



Report of the
**Joint Defense Science Board/
Threat Reduction Advisory Committee**
Task Force on

The Nuclear Weapons Effects National Enterprise

June 2010

Office of the Under Secretary of Defense
For Acquisition, Technology, and Logistics
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The DSB is a Federal Advisory Committee established to provide independent advice to the Secretary of Defense. Statements, opinions, conclusions, and recommendations in this report do not necessarily represent the official position of the Department of Defense. The task force on the Nuclear Weapons Effects National Enterprise completed its information-gathering in June 2007.

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**DEFENSE SCIENCE
BOARD**

May 28, 2010

**MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR
ACQUISITION, TECHNOLOGY & LOGISTICS**

**SUBJECT: Final Report of the Defense Science Board Task Force on Nuclear
Weapons Effects National Enterprise**

I am pleased to forward the final report of the Defense Science Board Task Force on Nuclear Weapons Effects National Enterprise. This report offers important considerations regarding the state of the nuclear weapons effects enterprise and the need for leadership awareness and intervention.

Nuclear weapons remain a serious threat to our nation's security. The nation's capability to deter against this threat and provide assurance to our allies requires that US nuclear and conventional forces are able to operate in a nuclear environment. Unfortunately, the nation's expertise and capability to operate in a nuclear environment have decayed. As a result the Department of Defense and the nation are not as well prepared as it should be to deter, defend, and mitigate an attack.

This study serves to renew attention on the nation's nuclear weapons effects enterprise. It offers recommendations for rebuilding critical capabilities, for improved collaboration throughout government stakeholders, and for enhanced attention at the leadership level. I endorse all of the study's recommendations.

Paul G. Kaminski

Paul G. Kaminski
Chairman



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DEFENSE SCIENCE
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MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board Task Force on Nuclear Weapons Effects National Enterprise

Nuclear weapons remain a serious—and, some believe, growing—threat to U.S. forces, affecting the survivability of critical systems for mission assurance. The potential use of nuclear weapons on the battlefield was not eliminated at the end of the Cold War. Regional proliferation risks are growing. A global market place has made acquisition of information and components to develop nuclear weapons more accessible. Perhaps most important is the fact that U.S. superiority in its conventional forces makes nuclear weapons attractive to potential adversaries who could never compete against such a robust arsenal of systems.

At the same time, however, U.S. attention and capabilities to counter nuclear weapons have been atrophying for many years. Intelligence assets are focused elsewhere. Military and civilian leaders in DOD are poorly educated on military operations in nuclear environments, and have little understanding of nuclear weapons and the issues surrounding their use against our nation. U.S. counters (outside of missile defense) have received little attention in over two decades, especially defensive measures to ensure continued operations in radiation environments. Technical expertise and infrastructure have decayed significantly. Investments in nuclear survivability have declined.

The task force believes that this state of affairs—the atrophy in attention to, understanding of, and investment in nuclear survivability—is dangerous and needs to be reversed. This report is intended to serve as a wake-up call. It provides a fresh look at the strategic landscape and offers a clear assessment about the risks of allowing the erosion to continue. And, should DOD's leadership choose to heed the wake-up call, the task force offers recommendations for action in the body of the report. Key among them is the following:

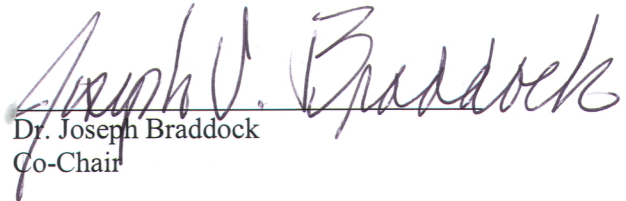
- Immediate attention should be given to:
 - Making nuclear survivability a routine issue for leadership attention, focused in the current context of growing horizontal proliferation by both state and non-state actors.

- Taking the first step in establishing a national enterprise by forging an agreement with the Department of Energy to reverse the decline in the nuclear weapons effect enterprise. Engage the intelligence community as well.
- In the near term, actions should focus on: advancing the human skills base; improving the Department's understanding of reliance on net-centricity and unmanned systems in a nuclear environment; updating survivability standards; and pursuing radiation hardening advances.
- In the long term, the Department needs to move to a model-based approach for the weapons effects enterprise to make up for the lack of underground testing; expand agreements to collaborate with other agencies with a stake in the enterprise; and ensure that a minimum "national enterprise" capability in trained expertise and above-ground simulators is sustained.

The task force believes that implementing the recommendations of this task force can lead to significant improvements in the posture of critical capabilities for national security.



Dr. Miriam John
Co-Chair



Dr. Joseph Braddock
Co-Chair

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Executive Summary

Actions—both by others and of our own doing—are combining to create potentially tragic consequences on military operations involving the effects of nuclear weapons on the survivability of critical systems for mission assurance.

- Regional proliferation risks are growing, accompanied by nation state policy and doctrine that acknowledge limited nuclear use as a legitimate war fighting option.
- U.S. counters, especially defensive measures to ensure continued operations in radiation environments, are being reduced—by our own choices.
- Intelligence resources are focused elsewhere.
- Leadership is poorly educated on military operations in nuclear environments.
- The reliance on commercial off-the-shelf components in U.S. military systems has grown while nuclear survivability requirements, testing, and evaluation have declined—both dramatically.

As a result, the nation lacks a clear understanding of the response to nuclear radiation exposure of general purpose forces, the Global Information Grid (GIG) and the GIG-edge, and critical infrastructure on which the Department of Defense (DOD) relies. Moreover, the technical expertise and infrastructure to help remedy the situation has decayed significantly. Investments in addressing nuclear survivability have declined precipitously.

How did this atrophy of attention and capability come about? **The root causes seem to lie deep in the corporate point of view among DOD leadership that has developed since the end of the Cold War about these matters.** A number of factors have contributed. Nuclear weapons have not been used, other than in deterrence, for over sixty years. And for the past twenty years, even the deterrent uses have been less immediate and direct, and have seemed less important than before. Since the first Gulf War, conventional operations of great difficulty and importance have consumed DOD and national attention, and have displaced nuclear deterrence as the reigning paradigm. Furthermore, there seems to be widespread belief that the United States will be able to deter enemy use of nuclear weapons. For all these reasons, the possibility that U.S. forces would have to operate effectively in a nuclear environment simply

seems, in this view, to be extremely remote. Finally, the costs of hardening military systems, and the difficulty of developing ways of operating forces to be effective in a nuclear environment, seem larger to many than the likelihood of the threat warrants—and are assumed to be greater in real dollars than they actually are. The complicated—and, to many decision-makers, arcane—nature of assessing the nuclear cost/risk trades exacerbates the problem. As a result, fewer and fewer military and civilian leaders in DOD have had experience with nuclear weapons and issues around them ... and the downward spiral continues.

The task force believes that this point of view, though generally tacit (and often denied when alleged) holds sway widely in DOD—how else could one explain what has happened? The task force also believes this point of view is profoundly wrong and dangerous. It is wrong in part because, although deterrence seems to have worked during the Cold War, the situation is different today. Some adversaries today are *prima facie* undeterrable. Some may be desperate. Some may believe that asymmetries in the perceived political stakes of war, perhaps compounded with perceived U.S. unwillingness to break the “nuclear taboo,” will prevent the United States from retaliating forcefully against their use of nuclear weapons.

One of the enduring lessons from the Cold War is that for deterrence and assurance of allies to be effective, the United States must be able to control escalation, which in turn requires—for deterrence—U.S. nuclear and conventional forces to be able to operate in a nuclear environment. Furthermore, the shoe is now on the other foot: it is precisely the superior capability of U.S. conventional forces that contributes to making nuclear weapons attractive to adversaries. Finally, hardening against, and operating effectively in, a nuclear environment is not as costly as often assumed, and technologies are emerging to further reduce the cost. All in all, we believe it is a prudent price to pay.

The task force is not sure how to change the mind-set just described, other than to urge DOD leadership to heed the wake-up call that this report is intended to provide by looking at the strategic landscape with fresh eyes and thinking harder about the risks of allowing the erosion to continue. But if DOD leadership does want to heed the wake-up call, the task force offers many recommendations for action in the body of this report, summarized as follows.

What needs to be done now:**The following is the first and most crucial of all the recommendations in this report:**

- Make nuclear survivability a routine issue for leadership attention as it used to be during the Cold War, but focused in the current context of growing horizontal proliferation by both state and non-state actors.
 - Ensure balanced investments among all weapons of mass destruction modalities, which means—at a minimum—increasing resources focused on nuclear survivability, both funding and personnel.
 - Require routine reporting on survivability of critical fielded capabilities in the Defense Readiness Reporting System.
 - Restore operational knowledge and reflect it in the planning and training base.
 - Understand the operational limitations in a nuclear environment of existing and near-term additions to general purpose forces, the Global Information Grid, GIG edge, and critical infrastructure needed to generate and sustain forces.
- Take the first step in establishing a “national enterprise” by forging an agreement with the Department of Energy to reverse the decline in the nuclear weapons effects enterprise. Begin discussions with the Director of National Intelligence to expand the agreement to the intelligence community.

What needs to be done in the near term:

- Formulate with the Department of Energy a professional nuclear weapons effects collaboration and mentoring program to expand and advance the human skills base. Over time expand this to the military and private sectors.
- Improve understanding of both strategic and general purpose force operations reliant on net-centricity and unmanned systems in nuclear environments.
- Establish on-going reviews and threat assessments to update survivability standards.
- Pursue radiation hardened advances better coupled to commercial suppliers.

- Expand the agreement with the Department of Energy to the intelligence community.
- Ensure funding to upgrade and especially sustain existing nuclear simulators and prevent shutting down existing simulators.

What needs to be done in the longer term:

- Move to a model-based approach for the weapons effects enterprise to make up for the lack of underground testing. The approach should take advantage of advances in both aboveground simulators and high performance computing developed as part of the Department of Energy’s Science Based Stockpile Stewardship Program.
- Expand agreements with the Department of Energy and the intelligence community to other agencies with a stake in the enterprise, especially the Department of Homeland Security.
- Ensure that the minimum “national enterprise” capability in trained expertise and aboveground simulators is sustained.

If the recommendations of the task force are implemented, the posture of critical capabilities for national security can be significantly improved. But more importantly, leadership will move a long way toward reversing the atrophy in attention and understanding of nuclear issues that characterize—dangerously—the mindset today.

Chapter 1. Introduction

The Nuclear Weapons Effects National Enterprise task force was formed at the request of the Under Secretary of Defense for Acquisition, Technology, and Logistics; the Assistant to the Secretary of Defense for Nuclear, Chemical, and Biological Matters; and the Director of the Defense Threat Reduction Agency. Its purpose was to assess progress against an earlier report of the Defense Science Board, *Nuclear Weapons Effects Test, Evaluation, and Simulation* (published April 2005), and to expand upon that report's identification of the need for a "national enterprise" across appropriate departments and agencies in the government. The task force enjoyed the support of the Department of Energy's Under Secretary for Nuclear Security, who also serves as the Administrator of the National Nuclear Security Administration (NNSA).

In this study, "enterprise" means the full set of expertise, facilities and other capabilities that can support military planners, acquirers, and operators in assessing the ability to operate in a radiation environment. That set includes:

- knowledgeable military operators and specialists (within the military services)
- assessment and evaluation expertise in key agencies and laboratories (human and computational)
- simulation testing and experimental capabilities (physical machines and the expertise to operate them)
- science and technology, research and development (expertise and programs)

The terms of reference for the study, purposely construed to cast a wide net, called for the task force to:

- Assess standards for nuclear survivability based on an assessment of current and emerging nuclear capabilities of potential adversaries.
- Review the lists of the critical war fighting and enabling systems and capabilities that must function through, or immediately after, a nuclear event.
- Assess these critical systems and capabilities against the applicable standards and how well vulnerabilities are being addressed through the tradeoffs between hardening and other mitigation schemes.

- Recommend a “national enterprise” emphasizing a modeling and simulation based approach augmented by the necessary experimental capability required to develop, validate, and verify the models.
- Propose a viable business model that would provide sustained support for a baseline effort coupled to “campaigns” for new or modified major systems and surveillance programs that would utilize the “national enterprise.”
- Evaluate the need for an ongoing oversight body to assure that the needed transformation to the modern “national enterprise” occurs.

This broad directive was established because, at the outset of the study, the sponsoring leadership felt that little progress had been made since publication of the earlier report. Moreover, proliferation by actors outside of the original five nuclear powers (United States, Russia, China, United Kingdom, and France) seemed to be getting more serious. At the same time, Russia was pursuing modernization of its theater forces and China was expanding its strategic capabilities. Both concerns—lack of progress within the U.S. enterprise and growing horizontal and vertical proliferation—proved well founded.

The chapters that follow document the analysis, findings, and recommendations that result from the task force deliberations. Chapter 2 describes the current and emerging threat environment and the challenges facing the United States in the nuclear arena. Based on this environment, Chapter 3 contains an assessment of the radiation survivability of critical U.S. capabilities—a reality that calls for action on the part of the Department of Defense and the nation. Key factors that contribute to this assessment—our current military operational approaches and capabilities, and the health of the nuclear weapons effects national enterprise—are discussed in more detail in Chapters 4 and 5. Findings and recommendations are presented in Chapter 6; the final chapter summarizes how implementing these recommendations in a time-phased manner would improve our nation’s radiation survivability posture.

Chapter 2. Threats and Challenges

The current and emerging threat environment has become more diffuse, uncertain, and difficult to characterize. Over the past decade the United States has built up a highly capable conventional force, surpassing that of any other nation. The strategy of employing nuclear weapons as a hedge against overwhelming U.S. conventional force superiority has become important to current and potential adversaries. In fact, the limited use of nuclear weapons as a potential war fighting tool appears acceptable by many nations and groups, in sharp contrast to the strategic deterrent role for nuclear weapons in the United States.

Consequently use of a nuclear weapon on the general purpose battlefield is a growing possibility. Space systems and missile defense must also account for operations in a radiation environment and, of course, strategic offensive systems must continue to be survivable to nuclear effects. Besides nuclear weapons, other radiation threats, both natural and man-made, are creating survivability challenges that must be addressed. Each system generates its own set of unique requirements, and many systems, both nuclear and non-nuclear, must be capable of operating in a nuclear environment. Hardening, redundancy, operational changes from current baselines, rapid reconstitution, or combinations of these may be necessary to achieve a sound strategy for operating effectively in a nuclear environment.

In conducting this study, the task force chose to categorize the broad array of radiation environments into three classes:

- **Category A.** Environments where exposure is certain and the impact potentially significant.
- **Category B.** Strategic nuclear engagements, where the probability is extremely low, but the consequences too severe to take the risk.
- **Category C.** Limited use of nuclear weapons by regional powers and proliferators, with the potential for substantial loss of life, operational impacts on U.S. general purpose forces and supporting assets, and escalation to nuclear war.

The task force addressed all three categories, but concentrated on the third because of growing concerns about proliferation and the accompanying issues associated with survivability of U.S. conventional war fighting capabilities.

Appendix A provides a primer on the range of nuclear effects that forces might face.¹

Category A: Certain Exposure

This class of survivability challenges is characterized by exposure that is guaranteed and whose consequences, either immediate or over time, can be serious. Natural radiation exposure in space is one example. It has long been understood and accommodated in satellite design.

Department of Defense (DOD) forces operate in substantially varied settings that result in assured exposure to natural and man-made environments. As a result, they must be designed, fielded, and operated to mitigate or insulate operators and operations from the effects generated by these environments. A large number of these effects are similar to those produced by nuclear weapon detonations with respect to the fundamental particle (e.g., proton, electrons, neutron, charged nuclei) interactions with the systems or components exposed. However, environmental magnitudes, time histories, and areas of exposure differ such that hardening against, or mitigating the effects produced by Category A sources does not necessarily guarantee survivability to nuclear weapons effects. For purposes of this report, cases cited and comparisons are confined to classes of so-called radiation effects—those produced by environments and their effects derived from interactions with fundamental particles and electromagnetic radiation.

As an example, the earth, its people, and man-made creations are subjected to cosmic radiation—that is, extremely high energy nuclei originating galactically and beyond. These also produce atmospheric showers of high energy fundamental particles. All create environments of concern, especially for integrated circuit elements of the electronics proliferated in the world today. The feature size of components of these elements is now small enough (~ 200 to 300Å) so that switching and other operations can be upset by cosmic ray interactions.

Clear cases in this category involve space-based platforms, systems, and systems-of-systems (e.g. Global Positioning System). These systems are subjected to the solar wind, consisting principally of protons and the environments caused by its interaction with the earth's atmosphere and magnetic field. In addition, solar flares or coronal mass ejections (heavy ions and electrons) also produce widespread electromagnetic fields exposing vast areas to an analog of a wide area nuclear weapon environment—electromagnetic pulse. On a much smaller and

1. More in-depth threat assessments than presented in this report are classified.

localized scale, both lightning and high-powered microwaves produce similar electromagnetic field amplitudes, but different time histories.

Some civilian and a variety of military equipment have the potential to either deliberately or accidentally cause the imposition of high amplitude transient and/or steady state electromagnetic fields on personnel and/or military equipment in the vicinity of the generated radiation field. Examples include:

- proximity to high-powered radars or communications transmitters
- deliberate jamming by traditional and nontraditional means and pathways
- employment of non-lethal devices using electromagnetic radiation for crowd control or security
- high power microwave sources, both pulsed and continuous wave
- high energy lasers, including short-pulsed and continuous wave

In summary, DOD personnel and equipment are subjected to certain or highly probable radiation environments—both natural and man-made. These form an exposure base case. DOD has for the most part established and, when needed, updated standards for design, test, and evaluation to provide adequate performance for mission assurance. Where technical protection and mitigation are limited, appropriate architectures (including redundancy); concepts of operation; and tactics, techniques, and procedures must be employed. The approaches adopted are usually not sufficient to ensure survivability to radiation effects produced by a nuclear weapon, however, because the magnitude and dynamics differ significantly.

Category B: Strategic Nuclear Engagements

This class of survivability challenges focuses on strategic nuclear engagements. The emergence of stealth, precision, and speed within conventional forces has blurred the Cold War distinction between strategic and tactical forces. Indeed, the role of conventional offensive forces for strategic engagements has long been recognized and reinforced in recent defense policy. As but one example, the 2010 Quadrennial Defense Review (QDR) directed further expansion of “future long-range strike capabilities” as “one means of countering growing threats to forward-deployed forces and bases and ensuring U.S. power projection capabilities.”² For the purposes of this report, the task force considered the following assets as critical

2. U.S. Department of Defense, *Quadrennial Defense Review Report* (Washington, D.C.: Government Printing Office, 2010), p. 32.

to strategic war fighting—that is, their functions must be guaranteed survivable in order to hold at risk the adversaries’ highest value targets:

- U.S. offensive nuclear forces,³ including the warheads, missiles, basing, bombers, and national command and control with supporting intelligence, surveillance, and reconnaissance (ISR) and networks
- strategic missile defense, even against light attacks
- conventional strike assets and supporting command, control, communications, computers, and intelligence, surveillance, and reconnaissance (C4ISR) systems with strategic missions

While the probability of nuclear attack or exchange can be considered very low, the consequences of inviting such a scenario by failing to rigorously ensure the survivability of our own strategic forces would be too enormously damaging to take the risk. However, since the end of the Cold War, there has been significant retrenchment from concerns about nuclear survivability of strategic military forces. Some will claim that the exceptions are U.S. nuclear weapons and related command and control systems, but even in this case, the attention to individual elements has become a subject of variation (see Chapters 4 and 5).

Category C: Regional Engagements

The class of survivability challenges of most concern, in the judgment of this task force, is the growth in regional contingencies in which nuclear weapons would be in play. Trends that contribute to this possibility are serious.

For the past three decades, U.S. general purpose forces and assets overseas have been successfully attacked by nation states and terrorists. Iran’s attack on the U.S. embassy in Tehran, 241 service members killed in Lebanon, 19 Air Force personnel killed and 64 wounded at Khobar Towers, 17 sailors killed and 30 wounded on the *USS Cole*, all serve as examples. While these attacks made use of conventional explosives, nation states are also facilitating regional nuclear proliferation. Terrorists are intent on attacking U.S. forces, the homeland, and allies, by any means and the Taliban have stated their interest in nuclear weapons.

At the top of U.S. concerns should be the fact that foreign nuclear activities worldwide are not negligible in either size or potential consequence for the

3. The most challenging survivability demands are placed on nuclear warheads and some of the delivery platforms when required to function in environments that include both adversary nuclear defensive interceptors and U.S. fratricide effects (from multiply targeted warheads on the same target).

United States. It is clear that the foreseeable future will not be nuclear free. Although our nation no longer seems 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 an unprecedented proliferation of nuclear technology, nuclear weapons, and potential delivery platforms. The United States now faces smaller arsenals but more numerous real and potential adversaries that possess or may acquire nuclear weapons in a geopolitical world where alliances can, and do, change rapidly.

In addition to traditional powers that are developing nuclear doctrine and capabilities to match, the United States must effectively deal with nation state proliferators whose capabilities and intentions are not well understood, as well as with terrorists with a declared intent to acquire and use nuclear weapons. While command and control of nuclear weapons remains strong in the United States and in some of the other major nuclear powers, proliferation in less stable nations could produce a higher probability of loss of control of special nuclear materials or of a nuclear weapon itself.

Two concrete examples illustrate the concern. One is the growing potential for conventional conflict along Russia's periphery—as shown by the 2008 Russia-Georgia war—that could ensnare the United States in a spiral of escalation that could cross the nuclear threshold. A second potential scenario envisions an adversary country detonating a nuclear device at high-altitude to deter further U.S. aid to a potential ally. The burst would produce an electromagnetic pulse (EMP) of energy that would disrupt electronic systems and impact the infrastructures required to support U.S. operations in both military and civilian sectors. This type of high-altitude threat would also likely enhance the earth's radiation belts with fission electrons. Such a phenomenon would reduce satellite lifetimes over subsequent weeks and months with potentially significant consequences for the reconnaissance, communications, navigation and commercial space communities... all with no direct loss of life. There would almost certainly be an asymmetric impact on exposed electronic systems since the United States and its forward deployed forces are disproportionately dependent on advanced electronics and supporting networks.

Traditional Powers with New Doctrine: A Mirror Image of NATO Theater Nuclear Forces of the Cold War?

Russia and China, as well as France and the United Kingdom, continue to invest in and upgrade their nuclear weapons capabilities. In both Russia and

China, although more so with Russia, there is a troubling consistency in matters associated with nuclear weapons among:

- post-Cold War public rhetoric
- expert U.S. analysis and observed peer country research, development, test, and evaluation (RDT&E) programs
- military field exercises and field testing in related programs of new missiles

Taken together, they depict a nuclear weapons future that puts U.S. resources and interests at risk.

Statements about Russia's increased reliance on nuclear weapons have become commonplace since 1993, when Russia formally dropped its policy of "no first use." Analysis of official documents, as well as official and unofficial statements, suggests that the main innovation has been a new mission assigned to nuclear weapons, that of deterrence of—and use during—limited regional wars.^{4,5,6} This new policy has been codified in the 2010 Russian Military Doctrine⁷ after debate during the Putin presidency. Missions assigned to nuclear weapons have been confirmed and detailed. Formal, unclassified Russian statements and official documents underscore the importance of nuclear use in regional engagements involving general purpose forces if an adversary were to threaten Russia's continued existence. Even if the United States were not involved in the initial stages of these kinds of regional conflicts, there is the potential to be drawn in to aid U.S. allies or friends. The 2008 Russia-Georgia war highlights the growing likelihood of such conflicts along Russia's periphery.

The Russian technical community, in addition to addressing stockpile safety and reliability issues, is working on modernized designs over a range of applications.^{8,9} In addition, since 1999, the Russian military has regularly conducted large-scale maneuvers that have played out several conflict scenarios,

4. Nikolai Sokov, *Russia's Nuclear Doctrine*, Center for Nonproliferation Studies (CNS) Report, August 2004.

5. Kontseptsiya natsionalnoy bezopasnosti Rossiiskoy Federatsii Utverzhdena Ukazom Prezidenta RF ot 17 dekabrya 1997 g. No 1300, (<http://www.scrf.gov.ru/documents/decrees/2000/24-1/html>).

6. Voyennaya Doktrina Rossiiskoy Federatsii, Utverzhdena Ukazom Prezidenta, RF ot 21 aprelya 2000 g. No. 706.

6. Voyennaya Doktrina Rossiiskoy Federatsii, (http://news.kremlin.ru/ref_notes/461) ot 5 fevralya 2010.

7. *America's Strategic Posture: The Final Report of the Congressional Commission on the Strategic Posture of the United States*, Hon. William Perry, Chairman, United States Institute of Peace Press, 2009.

8. *U.S. Nuclear Deterrence in the 21st Century: Getting It Right*, report of the New Deterrent Working Group, Center for Security Policy Press, 2009.

including those with the use of nuclear weapons. As a result, many maneuvers held in the past five years or so, provide important insights into the doctrinal and operational details missing from key policy documents.^{10,11,12,13,14} Russian strategies, doctrine, training, and new low yield weaponry are maturing in a manner that reinforces preparation for operations in a nuclear environment, even on their own soil, across a range of engagements.

The numbers of public statements that supplement the actions described above are considerable. For example, in May 1999, during the NATO bombing of the former Yugoslavia, high-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 over the continental United States that would paralyze our nation. In response to possible U.S. deployments of missile defense systems in Europe, Russia announced the testing of new missiles that Kremlin officials boast could penetrate any defense system. First Deputy Prime Minister Sergei Ivanov has also repeatedly said that Russia would continue to improve its nuclear arsenals, including newer, lower yield, advanced nuclear weapons to be delivered with precision.¹⁵ Finally, in a related dispute over the 1990 Conventional Forces in Europe (CFE) Treaty, Moscow in 2007, suspended observance of the treaty and has threatened to withdraw from CFE altogether if the United States and other CFE states parties do not ratify the 1999 Adapted CFE Treaty.^{16,17}

The evolution of China's nuclear doctrine and programs are similarly ambitious but discussed less openly. Unclassified analyses on China's nuclear capabilities have identified numerous institutes and researchers involved in areas related to nuclear weapon programs, including electromagnetic pulse research, sub-critical testing and nuclear materials programs.^{18,19}

10. Nikolai Sokov, *Russia's New National Security Concept: The Nuclear Angle*, Center for Nonproliferation Studies Report, January 2000.

11. Statement by Sergey Ivanov, available at <http://www.mil.ru/articles/article3667.shtml>

12. Vladimir Putin, "Zaklyuchitelnoe Slovo na Soveshchani s Rukovodyashim Sostovom Vooruzhennykh Sil Rossii", October 2, 2003 (available at <http://www.president.kremlin.ru/text/appears/2003/10/53277.shtml>).

13. Yuriy Golotyuk, "I v Vozdukh Tozhe Problemy" *Vremya novostey*, February 19, 2001.

14. "Strategicheskaya Komandno-Shtabnaya Treniroivka VS Rossii", *Nezavisimaya gazeta*, February 17, 2001.

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

16. Statement by the Delegation of the Russian Federation, (http://www.osce.org/documents/fsc/2007/12/28850_en.pdf December 12, 2007).

17. "Russia Suspends Arms Control Pact," BBC News, July 14, 2007 (<http://news.bbc.co.uk/2/hi/6898690.stm>).

18. Brooke Dean and Scott Tatlock, *Locust Hunter Project Report: Sub-Critical Testing*, DGI-CIRA Report, May 2007.

Information in the references cited previously point out that China and Russia now consider nuclear attack options that, unlike their Cold War plans, employ EMP as a primary or sole means of attack. There is an emphasis on tactical and regional use of nuclear weapons in addition to the more traditional strategic employments, which, although lower in priority, have not been eliminated. Finally, as widely reported in the press, Russia continues to support nuclear aspirants such as Iran with nuclear reactor development.

Proliferators Whose Capabilities and Intentions We Don't Understand

Many nations besides Russia and China, particularly those with limitations in their conventional forces and/or facing hostile neighboring states, view nuclear weapons as an equalizer to conventional threat superiority. The potential exists for the United States to be drawn into a conflict in which its troops and systems would be exposed to a nuclear environment, including both ionizing and electromagnetic radiation.²⁰

The roster of nuclear-capable nations has a growing number of entries. During the next decade or two, it is likely to lengthen, not shorten, unless positive outcomes in diplomatic efforts are achieved. The attitudes of these nations regarding nuclear weapons vary widely, as do their views of the United States. Moreover, neither is static. For example, views regarding the role of nuclear weapons in current regimes in North Korea, which aggressively threaten provocation, proliferation and use for diplomatic and military purposes, contrast with India's views, which are largely deterrence based.

The known role of proliferant nation scientists in the further proliferation of nuclear know-how and technologies cannot be ignored as seeds for the worldwide global nuclear community of the next decade. Moreover, states such as North Korea and Iran, which may be unpredictable and difficult to deter, may also be

19. Alison Peet and Susan Puska, *LOCUST HUNTER 5.0 Special Report: Electromagnetic Pulse (EMP) Resistance Testing and Certification*, DGI, April 2009.

20. For example, U.S. forces may 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 by exploiting such a situation, which frequently exists in Asia and the Middle East.

developing the capability to pose a nuclear threat to their neighbors and the United States and its military forces.²¹

Terrorists with Intent

Terrorist groups have no state identity, may have only one or a few weapons, and are motivated to attack the United States without regard for their own safety. A growing number of militant Islamic groups continue to advertise their intent to strike the United States. Since September 11, 2001, the United States has been primarily focused on thwarting al-Qaeda and its operatives that have been attacking U.S. interests, primarily overseas.

In the wake of the wars in Iraq and Afghanistan, and our nation's continued long-term commitment to stabilizing and pursuing democracy, other terrorist organizations, allied with al-Qaeda or not, may also pose a significant threat to American interests as U.S. policies and strategy evolve in their regions of operation over time. Non-Islamic terrorist and insurgent groups, such as the Revolutionary Armed Forces of Colombia (FARC), may also pose a growing threat to the United States and its allies. Moreover, non-traditional and potential emerging threats from non-state actors such as anti-globalization activists and organized crime could further complicate the U.S. counterterrorism mission, as well as frustrate other political, economic, and technological goals.

Terrorist attacks are likely to be directed toward civilian and/or urban targets where heat, blast, and fallout would be the dominant problems. Few, if any, civilian systems are designed to operate in a nuclear environment. Terrorists may not gain access to a specifically designed EMP weapon, but even crudely designed nuclear devices can produce significant impacts on electronic and communications systems, as well as contaminate large areas. Moreover, in 20 years or so, arms merchants may be able to obtain most of what the terrorist would need.

High Altitude EMP Attacks

Recent congressional concern has focused attention on the high altitude EMP threat. The results of a specially legislated commission stated:

21. In fact, a newly released Central Intelligence Agency report indicates that "Iran continues to develop a range of capabilities that could be applied to producing nuclear weapons, if a decision is made to do so." See: Bill Gertz, "CIA Says Iran Has Capability to Produce Nuke Weapons," *Washington Times*, March 30, 2010.

“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 to the operational capability of our military forces.

“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.”²²

This type of detonation would likely damage key weapon systems and support capabilities, including satellite navigation systems, intelligence and targeting systems, communications resources, and many other militarily significant platforms. Battlefield impacts would be significant, particularly if our nation’s large, technically superior, but electronically dependent force is unprepared to operate in a severely degraded environment. Contributing to that degradation are not only the direct effects, but also the likely more widespread effects on logistics and supply, and if targeted at the United States, the damage to its critical infrastructure.

Summary

The likelihood that U.S. forces will have to have the capability to operate effectively in a nuclear environment has probably increased since the end of the Cold War. While massive arsenal-exchange scenarios like those of the Cold War are much less likely, limited nuclear engagements may be more likely. Many potential adversaries, both state and non-state, have stated that nuclear weapons are a viable war fighting capability to protect their interests regionally and to counter U.S. conventional superiority. Declared states, including Russia and China, are modernizing their capabilities, and in the case of Russia, building new “theater”

22. *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, Volume I, Executive Report, 2004.*

weapons and developing the accompanying doctrine and training. Non-state actors have repeatedly declared their desire to acquire, and intent to use, such weapons in attacks on U.S. interests, including the homeland. This emerging proliferation environment, with its complexity and unpredictability, should be motivating plans, policies, and actions in the U.S. war fighting community as it looks to the future, not only for EMP, but also for a full range of effects typical of ground and low-altitude detonations expected in battlefield scenarios.

Chapter 3. Assessment of Radiation Survivability of Critical Capabilities

In the context of the categories of the threats and challenges described in the previous chapter, the task force used its expert judgment to assess the current state of the major elements of U.S. war fighting capabilities and the infrastructure on which they depend with respect to their survivability.

That assessment is summarized in general terms in Figure 1. Each element was judged as to how well it meets its required survivability levels; for example, nuclear reentry vehicles have an extremely high survivability requirement, which the task force judged it meets with high confidence, while only a small fraction of general purpose forces are judged survivable. The figure also indicates the scale of the problem for each element—namely how many entities, to an approximate order of magnitude, are at risk.

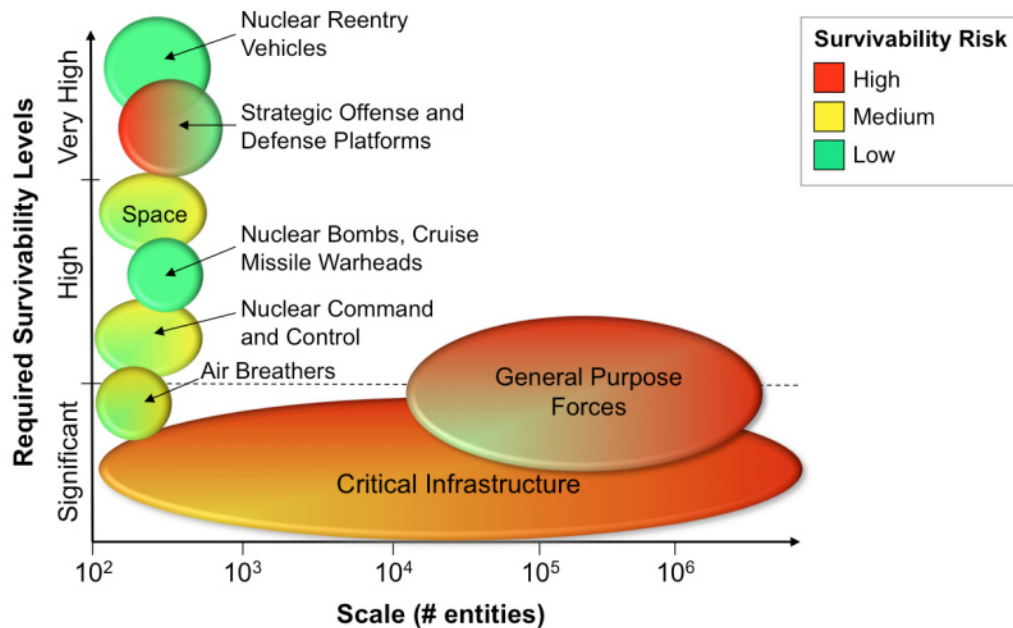


Figure 1. Current Survivability Risks of Critical Capabilities Against Nuclear Weapons Effects

The rationale for the assessment of each element is as follows:

- **Nuclear reentry vehicles** refer to the warheads alone. Very high survivability requirements derive from the most stressful operational scenarios. Considerable design, experimentation, simulation, and testing go into assuring that those requirements are met and maintained.
- **Strategic offense and defense** refers to most of the delivery platforms/systems (intercontinental ballistic missiles, submarine-launched ballistic missiles, ballistic missile submarines, interceptors), which have very high survivability requirements. Legacy strategic offense platforms, designed with hardened subsystems and deployed with operational survivability as part of the concept of operations, account for what green there is, *although the status of many of the platforms has not been tested for some time*. Missile defense components vary in how well survivability requirements have been addressed, from good to untested.
- **Space systems** refer to the full array of satellites to support war fighting needs. All have to accommodate prolonged exposures to natural radiation environments in space, but only dedicated DOD and intelligence community assets have additional hardening requirements to address space-based threats, and even those are highly variable. Commercial satellites that support a wide array of military communications needs are not hardened beyond expected natural operating environments.
- **Nuclear bombs and cruise missile warheads** refer to the bombs or warheads alone. These have lower survivability requirements than re-entry vehicles based on expected operational scenarios. Considerable design, experimental, simulation, and testing go into assuring that those requirements are met and maintained.
- **Nuclear command and control network** refers to the dedicated network that if called on, would support the use of U.S. nuclear forces. Historically these networks are isolated, hardened, redundant, and protected. Concerns are being raised about planned upgrades and migration to modern network configurations and protocols.
- **Air breathers** refer to the nuclear capable bombers and cruise missiles. These have somewhat lower survivability requirements than the nuclear devices because of stand-off and/or difficulty of detection/intercept by air defenses. Legacy systems are designed and tested to meet requirements,

but there is some question about how well key hardening features are maintained.

- **Critical infrastructure** refers to that part of the civilian and military infrastructure on which military operations are dependent (e.g., commercial communications networks, transportation routes in the continental United States, and nodes supporting logistics and resupply). Responsibility for this infrastructure is distributed throughout government and the private sector according to assignments made by the Department of Homeland Security. Resources devoted to “harden” elements of this infrastructure are directed at more conventional types of attacks and vulnerabilities, which are not necessarily prioritized consistent with DOD priorities, nor do they begin to address nuclear survivability.
- **General purpose forces** refer to U.S. conventional war fighting and indigenous support personnel and equipment subject to “harm’s way” at any given time. For nearly two decades, nuclear survivability via hardening of equipment and/or operational contingencies to enable “fighting through” has been neglected. Some legacy systems are still operational and the U.S. Army has maintained nuclear survivability as a key performance parameter for new acquisitions (which, however, can be waived by proper authorities). Even for those newer Army systems where survivability has been required for acquisition, a hardness maintenance and surveillance program has often not been.

Addressing these shortfalls in survivability requires a risk management approach since physical hardening of every entity within each major element is not only unaffordable, but in some cases, undoable. Even during the Cold War, when nuclear survivability was an accepted factor in operational planning and acquisition, a balanced approach to minimize risk within limited budgets was the normal practice. The community needs to re-learn that approach.

In those cases where survivability must be guaranteed, there is little choice but to invest in the expense of hardening. (See Appendix B for a discussion of what this involves and the impact of ever smaller feature sizes in microelectronics.) However, where required survivability levels are lower, trades between the costs of hardening some or all components and other measures can be made. Other measures include operational mobility; backup and redundant capabilities not co-located; and/or tactics, techniques, and procedures (TTPs) that offer operational alternatives for achieving the same mission outcome. Figure 2 illustrates these points. Across the board, good design and development

practices can minimize the impact of the pervasive use of commercial-off-the-shelf components in today’s military systems (see the list at the end of Appendix B).

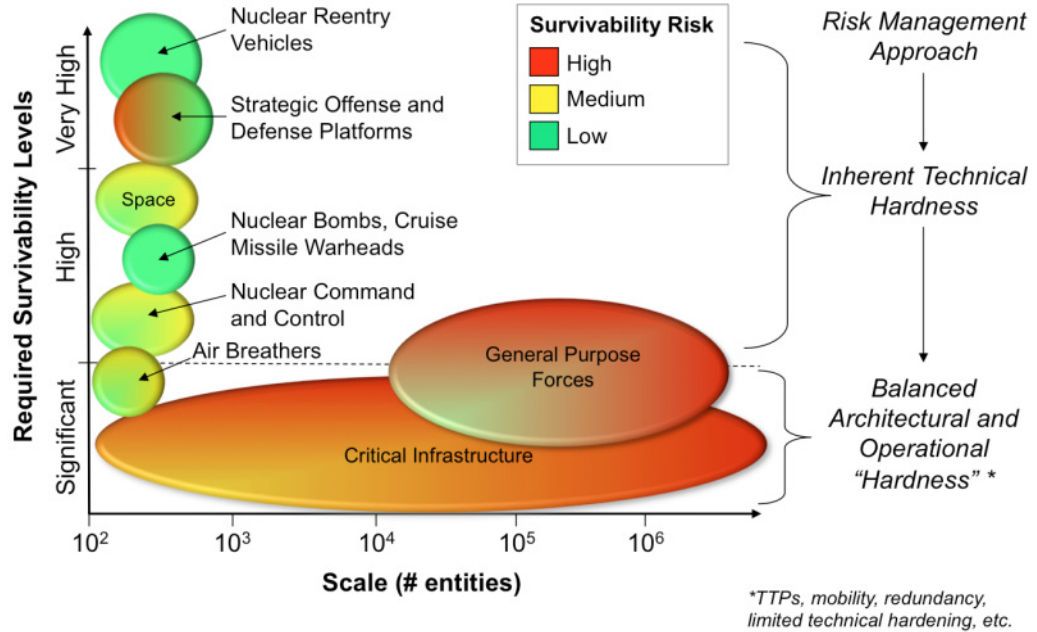


Figure 2. Managing Nuclear Weapons Effects Risks

The next two chapters will describe in more detail the key factors contributing to this assessment that put critical war fighting assets and supporting capabilities at risk—examining how current military operational approaches and capabilities have led to vulnerabilities to nuclear effects and how the health of the nuclear weapons effects enterprise affects our nation’s overall survivability posture.

Chapter 4. Military Operations and Capabilities

Not only should the threat picture of Chapter 2 be cause for concern, but factors of our own nation's doing are creating a situation demanding action. These factors include:

- leadership neglect and with it, a military grown thin in nuclear war fighting expertise
- the evolution of general purpose forces to networked, commercial-off-the-shelf (COTS) dependent systems
- the failure to maintain nuclear survivability as a requirement in most general purpose forces components

This chapter addresses these factors and leads to the not-too-surprising assessment of the next chapter that the nuclear weapons effects enterprise is in poor health.

Leadership Neglect

As noted in Chapter 2, the asymmetric appeal for an adversary to employ nuclear effects may be “too good to pass up.” Potential U.S. vulnerabilities, as described in Chapter 3, may be attractive to an enemy who could “bring this country to its knees” by possessing the capability to generate nuclear effects.

The term “potential vulnerabilities” is important in this context. It comes from the fact that **we simply do not know what our nation's vulnerabilities are**, particularly those of our general purpose forces. This state stems from years of little or no testing of U.S. forces and supporting systems, such as space or command and control. It also results from a DOD requirements process for new systems in which nuclear survivability is placed in the trade space and is almost always traded away in the final system design. The situation is further exacerbated by the failure to include “red” use of nuclear weapons in exercises and war games sufficiently to determine needed changes in training, techniques, and procedures. Behind these actions—or lack thereof—is either the conscious or unknowing dismissal of nuclear survivability by U.S. policy making and congressional establishments. Statements have been made by senior decision-makers that U.S. conventional superiority is such that others “would not dare” attack our forces or nation with nuclear weapons, or if they did, U.S.

general purpose forces could readily prevail. Such attitudes fail to consider the potential physical and political cascading effects of limited, regional use of nuclear weapons. The impacts of these potential vulnerabilities could be far-reaching, as illustrated by the examples which follow.

Questions about Mission Assurance

Potential vulnerabilities of America's military forces are most apparent in its conventional forces. They exist most significantly when these forces are massed, i.e., when garrisoned at home bases during peacetime or, during crises, at ports of debarkation for ground forces, at deployed airfield locations for air forces, and for carrier battle groups deployed in formation. The widespread use of COTS electronics and the growing dependence on networked systems places all aspects of U.S. war fighting at risk. (See next section "Shift to Networked, COTS-Based Systems.")

Contemporary scenarios involving U.S. defense of Taiwan and U.S. assistance to South Korea against a North Korean invasion could place U.S. forces and supporting systems in stressing nuclear effects/radiation environments. For example:

- **Conventional fighting platforms and vehicles.** These systems are highly dependent on computers and electrical circuitry for effectiveness. The danger from radiation induced upset or burnout of improperly or unshielded computers, radios, and offensive/defensive systems could render the combat system either partially or fully ineffective.
- **Command, control, communications and intelligence, surveillance, and reconnaissance systems.** Net centricity and situational awareness to enable battlefield agility are huge force multipliers for U.S. forces. If these systems/interfaces are unprotected from nuclear effects, then U.S. forces could be rendered blind, deaf and mute.
- **Rear echelon logistics, repair and maintenance capabilities.** Sensitive test and repair equipment, if vulnerable to radiation effects, will fail, resulting in critically negative effects on U.S. forces' staying power. In addition, the "just-in-time" nature of modern logistics relies on open networks and computers operating seamlessly with the information systems of commercial suppliers—all of which are likely to fail in a nuclear environment.

Mindsets of Decision-Makers

A major concern of the task force is the widespread lack of awareness, attention, and concern for this issue among senior government leaders. Many of the post-Cold War generation of decision-makers simply do not have this issue on their “radar scope,” while others pay little or no attention to it because they fail to see it as a legitimate concern. Approaches among today’s senior policy and congressional leadership range from “no one would dare use a nuclear weapon against the United States or its forces,” to dismissal of the issue as a “legacy of the Cold War,” to “it’s just too expensive to deal with,” to “anything we do will promote further proliferation and/or use.”

Within the U.S. military there is also a general lack of attention toward nuclear survivability issues. Although modest programs for “nuclear education” exist, they train a very small number of personnel who are assigned typically to staff positions at combatant command headquarters or agencies and Service staffs in Washington, D.C. A notable exception is the FA-52 specialists in the Army, a cadre maintained to assure that critical Army programs properly address survivability issues.

Aside from non-mandatory courses in personnel survivability in contaminated environments, there is no evidence of service training or education programs for understanding and operating on a battlefield where platforms, vehicles, and supporting systems may be impacted by nuclear weapon effects.

How Did the Atrophy of Attention and Capability Come About?

The root causes seem to us to lie deep in DOD and its leadership’s corporate point of view that has developed since the end of the Cold War. Nuclear weapons have not been used, other than in deterrence, for over sixty years. And for the past twenty years, even the deterrent uses have been less immediate and direct, and have seemed less important than before. Since the first Gulf War, conventional operations of great difficulty and importance have consumed DOD and national attention, and have displaced nuclear deterrence as the reigning paradigm.

Furthermore, there seems to be widespread belief that the United States will be able to deter enemy use of nuclear weapons, with the exception of terrorist use. (In that case, however, the impacts of survivability shortfalls tend to be further dismissed since the canonical nuclear terrorism scenario involves the use of only one or two weapons against civilian targets.) For all these reasons, the

possibility that U.S. forces would have to operate effectively in a nuclear environment simply seems, in this view, to be extremely remote.

Finally, the costs of hardening military systems, and the difficulty of developing ways of operating forces to be effective in a nuclear environment, seem larger to many than the likelihood of the threat warrants. (For example, as noted in a prior DSB report,²³ the Army has maintained a data base that indicates that if hardening is incorporated as an integral part of the initial design, most equipment suffers a 1 to 2 percent increase in cost.) The complicated—and, to many decision-makers, arcane—nature of assessing the nuclear cost/risk trades exacerbates the problem. These factors have resulted in fewer and fewer of the military and civilian leaders in DOD having experience with nuclear weapons and the issues that surround them. This in turn exacerbates the point of view to which we attribute the problem.

The task force believes that this point of view, though generally tacit (and often denied when alleged), holds sway widely in DOD—how else could one explain what has happened? We further believe it is profoundly wrong and dangerous. It is wrong in part because although deterrence seems to have worked during the Cold War, the situation is different today. Some adversaries today are *prima facie* undeterrable. Some may be desperate. Some may believe that asymmetries in the perceived political stakes of war, perhaps compounded with perceived U.S. unwillingness to break the “nuclear taboo,” will prevent our nation from retaliating forcefully against adversary use of nuclear weapons.

One of the enduring lessons from the Cold War is that for deterrence of adversaries and assurance of allies to be effective, the United States must be able to control escalation, which in turn requires—for deterrence—U.S. nuclear and conventional forces to be able to operate in a nuclear environment. Furthermore, the shoe is now on the other foot: it is precisely the great capability of U.S. conventional forces that contributes to making nuclear weapons attractive to adversaries. Finally, Army experience through their continued, albeit selective, attention to survivability continues to reinforce the fact that hardening against, and operating effectively in, a nuclear environment is not as costly as often assumed. Technologies are emerging to further reduce the cost, as smaller electronic feature sizes are forcing commercial developers to build in hardening to guard against naturally occurring upsets. All in all, we believe renewing the commitment to nuclear survivability is a prudent and affordable step to take.

23. *Report of the Defense Science Board Task Force on Nuclear Weapon Effects Test, Evaluation, and Simulation* (Washington, D.C.: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics), April 2005.

Shift to Networked, COTS–Based Systems

The evolution of U.S. conventional war fighting to highly networked, information driven concepts of operations, enabled by COTS–based electronics, has introduced a major reason for concern with respect to nuclear survivability. There is limited test experience and analysis, almost exclusively for the Army’s specifically hardened platforms, to predict how modern and upgraded war-fighting capabilities, especially the networked command and control “nervous system,” will function should they be subjected to a severe and/or widespread radiation environment.

Reliance on COTS Electronics

Modern electronics control the operation of all defense systems—yet defense requirements no longer influence electronics technologies. This asymmetric relationship is a result of the fact that electronic component availability is driven by the ~\$250 billion worldwide commercial semiconductor component market. Only 5 percent of the world electronics market is “government,” which includes chips for government computers, cell phones, and other office applications. An even smaller fraction of the government electronics market goes to military-specific electronics. With such a small market share, government has little to no influence on semiconductor products, in contrast to the early days of the integrated-circuit industry.

In 1961, government contracts represented 92 percent of the world’s integrated-circuit market and drove technology and product development. Today, International SEMATECH coordinates the development of needed manufacturing equipment and associated technology based on their best estimate of the world’s commercial market through the International Technology Roadmap for Semiconductors (ITRS). Thus, instead of leading semiconductor technology development as they did in the early days of semiconductor products, U.S. military systems now adapt what they can from leading-edge chips that target mainstream commercial applications—as does every other military in the world.

The ITRS roadmap predicts increasing capability for leading-edge chips—both digital and mixed signal—with increasing processing power that will enable faster response and more functionality for all electronic systems. While defense systems benefit from increasing digital processing power, semiconductor products for most large commercial markets do not have to face the environments that characterize military applications—extremes of heat, cold,

shock, and radiation. Typical radiation environments may include nuclear radiation such as electromagnetic fields, X-rays, gamma rays, electrons and neutrons, and space radiation such as protons, ionized heavier ions, electrons, and atmospheric neutrons. These radiation environments establish unique requirements that not only separate military from commercial systems, but also place more difficulty and challenges on designers to develop survivable DOD systems in the future as feature sizes of electronics continue to shrink. These DOD systems include: (1) telecommunication networks on the ground to serve command control centers; (2) mobile combat equipment; (3) missile defense systems; (4) combat ships; (5) surveillance, meteorology, and telecommunication satellite systems; and (6) ballistic missile systems.

The continuing decrease of feature size in integrated circuits and the commensurate decrease in stored charge representing information are leading to an increased sensitivity to single-event-upset (SEU) with device scaling, especially for any high density memory device. The decrease in the upset threshold of highly scaled technologies has made them sensitive to alpha particle induced upset. These factors have made soft errors a significant reliability concern for commercial integrated circuit manufacturers, not only in space environments, but also in ground-based systems. Continued scaling of technologies will likely further exacerbate the SEU problem by increasing the likelihood of multiple bit upsets and increased upsets due to single-event transients. How serious a problem this creates for military electronics is not known because components have not been systematically tested and analyzed, but the bottom line is that each new generation is more vulnerable to radiation effects than previous ones.

Another important point is that no system is built only with leading-edge chips. Older technologies are used in electronic systems to condition power, actuate mechanical devices, and interface to sensors. These technologies are generally one or two generations behind the latest in the commercial market. The older technologies tend to have more immunity to ionizing radiation than the most modern integrated circuits (those made with transistors whose minimum dimension is 0.18mm or smaller). However, they too may be vulnerable, but in too many cases, their vulnerabilities have not been characterized. Moreover, in systems with a range of generations of electronics, where and how failures in the system will occur are unknown. (Appendix B has a more complete technical discussion of the upset/failure mechanisms of microelectronics when exposed to high energy radiation.)

Network Operations in Radiation Environments

The Department of Defense has underwritten major force application innovations and improvements in overall force effectiveness and efficiency through collaboration enablers which are network-based. For the following discussion, the network focus is on the global common user instantiation called the Global Information Grid (GIG) and its integrated “Edge” networks. This combination serves by far the largest user population including users from other departments and agencies. The general insights and conclusions derived apply equally to specialized networks, including space assets, not discussed here.²⁴

The nature of the two components of the global network—“long haul” optical fiber and the “Edge” networks—are substantially different. The “long haul” optical fiber and related facility elements were purchased from commercial network operators and their suppliers. DOD operations of the “long haul” network employ, for the most part, “commercial components”—fiber, electronics, software, concepts of operation, procedures training, and management. DOD can control topology redundancy and other architectural features. It can also replace or add to concepts of operations, procedures, and training within the constraints of the basic facilities hardware and software.

In contrast, the “Edge” networks are designed, fielded, and operated by the military services. Although much of their underlying hardware and sometimes software is commercially derived (servers are but one example), their architecture; concepts of operations; tactics, techniques, and procedures; and management and training are Service designed on an integrated rather than an overlaid basis (as is the “long haul” portion).

The Service “Edge” networks are wireless to support a broad spectrum of maneuver operations on land and sea and in the air. The most sophisticated of these are MANET networks—M(obile) A(dhoc) NET(works) which are intended to be self-forming and self-healing. The “Edge” networks must deal with substantially more challenges than their “long haul” counterparts, which are comprised of predominantly fixed facilities and a controlled topology. However, the smaller scale and separable components of the “Edge” networks do allow, in principle, for isolation and characterization with respect to their radiation upset susceptibility. In contrast, the effects from natural, man-made and/or nuclear

24. For the reader requiring greater detail about the interaction of network performance and effects—nuclear and conventional—inquiry should be made to the Director, Defense Threat Reduction Agency relative to its mission activities under a program called Balanced Survivability Assessment.

weapon environments have a character and scale that goes beyond manageable complexity for most commercially-based “long haul” network segments.

In practical terms, while prediction of extended fixed facility exposure outcome is for the most part inadequate, it is possible to experimentally address “Edge” individual network elements. It is feasible in some cases for smaller “longhaul” network nodes. Predicting the results of the exposure of large numbers of nodes in either network is problematic because of both methodological and computing limitations. Some of the latter may diminish with the next major computing advances but methodological challenges remain.

It is therefore necessary to develop and complement technical means for mitigation with a consequence management strategy and to plan, train, rehearse, and exercise leaders and staffs for operations in degraded environments. In the end, it is the quality and performance of humans which is the main offset to the challenges of exposure to both assured and deliberate conventional exposure and nuclear weapons environments and their effects.

Failure to Assess and/or Maintain Nuclear Survivability

With the end of the Cold War, the requirement for nuclear survivability was quickly put at the bottom of the list of key performance parameters, or largely dropped altogether. This has impacted both new and already fielded systems. In both cases, the task force found that little has changed since an earlier Defense Science Board (DSB) task force addressed this topic,²⁵ with one significant exception. The EMP Commission was successful in helping to motivate a new department instruction (DoDI 3150.09, “The Chemical, Biological, Radiological and Nuclear [CBRN] Survivability Policy,” September 2008) for critical system survivability in weapons of mass destruction (WMD) environments. The instruction establishes a management oversight group with responsibility for implementation of the instruction with respect to nuclear survivability, and requires a biennial report to Congress on progress with respect to EMP. In turn, the Air Force has looked into reinstating its defunct oversight function, while the Marines are working with the Army to understand the EMP hardness of some of their systems. The Navy is developing an aircraft survivability process with the help of the Defense Threat Reduction Agency (DTRA). The commission and the prior DSB task force also raised awareness at U.S. Strategic Command. The

25. Defense Science Board, *Nuclear Weapon Effects Test, Evaluation, and Simulation*, April 2005.

command has reconstituted a capability to assess the survivability of mission critical components in its strategic systems domain and is motivating remedial actions by the Services where needed. However, hardness maintenance/hardness surveillance programs for most fielded systems originally acquired with survivability requirements are generally not resourced.

New Systems

Many new systems have not been explicitly required to meet nuclear survivability standards from their inception. Included are the interceptors for missile defense²⁶ and the F-22. Hardening has been postponed to downstream spirals, which is likely to be cost prohibitive.²⁷

Some notable progress, however, is starting to occur. The Army elevated its watchdog agency, the U.S. Army Nuclear and Combating WMD Agency (USANCA) to Army Staff reporting. In addition, new designs must address the EMP requirements of MIL-STD-461/464. New guidance, developed by the Navy with support from DTRA, for aircraft EMP hardening and testing is in final review prior to publication. The EMP military standard for protection and test of maritime assets has been started with a target of 2014 for publication. However, these military standards cannot be universally applied because of the reliance on COTS equipment, and they can be dropped in the trade space associated with the Joint Capabilities Integration and Development System (JCIDS) and Capability Based Planning processes.

Fielded Systems

With the exception of Navy strategic systems, significant cutbacks have occurred in the area of performance evaluations of other Navy assets in a nuclear effects environment. While it is anticipated that fielded Navy systems are expected to perform well in categories of physical stress (shock, wave surges, etc.) and EMP due to inherent ship and equipment normal operating environments, testing of survivability in more extreme nuclear environments has not been undertaken in many years. With the exception of EMP on aircraft (in particular, the E-6), nuclear survivability requirements are no longer a key performance parameter in new ship and weapon system designs.

26. The Missile Defense Agency has developed a survivability standard and worked to harden the ground systems.

27. Army data over several decades indicate that the cost of hardening a new system from the outset is in the range of 2-10 percent of the base cost of the system. Hardening once the system is built can be 10s of percent, or even more.

Air Force systems have posed greater concerns in the past decade. The attention paid by the Navy's Strategic Systems Program Office to survivability maintenance and assessment of its nuclear forces is matched in the Air Force for its intercontinental ballistic missile (ICBM) force. However, although visual inspection of bombers is a requirement, actual testing is not. Conventional forces elements are not assessed. The Air Force is in the process of reinstating its survivability assessment program, but it is still to be determined how effective its efforts will be. Even the Army's relatively influential agency for new system acquisition, USANCA, has no authority to insist on assessments of fielded systems.

The task force applauds the continuing efforts of the Navy and Air Force ICBM wings to maintain the survivability of their strategic forces. But even strategic nuclear systems might be subject to different environments than the Soviet era threats for which they have been hardened. Other nations are building different weapons to accomplish different objectives and, therefore, have the potential to introduce different effects. A revisit of "red" nuclear environments should occur routinely as Red Book results are updated.²⁸

How the Mix of Old and New Will Perform Together

We simply do not know how the mix of old and new systems will perform together. At any point in time, the military will be operating with a spectrum of capabilities spanning vintages from the Cold War to the present. These forces will have mixed levels of protection, yet they are highly interconnected and interdependent. Older designs might be expected to be more robust because their designs incorporated more concern for surviving a nuclear effects environment. However, that depends strongly on how well critical components, such as seals and connectors, have been maintained. Without periodic retesting, one cannot say with certainty. Our nation's ignorance of the survivability of new systems built with modern electronics should create concern for military operators on its own, but when combined with uncertainties for older systems, operators should be prepared to be surprised. It is entirely possible that the failure of a single critical node could take out an entire system.

28. The "Red Book," a long term responsibility of the Defense Threat Reduction Agency and its predecessor agencies, is a compendium of calculated adversary generated nuclear outputs. A new cycle of revisions is scheduled to be completed in August 2010.

Chapter 5. The National Nuclear Weapons Effects Enterprise

The factors discussed in the previous chapter have produced a decline in priority and investments that has created an alarming atrophy in the nuclear weapons effects enterprise (NWE). The nuclear weapons effects enterprise, as defined by the task force, is comprised of the following elements:

- **Knowledgeable military operators and specialists, within the Services.** Operators with sufficient training and understanding of weapons effects to plan and exercise in ways to assess mission execution in a nuclear environment, aided by specialists with deep domain knowledge.
- **Expertise in key agencies, the intelligence community, and national security laboratories.** Technical professionals fluent in the use of computational tools that allow them to predict potential effects environments, and assess and evaluate those effects on both humans and equipment.
- **Effects simulators and skilled operators.** Expertise and sophisticated aboveground radiation simulators engaged in experimentation and testing to validate models and/or to evaluate performance of critical equipment or components.
- **Science and technology community.** Career professionals dedicated to advancing the fundamental understanding of effects generated by nuclear or radiation devices, the interaction of those effects with materials and components of interest, and approaches to mitigate the impact of those effects on the system's physical performance—through a combination of theory, advanced computations, and experimentation—in close partnership with the assessment and simulation elements. Historically the bulk of science and technology research has been conducted through the DTRA and its predecessor agencies (Defense Nuclear Agency and Defense Special Weapons Agency) and the Department of Energy's nuclear weapons laboratories (Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Sandia National Laboratories).

The elements of the enterprise should be (and were throughout most of the Cold War) interconnected in a manner to ensure mission success by evaluating the tradeoffs among the options for defending against and/or recovering from exposures. DTRA and its predecessors have been the leading DOD organization for brokering among the various actors in the nuclear weapons effects community.²⁹

Table 1 provides the task force's assessment of the state of health of each element of the enterprise. The assessment distinguishes between general purpose/conventional force aspects, and strategic forces and assets. With the exception of some knowledgeable specialists supporting strategic force elements that reside in the Army's USANCA, Navy strategic systems, and U.S. Strategic Command, general military understanding of how to plan and execute military operations in nuclear environments is poor. The result is not surprising given the neglect this area has suffered for 15 years. For example, DTRA's investment alone has shrunk by a factor of 10 from its' end-of-Cold-War levels. At the same time, investments in passive defense against chemical and especially biological weapons have grown five- to seven-fold in DOD, and many more times that throughout the government, in the same time period. Nuclear survivability investments are now less than a few percent of the passive WMD defense budget. (The reader is advised, however, that the growth in investment to counter biological and chemical threats was long overdue, so that these areas should not be regarded as a source for remedying the nuclear survivability problem.)

While operator knowledge can be restored in the near term through training, the reinstatement of technical expertise, and the facilities to enable their work, in the assessment, simulator, and science and technology communities will take a decade or more to restore because of the domain knowledge required and the investment in both computational modeling and simulator experimentation needed. Even with sustained investment to rebuild both human and physical capabilities, however, a shift in focus and approach will be needed since a mainstay of the old program, underground nuclear testing, is no longer an option.

29. It could be argued, appropriately, that the special radiation hardened electronics foundries supported by the Departments of Defense and Energy should also be a part of the enterprise. The task force did not focus its attention on this topic, however, because it is the subject of periodic assessments by DOD on its own. Appendix C provides a brief description of its status.

Table 1. Assessment of State of Health of Elements in the Nuclear Weapons Effects Enterprise

Nuclear Weapons Effects Enterprise Elements	Assessment: General Purpose Forces Global Information Grid National Command and Control Critical Infrastructure	Assessment: Strategic, space forces/assets
Knowledgeable operational military leaders, planners, and executors who are supported with products and services from rest of the enterprise	Shortage of knowledgeable operators; products and services not being used (Red)	Some knowledgeable specialists, but shortfalls exist in most places (Yellow/Green)
Assessment and evaluation experts and their tools (environmental and prediction codes, etc.) supporting operators and developers	With limited exceptions, response unknown and mitigation options not formulated. Less experienced workforce learning in near isolation from operators (Yellow/Red)	Mix of aging and less experienced professionals at Department of Energy labs; aging expertise in DOD. Current tools inadequate for high confidence designs; large safety margins result. (Yellow/Red)
Expertise and facilities for effects simulation to test equipment, experiment with new designs, and validate new codes	Used in a few cases; simulator shortfalls now in evidence (Red)	Simulator shortfalls now in evidence (Red)
Science and technology (S&T) and research and development community addressing new challenges, advancing fundamental knowledge, and tools used by all other components	Already small S&T program in decline (Red)	Already small S&T program in decline (Red)

Note: Green = Sufficient to meet national needs
 Yellow = Concerns about future capabilities
 Red = Immediate attention needed

Understanding Weapons Effects without Underground Testing

During the Cold War, the principal scenarios of interest focused on massive engagements involving tens to hundreds of high-yield weapons detonated in a relatively short period of time. The knowledge base, codes, and simulators focused on the extremes of performance demanded for rapid penetration against nuclear defenses, fratricide avoidance, and nuclear pin down of enemy assets. Valuable and irreplaceable data were collected on system and component performance in nuclear environments, but fundamental understanding of the physics of nuclear weapons effects and the ability to predict the response of systems to the effects was not the focus. As such, large gaps in our nation's knowledge base remain.

A prime example is the Fish Bowl series of atmospheric tests that produced a widespread high-altitude electromagnetic pulse (HEMP). These tests were hastily planned and among the last to occur prior to the 1962 moratorium on nuclear testing in the atmosphere. The data recording equipment for Starfish, a 1.4 megaton burst at 400 kilometer altitude, was not optimally set to capture the unexpected phenomenon. After the tests were concluded, the observations in that test series were explained, but it was no longer possible to obtain additional data from well-planned experiments to improve understanding of the complex phenomenon. Atmospheric tests to explore variations in HEMP levels and system response for different weapon yields and burst altitudes did not occur. The observed effects on systems at the time of the U.S. tests are largely anecdotal. Almost all of the system response data on which subsequent designs have been qualified have resulted from tests in HEMP simulators at Cold War threat levels.

Extrapolation of the Cold War era data to determine how modern day electronics might respond to likely nuclear scenarios today is hampered by large uncertainties. For example, the ability to draw conclusions on the impact of HEMP on modern communications networks, e.g. the Global Information Grid or the commercial Internet, is constrained by limited knowledge about the weapons of potential adversaries, rapidly occurring changes in electronics technology, and the lack of physics-based codes and high-fidelity simulators for analyzing and testing complex networks. Past experience has demonstrated that such constraints result in system response prediction errors that can be two to three orders of magnitude or greater. Figure 3 shows the estimated uncertainties in understanding system effects as a function of the degree of knowledge of the system gained through testing.






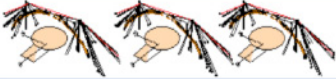
Information Available		Uncertainty
Information Available		>1000X
Inspections		
Low Level Coupling		>100X
Damage Testing of Components		>50X
System Level Test		>10X
Multiple System Level Tests		2-3X

Figure 3. Uncertainties in Understanding System Effects

Protecting systems against hostile nuclear environments relies on a combination of modeling and simulation and testing. Typical nuclear environments of interest are shown in Figure 4. From 1962 to the early 1990s, testing was conducted in aboveground tests (AGTs) in laboratories or nuclear weapon effects simulators, and in underground nuclear tests (UGTs). The cessation of UGTs in the early 1990s has made it necessary to rely on AGTs and models. Data collected in past UGTs has proved of little value because of limited instrumentation and measurements made on components no longer available. In DOD, the inability to sustain the AGT test infrastructure for high fidelity, threat level testing is now driving the community to depend more on modeling and simulation than ever before. This commonly called “model-based approach” relies on AGTs to validate the models on well characterized, small-scale systems. The models are then used to validate the hardness of larger scale systems.

Engineering solutions to reduce system vulnerabilities to nuclear effects have been developed, demonstrated, and applied to many types of systems. In addition to the use of codes and simulators, design margin is used to compensate for uncertainties in threat levels, system response, and test limitations. Hardening design approaches for reducing system vulnerabilities must balance the protection requirements at the component, subsystem and system levels. Tradeoffs between performance and protection, e.g., the amount of shielding and the use of radiation hardened parts, must also be made.

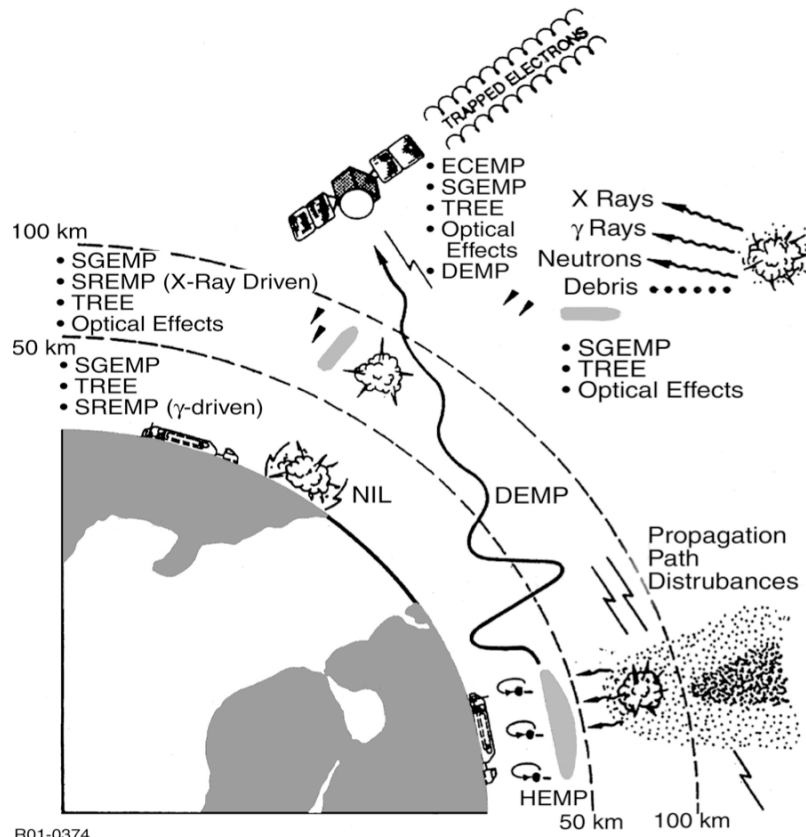


Figure 4. Typical Nuclear Environments of Interest

Future system protection strategies that depend more on codes to guide the design will require much better understanding of physical phenomena than what is known today. Examples include thin-air system-generated electromagnetic pulse (SGEMP), upset in distributed electronics and networks, lightweight mirror deformation, material response at cryogenic temperatures, and thermal/structural responses of new materials or new fabrications. Formidable challenges exist to migrate from a test-based to a model-based system hardness validation paradigm. The role of AGT will become even more important as the use of simulators expands from component hardware qualification to include more sophisticated measurements on well characterized small-scale systems which help validate the models. Examples of phenomena that currently cannot be easily modeled or simulated in AGTs include SGEMP response of large or complex antennas, potential enhanced SGEMP response in cables and potted circuits, and the response of complex interdependent networks to HEMP.

In some cases, analysis may be the only way to investigate system hardness. Two examples are radiation effects on microelectronics exposed to very high fluences and determining the hardness of large complex systems to prompt x-rays effects. Very high fluence levels exceed what simulators can produce today. Existing test facilities, including the National Ignition Facility, cannot yet provide the test volume and the highest fluences that might be needed for full system-level testing.

Modeling new systems will face special challenges not previously encountered. Future systems will have increased performance requirements, e.g. system-on-a-chip, and use novel materials and faster and smaller electronic components. With each passing year, the AGT/UGT database becomes less relevant. A new generation of modern electronics enters the marketplace about every two years. Confidence in existing models is strongly dependent on code and data comparisons from AGT and UGT data and, in some cases, the correlation of the two data sets. As this data approaches obsolescence, extrapolation to support code validation will become increasingly difficult. Ever more sophisticated testing will be required to provide response data for new materials and components, assess vulnerabilities and revise models, and develop new hardening methods.

Progress in Computational and Simulation Capabilities

In spite of all the challenges noted in the prior section for migrating to a model-based approach to survivability design and assessment, the advances in computational and aboveground testing capabilities gave the task force optimism in the potential for success.

Advances starting in the mid-1990s associated with microelectronic processors of ever increasing speed, high density memories, and high speed interconnects made feasible the development of massively parallel computers at a scale to support simulation of the fundamental phenomena of a nuclear explosion. The timing was fortuitous in that the moratorium on underground nuclear testing initiated in October 1992 was forcing a shift to a model-based approach for designing weapons and assessing their performance and reliability. The Department of Energy initiated the Science Based Stockpile Stewardship (SBSS) Program comprised of two major elements:

- The Accelerated Strategic Computing Initiative (ASCI) program to build state-of-the-art codes and computers. (It matured into the Advanced Simulation and Computing (ASC) Program.)

- Improved aboveground simulators, both new (e.g., the National Ignition Facility) and existing (e.g., Z-Refurbished), to augment legacy underground test data for validating the codes.

Although predominantly focused on predicting the yield and performance of U.S. nuclear weapons, a small part of the ASC program provided a number of modeling and simulation capabilities related to nuclear weapons effects. These physics-based codes advanced the ability to model the response of critical components in a nuclear warhead to radiation exposure. The codes have been used successfully, in combination with simulator and laboratory testing, to support replacement component certifications (e.g., various neutron generators) as well as certification of the arming, fuzing, and firing subsystem for the W76. These accomplishments have provided confidence in a model-based approach for qualifying hardware components for nuclear survivability.

The DOD has the opportunity to leverage these codes, as well as contribute to expanding model and simulation capabilities. The ASC effects codes provide the capability to model difficult geometries and allow a designer to assess performance in a wider range of environments not possible through physical testing alone. However, many more phenomena remain to be modeled and the introduction of new materials and components, both in our weapons and those of others, make the modeling challenge one that should be ongoing. Moreover, extending validated component modeling to complex, dynamic networks is a challenge that is yet to be addressed outside of preliminary assessments by DTRA.

Along with the models, continued upgrading of the simulators is also needed. The National Ignition Facility and Z-Refurbished fill only part of the needs. Figure 5 illustrates the photon energy range for various x-ray spectra of interest. The radiation effects are highlighted and identified above the graph. There are cold x-ray effects that generate thermal shock and impulse effects, whereas at higher energies, one observes cable SGEMP (system generated EMP) and BOX IEMP (internal EMP) or internal package effects in the warm x-ray regime between 10 to 100 keV. At even higher energies for simulation and penetration reasons, one studies transient radiation electronic effects (TREE). This is where many of the simulators lie today. None of the simulators have the capability like a nuclear underground test to provide a cold threat spectrum for large volumes of the size of a missile or a satellite, but modest investments in existing facilities have allowed them to continue to maintain their capabilities. The National Ignition Facility offers the opportunity for larger scale experiments and tests.

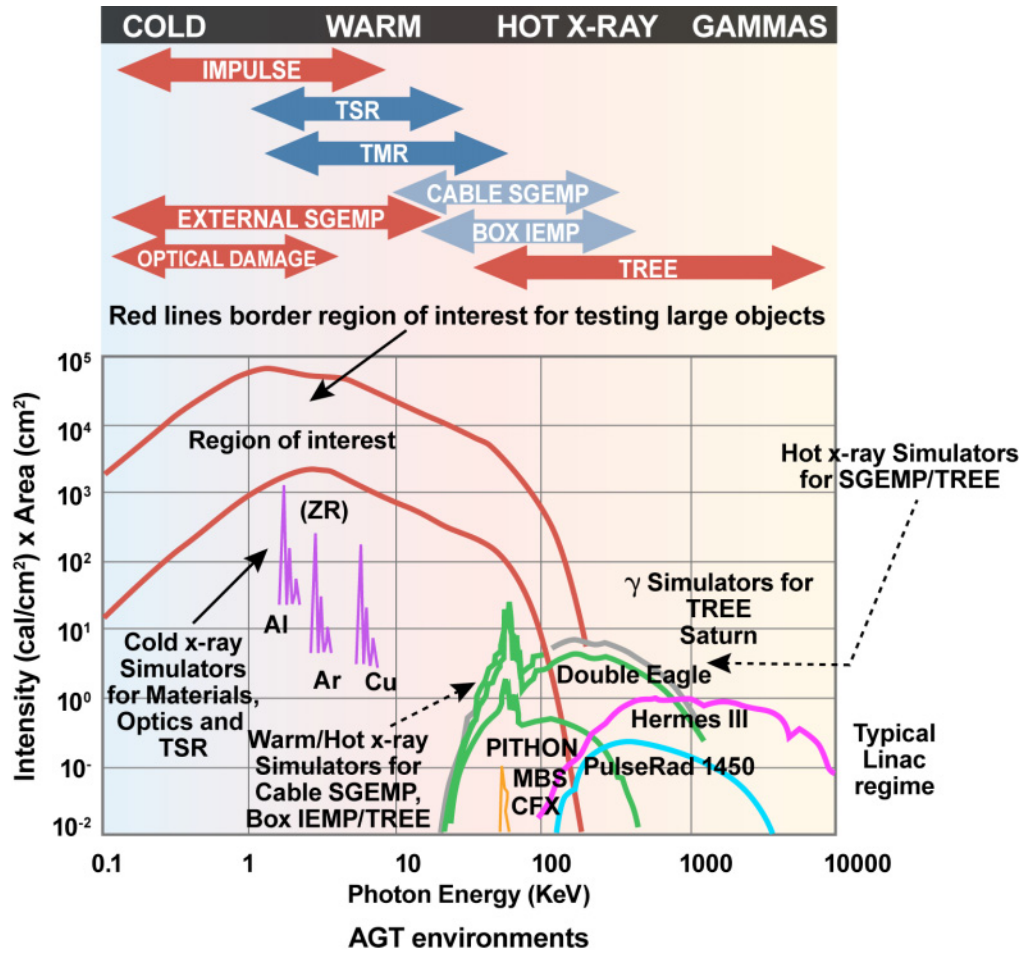


Figure 5. Radiation Effects versus Photon Energy and Test Facilities

In order to study the radiation response of electronics at an affordable cost where a number of shots can be taken to study the effect of orientation, a high-energy photon source is the choice. However, high-energy penetrating photon sources may not generate the same response as that produced by photons in the medium energy range. Such an example is in the case of internal EMP or cable responses. Here the electrons that are emitted by the surfaces of metals either buried deep within materials or from metals only shielded lightly generate responses that have different signatures or polarities. At energies below 10 keV, much of the photons are absorbed in the surfaces of packages where thermal heating and thermal shock effects are important.

Core Simulator Capabilities

The task force took advantage of the efforts of the Joint Simulator Working Group (JSWG),³⁰ which undertook its assessment near the same time as the task force's initial information gathering activities. The task force agreed with the working group conclusion that a core set of weapons effects simulators would be needed in the future. The Working Group's recommendations are summarized in Table 2.

The simulators would continue to serve their historic role for selective component testing and qualification, but they should also assume ever larger roles for validating model development as the enterprise shifts to a model-based approach. Particular issues identified included the following:

- The capabilities provided by the West Coast Facility—Double-EAGLE, Python, Modular Bremsstrahlung Source (MBS), and PR1150—need to be retained to support future requirements. If the new GFE commercially funded West Coast Facility business model does not prove viable, then Sandia's Saturn machine becomes a critical asset to substitute for the Python and Double-EAGLE capabilities, along with the Air Force Little Mountain facility for the Pulserad and MBS capabilities. Alternatively, DTRA would need to re-assume stewardship of the West Coast Facility.
- The NNSA facilities, which have been used primarily for the Stockpile Stewardship Program and Inertial Confinement Fusion program, have the potential to provide high-fidelity and/or high-fluence radiation sources for code validation and system-level experiments. These facilities include the Z-Refurbished (ZR) pulsed power machine at Sandia National Laboratory; and the National Ignition Facility at Lawrence Livermore National Laboratory.
- There is the need to establish a path to eliminate the shortfall due to the shut-down of Sandia Pulsed Reactor (SPR) III. The Quantification of Alternatives to SPR (QASPR) program at Sandia National Labs is a potential pathway to close a portion of the shortfall for specific component technologies. However, presently QASPR remains unproven

30. The Joint Simulator Working Group (JSWG) was a joint effort of the National Nuclear Security Administration, the Department of Defense, and the United Kingdom's Ministry of Defense. The JSWG objective was to develop a business model for the national enterprise to sustain the minimum suite of nuclear weapons effects simulator capabilities needed to support the development and certification of survivable strategic systems using a combination of modeling and simulation and testing. A more comprehensive assessment to include needs for general purpose forces would include thermal radiation and other testing capabilities found in the Services.

and would have to be expanded to a broader range of current and emerging technologies to fully replace SPR III. Consequently, several core facilities are needed for QASPR (Annular Core Research Reactor, Ion Beam Laboratory, and an appropriate linear accelerator [e.g., Medusa at Hill Air Force Base]). If QASPR does not meet its objectives, a pathway for a reconstituted SPR or new fast neutron facility at a Department of Energy or DOD facility that could share the high security costs with other activities should be developed.

Dwindling Expertise

Progress in computer codes and more capable effects simulators, largely for other purposes (i.e., weapon design), gave the task force some hope for transforming the weapons effects enterprise. But without the technical expertise, it simply will not happen. The technical complexity of this area requires a highly trained cadre of multidisciplinary scientists and engineers who are willing to dedicate their talents and careers to the nuclear weapons effects mission. Attracting new talent will require recognition at the highest levels of government that a different kind of nuclear threat has emerged and that it presents technical challenges not encountered before. Recreating the enterprise, adapted to current national security needs, could serve as the first tangible indication of that mandate.

But time is of the essence! Post-Cold War investments, especially by DOD, have not attracted the next generation workforce to enter the nuclear weapon effects career field. The continued erosion of the nation's intellectual capacity to deal with the new and mounting challenges adds to the urgency of taking action now. The specialized skills needed for nuclear weapons effects take many years to acquire. Only a handful of experts remain who developed the theoretical underpinnings to explain nuclear phenomena, designed and fielded the AGT and UGT experiments to understand effects, and developed and applied the hardening technology for systems protection. Most of the experienced members of the nuclear weapons effects community that might serve as mentors for the future workforce have passed on, left the field, retired, or are nearing retirement. The residual skill base is an aging workforce with few replacements in the pipeline.

Table 2. Nuclear Weapons Effects Simulator Capabilities

Nuclear Weapon Environment	Test Facilities	Comments
Prompt and modified neutron	Sandia Pulsed Reactor III (or equivalent)* Annular Core Research Reactor White Sands Missile Range Fast Burst Reactor (also combined gamma) Los Alamos Neutron Science Center, Ion Beam Laboratory, and Rotating Target Neutron Source	For nuclear warhead subsystem space simulations For nuclear warhead components For ground systems, satellites, and interceptors For component tests and model validation
Prompt cold X-rays (plasma radiation source)	Upgraded Saturn and/or Double Eagle National Ignition Facility and/or Z-Refurbished (ZR)	For space system components/optics For future re-entry vehicle/re-entry body (RV/RB) material and interceptors
Prompt warm/hot X-rays (Bremsstrahlung source)	Upgraded Saturn and/or Pithon Modular Bremsstrahlung Source	For medium-dose electronics and cables For hardness surveillance and low-dose boxes
Prompt gamma	High-Energy Radiation Megavolt Electron Source (HERMES) III Pulserad (1150 or 958)	High dose-rates for strategic systems Low dose-rates for satellites and interceptors
Electromagnetic pulse	White Sands Missile Range Horizontally Polarized Dipole (HPD) Facility (2 nd generation) Naval Air Warfare Center HPD Facility, Vertically Polarized Bounded Wave	For Army systems For aircraft and missiles
Source region electromagnetic pulse	HERMES III	For Army vehicles and field command, control, and communication systems
Impulse	Light Initiated High Explosive (LIHE) at Sandia National Labs Flyer-plate (magnetic or LIHE)*	For RV/RB internal components/mounts For future RV/RB aeroshells
Blast and shock	Large Blast Thermal Simulator Sandia National Laboratory Thunder Range	For ground vehicles, structures, non-ideal air blast (NIAB) simulations For RV/RB systems
Disturbed atmospheric radio frequency/infrared/visible	Communication Channel Scintillation (Wide-band Channel Simulator) Optical background (Nuclear Optical Dynamic Display System)	For military satellite communications, interceptor in-flight communications, and seekers

*Not currently available.

Chapter 6. Findings and Recommendations

Principal Findings

A near “perfect storm” is brewing—one in which the threat of nuclear use against U.S. forces is growing at the same time that our nation’s understanding of if/how we can operate in such environments has all but disappeared. Yet it is not possible or advisable to go back to the Cold War approach that relied heavily on over-design and testing—**far too much has changed.**

- Driven by political exigencies, the United States continues to reduce the number of strategic systems deployed as the ultimate instrument of deterrence. These actions in turn place an ever higher premium on the reliability of the remaining deployed systems, or conversely, a greater demand on understanding uncertainties in their performance across an ever widening set of potential operating environments.
- General purpose forces and the GIG are becoming targets of current or potential adversaries. Reliance on COTS in critical war fighting systems has grown dramatically, with the commercial components themselves evolving even within a single procurement cycle. Today, systems are generally manned and/or stationary or slow moving, making radiation exposure mitigation difficult to achieve. On the other hand, as our military shifts to greater reliance on unmanned systems with their inherent dependence on the networks through which they operate, little, if any attention, has been given to their survivability or to operational concepts that ensure the critical functionality they provide should they be unable to perform.
- We no longer have the ultimate proof afforded by underground testing. The scale of aboveground simulators will not allow exposure of large, complex systems.

At the same time, there have been technical advances that offer promise in addressing the security complexities, and budget realities, the nation faces.

- The National Nuclear Security Administration’s successes in its Science Based Stockpile Stewardship Program have laid a foundation for a model-based approach to assessing and ensuring nuclear survivability, one in which testing and qualification where possible with aboveground simulators remains important, but the simulators also assume an expanded role in model validation. The computational hardware continues to advance in both capacity and speed to allow addressing phenomena at the fundamental “physics” level. And models at that fundamental level are unraveling previously unexplained mysteries of hydrodynamics.
- While simulators and testing are still required, their use is expanded from “pass/fail” testing of hardware to support for model validation and establishing performance margins at the device and component levels. New and/or modified simulators, with significantly improved diagnostics, are coming on line that could be pushed even further in this direction.
- Although still a long way from full system qualification through modeling and simulation, experimentally validated models specific to some new life extension weapon components have been utilized to qualify, with high confidence, those components for the radiation environments for which they are designed. The model-based approach, by allowing exploration of a much broader part of the operating parameter space, is helping to quantify the uncertainties, as well as the expected performance of key components. This is true not only in cases where integrated testing is no longer feasible, but also to extend from integrated test results that are available to the full set of potential radiation environments systems may encounter.
- Ever smaller feature sizes in commercial electronics are leading to a need for some level of designed-in hardening because of upsets caused from natural sources. This offers an opportunity for DOD to work proactively with commercial chip designers early in the development process where hardening can be much more cost-effective.

In short, the path forward not only cannot, but indeed should not, replicate the past.

Recommendations: Military Operations and Capabilities

This first set of recommendations is targeted to and for military operators.

RECOMMENDATION 1. IMPORTANCE OF NUCLEAR SURVIVABILITY

The Chairman of the Joint Chiefs of Staff and the Service Chiefs, in “line-of-sight” fashion, should issue unambiguous guidance that restates the importance of nuclear survivability, as evidenced by the following steps:

- Nuclear scenarios should be re-introduced into Service and Joint experimentation, games, planning, rehearsal, and exercises.
- An education program on radiation effects and operating in nuclear environments should be implemented in the schools.
- Critical functions/capabilities that must be assured to operate through a nuclear environment should be identified by each combatant command.
- Annual reporting in the Defense Readiness Reporting System (DRRS) for nuclear survivability of critical functions/capabilities, to include how the assessment was made, should be required.³¹
- Where missing or inadequate, but required, hardness maintenance/hardness surveillance programs should be properly resourced.

RECOMMENDATION 2. TECHNICAL EXPERTISE AND CAPABILITIES

The Under Secretary of Defense for Acquisition, Technology and Logistics (USD [AT&L]) should ensure that appropriate technical expertise and capabilities are available to the Services by:

- Assigning DTRA responsibility for technical support to experimentation, gaming, exercises, education, and DRRS assessments related to nuclear survivability.
- Ensuring through DTRA, the Army, and the Department of Energy, that testing capabilities are available, and through the Office of the Secretary of Defense, Operational Test and Evaluation, that critical systems can be, and are, assessed if needed.

31. The task force observed that the Survivability Assessment group at U.S. Strategic Command offers an excellent model for leadership commitment and a balanced assessment process.

RECOMMENDATION 3. RADIATION SURVIVABILITY

The Services should evaluate, and where needed, test “smartly” fielded platforms and systems for radiation survivability.

- The initial focus should be to separate what is already known (e.g., some legacy systems) from what is not known, but should be (e.g., networks and unmanned systems). DTRA should serve as the principal Department resource for technical expertise and for arranging access to test and evaluation capabilities which may reside in other agencies or departments. The different requirements between strategic and most general purpose force components suggest that each category be addressed on its own terms, but opportunities for synergy and/or integration should also be identified.
- Given the “don’t know” list regarding the survivability of key systems and/or the pathways for assuring mission functionality, the Services and Joint community should use experimentation and/or gaming to prioritize analysis and testing.

RECOMMENDATION 4. CURRENT SYSTEM ASSESSMENTS

DTRA should also get ahead of current system assessments by working with the combatant commands and Service program offices to develop and assess new options for the use of potentially more survivable capabilities, such as unmanned platforms and alternative networks. (Table 3 illustrates the scope of challenge in understanding the survivability of a typical unmanned platform.)

Table 3. Nuclear Radiation Effects for Unmanned Systems

Radiation Effect	Occurrence of Effects			
	Part	Board	Package	System
Thermal mechanical shock – X-ray	X	X	X	X
Prompt X-ray/gamma dose rate				
– Rail-span collapse	X			
– Photoionization burnout	X			
– Latch-up	X			
– Secondary breakdown	X			
– High versus low dose rate	X			
Total ionizing dose – e, X-ray,	X			
Neutron displacement damage	X			
Neutron single event upset	X			
Internal electromagnetic pulse – X-ray	X	X	X	X
System generated electromagnetic pulse – X-ray	X	X	X	X
Electromagnetic pulse	X	X	X	X
Thermal			X	X

Recommendations: Creating a Nuclear Weapons Effects National Enterprise

The more diffuse nature of both threats and targets led the task force to the conclusion that the nation can no longer afford the stove-piped approach of the Cold War. Instead today’s environment calls out for a “national enterprise” to address nuclear survivability because of the complexity of the problem and the expense needed to address it—both in dollars and intellect.

Several departments have requirements and/or capabilities for nuclear survivability (see Table 4), but DOD is the majority stakeholder. The Services resource existing forces and programs of record, and Health Affairs has principal responsibility for understanding human response in extreme exposure environments. The Services are responsible for maintaining a test and evaluation infrastructure, although that infrastructure is at a significantly reduced level from Cold War capabilities, to support assessments. DOD also has responsibility, among the critical infrastructure sectors for homeland security, for the defense industrial base.

Table 4. Primary Department and Agency Responsibilities for Assuring Capabilities

	Intelligence Community	Department of Defense	Department of Energy/National Nuclear Security Administration	Department of Homeland Security
Stockpile		X	X	
Strategic Offense		X (Air Force & Navy)		
Strategic Defense		X (Services, Missile Defense Agency)		
Space Assets	X	X		
General Purpose Forces		X (Services)		
National Command, Control, and Networks		X (many)		X
Critical Infrastructure	X	X	X	X
Science and Technology, Tech Base		X (Defense Threat Reduction Agency, Army, Navy)	X	
Industry Design Teams	X	X	X (Laboratories)	X

The Department of Energy has responsibility for ensuring the survivability of the nuclear stockpile and the nation’s energy infrastructure. It has maintained a significant fraction of its Cold War simulator capability and technical expertise and built new capabilities, as well, as part of its Stockpile Stewardship Program of the last decade and a half. In addition, it has laid the foundation for the model-based approach the task force believes is the right path forward.

Other important departments or agencies include the intelligence community, most especially those agencies with space asset ownership and special network responsibilities, and the Department of Homeland Security, where the lead for critical infrastructure and the National Command, Control, and Communications system is assigned.

With these factors in mind, the task force developed the following recommendations for establishing a “national enterprise.”

RECOMMENDATION 5. LEADERSHIP FOUNDATION

To lay a foundation for a National Nuclear Weapons Effects Enterprise, the Secretaries of Defense and Energy, and the Director of National Intelligence should enter into a memorandum of understanding that addresses the military, intelligence, programmatic, and technical requirements for such an enterprise and its transformation to meet future national security requirements.³² Key aspects of the memorandum should include:

- Reestablishing an aggressive program of threat assessment, evaluation of uncertainties, and red teaming.
- Correcting the under-resourcing in both expertise and infrastructure to support the enterprise through development and implementation of a 10-year interdepartmental plan for rebuilding the science and technology and test and evaluation elements of the enterprise. Attention and investment related to nuclear survivability should be on par with that given to chemical or biological defense.
- Establishing the model-based approach as the technical foundation for the future enterprise.
- Waiver of all non-interference clauses, such that each department's or agency's capabilities can be tapped seamlessly by the governing body of the enterprise.
- Continued oversight function by independent expertise until the enterprise matures, with annual reporting to the Assistant to the Secretary of Defense for Nuclear and Chemical and Biological Defense Programs (ATSD [NCB]) on the health and progress against the 10-year plan.

The annual assessments called for in the previous set of recommendations related to military operations can serve as the driver for prioritizing both near-term activities and longer-term investments. DTRA can serve a pivotal role in compiling and sorting the various combatant command and Service assessments and advising enterprise leadership on priorities.

32. By the time this report was drafted, DTRA and NNSA had negotiated and successfully signed a memorandum of understanding for mutual cooperation and threshold funding to support a number of nuclear related missions of common interest. Nuclear weapons effects is included.

RECOMMENDATION 6. DESIGN, DEVELOPMENT, AND ACQUISITION

Several institutional steps are recommended to ensure the deliberate and informed assessment and achievement of nuclear survivability in new system acquisition:

- The Office of the Secretary of Defense, with support from the Joint Staff J8 Directorate (Force Structure, Resources, and Assessment), should re-institutionalize the Nuclear Effects/Weapons of Mass Destruction Survivability in the DOD Acquisition Guide by placing a DOD Instruction at the 5000 level and ensuring its flow down to subordinate documents.³³
- J8 should monitor that “reliable operations in nuclear environments” is explicitly addressed by any program in the Joint Capabilities Integration and Development System (JCIDS).
 - The Office of the Under Secretary of Defense for Policy should ensure that nuclear deterrence and use scenarios are a prominent part of the Defense Planning Scenarios.
 - USD (AT&L) and the Vice Chairman, Joint Chiefs of Staff should assume joint decision authority for waiving survivability requirements, on the recommendation of ATSD (NCB), for all programs critical to joint mission assurance.
- USD (AT&L) and the Administrator of NNSA should ensure the availability and evolution of design tools and unique validation capabilities. (See “near term technical recommendations” following.)
- DTRA should continue to work with the Defense Advanced Research Projects Agency and NNSA to seek alternatives to captive commercial foundries for radiation hardened micro-electronics, including support for research and development in innovative technologies that are inherently hard.

RECOMMENDATION 7. TECHNICAL ENTERPRISE: NEAR TERM

Near term recommendations to provide stop-gaps for the technical part of the enterprise include:

- DTRA has transitioned the West Coast Facility to L-3 to operate as a commercial, fee-for-service facility, but is maintaining ownership of the

33. As this report was being drafted, DOD issued DODI 3150.09 “The Chemical, Biological, Radiological, and Nuclear (CBRN) Survivability Policy.”

machines and monitoring their use, operational status, and modernization needs. Should this business model not prove viable, then DTRA should be prepared to reassess options for maintaining capabilities which the West Coast Facility currently provides in support of a wide range of government and defense industrial base customers.

- The task force was not convinced of the long term adequacy of the QASPR approach for fast neutron exposure qualification. A sustainable, long term strategy should be developed between the Departments of Energy and Defense. Until that is settled, Sandia's Annular Core Research Reactor (ACRR) and White Sands Missile Range (WSMR) capabilities must be maintained.
- The Deputy Secretary of Defense should ensure continued commitment by the Army and Navy, respectively, to maintain weapons effects testing capabilities at White Sands (Fast Burst Reactor, Electromagnetic Environmental Effects, etc.) and Pax River (Vertically and Horizontally Polarized Simulators).
- NNSA should clarify the access model and user requirements to DOD for use of the National Ignition Facility.
- The NNSA-DTRA Modeling and Simulation Working Group's roadmap for model development should be independently reviewed and integrated with the plans of the Simulator Working Groups to create the initial draft of the technical part of the 10-year enterprise plan called for in recommendation 5.
- DOD (principally DTRA and the Services) and NNSA should establish a continuing program to develop and advance the people with the advanced expertise needed for the nation's nuclear weapons effects capability.³⁴
 - The initial basis of the program should be an exchange of personnel among the Departments of Defense and Energy and the NNSA laboratories to teach operations, system design, code development, simulator advancement and hardening innovations.
 - The Military Research Assistant program, in which the Services assigned promising, advanced degree junior officers to the Department of Energy weapons laboratories for a tour of duty, should be resurrected.

34. The task force did not see this as limited only to nuclear weapons effects, but that should be the minimum focus.

RECOMMENDATION 8. ACHIEVING THE MODEL-BASED ENTERPRISE

In the longer term, but starting immediately, the technical basis of the enterprise should transition to one that is model-based. This will require several actions:

- USD (AT&L) should require that the science and technology and design communities shift to the new approach where they:
 - emphasize understanding basic science underlying radiation effects
 - encode that understanding in computer simulations with predictive capabilities well beyond current codes
 - extend the models to address distributed, networked systems
 - expand the role of experimental facilities from hardware testing to validation of physics models in simulated, well characterized radiation environments
 - quantify margins and uncertainties to guide design and operational practices, as well as prioritize future scientific directions
 - ATSD (NCB) should charter a joint DOD-NNSA working group to update prior modeling and simulation, and simulator capability needs that would address the broad set of survivability needs (e.g., strategic and general purpose forces, infrastructure, space, networks, etc.) discussed in this report. As the basis for the enterprise 10-year plan, the working group recommendations should be vetted by an independent oversight group and enlist the input and support of the Defense Test Resource Management Center.
 - DTRA and NNSA should develop and implement a long-term plan for rebuilding and maintaining technical talent required to support the enterprise.
 - The memorandum of understanding among the Departments of Defense and Energy and the intelligence community should be expanded to bring in the Department of Homeland Security. The enterprise should expand its focus to address intelligence and critical infrastructure issues.
-

Chapter 7. Summary

The task force urges DOD leadership to heed the wake-up call that this report is intended to provide.

Regional proliferation risks are growing, accompanied by nation state policy and doctrine that acknowledge limited nuclear use as a legitimate war fighting option. U.S. counters, especially defensive measures to ensure continued operations in radiation environments, are being reduced—by our own choices. Intelligence resources are focused elsewhere. The leadership is poorly educated on military operations in nuclear environments. The reliance on COTS in U.S. military systems has grown while nuclear survivability requirements, testing, and/or evaluation have declined—both dramatically. As a result, the nation lacks a clear understanding of the response to nuclear radiation exposure of general purpose forces, the Global Information Grid and the GIG-edge, and critical infrastructure on which DOD relies. Moreover, the technical expertise and infrastructure to help remedy the situation has decayed significantly. Investments in addressing nuclear survivability have declined precipitously while investments in addressing other WMD modalities, especially biological, have increased.

Recasting the recommendations of the previous chapter into a time-phased set of actions, **DOD should immediately:**

- Make nuclear survivability a routine issue for leadership attention as it used to be in the Cold War, but focused in the current context.
 - Ensure balanced investments among all WMD modalities, which means increasing resources focused on nuclear survivability—both funding and personnel.
 - Require routine reporting on survivability of critical fielded capabilities in the Defense Readiness Reporting System.
 - Restore operational knowledge and reflect it in the planning and training base.
 - Understand the limitations of existing and near-term additions to general purpose forces, the GIG, GIG edge, and critical infrastructure needed to generate and sustain forces.
- Take the first step in establishing a “national enterprise” by forging an agreement with the Department of Energy to reverse the decline in the nuclear weapons effects enterprise. Begin discussions with the Director,

National Intelligence, to expand the agreement to the intelligence community.

Over the next two to three years, DOD should:

- Formulate with the Department of Energy a professional nuclear weapons effects collaboration and mentoring program to expand and advance the human skills base.
- Improve understanding of both strategic and general purpose force operations reliant on net-centricity and unmanned systems in nuclear environments.
- Establish on-going reviews and threat assessments to update survivability standards.
- Pursue radiation hardened advances better coupled to commercial suppliers.
- Expand the agreement with the Department of Energy to the intelligence community.

In the longer term, DOD should:

- Move to a model-based approach for the weapons effects enterprise to make up for the lack of underground testing. The approach should take advantage of the advances in both aboveground simulators and high performance computing developed as part of the Department of Energy's Science Based Stockpile Stewardship Program.
- Expand agreements with the Department of Energy and the intelligence community to other agencies with a stake in the enterprise, especially the Department of Homeland Security.
- Ensure that the minimum "national enterprise" capability in trained expertise and aboveground simulators is sustained.

Implementing the recommendations of this task force can lead to significant improvements in the posture of critical capabilities for national security. The "reds" of the task force's current assessment can indeed shift to "yellow to green" (Figure 6).

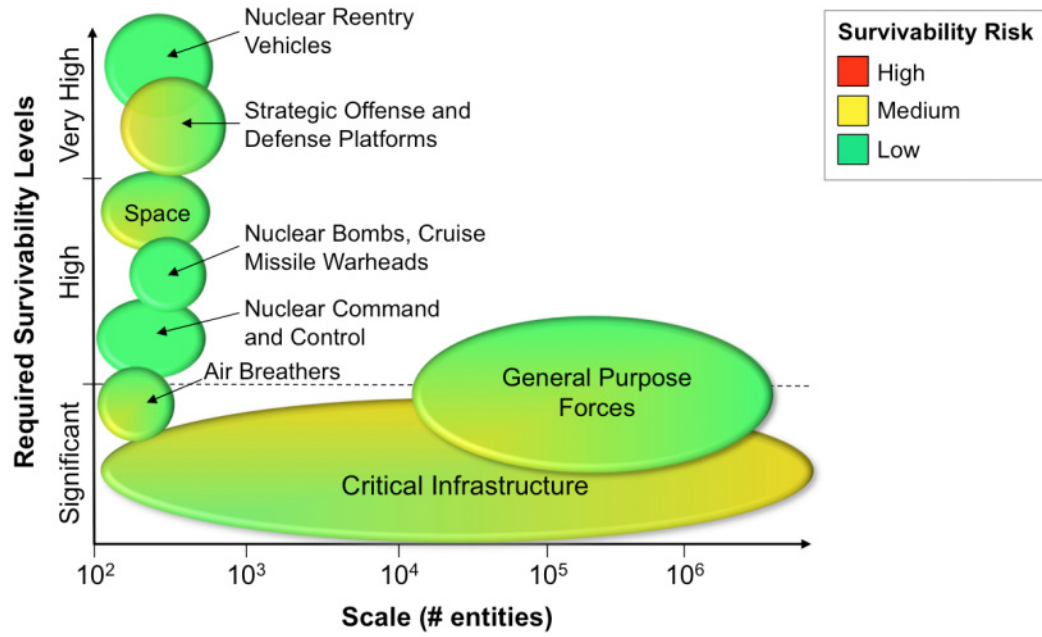


Figure 6. The Ten Year Picture, If Action is Taken

Appendix A. A Primer on Nuclear Weapons Effects

This appendix serves as a primer for nuclear weapon output, environments, and effects. To this end, this document relies heavily on existing literature, in particular on the *Nuclear Weapon Effects Technology, Section VI* (Reference 1). The authors have arranged the sections and have additional information, as needed, to make it an effective primer.³⁵ The companion bibliography provides a set of reference documents that cover this topic.

A nuclear detonation is characterized by an immediate, rapid, and brief release of nuclear radiations (immediate and residual), followed by a rapidly developing fireball (if in the atmosphere), which emits intense thermal radiation (heat and light), and generates a powerful pressure pulse, which travels out from the point of burst (shock or blast wave). It also causes ionization of the upper atmosphere, which is the fourth output of a nuclear detonation—the electromagnetic pulse (EMP). All pose problems for the survival of friendly systems and can lead to the destruction or neutralization of hostile assets. Understanding nuclear weapon effects requires knowledge of three related components. They are nuclear weapon:

1. output
2. environments
3. effects

Combined together, they become what are known generally as nuclear weapon effects. Nuclear explosions are generally classified as air bursts, surface bursts, subsurface bursts, or high altitude bursts.

Background

A nuclear detonation creates severe effects including blast, thermal pulse, neutrons, x- and gamma-rays, radiation, EMP, and ionization of the upper atmosphere. Depending upon the environment (air, surface,...) in which the nuclear device is detonated, blast effects are manifested as ground shock, water shock, “blueout,” cratering, and large amounts of dust and radioactive fallout. All

35. This appendix was prepared by A. Sharif Heger and Robert P. Weaver of Los Alamos National Laboratory, and Todd J. Hoover of Lawrence Livermore National Laboratory.

pose problems for the survival of friendly systems and can lead to the destruction or neutralization of hostile assets.

Nuclear detonations can be the most devastating of the weapons of mass destruction. To make this point one need only recall the pictures from Hiroshima or the international furor over the accidental but enormous radiation release from the Chernobyl power plant. The contamination from Chernobyl was significantly larger than would have been expected from a nuclear detonation of about 20 kilotons (kt) at ground level, but was comparable in extent to what might result from a “small” nuclear war in which a dozen or so weapons of nominal yield were exploded at altitudes intended to maximize blast damage. Hence, for those nations concerned about being the victims of a nuclear attack, the requirement for understanding and implementing ways of mitigating nuclear weapons effects is important. It is just as important for the user of a nuclear weapon to understand (and be able to mitigate) nuclear weapon effects on its own forces, not merely on the delivery vehicle, unless it can be certain that there will be no nuclear retaliatory strike.

Some important nuclear weapons effects are subtle in their action, producing no obvious visible damage to targeted systems. If these effects are to be employed deliberately, the using state must understand them well. To do so, requires experimental simulation and substantiated computation codes. In the absence of nuclear testing, simulation equipment, numerical simulation, and theoretical analysis of nuclear weapons effects are the only means states can verify how these effects will affect their own forces and those of their opponents in a nuclear environment. Nuclear weapon effects simulation, as well as survivability and hardening programs, have both offensive and defensive aspects, and may be desired by both nuclear possessor states and those with neither nuclear weapons nor plans to build them.

Although some nuclear weapons effects such as blast and cratering have analogs in the effects of conventional weapons, many nuclear weapons effects are unique to nuclear use. In addition, blast and other “common” weapons effects are likely to be much more powerful in the nuclear case than in the realm of conventional weapons. Nuclear weapon effects are so severe and complex that combinations of two or more simultaneously (as in a real event) may not add linearly, complicating the design and construction of physical simulators or the writing and validation of computer simulation codes (predictability).

Underground Nuclear Weapons Testing

Underground testing has provided much insight into weapon design, radiation effects—those from gammas, neutrons, and x-rays—on military systems, selected aspects of shock and blast, thermal effects, and source region EMP (SREMP). Countries with limited defense budgets are less likely than the major nuclear powers to have had exhaustive underground testing programs.

Output

The energy of a nuclear explosion is transferred to the surrounding medium in three distinct forms: blast, thermal radiation, and nuclear radiation. The distribution of energy among these three forms will depend on the yield of the weapon, the location of the burst, and the characteristics of the environment. For a low-altitude atmospheric detonation of a moderate sized weapon in the kiloton range, the energy is distributed roughly as follows:

- **Thermal radiation:** 30-50 percent of total energy made up of a wide range of the electromagnetic spectrum, including infrared, visible, and ultraviolet light and some soft x-ray emitted at the time of the explosion.
- **Blast:** 40-60 percent of total energy.
- **Ionizing radiation:** 5 percent of total energy initial ionizing radiation consisting chiefly of neutrons and gamma rays emitted within the first minute after detonation.
- **Residual radiation:** 5-10 percent of total energy. Residual nuclear radiation is the hazard in fallout. Considerable variation from this distribution will occur with changes in yield or location of the detonation.

Although it is convenient to characterize the output of a nuclear weapon in the order of thermal, blast, radiation, and EMP, these phenomena do not occur in that sequence and there is indeed a considerable overlap in their time history.

Environment Created by the Fireball

Immediately upon formation, the fireball begins to grow rapidly and rise like a hot air balloon. Within a millisecond after detonation, the diameter of the fireball from a 1 megaton (Mt) air burst is 150 meters. This increases to a maximum of 2,200 meters within 10 seconds, at which time the fireball is also rising at the rate

of 100 meters/second. The initial rapid expansion of the fireball severely compresses the surrounding atmosphere, producing a powerful blast wave.

As it expands toward its maximum diameter, the fireball cools, and after about a minute its temperature has decreased to such an extent that it no longer emits significant amounts of thermal radiation. The combination of the upward movement and the cooling of the fireball give rise to the formation of the characteristic mushroom-shaped cloud.

As the fireball cools, the vaporized materials in it condense to form a cloud of solid particles. Following an air burst, condensed droplets of water give it a typical white cloudlike appearance. In the case of a surface burst, this cloud will also contain large quantities of dirt and other debris which are vaporized when the fireball touches the earth's surface or are sucked up by the strong updrafts afterwards, giving the cloud a dirty brown appearance.

Effects

The dirt and debris become contaminated with the radioisotopes generated by the explosion or activated by neutron radiation and fall to earth as fallout. The relative effects of blast, heat, and nuclear radiation will largely be determined by the altitude at which the weapon is detonated.

Blast and Shock Effects from Nuclear Detonations

Although thermal radiation, EMP, and ionizing radiation from a nuclear blast are all damage producing, at yields below about a megaton the blast and shock produced by a nuclear weapon are the predominant means of damaging a target. For some targets, such as underground bunkers and missile silos, blast and shock are virtually the only effective destructive mechanisms.

Nuclear Thermal Radiation Effects

The intensity of thermal radiation decreases only as the inverse square of the distance from a nuclear detonation, while blast, shock, and prompt ionizing radiation effects decrease more rapidly. Thus, high-yield weapons are primarily incendiary weapons, able to start fires and do other thermal damage at distances well beyond the radius at which they can topple buildings or overturn armored vehicles.

Transient Radiation Effects in Electronics and System-Generated Electromagnetic Pulse

An understanding of transient radiation effects in electronics (TREE) and system generated electromagnetic pulse (SGEMP) is of critical importance in designing and building equipment that can survive a nuclear attack. It is not clear, however, that a nation having limited financial and technical resources could develop unique radiation-hardened devices and/or systems. These countries could, however, test a few critical subsystems or systems in an established foreign simulation facility. Although there are certain aspects of TREE and SGEMP technology that are of general scientific interest, for nations which have interests in the acquisition of nuclear weapons, the desire to evaluate and test systems at SGEMP and TREE dose rate levels typical of nuclear weapons is a useful indicator that they plan on nuclear combat, whether as a user or as a victim of the weapon.

The quantification of both phenomena is critical to the design of optical and electronic packages which can survive these effects. Ideally, such subsystems should be produced without significant increases in either cost or weight. Because the radiation that causes TREE and SGEMP is relatively strongly absorbed in the atmosphere, both phenomena are of primary importance to space systems exposed to high-altitude, high-yield nuclear detonations. Survivability analysis of semiconductor electronics requires quantitative understanding of at least the following:

- Ionization effects (both total dose and dose rate) which produce enhanced photocurrents in the transient state and can also cause permanent trapping of free charge in metal oxide semiconductor (MOS) devices.
- Displacement effects (displacement of lattice atoms leading to changes in the bandgap energy levels) and thermomechanical shock induced by the rapid deposition of energy from the nuclear detonation.

These effects depend not merely on total dose but also on dose rate. Naturally occurring effects include total dose from electrons and protons trapped in the Van Allen belts and single-event upset (SEU) or even single-event burnout. SEU results when enough ionization charge is deposited by a high-energy particle (natural or man-produced) in a device to change the state of the circuit—for example, flipping a bit from zero to one. The effect on a power transistor can be so severe that the device burns out permanently. Large x- and gamma-ray dose rates can cause transient upset and permanent failure. These dose rates are delivered over a 10 to 100 nanosecond time period. Delayed gammas in a 1 to 10 microsecond period at the same dose rate can cause latchup and burnout of devices. Latchup is the

initiation of a high-current, low-voltage path within the integrated circuit and causes the circuit to malfunction or burnout by joule heating.

Electromagnetic Signal Propagation

The large quantities of ionizing radiation produced by a high-altitude, high-yield nuclear detonation can severely change the environment of the upper atmosphere, producing heavily ionized regions, which can disrupt electromagnetic waves passing through those zones. These disturbed regions can easily be the size of North America and can persist for tens of hours. The trapping mechanism for these high-energy electrons may be similar to that which produces the Van Allen radiation belts. The actual degree of communications interruption is dependent upon the scenario and includes weapon yield and height of burst, time of day, cloud cover, latitude and longitude of the burst, the specific communications path, and the time after the detonation. Other systems which may be affected by nuclear weapons effects on electromagnetic wave propagation include sensors in the infrared (IR), visible, and ultra violet regions, and laser communications which may be affected by the background infrared. A very hot (but transparent) region of the atmosphere can act as a lens to refract a laser communications beam off of its intended receiver.

Radar beams are both attenuated and refracted when passing through a nuclear fireball at altitudes below 25 kilometers. At these altitudes the mean free path is small, and it is reasonable to speak of the fireball as being in local thermal equilibrium. Under these circumstances it is difficult to track incoming reentry vehicles. Optical systems will suffer increased noise levels both because of ionized regions and from blackbody radiation from the fireball, and long-wave infrared systems may be unable to see through the fireball to a reentry vehicle in the distance and may not be able to see a reentry vehicle nearer to the sensor than the fireball because of the background.

No high-altitude nuclear tests have been carried out by the United States since the ratification of the 1963 Limited Test Ban Treaty. Apparently, few IR data were obtained from the Checkmate, Kingfish, Orange, and Starfish high-altitude tests, so the visual information from those tests has been extrapolated to the IR regime. The main sources of high-altitude IR which would produce clutter include plasma emission, molecular and atomic emission from excited states, and emission from uranium oxide. All of these are functions of electron density. At frequencies above about 300 megahertz (ultra high frequency, super high frequency, and extremely high frequency), signals may be disrupted by

scintillation, primarily characterized by intermittent fading and multipath transmission. These effects may persist for long periods and can degrade and distort a signal almost beyond recognition (for example, the plasma clouds are dispersive so that the speed of all frequencies of electromagnetic radiation is not equal in the cloud). Temporal and frequency coherence can both be destroyed.

High-Altitude Electromagnetic Pulse

A high-altitude nuclear detonation produces an immediate flux of gamma rays from the nuclear reactions within the device. These photons in turn produce high energy free electrons by Compton scattering at altitudes between (roughly) 20 and 40 kilometers. These electrons are then trapped in the earth's magnetic field, giving rise to an oscillating electric current. This current is asymmetric in general and gives rise to a rapidly rising radiated electromagnetic field called an electromagnetic pulse (EMP). Because the electrons are trapped essentially simultaneously, a very large electromagnetic source radiates coherently.

The pulse can easily span continent-sized areas, and this radiation can affect systems on land, sea, and air. The first recorded EMP incident accompanied a high-altitude nuclear test over the South Pacific and resulted in power system failures as far away as Hawaii. A large device detonated at 400–500 kilometers over Kansas would affect all of the continental United States. The signal from such an event extends to the visual horizon as seen from the burst point.

The EMP produced by the Compton electrons typically lasts for about one microsecond, and this signal is called HEMP. In addition to the prompt EMP, scattered gammas and inelastic gammas produced by weapon neutrons produce an “intermediate time” signal from about one microsecond to one second. The energetic debris entering the ionosphere produces ionization and heating of the E-region. In turn, this causes the geomagnetic field to “heave,” producing a “late-time” magnetohydrodynamic (MHD) EMP generally called a heave signal.

Initially, the plasma from the weapon is slightly conducting; the geomagnetic field cannot penetrate this volume and is displaced as a result. This impulsive distortion of the geomagnetic field was observed worldwide in the case of the Starfish test. To be sure, the size of the signal from this process is not large, but systems connected to long lines (e.g., power lines, telephone wires, and tracking wire antennas) are at risk because of the large size of the induced current. The additive effects of the MHD-EMP can cause damage to unprotected civilian and military systems that depend on or use long-line cables. Small, isolated systems tend to be unaffected.

Military systems must survive all aspects of the EMP, from the rapid spike of the early time events to the longer duration heave signal. One of the principal problems in assuring such survival is the lack of test data from actual high-altitude nuclear explosions. Only a few such experiments were carried out before the Limited Test Ban Treaty took effect, and at that time the theoretical understanding of the phenomenon of HEMP was relatively poor. No high-altitude tests have been conducted by the United States since 1963.³⁶ The “acid test” of the response of modern military systems to EMP is their performance in simulators, particularly where a large number of components are involved. So many cables, pins, connectors, and devices are to be found in real hardware that computation of the progress of the EMP signal cannot be predicted, even conceptually, after the field enters a real system. System failures or upsets will depend upon the most intricate details of current paths and interior electrical connections, and one cannot analyze these beforehand. Threat-level field illumination from simulators combined with pulsed-current injection is used to evaluate the survivability of a real system against a HEMP threat.

Source Region Electromagnetic Pulse

Source region electromagnetic pulse (SREMP) is produced by low-altitude nuclear bursts. An effective net vertical electron current is formed by the asymmetric deposition of electrons in the atmosphere and the ground, and the formation and decay of this current emits a pulse of electromagnetic radiation in directions perpendicular to the current. The asymmetry from a low-altitude explosion occurs because some electrons emitted downward are trapped in the upper millimeter of the earth’s surface while others, moving upward and outward, can travel long distances in the atmosphere, producing ionization and charge separation. A weaker asymmetry can exist for higher altitude explosions due to the density gradient of the atmosphere.

Within the source region, peak electric fields are much larger than those from HEMP and pose a considerable threat to military or civilian systems in the affected region. The ground is also a conductor of electricity and provides a return path for electrons at the outer part of the deposition region toward the burst point. Positive ions, which travel shorter distances than electrons and at lower velocities, remain behind and recombine with the electrons returning through the ground. Thus, strong magnetic fields are produced in the region of ground zero.

36. In addition to the more familiar high-yield tests mentioned above, three small devices were exploded in the Van Allen belts as part of Project Argus. That experiment was intended to explore the methods by which electrons were trapped and traveled along magnetic field lines.

When the nuclear detonation occurs near to the ground, the SREMP target may not be located in the electromagnetic far field but may instead lie within the electromagnetic induction region. In this regime the electric and magnetic fields of the radiation are no longer perpendicular to one another, and many of the analytic tools with which we understand electromagnetic coupling in the simple plane-wave case no longer apply. The radiated electromagnetic field falls off rapidly with increasing distance from the deposition region (near to the currents the EMP does not appear to come from a point source). As a result, the region where the greatest damage can be produced is from about 3 to 8 kilometer from ground zero. In this same region structures housing electrical equipment are also likely to be severely damaged by blast and shock. The threat to electrical and electronic systems from a surface-burst EMP may extend as far as the distance at which the peak overpressure from a 1-megaton burst is 2 pounds per square inch (Glasstone and Dolan).

One of the unique features of SREMP is the high late-time voltage which can be produced on long lines in the first 0.1 second. This stress can produce large late-time currents on the exterior shields of systems, and shielding against the stress is very difficult. Components sensitive to magnetic fields may have to be especially hardened. SREMP effects are uniquely nuclear weapons effects.

During the Cold War, SREMP was conceived primarily as a threat to the electronic and electrical systems within hardened targets such as missile launch facilities. Clearly, SREMP effects are only important if the targeted systems are expected to survive the primary damage-causing mechanisms of blast, shock, and thermal pulse.

Blast and Shock

Blast and shock waves produced by nuclear explosions are the principal means for destroying soft targets. Ground shock from a low-altitude, surface, or underground burst may be the only way to destroy hardened underground structures such as command facilities or missile silos. In the absence of atmospheric and underground nuclear testing to determine the survivability of structures, means must be found to simulate the phenomena associated with a nuclear explosion.

For blast and shock this can be done either in a large-scale, open-air test employing chemical explosives or in a specially designed test facility which can also produce thermal fluxes comparable to those from a nuclear weapon. The air blast from a nuclear explosion is, however, different from that produced by

conventional explosives. Because of the intense thermal pulse, the surface and near-surface air mass surrounding ground zero is heated rapidly. Within this heated region, the blast wave travels more rapidly than it does in the cooler air above. As a result, blast waves reflected from the ground travel outward and merge with the direct blast wave from the explosion. This produces a nearly vertical shock front called the Mach stem, which is more intense than that from the direct blast.

To simulate the Mach stem with tests using high explosives, scientists have employed helium-filled bags at ground level surrounding the high explosives used in the test. Because such tests can only be scaled and do not replicate the actual effects of a nuclear explosion, only scale models of test objects could normally be used. More recently, national attention has focused on a higher pressure regime than can be attained in open-air testing and on the construction of large simulators capable of reproducing simultaneously the blast and the thermal pulse from a nuclear detonation. These simulators typically employ a fuel-oxygen mixture, for example, liquid oxygen and finely powdered aluminum, and consist of long semicircular tubes. These simulators can even approximate the effects of soil type on blast wave propagation as well as the entraining of dust in the blast wave.

Thermal Radiation

Thermal radiation decays only as the inverse square of the distance from the detonation. Thus, weapons in the megaton class and above are primarily incendiary weapons, able to start fires and do other thermal damage at distances well beyond the radius at which they can topple buildings or overturn armored vehicles. The effect of thermal radiation on unprotected human beings is likely to be very serious, producing flash burns over large areas of the body. The response of a structure to the thermal pulse from a nuclear weapon depends upon its composition (wood, masonry, concrete); the type and albedo of any exterior paint; the transparency of any windows facing the burst; the type, texture, and composition of roofing; and even the presence or absence of awnings and shades. For weapons in the 1 to 200-kiloton region used against structures commonly found in the West, blast effects are likely to predominate; larger weapons will have the ability to start fires at distances far greater than they can inflict significant blast damage. Films of tests conducted in Nevada in the 1950s confirm that at the extreme distance at which wood-frame houses can be ignited by lower yield weapons, the buildings are blown apart seconds later by the blast wave, while structures which survive the blast do not ignite after the blast. Tests conducted in

the Pacific using megaton-class weapons show the opposite effect. Secondary fires started by broken gas mains, electrical short circuits, etc., are not considered here.

Summary of the Effects

Table A-1 summarizes the most important effects of nuclear explosions under certain conditions.

Table A-1. Important Nuclear Explosion Effects

Effects	Explosive Yield/Height of Burst			
	1 kt/ 200 m	20 kt/ 540 m	1 Mt/ 2.0 km	20 Mt/ 5.4 km
Blast—effective ground range (GR/km)				
Urban areas almost completely leveled (20 PSI)	0.2	0.6	2.4	6.4
Destruction of most civil buildings (5 PSI)	0.6	1.7	6.2	17
Moderate damage to civil buildings (1 PSI)	1.7	4.7	17	47
Thermal radiation—effective ground range (GR/km)				
Conflagration	0.5	2.0	10	30
Third degree burns	0.6	2.5	12	38
Second degree burns	0.8	3.2	15	44
First degree burns	1.1	4.2	19	53
Effects of instant nuclear radiation—effective slant range* (SR/km)				
Lethal** total dose (neutrons and gamma rays)	0.8	1.4	2.3	4.7
Total dose for acute radiation syndrome**	1.2	1.8	2.9	5.4

* For the direct radiation effects the slant range instead of the ground range is shown here, because some effects are not given even at ground zero for some burst heights. If the effect occurs at ground zero the ground range can simply be derived from slant range and burst altitude.

** “Acute radiation syndrome” corresponds here to a total dose of one gray, “lethal” to ten grays. Note that this is only a rough estimate since biological conditions are neglected here.

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Appendix B. Hardening Microelectronics

Radiation Threats to Performance of Integrated Circuits

High-energy radiation (the kind that penetrates the package surrounding the semiconductor chip) causes three major threats to integrated circuits.³⁷

- **The first threat category consists of dose-rate exposure**, in which ionizing radiation generates on-chip currents that compete with and interfere with the desired currents that control the functionality of integrated circuits. Photocurrents generated may cause temporary loss of stored information or disrupt functional operation of an integrated circuit or in some cases cause permanent damage to a device.
- **The second threat category consists of total-dose effects**, in which incoming radiation disorders the very semiconductor material itself to change the operating characteristics of the transistors that comprise the integrated circuit.
- **The final threat category consists of single-event effects**, in which a space environment particle, such as a cosmic ray (an energetic nucleus with millions of electron volts of energy for each nuclear subparticle) strikes a single transistor, creating localized currents that are not present during normal operation. Energetic particles (e.g., protons, neutrons, and heavier ions) can also cause displacement damage in silicon and other semiconductor materials as the size of the transistor shrinks. In addition to causing total dose ionization degradation and displacement damage, these energetic particles can also cause single-event effects. As a single high-energy particle strikes a material, it generates a dense plasma of electron-hole pairs along the path of the particle, which can trigger a variety of single-event effects. Single-event effects are classified into two types: soft errors, which cause no permanent damage and may be correctable, and hard errors, which result in permanent damage to the device.

³⁷. More detailed explanations of the phenomena described in this section are considered sensitive and have not been presented in this report.

Prudent Design Practices

A number of practices and tools can help address concerns about maintaining the integrity and continuity of microcircuit operations in radiation environments. The list in the text box, although not exhaustive, illustrates that much can be done, but each may come with some expense. That expense is most wisely incurred at the outset of the design. The task force noted that Army data suggest that radiation hardening of key components in new acquisitions typically adds fractions to a few percent to design costs, while retrofits are most typically unaffordable.

How Do We "Harden" with Commercial-off-the-Shelf? Good Design Practices and Tools That Help

- Parts selection through up-screening by radiation characterization
- Process technology selection, i.e., CMOS/bulk, CMOS/epitaxial, CMOS/SOI, bipolar dielectric, bipolar bulk
- Design using radiation-degraded parameters caused by neutron and ionizing dose effects
- Dose rate characterization at high and very low rates
- Current limiting
- Shielding or localized shielding
- Software and hardware error detection and correction
- Constant refreshing
- Redundancy or triple voting logic
- Minimize the number of selected suppliers and part count
- Minimize the number of active components
- Use hardened parts in critical circuits of a system, i.e., PROMs, custom ASICs
- Use of power and ground planes to isolate noise
- Conformal coating of the multilayered boards
- Minimize large cross-coupling capacitance, careful routing of traces
- Watch-dog timer for microprocessor
- EDAC to scrub SRAMs
- Detection, recycle power and recovery circuitry against latch-up
- Use hardened nonvolatile memory, energy storage backup, or ROM for storing critical data
- Test, test, test!

Appendix C. Radiation Hardened Foundries

A number of hardening techniques can be implemented at the parts, board, subsystem, and system levels. At the semiconductor level, a number of foundries have been dedicated over the past several decades to developing and designing hardened chips. Some military programs had captive lines to maintain the hardness assurance of the parts. In the 1990s, with reduced defense spending, many programs were cut and the threat requirements were reevaluated.

A declining demand for radiation hardened systems led to a downsizing in the number of radiation hardened (rad hard) foundries. In the late 1980s, the United States had about twenty foundries capable of developing rad hard semiconductor devices with ionizing dose hardness greater than 300 krad(Si). Some of them included Honeywell, Harris, UTMC, LM Manassas, TRW, Texas Instruments, National Semiconductor, RCA, Westinghouse, IBM, AMI, and Motorola. Today Honeywell, Intersil (formerly Harris), and BAE (formerly LM Manassas) are the few commercial foundries that can demonstrate ionizing dose hardness greater than 300 krad(Si). Honeywell is the only commercial supplier that has advertised their parts hardness to 1 Mrad(Si). The number of foundries that are continuing to provide strategic radiation tolerant parts has dropped dramatically (Figure C-1). In addition, the number of available nuclear simulators has significantly been reduced, along with the cadre of expertise that understood nuclear hardening design at the parts and system levels.

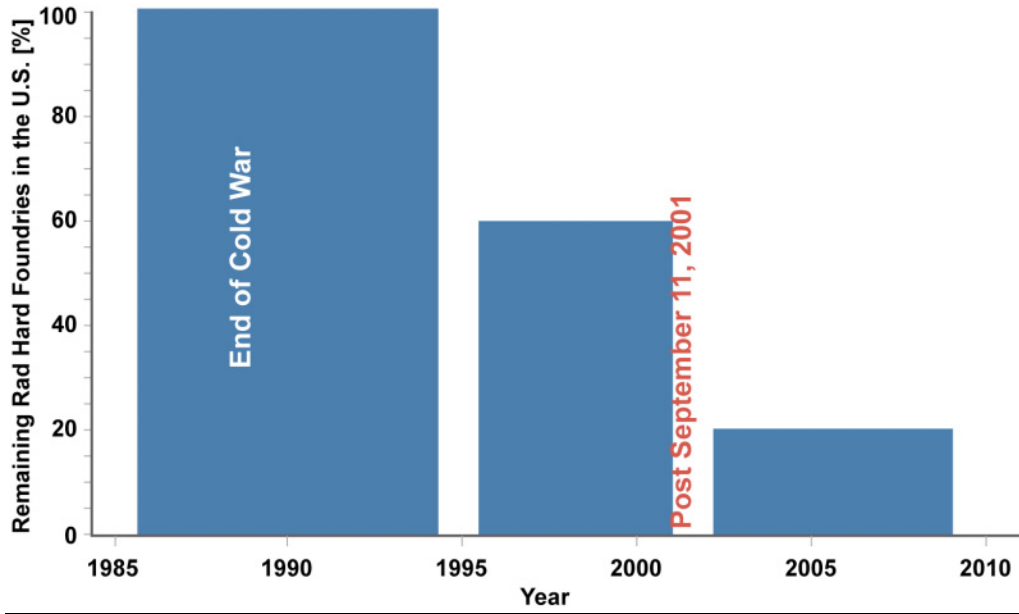


Figure C-1. Radiation Hardened Foundries in the United States

Terms of Reference



ACQUISITION,
TECHNOLOGY
AND LOGISTICS

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

NOV 3 2006

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD CHAIRMAN, THREAT REDUCTION ADVISORY COMMITTEE

SUBJECT: Terms of Reference -- Joint Defense Science Board (DSB)/Threat Reduction Advisory Committee (TRAC) Task Force on the Nuclear Weapons Effects (NWE) National Enterprise

Request you form a Joint DSB/TRAC Task Force to assess the Nation's NWE Enterprise.

An April 2005 DSB Task Force on "Nuclear Weapons Effects Test, Evaluation and Simulation" identified the need for the Department of Defense (DoD) and the Department of Energy (DoE) to define and support a "national" enterprise for NWE modeling, simulation, test, and evaluation capabilities. Defense Threat Reduction Agency (DTRA) in DoD and the National Nuclear Security Administration (NNSA) in DoE, have signed a Memorandum of Understanding to coordinate on such matters and are discussing the integrated set of capabilities as envisioned in the national enterprise model. Still, the model has not yet been realized.

The need has recently grown more acute as Agencies and Services that have sponsored key simulator capabilities -- lacking a requirements pull from the Combatant Commanders and Services -- are facing simulator facility closures because of lack of paying users. The DSB report contends the capabilities are not ones the government should expect to be underwritten entirely by defense industry or Service customers, and, as a result, the government must be prepared to underwrite to some degree such national capabilities. At the same time, however, the Combatant Commands and Services must step up to the responsible consideration of nuclear survivability as part of the capabilities planning and resourcing process in DoD.

I request the joint DSB/TRAC task force elevate nuclear survivability as an important "requirement" and ensure a viable NWE assessment capability for the future. To this end, the task force is to:

1. Review and assess for adequacy of the:
 - a. Existing DoD standards for nuclear survivability, based on an assessment of current and emerging nuclear capabilities of potential adversaries.



b. Lists in DoD of critical warfighting and enabling systems and capabilities that must function through, or immediately after, a nuclear event.

c. Present and planned DoD programs and procedures for assessing these critical systems and capabilities against the applicable standards. Consider how well the DoD addresses vulnerabilities through the tradeoffs between hardening and other mitigation schemes.

d. Present and planned suite of test and simulation facilities used by DoD to support the DoD survivability programs.

2. Recommend a “national enterprise” for DoD and DOE to meet nuclear survivability program objectives in the future (2015 and beyond) that:

a. Includes DoD and DOE infrastructure.

b. Emphasizes a modeling and simulation-based approach, augmented by the necessary experimental capability necessary to develop, validate, and verify the models.

c. Provides for a transition from the current enterprise to the new approach without loss of present capability to support survivability program objectives.

d. Includes a viable business model that would provide sustained support for a baseline effort coupled to “campaigns” for:

(1) New or modified major systems.

(2) Hardness surveillance and maintenance programs of existing critical systems.

3. Evaluate the need for an ongoing oversight body or other management approach to assure the needed transformation to the modern national enterprise occurs.

The task force should coordinate with and/or leverage the:

1. Second phase of the congressionally sanctioned EMP Commission due to complete its work in 2007.

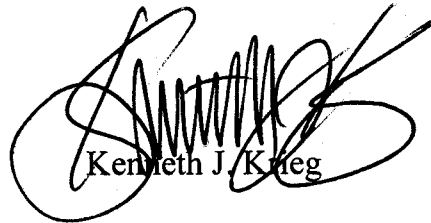
2. Army’s effort to address EMP issues.

3. Commercial space sector approach to radiation hardening using COTS components.

The task force will be sponsored by me as USD(AT&L) and the Assistant to the Secretary of Defense for Nuclear and Chemical and Biological Programs. Request the

NNSA Administrator support NNSA involvement. The task force will be co-chaired by Dr. Miriam John and Dr. Joseph Braddock. The executive secretaries will be Ms. Joan Pierre from DTRA and Dr. Ralph Schneider from NNSA. Commander Cliff Phillips will serve as the Defense Science Board representative.

The Task Force will operate in accordance with the provisions of Public Law 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 title 18, United States Code, section 208, nor will it cause any member to be placed in the position of acting as a procurement official.



Kenneth J. Krieg

cc:
Administrator, NNSA

Task Force Membership

NAME	AFFILIATION
Chairs	
Dr. Joseph Braddock	Private Consultant
Dr. Miriam John	Private Consultant
Members	
Mr. Franco Cristadoro	Northrop Grumman/U.S. Air Force
Mr. Bill Delaney	MIT Lincoln Laboratory
Dr. John Foster	Private Consultant
Dr. Bryan Gabbard	Defense Group, Inc.
Dr. Gary Lum	Lockheed Martin
Maj Gen Thomas Neary (ret)	SAIC
Gen Jack Vessey (ret)	Private Consultant
Dr. Rich Wagner	Los Alamos National Laboratory
Dr. Stephen Younger	Department of Energy
Executive Secretaries	
Ms. Joan Ma Pierre	Defense Threat Reduction Agency
Dr. Ralph Schneider	National Nuclear Security Administration
Government Advisors	
Dr. Wendee Brunish	Los Alamos National Laboratory
Mr. Curtis Buckles	OPNAV/N514
Lt Col Steven Creighton	Defense Threat Reduction Agency
Mr. Dwayne Curtiss	Navy Strategic Systems Programs
Dr. Christopher Deeney	National Nuclear Security Administration
Mr. John Franco	Defense Threat Reduction Agency
Lt Col Kathy Gilmartin	U.S. Army/Nuclear and Combating WMD Agency
Mr. John Gipson	U.S. Strategic Command
Col Brian Groft	U.S. Army/Nuclear and Combating WMD Agency
Dr. Sharif Heger	Los Alamos National Laboratory
Dr. John Kuspa	Office of the Secretary of Defense, Nuclear Matters
Dr. James Lee	Sandia National Laboratories
Dr. David Lojewski	Defense Threat Reduction Agency
Dr. Len Lorence	Sandia National Laboratories
Mr. James McComb	Missile Defense Agency
Mr. Andy Metzger	U.S. Strategic Command
Dr. Billy Mullins	U.S. Air Force/A3S
Mr. John O’Kuma	U.S. Army/White Sands Missile Range
Ms. Marlene Owens	Office of the Secretary of Defense/Test Resource Management Center
Mr. Darrell Palmer	U.S. Air Force /A3S

NAME	AFFILIATION
Government Advisors (continued)	
Mr. Fred Sexton	National Nuclear Security Administration
Dr. Richard Singer	Office of the Director, Defense Research and Engineering
Mr. Jan Smith	Office of the Secretary of Defense/Test Resource Management Center
Dr. Tom Thomson	Lawrence Livermore National Laboratory
Mr. Robert Webb	Missile Defense Agency
Dr. Sharif Heger	Los Alamos National Laboratory
DSB Representative	
CDR Clifton Phillips, USN	Office of the Under Secretary of Defense for Acquisition, Technology and Logistics
Staff	
Barbara Bicksler	Strategic Analysis, Inc.
Ms. Stacy O'Mara	Strategic Analysis, Inc.

Presentations to the Task Force

NAME	TOPIC
November 8–9, 2006	
Ms. Judy Kim	DOD General Counsel Briefing
Dr. Charles Craft	Global Profile of Nuclear Activities
Mr. Scott Petrakis	Test Activities
Ms. Lacey Muhlfeld	Test Activities
Mr. Fred Celec	Electromagnetic Pulse Commission, Military Capabilities
Dr. John Kuspa & Mr. Steven Henry	DOD Plans for Electromagnetic Pulse Survivability
Dr. Jim Tegnelia	Defense Threat Reduction Agency's (DTRA) Desired Results
Mr. Randy Davis	Red Book Program Support to DOD Missions
Mr. Todd Hoover	Red Book Activities at Lawrence Livermore National Laboratory
Dr. Bob Weaver	Red Book Activities at Los Alamos National Laboratory
December 4–5, 2006	
Col Brian Groft	Army Nuclear Survivability
Mr. Bill Cooper	Capabilities Based Planning/Joint Capabilities Integration and Development System (JCIDS)
Mr. Robert Webb	Missile Defense Agency High Altitude Exo-Atmospheric Nuclear Survivability (HAENS) Standard
Mr. John Franco	NNSA/DTRA Simulator Working Group
Dr. David Crandall	NNSA Nuclear Survivability Program
Mr. Andy Metzger	U.S. Strategic Command Requirements for Nuclear Effects
Dr. Joe Braddock	Red-Blue Perspectives on Nuclear Weapons
Mr. John Ingram	Vulnerability and Hardening
January 8–10, 2007	
Dr. Victor Gavron	Review of Los Alamos Neutron Science Center Capabilities
Lt Col Steve Creighton	Defense Threat Reduction Agency Modeling and Simulation
Dr. Brian Aubert	Assessment of Weapon Effects (Los Alamos National Laboratory)

January 8–10, 2007 (continued)	
Mr. Ron Parker	Weapon Qualification Tests (Los Alamos National Laboratory)
Mr. John Franco	DTRA/NNSA IPT Results Update
Mr. Cliff Giles	Foreign Electromagnetic Pulse Simulators
Dr. Chris Wallace	Conventional Electromagnetic Pulse
Dr. James Lee	Weapon Reliability in Nuclear Environments
Dr. Mark Hedemann	W76-1 Design and Qualification
Dr. Len Lorence	Predictive Capabilities Framework
Dr. Charles Barbour & Dr. James Lee	Design and Qualification without SPR
Dr. David Price	Welcome to Pulse Sciences
Dr. Peter Sincerny	Customer Base and Business Model for West Coast Facility
Dr. Peter Coakley	Systems, Simulation, and Modeling
Mr. Ed Moses	National Ignition Facility Overview
Mr. Tom Thomson	Outputs, Environments, and Effects
Mr. Kevin Fournier & Mr. Mike Tobin	Nuclear Weapons Effects Testing at the National Ignition Facility
Mr. Jon Fisher	X-ray Effects Testing at OMEGA and National Ignition Facility
Mr. Brian MacGowan	National Ignition Facility as a Facility User
Mr. Todd Hoover	Red Book Work
February 14–16, 2007	
Dr. Ronald Jost	Overview of the Global Information Grid
Mr. John O’Kuma	Army Nuclear Weapons Effects Facilities and Capabilities
Ms. Phyllis Ferguson	Business Model for Major Test Facilities
Lt Col Christopher Kinnan	Air Force Survivability Assurance
Mr. Curt Buckles	Navy Survivability Assurance
Dr. Len Lorence	Update on Modeling and Simulation IPT
Ms. Joan Ma Pierre	Update on L-3 Projections of X-ray Facility Use
Dr. Joe Braddock	Army-DTRA-ASB Workshop
DIA Representatives	Current Assessment Plan/Electromagnetic Pulse Commission
LLNL, LANL, and Sandia Representatives	Lab Contributions/Electromagnetic Pulse Commission

March 29–30, 2007	
Dr. Peter Sincerny	L-3 Simulator Privatization Plan
Dr. Tom Mahnken	Defense Planning Scenarios
Mr. William Keller	SCI Discussion
Mr. Mike Tobin	Testing at the National Ignition Facility
April 30–May 1, 2007	
Mr. Fred Sexton	Strategy to Develop a Nuclear Weapons Effects Enterprise
Mr. Adrian Gannon	UK Weapon Effects Simulator & Analysis
May 17–18, 2007	
Lt Col Steve Creighton	IPT Update
Dr. John Zolper	Defense Advanced Research Projects Agency's Radiation Hard by Design Program
June 21–22, 2007	
Mr. William Thoms	Defense Information Systems Agency Discussion
Dr. Bryan Gabbard	Assuring Future DOD Nuclear Capabilities

Glossary

ACRR	Annular Core Research Reactor
AGT	aboveground test
ASC	Advanced Simulation and Computing
ASCI	Accelerated Strategic Computing Initiative
ATSD (NCB)	Assistant to the Secretary of Defense for Nuclear and Chemical and Biological Defense Programs
C4ISR	command, control, communications, and computers, and intelligence, surveillance, and reconnaissance
CBRN	chemical, biological, radiological, and nuclear
CFE	Conventional Forces in Europe
COTS	commercial off-the-shelf
CMOS	complementary metal oxide semiconductor
CNS	Center for Nonproliferation Studies
DEMP	dispersed electromagnetic pulse
DOD	Department of Defense
DRRS	Defense Readiness Reporting System
DSB	Defense Science Board
DTRA	Defense Threat Reduction Agency
ECEMP	electron caused electromagnetic pulse
EMP	electromagnetic pulse
FARC	Revolutionary Armed Forces of Colombia
GIG	Global Information Grid
HAENS	High Altitude Exo-atmospheric Nuclear Survivability
HEMP	high-altitude electromagnetic pulse
HERMES	High-Energy Radiation Megavolt Electron Source
HPD	Horizontally Polarized Dipole
IEMP	internal electromagnetic pulse
ICBM	intercontinental ballistic missile
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
ITRS	International Technology Roadmap for Semiconductors
JCIDS	Joint Capabilities Integration and Development System
JSWG	Joint Simulator Working Group
keV	kiloelectron volt

kt	kiloton
LHE	light initiated high explosive
MANET	mobile adhoc networks
MBS	Modular Bremsstrahlung Source
MCTL	Militarily Critical Technologies List
MHD	magnetohydrodynamic
MOS	metal oxide semiconductor
Mt	megaton
NIAB	non-ideal air blast
NNSA	National Nuclear Security Administration
NWE	nuclear weapons effects
QASPR	Quantification of Alternatives to SPR
RB	reentry body
RDT&E	research, development, test, and evaluation
RV	reentry vehicle
S&T	science and technology
SBSS	Science Based Stockpile Stewardship [Program]
SEU	single-event-update
SGEMP	system generated electromagnetic pulse
SOI	silicon-on-insulator
SPR	Sandia Pulsed Reactor
SREMP	source region electromagnetic pulse
TREE	transient radiation electronic effects
UGT	underground test
USANCA	U.S. Army Nuclear and Combating WMD Agency
USD (AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
WMD	weapons of mass destruction
WSMR	White Sands Missile Range
ZR	Z-Refurbished