Strategic Weapons in the 21st Century: Rethinking Nuclear and Non-Nuclear Elements of the Deterrent

Science and Deterrence
Narrative for Workshop Discussion

Co-Chairs: Bill Schneider and John Immele
Rapporteur: Mark Domzalski

This topical area is focused on the following question: What are the science and technology opportunities and challenges associated with maintaining a credible deterrent in the 21st century?

The centrifugal forces unleashed in Europe, Asia, the Middle East, and Africa following the collapse of Soviet military power, authority, and influence has led to the creation of a threat environment that differs fundamentally from the character of threats we faced in the 20th century. For most of the 20th century we had ample strategic warning and sufficient insights into the nature of the adversary's capabilities to permit the development and deployment of forces optimized to deter or defeat the threat.

The 21st century threats posed to the United States (US) and its allies have the property that we are unable to characterize adversary threats far enough in advance to develop and deploy military forces that are optimized against them. Moreover, the cost of recapitalizing the platform inventory to adapt to new threats would be prohibitive. Because we can no longer depend on planning that is threat based, it has become necessary to create highly flexible capabilities that permit military options to be reconfigured as threats emerge. The evolution of the threat from nation-state adversaries to those that may represent neither a state nor an army also poses a fundamental challenge to classic notions of deterrence – in effect, the US presents allies and potential adversaries alike with a capability-based deterrence: weapons, science and technology (S&T) and manufacturing infrastructure that are adaptive and responsive to the uncertain future.

The cumulative effect of evolutionary changes in the capabilities of general purpose forces over the past two decades have had a revolutionary impact on these capabilities that has dissuaded most nations from attempting to create similar capabilities. Instead, several of these nations (e.g. Iran, North Korea) have chosen to invest in asymmetric capabilities including weapons of mass destruction (WMD), anti-access technologies, and clandestine support for terrorism.

In response to these circumstances, the US government has had to evolve its Cold War deterrence policy into a broader concept that has integrated the full-range of its military capabilities (kinetic and non-kinetic/non-nuclear and nuclear) into a policy continuum that seeks to assure security partners that these capabilities can be applied when needed. Further, in an effort to devalue adversary investment in WMD, the US also seeks to dissuade nations or sub-national groups from seeking to acquire WMD. Failure to dissuade will then require the application of traditional concepts of deterrence and the defeat of adversary capabilities.[1]

These more comprehensive policy aspirations cannot be achieved with Cold War concepts and capabilities – the full range of non-nuclear capabilities need to be brought to bear and integrated into what has been described as the "new triad" of nuclear and non-nuclear strike, defenses, and a responsive nuclear weapons manufacturing and development infrastructure integrated through a modern Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) system. The focus on C4ISR modernization has enabled the US to network its inventory of platforms in a manner that makes network rather than platform capabilities the decisive characteristic of military performance. The network-centric character of US military modernization has in turn enabled a more direct and calculated coupling between political ends and military means that allows a leadership focus on effects-based military operations. These policy aspirations require new military capabilities that in turn depend for their enabling characteristics on new technologies.

Nuclear Capability-Based Deterrence

In the context of the "new triad", "capability" was emphasized in Nuclear Posture Review (NPR) 2001 - and similarly in the 1994 NPR – because it

- Enables lower numbers of active and inactive nuclear weapons (NW).
- Enables responsiveness / adaptation to new threats or technical surprise as well as new opportunities (e.g., nonproliferation, nuclear weapons security for other Nuclear Weapons States (NWS)).
- Essential to understanding nuclear intelligence / threat of proliferation.
- Essential to anticipating vulnerabilities to nuclear terrorism.
- Essential to sustaining stockpile confidence without nuclear testing (with or without Reliable Replacement Warhead (RRW)).

The principal elements of capability-based deterrence are the weapons themselves (albeit fewer), the S&T infrastructure (Labs) and the manufacturing infrastructure. <u>At the highest level, a major role of S&T is not just to provide - but also to demonstrate - capability to US leadership, allies, and potential adversaries.</u>

The previous sessions in this conference have covered the geopolitical context for nuclear weapons in the 21st century as well as doctrine and force structure. The session immediately preceding has introduced the notions of stockpile and infrastructure transformation in the context of readiness and responsiveness.

Our paper presents non-nuclear and nuclear S&T issues and challenges in that order because post-Cold War Presidents and Congresses on both sides of the aisle have sought to present US military capability with non-nuclear in high profiles and nuclear – while the ultimate backdrop – in lower profile and lower number of weapons.

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[1] These aspirations are reflected in the Nuclear Posture Review (2001). Excerpts from the report can be found at http://www.globalsecurity.org/wmd/library/policy/dod/npr.htm.

21st Century Science and Technology Setting

The transition from threat-based to capabilities-based military planning and a focus on linking political aims to the application of military power has had important consequences for the S&T themes in defense modernization over the past decade.

A. C4ISR

The residual C4ISR system inherited from the Cold War is ill suited to 21st century needs. The shift in requirements from a focus on episodic reconnaissance of the adversary's Order of Battle to the need for persistent surveillance to tag, track and locate (TTL) individuals, objects, and activities has imposed new demands on the underlying science and technology to sense, collect and process large (exabyte) volumes of data collected from persistent space, airborne, and terrestrial sensors.

B. Targets

Achieving the desired political outcome in a military campaign involves a transition from an exclusive focus on the attrition of adversary military forces and infrastructure targets that was characteristic of Cold War era military requirements. Instead, the political aim(s) of the campaign are to be achieved by the application of precise kinetic and non-kinetic effects on the value structure (which may include military forces) of the adversary. Moreover, in an effort to dissuade adversaries from investment in WMD, it is necessary to be able to hold at risk the infrastructure associated with the development, testing, manufacturing, and deployment of these capabilities wherever they may be located.

C. Weapons effects

Employment of modern weapon systems emphasizes their unique effects to produce the desired contribution to the political purposes of the military campaign. In conventional military operations these effects can be both kinetic and non-kinetic with the importance of the latter now growing rapidly. With kinetic effects, achieving a high order or precision with blast, fragmentation, penetration and/or thermal effects to minimize counterproductive collateral damage has grown significantly as information technology has been applied to military operations.

For nuclear weapons, they have three important effects that are unique – ionizing radiation, extraordinary energy density, and high thermal output. The improved effectiveness of conventional weapons as a result of precision navigation and the reduction in target location error and advanced energetic material, the role for the application of nuclear weapons to targets requiring high energy density has diminished.

Emerging Science and Technology Requirements[2]

The channeling of military applications of scientific ingenuity during last quarter of the 20th century can be expressed in three "technology vectors" that created decisive new military capabilities – increasing the speed and precision of military operations while reducing their signature. These three "vectors" – speed, stealth, and precision – integrated the military

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[2] This section draws heavily on the 2006 Summer Study of the Defense Science Board, *21st Century Strategic Technology Vectors* (http://www.acq.osd.mil/dsb/reports.htm) – publication forthcoming.

applications of many areas of advanced technology, especially information technology to produce these capabilities.

These capabilities reflected the needs of the Cold War to confront massed echeloned Soviet mechanized infantry, armored forces, and tactical air power. When these capabilities were embedded in joint operations, they have proved to be instrumental in increasing the effectiveness of US combined arms operations in post-Cold War campaigns including *Operation Desert Shield/Storm* (1991) and *Operation Iraqi Freedom* (2003).[3] The evolution of potential threats to the United States from non-state entities employing terrorism as a tactic has made it apparent that the capabilities created during the latter years of the Cold War, though of enduring importance, will not suffice to meet the needs of the 21st century. The Defense Science Board (DSB) has identified four additional inter-related and mutually reinforcing capabilities – human terrain preparation, ubiquitous surveillance and recording, contextual exploitation, and rapidly tailored effects – that respond to 21st century security needs. The interaction between these capabilities expands to the operational level, the tactical "OODA loop" (observe, orient, decide, act) that will permit US forces to operate within the decision cycle of future adversaries. These capabilities are in turn supported by twelve (12) enabling technologies summarized in the table displayed below.

Twelve Key Technology Area Enablers

Critical Capability	Technology Area
Human Terrain Preparation	• Human, Social, Cultural, Behavioral Modeling • Automated Language Processing • Rapid Training and Learning Methods and Aids
Ubiquitous Observation And Recording	• Day/Night All-Weather Wide Area Persistent Surveillance • Close-in Sensing and Tagging • Soldier-as-Collector
Contextual Exploitation	• Mega-scale Data Management • Situation Dependent Data Exploitation • Human/System Collaboration
Rapidly Tailored Effects	• Time-critical focused conventional strike • Influence Operations • WMD Protection and Mitigation

[3] For an assessment of the effectiveness of efforts to "transform" US military forces, see the 2005 Summer Study of the Defense Science Board, *2005 Summer Study - Transformation: A Progress Assessment Vols. I and II*, (http://www.acq.osd.mil/dsb/reports.htm).

A. *Human terrain preparation*

Scientific innovation in the late 20th century evolved the technologies of signature reduction in a manner that leveraged US strengths. In the 21st century, it is the "targets" which now benefit from their ability to conceal their signature. The US needs a deep understanding about how individuals, groups, societies, and nations behave – both allied and adversary. This understanding can be used to improve US military performance while shaping the behavior of adversaries prior to and during hostilities. Diminishing the impact of these circumstances will require advanced modeling of human social, cultural, and individual behavior. Adapting military forces to rapidly changing circumstances will require new technologies for rapid learning and automated language processing as well.

B. *Ubiquitous observation and archiving*

The need to monitor individuals, objects, and activities continuously in turn establishes a need for the technologies of persistent day/night-all weather wide area surveillance, as well as close-in sensing. Persistent wide area surveillance must be augmented by close-in tagging, tracking, and locating technologies so that individuals, objects, and activities that are the focus of interest can be continuously monitored. Moreover, to support persistent surveillance, the maintenance and exploitation of deep archives will be needed to permit monitoring over the complete life cycle of the target.

C. *Contextual exploitation*

A new set of information-rich exploitation and collaboration tools are needed to bridge the functional capabilities of ubiquitous observation and rapidly tailored delivery of scaled effects. Three enabling technology areas are mega-scale data management, situation dependent information extraction, and human/system collaboration.

The combination of these technologies will open new opportunities to automate the intersection of apparently independent events, actions, things or people, masked by military and civilian clutter. These tools will be used to extract related features, to enable time-critical targeting and intent recognition of evolving threats. Their development is being driven by the commercial sector and fueled by rapid innovations in underlying technologies such as computation, data storage, and software architecture.

D. *Rapidly tailored effects*

Achieving the desired political effect of military operations requires that military effects be rapidly tailored to the circumstances. The wide variety of circumstances where military power may be applied suggests that a highly differentiated set of effects that can be swiftly adapted to the circumstances ranging from information operations to nuclear effects will be needed. Military effects can be achieved through either kinetic and non-kinetic means that are either offensive, defensive, or both.

Information operations are described as the integrated employment of the core capabilities of Electronic Warfare, Computer Network Operations, Psychological Operations, Military Deception, and Operations Security, in concert with specified supporting and related capabilities, to influence, disrupt, corrupt, or usurp adversarial human and automated decision-making while protecting our own. Non-kinetic influence operations which include both classic information operations[4] as well as activities aimed at influencing the local population can have a powerful effect in the transition to and from hostilities in the "long-war" scenario that seems to be the most likely characteristic of international conflict for the next 10-20 years. However, influence operations need to be subsumed into the broader subject of strategic communications that takes into account all US government advocacy efforts that contribute to shaping opinion in the theater of operations.

Advances in precision weapon delivery that have been made over the past quarter century need to be extended to permit time-sensitive global strike capabilities. Such capabilities will permit strike operations with a response time of 30 minutes with long standoff ranges (> 1,000-km), two-meter accuracy, and without local support requirements.

WMD detection and mitigation will be an essential element of tailoring the application of military power to achieve specific effects. In an environment where nuclear proliferation may become more commonplace, it will be necessary to be able to detect nuclear materials associated with WMD as well as possessing environmental assessment and diagnostic tools that enable the US to operate and survive in an environment where WMD may be employed. It is in the field of tailored effects that the bridge to nuclear capabilities is reached. A process which continuously updates the target base to enable the national leadership to match those targets which can only be effectively struck with the unique capabilities of nuclear weapons with specific nuclear weapon designs is needed.

"Constructive choices" for US leadership in 4 (nuclear) areas:

1. **Nuclear Policy**
2. **High-level challenges for management of the stockpile stewardship program**
3. **Science-based challenges for stockpile stewardship**
4. **Nuclear Energy / Nonproliferation / Nuclear Terrorism issues in the 21st Century**

Constructive choices / questions / issues for implementing capability-based deterrence – nuclear policy

There are a wide variety of policy issues that this session must leave to others, e.g., overall force structure and weapons delivery platforms, whether nuclear deterrence should be limited to nuclear threats, etc. However, the weapons Labs / stockpile stewards are directly affected by two policy choices that remain before us. They have been discussed in earlier sessions, but are repeated here:

A. **RRW (a key building block)– Enabling stockpile and infrastructure transformation as well as maintaining / exercising the capability for new design while utilizing the science derived from the stockpile stewardship program.**

   The relaxation of yield-to-weight requirements for RRW will allow the complex to design for more manufacturable systems as well as transforming the stockpile (discussed in section 3). With the loss of processes, capabilities and personnel associated with the stockpile of the 1980s, the cost to manufacture legacy components is unaffordable, both fiscally and environmentally. Rather than trying to re-invent many high risk, costly legacy processes and materials, RRW designers have chosen to integrate manufacturing

[4] Joint Information Operations Publication, 3-13, Joint Chiefs of Staff, 13 February 2006

considerations into the basic design. The RRW design also incorporates safety and security features that help ensure not only weapon surety but also that of the infrastructure in the post-911 era. In the case of weapon and infrastructure security, designs that delay and deny access to nuclear materials help reduce the cost of security in the facing of a growing Design Basis Threat (DBT). The Preliminary Environmental Impact Statement for the National Nuclear Security Administration's (NNSA's) Complex 2030 is under way to detail the enterprise transformation that will support the nation's future deterrent mission.

The Presidential Decision Directives (in the mid-90s) that established the Stockpile Stewardship Program (SSP), expressly mandated capability for new designs if needed. The RRW is not exactly "new" because the design is pedigreed in nuclear tests before 1992, and its purpose is not a different military capability but rather to enable more confident certification and manufacturing of nuclear weapons many decades after the end of nuclear testing. Much has been said about training the next generation of nuclear designers – and occasionally it sounds self-serving. RRW exercises both NNSA and Department of Defense (DoD) to integrate together all of the working parts of the system (e.g., the electrical and mechanical interfaces) and it asks them to be innovative. It helps build a nuclear enterprise that "knows what to do" without the crutch of a basically unconstrained "win the cold war" 1980s blueprint.

B. Applying to nuclear deterrence concepts such as effects-based targeting which are accepted parts of non-nuclear deterrence

This is one of the issues that alarmed many policymakers in the first few years of this decade: very precisely delivered nuclear weapons with lower yield and / or earth penetrating capability. The basic idea of these "advanced" concepts is to reduce collateral damage. This is an essential – and accepted - part of targeting non-nuclear weapons. So, in situations in which the US is not contemplating an all-out nuclear war, do assuring allies and deterring adversaries require minimizing civilian effects to be credible?

We leave to policymakers the answer to this question, but it sure does affect what the stockpile stewards work on.

Sustaining Stockpile Stewardship for another Generation – high-level challenges / choices for the program

The SSP was forged in the 1990s as a consensus program. For those who wanted an end to nuclear testing as proof and support of our nonproliferation commitment, the price was a commitment to restoring the NW enterprise. For those whose priority was sustainable nuclear deterrence, the price was an end to nuclear testing. Part of the consensus was a more efficient, downsized enterprise. Time has tarnished the polish and luster of that original framework. But the most fundamental high-level question or choice is:

A. Shall the US nourish best-in-the-world, peer-reviewed weapons science and engineering (S&E) needed for capability-based deterrence?

The objectives remain certification and annual assessment of a smaller nuclear stockpile, anticipating and responding to new threats and opportunities by utilizing the maturation and agility of science-based stockpile stewardship. Good people are the key enabler.

A sub-issue here is, will RRW obviate the need for the best S&E?

- RRW with more design margin means fewer surprises or aging effects that require NNSA remanufacturing and/or modifications to DoD's NW custody or planning. Credible certification / assessment is not a one-time happening; it must continue for the life of the weapon. Should US decision makers accept anything less than the best in this regard?
- The transformation enabled by RRW is both enabled by best-in-the-world, peer-reviewed weapons S&E capability, and it will help sustain capability-based deterrence and responsiveness – the same responsive capability is essential to a smaller nuclear deterrent as well as anticipating and responding to new threats and opportunities.

Since capability-based deterrence is composed of both capable Labs and capable manufacturing, a companion question is:

B. How to best consolidate and modernize manufacturing, including Category I/II Plutonium at a single site?

With the end of underground nuclear testing (UGT) in 1992, the nation also had no new production scheduled for nuclear weapons. Without a projected schedule for new manufacturing, the production capabilities essentially atrophied. Over the past 15 years, we have lost the ability to restart streams and processes for many historic weapons materials. This is evidenced by the continually escalating costs for remanufacturing legacy material and components in the Life Extension Programs (LEPs) that have become cost prohibitive and are being cancelled for some systems.

RRW is designed to be manufacturable in today's world. The transformation to Complex 2030 will incorporate at all plants the best of commercial manufacturing innovations and quality control. It will also upgrade the Pantex Plant for increased assembly / disassembly throughput, use commercial light-water-reactors as the source of new tritium, outsource (where possible and cost-effective) non-nuclear component production to commercial suppliers, outsource synthesis and formulation of high explosive (HE) materials and disposition excess facilities.

There are several especially difficult issues: Complex 2030 vision includes a Consolidated Plutonium Center (CPC) for both Plutonium research and pit manufacturing. What pit capacity, e.g., 50 pits per year? 80? 125? What if most pits do live 100 years? A responsive Plutonium infrastructure must be resilient to very different alternative futures: very little pit manufacturing as well as replacing 500-1000 pits in the case of unforeseen failure. Should it be collocated with Highly Enriched Uranium (HEU) manufacturing – the Consolidated Nuclear Production Complex proposed in the Overskei report[5]?

The CPC is to become operational in 2022. More likely, even later. So for the meantime, there is a near-term issue: should we construct a Chemistry and Metallurgy Research building (CMR) Replacement at Los Alamos, especially to maintain capability and interim RRW manufacture from 2012 to whenever CPC is complete? If not, should "Super Block" remain open at Lawrence Livermore National Laboratory? We cannot plan on the present CMR remaining viable beyond 2010 or 2012.

C. Enhanced security and safety

Recent news articles have misrepresented the security issue both for nuclear weapons storage and for nuclear materials and components within the NNSA infrastructure. DBTs in the post-911 era have been conservatively set, and security measures have been adapted to defeat that threat. The trend is that every year or two NNSA has increased the DBT; the resultant cost of security has spiraled out of control: twice as many postulated attackers results in doubling of security costs. We must begin to implement alternative approaches that do not scale upward with every increase in the threat. The RRW includes features that render the weapons themselves more resistant to terrorist attack than systems now in the inventory; similarly, we must redesign and implement new security technologies in the manufacturing and assembly facilities to be more resilient to an escalating threat.

Assembly, disassembly and surveillance operations at the Pantex Plant have been very much encumbered in recent years by explosive and electrical safety concerns. Safety features improved over what is in most of the stockpile will be included in RRW. As with security, these features will have a significant benefit to the NNSA infrastructure – not just to the weapons themselves. Until then, however, explosive and electrical safety concerns are a significant challenge to NNSA, the Labs and plants.

D. Arming-fuzing-firing (AFF) technology and interoperability

There are 2 dimensions to interoperability: The first is not very controversial. AFF technology that enables all refurbished and replacement weapons to include next generation features for safety, security, manufacturability, radiation hardness certifiable without nuclear testing and embedded sensors for surveillance. Sandia National Laboratories' (SNL) proposed Common Adaptable Systems Architecture (CASA) implements those objectives, and facilitates utilizing warheads from different legs of the triad to back up one another (interoperability among nuclear systems).

The second dimension remains an open issue (politically) - whether advanced and usually very accurate delivery systems should be dual capable. Interoperability between nuclear and non-nuclear systems makes maintaining the overall force structure less expensive and easier to train – and it makes very accurate delivery of nuclear weapons practical. However, it is seen by some as an erosion of the barriers to escalation, or "nuclear firebreak".

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[5] *Recommendations for the Nuclear Weapons Complex of the Future*, Secretary of Energy Advisory Board, July 13, 2005, report can be found at http://www.seab.energy.gov/publications/NWCITFRept-7-11-05.pdf

E. Demonstrating program success in the near term

Recognizing a decline in DoD and Congressional confidence, NNSA has described in Congressional testimony its commitment to support the nuclear deterrent not just in the long term through transformation but over the next 18 months as well. Among a dozen or so initiatives, NNSA will: Eliminate the warhead surveillance backlog by the end of Fiscal Year (FY) 2007, achieve first production for the B61 LEP in FY 2006, and the W76 LEP in FY 2007, demonstrate 10 W88 pits per year war reserve production capacity at LANL in FY 2007 and extract tritium in 2007 from rods irradiated in a commercial nuclear reactor.

Best-in-the-world, peer-reviewed weapons S&E needed for capability-based deterrence, anticipating and responding to new threats, certification and annual assessment, stockpile surveillance - what does it look like?

The sine qua non of capability-based deterrence are the scientists and engineers – the stewards of stockpile stewardship - who adapt to new opportunities, who anticipate technological surprise or vulnerabilities to terrorism and in whom the national leadership must trust. The topics below are some of the technical challenges they must tackle:

A. Assessment & Certification without nuclear testing

- Assessment of Legacy systems – Continuing favorable assessment of legacy system performance, which generally have small, performance margins, depends crucially on the modern tools of SSP, including Quantification of Margin and Uncertainty (QMU). However, as issues identified through surveillance are resolved – through LEPs and other measures – performance uncertainties will grow. The consequences of the cumulative interaction of these uncertainties in the context of small performance margins are ultimately unknowable without resorting to nuclear testing.
- RRW Certification – Changes in military characteristics for RRW, including relaxation of constraints on weight, size, etc., enable design approaches with significantly increased performance margins. Confidence that these greater margins are far from performance cliffs is validated by data from years of nuclear test experience, including tests of many of the components in these designs, and the substantially enhanced experimental and simulation tools, and understanding of weapon physics derived from the successful SSP. With these larger margins, the design laboratories are confident that RRW designs can be certified without nuclear testing.

B. Grand challenges such as full-physics performance of a boosted primary continue to require advances in

- Computing – agile supercomputing with hybrid architectures, information / data structures and operating systems and with appropriate microphysics blended with full-scale radiation hydrodynamics. The latter epitomizes the challenges at the high-end of the computational spectrum that have been a principal driver for the Advanced Super-Computing (ASC) program and are moving us toward several peta-FLOPS of computing capability by 2010, and an exa-FLOPS computing capability by 2020.

- Radiography and hydro testing are uniquely important to NNSA and provide the only integrated, full-scale tests (albeit with some surrogate materials) of US nuclear weapons. NNSA must not only sustain (e.g., Dual Axis Radiographic Hydrodynamic Test (DARHT) facility) present capability but explore potential advances (e.g., proton-radiography).
- Science-based stewardship requires smaller experiments performed at a higher rate of iteration to better understand the "microphysics".
- High-Energy Density Physics (National Ignition Facility (NIF), SNL's Z-Machine) to support understanding of secondaries, boost physics, X-ray hardness.

The capabilities of an agile and adaptive science infrastructure are essential to predicting not just yield and performance of RRW and aging legacy systems but also weapons response to abnormal safety environments and terrorist attack scenarios.

C. Materials science

Plutonium and HE are not the only unique materials; their behavior has a great deal of leverage on the reliability of our nuclear stockpile. So have polymeric materials, uranium and ceramics – especially when collocated with one another. Fundamental understanding is essential to predicting material aging before it happens and to knowing whether to replicate or modify the material in remanufacture.

D. Explore new technologies to ensure that they are sufficiently mature to support SLEP / RRW programs

- Imbedded sensors to detect aging and corrosion.
- Innovative security devices that deny and delay terrorist access.
- High density, long-lived power sources.
- Inherently radiation-insensitive electronics.
- New processes / manufacturing technologies; materials science that enables leap-ahead engineering approaches.

E. Transforming Nuclear Test Readiness (NTR)

The objective has been to assure confidence in the nuclear deterrent if testing is required. On the other hand, many believe NTR undermines US credibility on article VI of the Non-Proliferation Treaty and the test moratorium.

Not only should RRW make nuclear testing less likely, but a maturing suite of small- and full-scale experimental capabilities, including those at Nevada Test Site (NTS), are transforming the character of our "readiness." Experimental physics and the measurements we would make today are not those of the1980s. Instead they are based on 21st century diagnostics developed for hydrodynamic testing and high-energy density physics (NIF, Z). Operations at NTS have been similarly transformed. NTR beyond that which "comes naturally" has been expensive financially – and even more so politically. Is it worth it?

F. Conduct high-risk and long-term research to ensure that US weapons scientists are at the leading edge and able to respond to an uncertain future (advanced computing and sensors, nanoscience, etc.)

Not only is this the science basis of stockpile stewardship, it is the unclassified side of the weapons Labs which the world sees. So it adds significantly to the "credibility of our capability."

G. Support non-Defense Program requirements for Non-Proliferation, Nuclear Intelligence, Counter Terrorism / Emergency Response

These are essential to stewardship of nuclear weapons in the larger sense. In addition, they exercise the stockpile stewards by posing new, challenging questions. This work also adds significantly to the "credibility of our capability."

Other challenges - Spread of nuclear power production expertise / technology in 21st Century Nuclear fuel cycles must (and Global Nuclear Energy Partnership (GNEP) does):

A. Reduce proliferation concerns

through recycling approaches that mix plutonium with other actinides to make it less attractive and which do not store or transport weapons capable material separately from the spent fuel. For example, GNEP integrates UREX+1a recycling of spent fuel with collocation of new fuel fabrication and actinide burning reactors at compact multi-process sites (nuclear processing center approach). A long-term goal should be "burning down" the world's existing supply of separated plutonium.

Advanced safeguards development and implementation is a key component. Another key approach proposed both by the Bush Administration and the International Atomic Energy Agency Director General is to halt spread of enrichment and reprocessing technologies by limiting the fuel cycle to existing NW states and a limited number of highly industrialized, trusted nations – perhaps even internationalizing these facilities.

B. Intrinsic resistance to terrorism

and nuclear security concerns through recycling approaches that do not store or transport weapons capable material separately from the spent fuel; no HEU.

C. Technology challenges

(for nonproliferation) include how to measure Plutonium and higher actinide content in the mixed-actinide UREX+ (Uranium Extraction) product and in pyro-processing itself, an accurate measurement of fissile content in the inhomogeneous spent fuel coming from the fast neutron reactor and the question of effective and efficient gas centrifuge safeguards will continually need to be addressed.

(for nuclear counterterrorism), there are a wide variety of technology opportunities, e.g., nano-scintillators for nuclear materials detection.

(for Nuclear Energy technology itself) economic viability of recycling / UREX+.