the document to the appropriate level within their chain of command as they see fit. The normal review cycle is 35 calendar days. Since ICD Stage I documents are Air Force-only products, the review process for Stage I documents ends with AFROCC validation. The specific document staffing flow charts are located on the AF/XORD web site at: https://www.afreqs.hq.af.mil/.

A2.2.2. Joint Staff Review/Certifications. AF/XORD submits all operational requirements documents to the JCIDS Gatekeeper process. Per CJCSI 3170.01, the entry point for documents is through the Knowledge Management/Decision System (KM/DS) to J-8 for formal JPD determination by the Gatekeeper and then Joint Staff O-6 review/certification (Figure A2.1). The DDJWCA serves as the JCIDS Gatekeeper and determines the JPD for each document. This designation determines the level of Joint Staff involvement in the review, certification, validation and approval of a document as depicted in Table A2.1. The specific document staffing flow charts are located on the AF/XORD web site at: https://www.afreqs.hq.af.mil/.

Figure A2.1. Notional Air Force O-6/Flag & Joint O-6 Review.

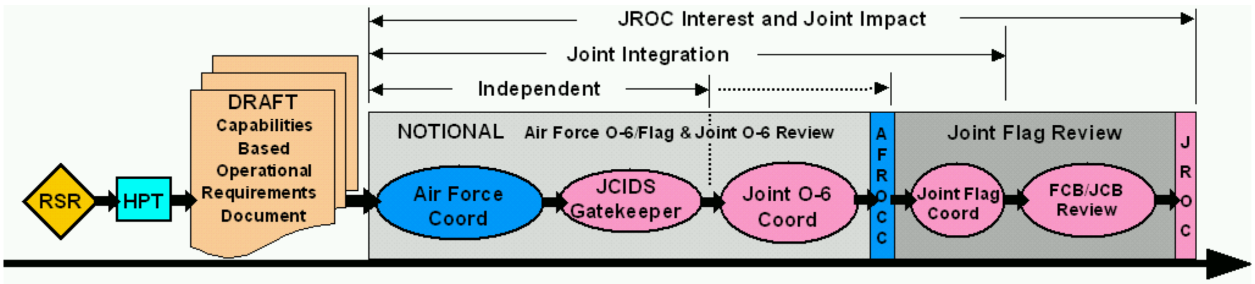


Table A2.1. Document Certification/Validation Authority.

Certification/ Validation	JROC Interest	Joint Impact	Joint Integration	Independent	Documents
Threat Validation	DIA/J-2	DIA/J-2	DIA/J-2	Service	All **
Intelligence	DIA/J-2	DIA/J-2	DIA/J-2	-	All
Insensitive Munitions*	J-4	J-4	J-4	-	CDD and CPD only
Interoperability	J-6	J-6	J-6	-	CDD,CPD and CRD only

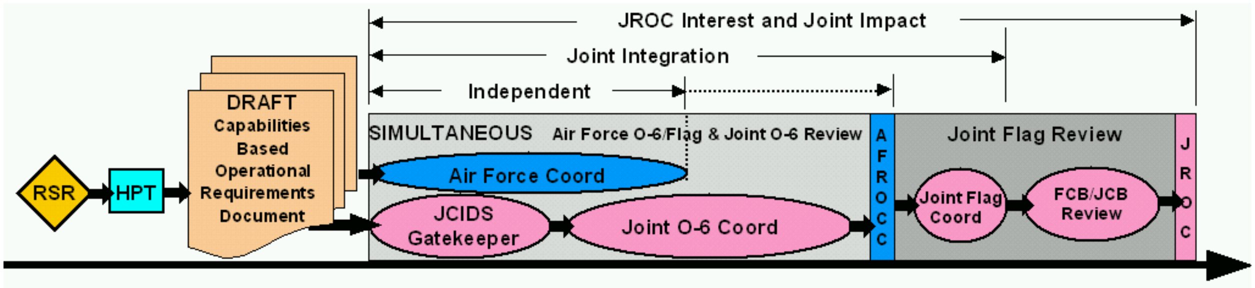
* Applies to munitions programs only

** For programs that consume, produce, process, or handle intelligence data

A2.2.2.1. JROC Interest and Joint Impact documents receive Joint Staff O-6 review before the AFROCC. Joint Staff Flag review and final certifications will be completed as part of the FCB/JROC process following AFROCC validation. Joint Integration documents must receive all the required certifications before the AFROCC.

A2.2.3. Simultaneous Reviews. Only when an AF/XOR-approved HPT develops a document may simultaneous Joint Staff O-6 and Air Force-wide review be accomplished (Figure A2.2).

Figure A2.2. Simultaneous Air Force O-6/Flag & Joint O-6 Review.



A2.3. Joint Programs. A joint program is managed and funded by more than one Service. This should not be confused with the JPDs as described in the Glossary. One Service is normally designated as the lead for a joint program and, unless the program is designated "JROC Interest", the Lead Service is the approval authority for the program's operational requirements documents.

A2.3.1. Air Force as Lead Service. When the Air Force is the Lead Service, AF/XOR will designate an Air Force Lead MAJCOM or Agency to sponsor the program. The Lead MAJCOM/Agency generally follows the document development and coordination processes described elsewhere in this instruction. In addition, the Air Force OPR identifies a counterpart office in each participating Service. Working through the other Service counterparts, the Air Force lead invites appropriate representation from the other Services to participate in drafting the document. Appropriate offices within the other participating Services will be included in the pre-AFROCC review and comment process. Using their own procedures, each participating Service should concur with the final version of non JROC Interest documents before they are submitted to the AFROCC.

A2.3.2. Other Service as Lead. When another Service is designated as lead for a joint program, AF/XOR will designate a Lead MAJCOM or Agency for Air Force participation. The Air Force lead should participate in drafting the document and managing document coordination within the Air Force. The Air Force participating sponsor has the option of presenting the document to the AFROCC.

A2.3.3. Joint Requirements Office for Chemical, Biological, Radiological, and Nuclear Defense (JRO-CBRN) Documents. JRO-CBRN is responsible for developing joint operational requirements for chemical, biological, radiological, and nuclear defenses with the participation of the Services. ACC is the Air Force Lead MAJCOM and AF/ILEX is the HQ USAF focal point for all JRO-CBRN documents. The AFROCC validates the requirements in the document, approves the Air Force Annex and forwards the document to the JRO-CBRN for final approval.

A2.4. Review of Non-Air Force Operational Requirements Documents with Joint Integration or Independent JPD. The Air Force may have the opportunity to review operational requirements documents developed by other Services, Defense Agencies, and Joint organizations during the JCIDS process. AF/XOR approves the Air Force position on the document and recommends the level of Air Force participation.

A2.5. Document Review. The MAJCOM/Agency review cycle begins when the document sponsor sends the document out for staffing. The HQ USAF review cycle begins when AF/XORD sends the document out for staffing. The Air Force review cycle for documents received from the Joint Staff (J-8) begins on the day J-8 forwards the document to AF/XOXR for staffing. No response by the suspense date is considered concurrence. Document reviewers use the Comment Resolution Matrix (or other automated format(s) as directed by AF/XORD) to provide their comments. Identify the significance of the comment as "Critical," "Substantive," or "Administrative" using descriptions below for reference. Convincing support for critical and substantive comments will be provided in a comment/justification format.

A2.5.1. Critical. A critical comment indicates non-concurrence with the document until the comment is satisfactorily resolved. Critical comments are restricted to Cost/Schedule/Performance Attributes, particularly KPPs, Concept of Operations, and other fundamental issues (such as sustainment, security, or violation of policies and directives) that would bring into question the rationale for the document to be approved. Documents with unresolved critical comments will not go to the AFROCC unless approved by AF/XOR. Document reviewers will not make critical comments on issues not related to their area of responsibility.

A2.5.2. Substantive. A substantive comment addresses a section in the document that appears to be, or is potentially unnecessary, incorrect, misleading, confusing, or inconsistent with other sections.

A2.5.3. Administrative. An administrative comment addresses typographical, format, or grammatical errors.

A2.6. Comment Resolution. Document sponsors consolidate all comments into a single comment resolution matrix (CRM) or other automated format as directed by AF/XORD and use the CRM to document actions taken in response to each comment. The document sponsor must document the rationale for not accepting a comment. The document sponsor resolves all critical comments before submitting the document for AFROCC review, unless otherwise approved by AF/XOR. Substantive comments should be addressed, but failure to do so does not result in non-concurrence on the final document. The sponsor must be prepared to address unresolved substantive comments at the AFROCC. The sponsor should address all administrative comments.

A2.6.1. Comment Resolution Timing. The normal comment resolution period is 15 calendar days. The sponsor will notify AF/XORD if it is anticipated that it will take longer than 15 days to resolve comments. If the comment resolution period exceeds 120 days, AF/XOR may direct the document to re-enter the document coordination process.

A2.6.2. Resolving Critical Comments. Resolve comments at the lowest possible level. If the document sponsor disagrees with a critical comment, contact the comment originator to seek resolution. If a critical comment cannot be resolved, the issue must be elevated as required to achieve final resolution. In extreme circumstances, the issue may go to the AFROCC for adjudication. The method and date of resolution must be documented in the CRM (e.g. "via telecon on xx date").

A2.7. Document Completion. After the document completes the staffing process, AF/XORD is responsible for obtaining final signature/approval and enters the approved document and all supporting material into the Requirements Document Library.

Appendix H: Department of Energy (DOE)

Department of Energy

NWE includes effects on our assets (survivability, vulnerability) and the assets of others (lethality, collateral effects).

Nuclear survivability of a military system is the ability of that system to perform its intended functions with no more that acceptable degradation during or after exposure to specified natural, intrinsic, diagnostic, hostile, and/or fratricide radiation and nuclear environments.

NNSA NWE Program

The nuclear survivability of the nuclear stockpile is the focus of the NNSA NWE program. An NWE program element for developing improved understanding of the relationships between warhead design features, outputs, and lethality and collateral effects has been scoped but has not been implemented. Only the survivability elements of the NNSA program are addressed here.

The NNSA NWE Program develops and sustains capabilities to support the nuclear survivability of the enduring and evolving stockpile, its certification and life extension, without relying on underground tests, through research and development, radiation hardening, modeling and validation, and aboveground testing. It develops validated computational tools to evaluate threat nuclear weapon radiation environments and system radiation responses, develops radiation-hardened technologies, and improves radiation sources and diagnostics.

Business Model

NNSA NWE tools and technologies are provided through major program elements of the Stockpile Stewardship Program, the goal of which is to maintain and enhance the safety, security, and reliability of the nation's nuclear weapons stockpile to counter the threats of the 21st century. Survivability is an element of reliability. Science and Engineering Campaigns, in collaboration with Directed Stockpile Work (DSW), Advanced Simulation and Computing (ASC), Readiness in Technical Base and Facilities (RTBF), and the Department of Defense (DoD), support Stockpile Life Extension Programs (SLEPs), Limited-life Component (LLC) replacements, and stockpile modifications.

> The Manager, Nuclear Survivability and Effectiveness Program at NNSA HQ (who is also the manager of the Nuclear Survivability Activity within the Engineering Campaign) and S&T program directors at the laboratories, together with the Manager, Radiation Effects Sciences Program at SNL, and the Outputs and Survivability Program leaders at LLNL and LANL, are the primary NNSA proponents and champions for nuclear survivability technology development and stewardship. Laboratory and NNSA DSW program directors rely on the developed and validated tools and technologies to qualify systems to their negotiated nuclear survivability requirements and are among the strongest proponents when needed for their programs. At SNL Radiation Effects Sciences is among its suite of critical capabilities.
>
> The ASC Campaign develops, verifies, and validates NWE simulation codes using experimental data generated by the Science and Engineering Campaigns. The Engineering Campaign, through the

Nuclear Survivability Activity also supports the development and initial implementation of radiation hardened microsystems. RTBF sustains the simulators and microelectronics infrastructure so that, when combined with investments and utilization by the campaigns and DSW, they remain technically and economically viable. Upgrades and new capabilities are developed with operating funds when practical, or with construction funds when appropriate. Utilization by DoD of the NNSA NWE simulators is through Work for Others agreements on a cost reimbursable and non-interference with DOE programs basis. Access by DoD to the advanced scientific computing resources of the NNSA weapons laboratories on the same basis is possible, but problematical because of heavy utilization by the Stockpile Stewardship Program.

While the campaigns and ASC generally perform research and development and establish nuclear survivability technologies, DSW invests in research and tools development and improvement when needed for system-specific applications and problems.

Status of DOE simulators and codes are depicted in Figures H-1 and H-2, respectively.

Issues and Trends in NWE and Impacts – NNSA

The most challenging issue facing the NNSA nuclear survivability program is the absence of a clearly articulated policy supported and enforced at the highest levels regarding the purposes of our nuclear stockpile. A substantial nuclear survivability program is clearly imperative if, in addition to deterring the use of WMD by regional, state, or sub-state aggressors, its purposes are to counter the threat of emergence of a peer, or near peer adversary, and to hold at risk high value targets that might be defended by nuclear interceptors in the first third of the 21st century.

Report language accompanying the House Energy and Water Appropriations Bill for 2005 explicitly questions "the continued high level of funding requested in the Nuclear Survivability campaign to assess the ability of the weapons in the stockpile to continue to function as designed during a massive nuclear exchange." And further states "In the post-Cold War world with no new weapon production ongoing, this activity is a waste of scarce resources."

These statements reflect a misunderstanding of the rationale for the nuclear survivability of our stockpile. Nuclear survivability enhances the credibility of our deterrent, hedges against the emergence of a peer, or near-peer adversary, enables the penetration of point nuclear defenses of high-value targets, reduces incentives for nuclear proliferation, and deters the use of weapons of mass destruction. Clearly, new nuclear survivability challenges exist in the present security environment - new weapons production is ongoing in other nations, our stockpile is being refurbished with new technologies and materials susceptible to nuclear effects, and ageing of the stockpile introduces new challenges to reliability, including nuclear survivability.

In this regard, both the Navy SSPO and the Air Force Ballistic Missile Office have revalidated their survivability requirements with the NNSA laboratories as active participants. Some STS requirements have been significantly altered in these re-evaluations.

An additional challenge is that gaps in stockpile refurbishment schedules make it difficult to defend nuclear survivability budgets for radiation effects research and development required to develop improved rad-hard design methods and tools and anticipate and solve problems before crises arise, and for hardness assurance verification of the enduring stockpile. In the near-term, adjustments in the NNSA nuclear survivability budget will likely occur when the development of nuclear survivability tools needed to qualify the W76-1 have been completed.

The impact of either challenge is potentially to drive the currently viable NNSA NWE program to a sub-critical state in which neither the expertise nor the infrastructure is capable of sustaining nuclear survivability. This would undermine the credibility of our deterrent (paper tiger), provide increased potential returns on investment to the proliferant, and greatly increase the time needed to respond to new nuclear threat environments.

Figure H-1. Fidelity and status of NNSA simulators

	HERMES	Saturn	Z	ACRR	SPR III	GIF	...
neutrons (exo)				x	X		
neutrons (endo)				X	x		
gammas (prompt)	X						
gammas (sustained)				X	x		
gammas (total)						X	
x rays (cold)		x	x				x
x rays (warm)		x	x				x
x rays (hot)		X					
Status	OP	OP	OP	*Maint	^Storage	OP	+Dev

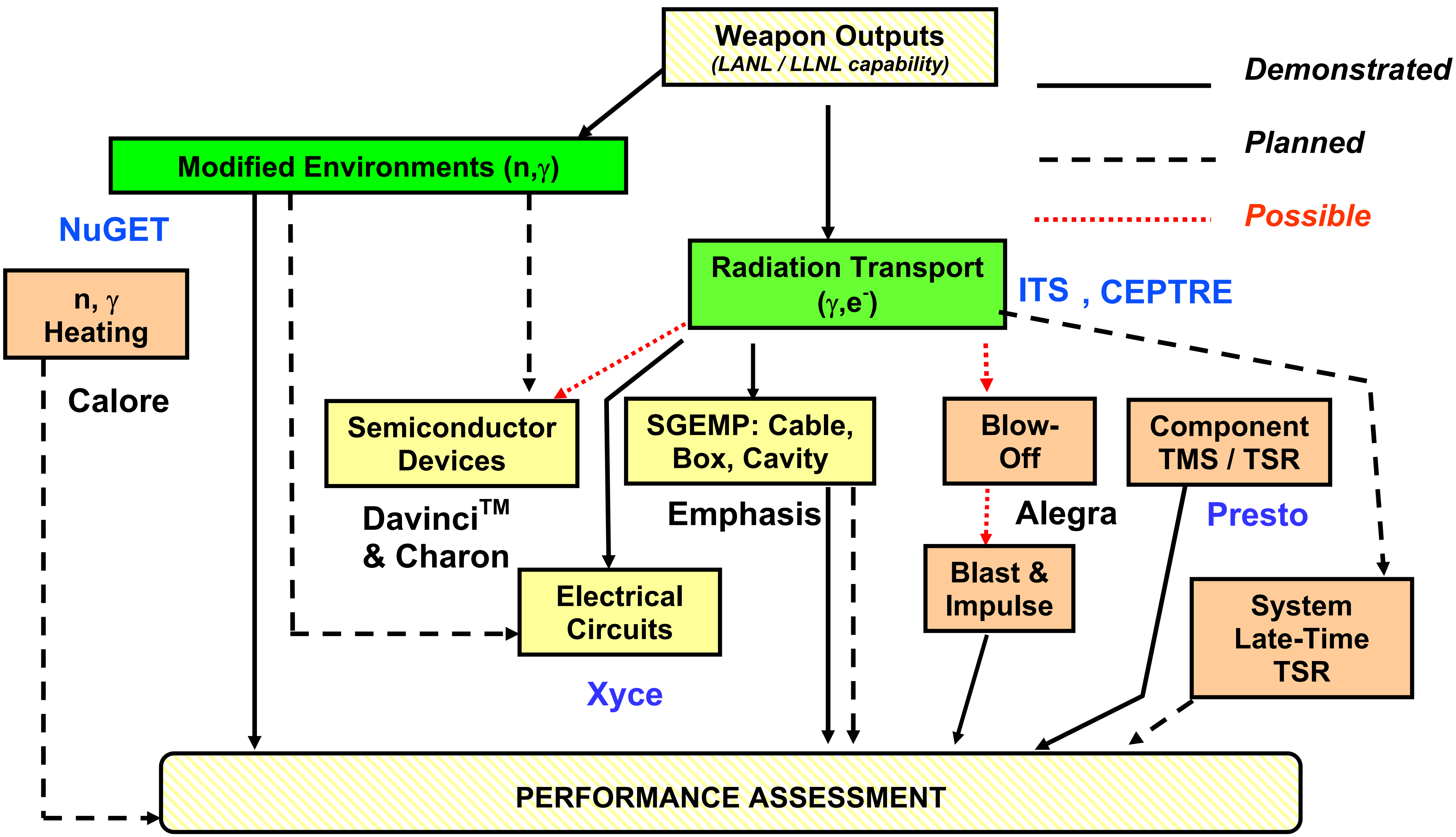
*Resume ops Dec '04 ^Long term storage after FY06 +192 beams FY08

X	High-fidelity environment
x	Useful experimental capability

Whenever possible and available, use high fidelity, cost-effective physical simulators and relatively less reliance on computational modeling. When no high fidelity simulator is available,

- **develop high fidelity computational physics models**
- **use physical simulators as development and validation tools**

Figure H-2. Status of NNSA survivability simulation codes



Appendix I: DTRA Assessment of NWE Capabilities and Gaps

Weapons of mass destruction constitute, arguably, the most dangerous threat to national security. Their emergence marked the beginning of a new era; indeed, this represented a civilization-changing event. They are mechanisms by which we can expect potential adversaries to seek asymmetric means for countering the overwhelming superiority of conventional U.S. military forces.

The existence and proliferation of nuclear and other weapons of mass destruction (WMD) demands a broad spectrum of U.S. defense capabilities to deter WMD use, destroy them in combat, and protect against their effects. Nuclear threat reduction is achieved by understanding the lethality and collateral effects of U.S. deterrent forces, assuring the survivability of offensive and defensive systems and infrastructure, understanding the potential effects of enemy weapons, and protecting citizens and soldiers from nuclear weapon effects. The nation's nuclear technical community has enabled these capabilities with computer models, simulator facilities, and protection technologies. However, since the end of the Cold War, U.S. investments in these areas have actually declined, even as threats have diversified and broadened.

Ten Likely, High Consequence Nuclear Threat Scenarios

Thermonuclear 3rd party asymmetric – high alt
Fission asymmetric against U.S. – high alt
Fission 3rd party parity – high alt
IND terrorist against U.S. - surface
IND terrorist against 3rd party - surface
RDD terrorist against U.S. - surface
HE against nuc/rad terrorist against U.S. - surface
HE against nuc/rad 3rd party parity - surface
HE against nuc/rad 3rd party asymmetric - surface
HE against nuc/rad terrorist against 3rd party - surface

A recent analysis of possible nuclear threat scenarios against U.S. interests by experts in the field revealed the extent that the landscape has changed since the Cold War ended. Whereas the Cold War demanded that we address massive use of large yield nuclear weapons by peer adversaries and survivability of retaliatory strategic assets, the current environment emphasizes low yield terrorist or rogue nation use and survivability of infrastructure and mission capability. By analyzing a broad range of possible scenarios in terms of probability and consequence, experts concluded that the threats the U.S. should be most concerned with ranged from single, high-altitude use to terrorist devices in cities and conventional explosives at nuclear sites. The nuclear weapon effects community is fairly well equipped to predict high-altitude nuclear effects, but confidently predicting effects from terrorist use in cities and explosions against nuclear sites represents a new direction that must be addressed. However, in all areas, including the high-altitude effects area, U.S. capability is dwindling as experts age and retire without significant influx of new personnel.

Capability gaps have appeared and widened in all three technical areas needed to reduce the nuclear threat: codes, simulators, and protection technologies. New models are needed to predict the effects of emerging enemy weapons and to allow the nation to prepare for and defend against attack. In the absence of underground nuclear testing, above ground simulators are needed to validate computer codes and to certify the survivability of current and future space and missile systems. Both codes and simulators are essential to develop technologies to protect the nation's infrastructure, space assets, and combat systems against the widespread effects of enemy nuclear weapons.

Once the threats are understood, protection technologies are needed to prevent or mitigate the impact of these threats. DTRA's plan will close these gaps by investing in research and development (R&D) to model enemy nuclear weapon effects in modern codes, to consolidate and upgrade simulators to assure U.S. defense system survivability, and to produce hardened microelectronic systems for use in space and on the battlefield. By executing this eight-year program, governmental, industrial, and academic technical bases will be fortified and focused on the nation's most pressing threat reduction needs.

What the Nation Needs

The nation must strengthen its capabilities to deter and defend against a full spectrum of future nuclear threats—from well-equipped adversaries with WMD to non-state enemies. To strengthen deterrence, U.S. nuclear forces must continue to be capable of defeating the most threatening targets, including enemy WMD and underground, hardened sites. We need knowledge and computer models to effectively plan retaliatory attacks and weapon effects simulators to assess and improve our knowledge and confidence in our deterrent capabilities. Our nation must be capable of conducting underground nuclear experiments, if necessary, to gain sufficient confidence in our capabilities to defeat future WMD threats.

Codes, simulators, and test readiness, which are needed to protect against enemy nuclear weapon effects, are the products of a diverse team of government, industry, academic, and allied technical experts; and that team must be revitalized for nuclear threat reduction to succeed. Protection technologies are especially important in view of our increasing dependence on digital systems and their potential vulnerabilities to the widespread effects of nuclear weapons. New technologies, test capabilities, and design methods are needed to ensure that satellites, sensors, weapon systems, and communications are effective in the face of nuclear attacks.

Concern about U.S. vulnerabilities to asymmetric threats, including improvised radiological dispersal devices, high-altitude nuclear threats (e.g., electromagnetic pulse (EMP) and radiation hazards in space), and radio frequency threats, extend nuclear survivability requirements to the commercial sector and the civilian infrastructure. Technical solutions for these problems will derive from defense applications. Strategic weapons and delivery systems are being extended beyond their originally designed life expectancy. A smaller, aging stockpile will require greater confidence that the remaining weapon inventory remains effective and reliable. Thus, current and future modifications to existing weapons require test facilities that can simulate the nuclear environments for system testing and validation.

Requirements

Nuclear requirements are derived from a number of sources: broad national policy, planning guidance from the SECDEF and OSD, needs of the Combatant Commands and Services, and DTRA R&D. Requirements arise from the acquisition and warfighter communities, as well as the DTRA's anticipation of the impact of new technologies and threats. Primary requirements areas are:

***Codes*.** Specific requirements are generated by combatant commands, military services, and contractors who design and build survivable weapon and communication systems. Nuclear weapon effects models are needed to support target planning, survivable system design, collateral effects estimation, and numerical simulations for response and recovery planning.

Simulators. Simulators are needed to certify the survivability and operability of systems in nuclear environments and to certify replacement components for strategic systems. The need for combined radiation environment testing of missile defense subsystems and systems will be reviewed in detail in FY04 as part of a DoD-Wide NWE Test Requirements Study. Simulators are needed to support code validation, agent defeat, and precision strike effects studies.

Protection Technologies. Protection technology requirements support both the acquisition community and warfighters directly for the hardness surveillance and maintenance of operational systems, and protection of personnel through dosimetry and radiation surveys. The Missile Defense Agency is a key customer as it develops survivable missile defense and space-based tracking systems as mandated by the Nuclear Posture Review (NPR). Strategic modernization and life extension programs for the Air Force and Navy require options for affordable survivability tailored to these new technologies. Appendix A describes these requirements in detail.

Gaps

Gaps are derived from analyses of environments created by nuclear weapon outputs and their effects on military systems. This plan, which identifies current technology gaps and the actions to close them, is a comprehensive three-part program that focuses on critical national needs:

Codes. Codes, which reflect our understanding of weapon effects, were primarily built for Cold War applications, in the northern hemisphere, where scenarios involved large numbers of high-yield weapons and the achievement of the military objective was the primary measure of success. For 21st century scenarios, with their multiple adversaries distributed throughout the globe and emphasis on reducing collateral effects, the codes must be updated to increase fidelity, detail, and provide global coverage. Additionally, codes need to be adapted to run faster and be user-friendlier in order to accommodate a shorter planning cycle for decision support.

Simulators. The nation needs the capability to verify that critical military systems can operate reliably in nuclear-disturbed environments and that our weapon systems are effective and reliable. Current simulators lack the fidelity and intensity necessary to provide threat-level environments for systems testing. X-ray simulators are limited in their ability to produce cold and warm x-rays for testing materials, optics, and structure; high-dose rates; and good spectral fidelity for electronics testing. The bandwidth of disturbed environments simulators must be increased to support new missile defense radars and interceptor communication systems. Scene generators for "red-out" simulation must be developed that can operate in the visible region of the spectrum to match advances in missile defense technology. Blast, shock, and EMP simulators must be enhanced to operate reliably and affordably, and with improved fidelity. Finally, simulators are needed to address agent defeat, code validation, and test readiness issues.

Protection Technologies. With increased emphasis on space dominance, critical space assets must survive natural and nuclear-disturbed environments while meeting strict weight and performance requirements, placing increased demands on hardening technology as microelectronic feature size decreases. Our current understanding of EMP is derived from both high-altitude nuclear detonations and EMP simulator testing of military and civilian systems. These data have enabled our understanding of High Altitude EMP (HEMP) generation and of the validity of analytical codes. The Defense Standardization and Specification Program (DSSP) has institutionalized HEMP environmental criteria, hardening practices, and assessment methods.

Unfortunately, DoD lacks the capability to accurately predict EM effects on systems, and the tools necessary to assess the impact of infrastructure degradation on DoD-related missions. Modern military systems, with increased reliance on commercial-off-the-shelf (COTS) equipment and commercial standards and design practices, require innovative, cost-effective hardening options so that DoD system developers can meet their requirements within cost and schedule. We lack the means for timely radiological survey and personnel exposure dosimetry to minimize and manage radiation exposure of personnel required to operate in a post-nuclear detonation or radiological environment.

As funding for nuclear effects technology programs has declined, the number of experienced workers in government and industry has also declined substantially. This reduction impacts the nation's ability to ensure that military systems are effective and reliable.

This plan describes how revitalizing the nuclear technology program will reverse the erosion. Plans for closing gaps in each of these areas are provided, as well as timelines, milestones, and deliverables. The plan also describes the resources (people and money) necessary to reach the desired end-state in each area.

The Nuclear Threat Reduction "End State"

The desired "end state" for the DTRA Nuclear Weapon Effects Program is a revitalized nuclear technology work force that will provide technologies to reduce nuclear threats for the 21st century and utilize the nation's existing stockpile. The requirements for weapon effectiveness and system survivability must be institutionalized and enforced. The supporting technical community must include a critical mass of talent and expertise across government, industry, and academia that can respond to the challenges posed by 21st century threats. Stable and sustained funding is necessary to provide the intellectual stimulation to attract the best and the brightest scientists and engineers. Even as the threat from strategic weapons is being reduced, new threats are emerging.

Appendix J: Acronyms

ACRR	Annular Core Research Reactor
AEDC	Arnold Engineering Development Center
AF/XON	Air Force Directorate of Nuclear and Counterproliferation
AF/XOS	Air Force Air and Space Operations
ACM	Advanced Cruise Missile
ALCM	Air-Launched Cruise Missile
APRF	Army Pulsed Reactor Facility
ASC	Advanced Scientific Computing
ASCI	Accelerated Strategic Computing Initiative
ATSD(NCB)	Assistant to the Secretary of Defense (Nuclear, Chemical and Biological Defense Programs)
BMDS	Ballistic Missile Defense System
C&R	circumvention and recovery
C2ISR	command and control
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CAD	computer-aided design
CONOPS	concepts of operation
COTS	commercial-off-the-shelf
CTEIP	Central Test and Evaluation Investment Program
DEPSECDEF	Deputy Secretary of Defense
DoD	Department of Defense
DoDD	Department of Defense Directive
DoE	Department of Energy
DNA	Defense Nuclear Agency
DSB	Defense Science Board
DSES	Defense and Space Electronic Systems
DSW	Directed Stockpile Work
DSWA	Defense Special Weapons Agency
DTRA	Defense Threat Reduction Agency
EMP	electromagnetic pulse
FARC	Revolutionary Armed Forces of Columbia
FBR	Fast Burst Reactor
FY	fiscal year
γ	gamma
GIG	Global Information Grid
HAENS	high altitude exo-atmospheric nuclear survivability
HERMES	High-Energy Radiation Megavolt Electron Source
HEU	highly-enriched Uranium
ICBM	Inter Continental Ballistic Missile
ICF	inertial confinement fusion
IEMP	internal electromagnetic pulse
ISR	intelligence, surveillance and reconnaissance
J8	Joint Requirements and Integration
JCIDS	Joint Capabilities Integration and Development System
JCS	Joint Chiefs of Staff
JFCOM	Joint Forces Command
keV	kiloelectron volt
LANL	Los Alamos National Laboratory
LBTS	Large Blast and Thermal Simulator
LEU	low-enriched Uranium

LIHE	light initiated high explosive
LINAC	electron linear accelerator
LLC	Limited-life Component
LLNL	Lawrence Livermore National Laboratory
MDA	Missile Defense Agency
M	million
MEMS	micro-electromechanical systems
MM	Minuteman
MOU	memorandum of understanding
n	neutron
NCES	Net-Centric Enterprise Services
NIF	National Ignition Facility
NNSA	National Nuclear Security Administration
NSSO	National Space Systems Office
NWE	nuclear weapon effects
OJCS/J8	Office of the Joint Chiefs of Staff/Joint Requirements and Integration
OSD	Office of the Secretary of Defense
PM	project manager
R&D	research and development
REBA	Relativistic Electron Beam Accelerator
RTBF	Readiness in Technical Base and Facilities
S&T	science and technology
SAF/AQQS	Secretary of the Air Force, Acquisition
SGEMP	system-generated electromagnetic pulse
SLBM	Sea-Launched Ballistic Missile
SLEP	Stockpile Life Extension Program
SNM	special nuclear material
SPRII	Sandia Pulsed Reactor III
SSP	Strategic Systems Programs
SSPO	Strategic Systems Program Office
STRATCOM	Strategic Command
STS	Stockpile to Target Sequence
TRADOC	Army Training and Doctrine Command
UGT	underground test
U.S.	United States
USAF	United States Air Force
USANCA	United States Army Nuclear and Chemical Agency
USD/AT&L	Under Secretary of Defense (Acquisition, Technology and Logistics)
USMC	United States Marine Corps
UV	ultraviolet
VEMPSII	vertically polarized electromagnetic pulse simulator
VJCS	Vice Chairman, Joint Chiefs of Staff
WMD	weapons of mass destruction
ZR	pulsed-power accelerators

Appendix K: List of Briefings Received by the Task Force

28-29 January 2004

DTRA Nuclear Weapon Effects Program	Col Dan Deforest	DTRA
NNSA Nuclear Weapon Effects Overview	Dr. Ted Luera	DOE/NNSA
Overview of DOT&E	Dr. Ernest Seglie	OSD

17-18 March 2004

JCS JCIDS Briefing	Col Walker	JCS J5
STRATCOM Briefing	Maj Cross	USSTRATCOM
Army Briefing	Dr. Chuck Davidson	USANCA
MDA HAENS Standard	Dr. Bruce Wilson and Mr. R.C. Webb	MDA
Navy Briefings	LCDR Rome Ruiz and LCDR Mark Galvin	Navy SSP
USAF Requirements Process Overview	Mr. James Miller	USAF

7-8 April 2004

EMP Commission Findings	Dr. John Crawford	EMP Commission
Sandia Critical Skills/Capability in Nuclear Effects	Dr. Jim Lee	Sandia National Laboratories (SNL)
Radiation Facilities & Applications	Mark Hedemann	SNL
SNL W76-1 Design/Qualification Process	Mark Rosenthal and Dave Beutler	SNL
ASC Hostile Environment Codes & Applications	Len Lorence	SNL
Hardening by Design vs. by Process	Dave Myers	SNL
EDNA Briefing	Tom Lockner	SNL
Z Tour	Jeff Quintenz	SNL
DECADE Briefing (DTRA)	LTC Brent Bredehoft	DTRA
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LLNL Outputs and Environment	Thomas Thomson Todd J. Hoover	LLNL
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NIF Tour	George H. Miller Craig R. Wuest F. Dean Lee	LLNL
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NIF Use Planning	Bruce E. Warner	LLNL
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Russia's Evolving Nuclear Weapon Doctrine	Staff	CIA
Asian Weapon Effects	Staff	CIA
Test Site Objectives	Staff	CIA
Foreign Output & Effects Review	Staff	CIA
Trends in Worldwide Nuclear Forces	Staff	CIA
Imagery Overview of Test Site Activities	Staff	NGA
Nuclear Challenges in Defense Planning Scenarios	Dr. Jim Thomason	IDA

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Appendix L: Congressional and NNSA Actions During the Review of This Report

The Task Force became aware, after agreeing upon findings and recommendations, that actions related to the DOE budget about which we were concerned came to pass. The FY05 appropriation for DOE's survivability campaign was indeed reduced by 2/3 from the request, which had represented a steady program profile from FY04. Moreover, the NNSA is planning to zero funding for the survivability campaign once qualification for the W76 is completed (FY07 in the current plan).