Report on
Scenario-Based Planning to Maintain the Credibility of the U.S. Nuclear Deterrent Against Emerging Threats

November 2019

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Disclaimer

This is a report of the Threat Reduction Advisory Committee, a Federal Advisory Committee established to provide the Department of Defense and the Secretary of Defense, through the Under Secretary of Defense for Acquisition and Sustainment, independent advice and recommendations on:

a. Reducing the threat to the United States, its military forces, and its allies and partners posed by nuclear, biological, chemical, conventional, and special weapons;
b. Combating weapons of mass destruction to include non-proliferation, counterproliferation, and consequence management;
c. Nuclear deterrence transformation, nuclear material lockdown, and accountability;
d. Nuclear weapons effects;
e. The nexus of counterproliferation and counter weapons of mass destruction terrorism, and
f. Other Acquisition and Sustainment Office and Defense Threat Reduction Agency mission-related matters, as requested by the Under Secretary of Defense for Acquisition and Sustainment.

The views expressed herein do not represent official positions or policies of the United States Government.

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November 2019

MEMORANDUM FOR USD(A&S) Ms. Ellen Lord

SUBJECT: Threat Reduction Advisory Committee Report on Scenario-Based Planning to Maintain the Credibility of the U.S. Nuclear Deterrent Against Emerging Threats

The Threat Reduction Advisory Committee (TRAC) is tasked by the Office of the Secretary of Defense and deliberates independently to review issues critical to combating weapons of mass destruction and related matters that confront the Department of Defense. Collectively, TRAC members bring in-depth expertise to provide actionable recommendations on issues of concern.

This memorandum formally transmits the TRAC Report on Scenario-Based Planning to Maintain the Credibility of the U.S. Nuclear Deterrent Against Emerging Threats, as requested by the Terms of Reference signed on September 4, 2018. The report reviews analytic approaches and measures to evaluate nuclear deterrence in a strategic setting that includes many actors and complex factors. It examines the importance of considering plausible challenging scenarios that might be created by changes in geopolitical forces and technological advances. The report highlights the value of tools to enhance such analysis. The report includes a summary of the identified issues and subsequent findings and recommendations, including near-term initiatives.

Following the completion of the work of the TRAC Task Force on Scenario-Based Planning to Maintain the Credibility of the U.S. Nuclear Deterrent Against Emerging Threats, this report was reviewed and deliberated among the members of the TRAC in accordance with provisions of the Federal Advisory Committee Act and unanimously approved in November 2019. The TRAC provides these findings and actionable recommendations that take into account cost and risk to forces and missions involving roles and responsibilities of the Department of Defense. The Committee stands ready to brief this report and discuss its content.

Ronald F. Lehman II

Ambassador Ronald F. Lehman, II
Chair
Threat Reduction Advisory Committee

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Threat Reduction Advisory Committee
Scenario-Based Planning to Maintain the Credibility of the U.S. Nuclear Deterrent Against Emerging Threats

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PURPOSE AND MISSION OF THE TRAC

The Secretary of Defense, under the Federal Advisory Committee Act of 1972, established the Threat Reduction Advisory Committee (TRAC) to provide independent advice and recommendations on matters relating to combating weapons of mass destruction and other mission-related activities. Eminent authorities in fields as varied as national security, nuclear physics, chemistry, biology, special operations, and public health are appointed for four-year terms subject to annual renewal by the Secretary of Defense.

Together the members provide advice and recommendations through the Under Secretary of Defense for Acquisition and Sustainment and the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs on the following topics:

- Reducing the threat to the United States, its military forces, and its allies and partners posed by nuclear, biological, chemical, conventional, and special weapons;
- Combating weapons of mass destruction to include non-proliferation, counterproliferation, and consequence management;
- Nuclear deterrence transformation, nuclear material lockdown and accountability;
- Nuclear weapons effects; and
- The nexus of counterproliferation and counter weapons of mass destruction terrorism.

For the complete TRAC Charter, see Annex D. For current TRAC membership, see Annex E.

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FOREWORD

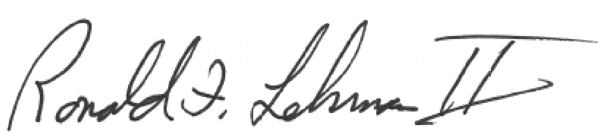
The TRAC Task Force on Scenario-Based Planning to Maintain the Credibility of the U.S. Nuclear Deterrent Against Emerging Threats was established by the Terms of Reference of 4 September 2018, signed out by the Under Secretary of Defense for Acquisition and Sustainment. In accordance with the Terms of Reference, this Report was submitted to the full TRAC for review and deliberation and was approved by consensus.

This report includes an analysis of the role of assessments, models, simulations, gaming, and exercises in exploring the changing strengths and weaknesses in the nuclear deterrence posture of the United States. In particular, the report looks at quantitative and qualitative attributes of deterrence, challenging scenarios that may be created in the years ahead by geopolitical or technological change, and current and emerging tools that may help assess strengths and weaknesses in specific contexts.

In addition to Findings and Recommendations, an expansion of the central sections of the Report, included as Annex A, can serve as a Primer on issues related to nuclear deterrence. This Primer also provides a foundation for analysis, modeling, simulation, and war gaming related to nuclear deterrence. Together with the body of this TRAC Report, this Primer helps support the continuing need to convey the key aspects of nuclear deterrence in today's strategic setting to all parts of the Department of Defense and to other audiences including Members of Congress, their staffs and the general public. Furthermore, a set of initiatives is provided to address integration and acquisition of DoD-wide modeling, simulation, and gaming tools. These points were added to be responsive in a timely manner to issues of immediate interest to the Office of the Secretary of Defense.

The TRAC and Task Force stand ready to provide further support as requested.

Major General William A. Chambers, USAF (Ret) (Co-Chair)



The Honorable Ronald F. Lehman, Ph.D. (Co-Chair)

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EXECUTIVE SUMMARY

The 4 September 2018 Terms of Reference (TOR) from the Under Secretary of Defense for Acquisition and Sustainment (USD(A&S)) directs the TRAC Task Force on Scenario Based Planning to Maintain the Credibility of the U.S. Nuclear Deterrent Against Emerging Threats to "...evaluate available methodologies...as well as realistic scenarios" "...for ensuring the credibility of the United States (US) nuclear deterrent over the next 10-25 years." In particular, the Task Force was asked to "...consider analytic and data-driven frameworks" and to "...identify options on how to more rapidly integrate a data-driven approach."

Further elaboration made clear that, given uncertainties about geopolitical and technological change, the thrust of the Task Force effort should focus on what current and future decision-makers might need to know, or should not miss, in evaluating what may be required to sustain an effective deterrent force over the next few decades. Deterrence can be defined narrowly to mean only the threat of punishment in response to aggression, but here we acknowledge that deterrence involves a wider range of activities including broader foreign policy, support for alliances, other instruments of national power, and incentives for military restraint. Whether the context requires the use of the narrow or broad definition of deterrence, the Task Force's analysis recognizes that confidence in our ability to meet national objectives for deterrence, assurance and hedging is inseparable from confidence that our nuclear forces can be deployed effectively and wisely. Deterrence analysis, assessment, planning, and training continue to become more complicated with the rise of multiple near-peer threats and multiple nuclear actors. Moreover, new technologies involving cyber, space, air or missile defense, hypersonics, anti-submarine warfare, autonomous delivery systems, advanced sensor capabilities, and artificial intelligence/machine learning add to the complexity of the strategic setting.

Useful tools to cope with the growing complexity are available in industry, and advanced capabilities have been demonstrated in the Department of Defense (DoD) and in national security-related communities, academia, and laboratories. Possibilities for much more capable, vivid, and realistic tools, however, are exploding, including the next wave of machine learning and artificial intelligence.

The key findings and recommendations of the TRAC are:

1. Current analytic tools are insufficient to provide senior leaders the high-quality data to support the evidence-based decision making needed to successfully tackle the complex nuclear deterrence challenges they face during the next 25 years.
2. Improved use of advanced analytic tools including simulations and war gaming to gain both experience and exploitable data would support necessary evidence-based decision making.
3. If modern tools for deterrence analysis were put in place now for use during the next decade, DoD could meaningfully aid decision makers to overcome the challenges surrounding the bloc modernization of nuclear deterrence forces as they transition from legacy systems to replacement systems.

Therefore, the TRAC recommends the creation of a Roadmap for modeling, simulation, and gaming of the nuclear deterrence challenge that:

- Integrates analytic tools to generate high-quality, statistically significant data to support strategic-level decision making to optimize the deterrent,
- Drives cost-effective acquisition of modeling and simulation,
- Includes both nuclear and conventional forces, Nuclear Command, Control and Communications (NC3)/C4ISR, across all domains, at every phase of confrontation and hostilities with nuclear-armed competitors, and
- Cuts across organizational boundaries and breaks down research and development (R&D), operational, and intelligence "stovepipes."

FINDINGS

- A return to great power competition, an expansion of the nuclear capability of potential adversaries, and the incorporation of the possible use of nuclear weapons into their defense doctrines has led to an increase in the salience of nuclear weapons and nuclear deterrence.
- In response, and after substantial delay, the US has embarked on a complex and intensive modernization program involving all three legs of its aging nuclear Triad. Coupled with a rapidly evolving technological and geopolitical landscape, legacy US forces face risks in their ability to conduct their defined missions effectively and thereby deter adversaries and assure allies.
- New threats could make the consequences of any delays worse given the existing, tightly-wound nuclear force modernization program. The margin for error is therefore limited. Even without delays in follow-on systems or unexpected early retirement of legacy systems, new geopolitical and technical challenges could generate need for an even more ambitious modernization program.
- Given program interdependencies, scarce resources, and transforming threats, advanced analytical tools could improve our understanding of risks, responses, and trades. Unfortunately, current data generated from or developed for simulations and gaming are of insufficient quantity and quality to empower the best evidence-based decision-making.
- Concern about growing technological and geostrategic uncertainties in the out years is sufficient to warrant a unified DoD effort to assess and exploit the best tools, generate the needed data, and carry out research employing, in part, modern simulation, modeling, and war gaming capabilities as means to inform ongoing analytic work, educate senior leaders, and support decision making.

1. Current analytic tools are insufficient to provide senior leaders the necessary, high-quality data to support the evidence-based decision making needed to successfully tackle the complex nuclear deterrence challenges they face during the next 25 years.

- Maintaining bipartisan support for nuclear modernization over a three-decade period is a significant challenge. Even with non-partisan commitment to enduring deterrence principles, the amount and durability of that support will require a compelling justification undergirded by a strong empirical foundation derived from sound analytical tools. These tools should use new data reflecting the real situation at the time as well as future projections.
- Multiple simultaneous DoD and Department of Energy (DOE) programs of record carry great technical and programmatic risk that could result in capability gaps that create US security vulnerabilities.
  - The modernization program may be delayed.
  - Legacy systems may not remain effective for their intended life-span.
- Given a rapidly evolving military-technological environment and the willingness of China and Russia to dedicate abundant state resources to these efforts, it is possible that even modernized systems may not be sufficient to meet designated missions.
  - Peer, near-peer, and asymmetric nuclear threats are emerging.
  - These new threats are exploiting advanced technology.
  - Some adversaries are using advanced simulations and gaming to probe for weaknesses in all our systems including both offensive and defensive forces and the Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) that support them.
- Combinations of premature legacy retirements, delayed modernization, and/or increased threats could greatly increase the scope of any capability gaps.

2. Improved use of advanced analytic tools including simulations and war gaming to gain both experience and exploitable data would support necessary evidence-based decision making.

- Emerging technology would permit more, better, and cheaper simulation/gaming tools but constraints on the current quantity and quality of nuclear simulation and exercises limit generation of data that could add great value for analysis, policymaking, planning, training, and evaluation including acquisition and intelligence assessments.
- Existing war gaming and other analytical efforts, while quite useful in providing experiential learning for participants from the policy and military communities, fall short of providing reliable data for structured, rigorous analysis regarding force posture and structure, or to inform acquisition programs.
- The nuclear community lags the rest of the military in the availability of modern tools for analysis, planning, and gaming.
- Specifically, extensive analytical efforts are needed that cut across all aspects of US nuclear forces, their ongoing sustainment and modernization programs, and a variety of plausible adversary courses of action, with an integrated approach to addressing the

challenges identified earlier, and their associated risks. Modern simulation, modeling, and gaming can add greatly to our assessments.

- In systems development and weapons effects, extensive data exist, but integrated analysis of nuclear deterrence strengths and weaknesses requires that new, more extensive data be generated through multiple iterations of simulations, games, and exercises with different players that include scenarios involving the actual use of nuclear capabilities in order to capture more parameters and more decision-making situations where nuclear use may have to be considered.
- Current simulations, games, and exercises lack sample sizes of data sufficient for fidelity in understanding the interactions of diverse actors and complex systems across a range of challenging scenarios.
- Repositories for such data are needed that can be accessed more widely and with modern information technology (IT) tools.
- The period in which modern tools for deterrence analysis may be most important coincides with a period in which Machine Learning (ML) and Artificial Intelligence (AI) are expected to become widely available for multiple applications. These developments should be exploited.
- The size and capabilities of key nuclear analytical staffs are, in key commands and organizations, a fraction of what they once were. Consideration should be given to designating and resourcing a sustained and advanced nuclear analytical effort, perhaps anchored by a dedicated organization acting as analytic arm.

3. If modern tools for deterrence analysis were put in place now for use during the next decade, DoD could meaningfully aid decision makers to overcome the challenges surrounding the bloc modernization of nuclear deterrence forces as they transition from legacy systems to replacement systems, with a particular emphasis on examining the FY29-FY39 time period.

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RECOMMENDATIONS

Create a Roadmap for modeling, simulation, and gaming of the nuclear deterrence challenge that:

- Integrates analytic tools to generate high-quality, statistically significant data to support strategic-level decision making to optimize the deterrent,
- Drives cost-effective acquisition of modeling and simulation,
- Includes both nuclear and conventional forces, Nuclear Command, Control and Communications (NC3)/C4ISR, across all domains, at every phase of confrontation and hostilities with nuclear-armed competitors, and
- Cuts across organizational boundaries and breaks down research and development (R&D), operational, and intelligence "stovepipes."

The Roadmap for developing deterrence-enhancing analysis, modeling, simulation, and gaming should accomplish the following.

- Encourage more advanced tools to assess the capabilities and performance of nuclear deterrence forces including traditional Triad delivery systems and warheads, but also go beyond them to address:
  - Dual Capable Aircraft (DCA), air and missile defenses, space operations, cyber operations, and the associated Nuclear Command and Control (NC2) and C4ISR,
  - Strategic-level games that test our capabilities and national decision-making, and
  - Game coverage from pre-conflict through escalation including nuclear use to war termination.
- Expand scenarios to examine challenges to nuclear deterrence itself. "What-ifs" include:
  - Unexpected technological challenges affecting the survivability or effective functioning of the various elements of the Triad, DCA, and NC3/C4ISR,
  - Significant geopolitical change,
  - Opponents who make decisions based on different assumptions, rules, or values,
  - Loss of a major weapon system because of a systemic problem, and
  - Fact-of-life delays in completing nuclear modernization.
- Invest in ML and AI for games of imperfect information to explore applicability to deterrence.

Such a "Roadmap" to better integrating modeling, simulation, and gaming of US forces, can:

- Help break down "stovepipes" and provide greater combinations of breadth and depth of understanding
- Enhance policy-making, strategy development, and assessment of plans
- Provide greater capability per dollar for the forces the US acquires, and for the analytical capabilities (both hardware and software) that are required.

FURTHER COMMENTS ON MODELING AND SIMULATIONS

- Planning for effective deterrence including its nuclear dimensions is proving to be more complex as challenging scenarios multiply and technologies advance.
- As China diversifies and expands its nuclear capabilities and as Russian public rhetoric, military doctrine, exercise behavior, capabilities development, and focus invoke the prospect of nuclear use in regional conflicts and other scenarios that the West had not seen as likely to involve nuclear threats, the ability to model, simulate, and game must focus on the most strategically significant, plausible scenarios while taking into account that more actors, more capabilities, and more scenarios may cross the threshold of high risk.
- A single, composite measure of merit for deterrence is unlikely to be reliable. Analysis of multiple measures of merit is necessary to account for the diverse views of the US, its allies, and its adversaries.
- Data from modeling, simulations, and gaming should be generated that can give greater insights into tipping points and margins of confidence in deterrence under different stresses.
- Deterrence metrics are valuable for gauging deterrence and identifying trends, but "surrogation" – the confusion of the metric with what it is supposed to measure – must be avoided. For example, the adequacy of a deterrent force is impacted by the numbers, yields, and types of nuclear weapons it can deliver, but these metrics are not themselves direct measures of deterrence.
- Advances in modern psychology and economics – from improvements in classical utility theory through the maturation of prospect theory with its emphasis on loss-aversion and relative rather than absolute gains – suggest new opportunities to apply modern behavioral science to deterrence analysis.
- Scenario-based planning may not always be precisely predictive, but sound simulation and gaming can enhance readiness to respond to real contingencies and the inevitability of surprise.
- DoD needs to understand what it can gain from the exploitation of these advance analytical, modeling, simulation, and gaming capabilities and what it risks if adversaries exploit these advances and the US does not.

SPECIAL COMMENTS ON WAR GAMES

- In addition to modeling efforts, validation using data from past exercises and system acquisitions coupled with more traditional analytical studies continues to be valuable and should be expanded. Often, advanced and traditional approaches can be integrated. For example, war gaming can be employed in an iterative way to inform ongoing analytical efforts as well as to educate senior leaders in the Department about risks and their mitigation.
- "Learning by doing" is highly constrained in the operational nuclear arena, but war games are an inexpensive (and sometimes the only) way to learn by doing.
- Current war gaming efforts yield anecdotes more than exploitable data and often anecdotes don't test the efficacy of our strategic capabilities.

- Because games are routinely concluded when the first nuclear weapon is employed, experience and data on the impact of nuclear use in the midst of high-intensity conventional warfare is seldom gained.
- DoD needs to explore ways in which games can provide insight into the pace of escalation.
- War games should explore the impact of alternative force structures on escalation dynamics.
- War games need to play scenarios all the way from pre-conflict through initiation of hostilities and first nuclear use to war termination to provide insights regarding optimal strategies for all stages of conflict, including the need to establish intra-conflict deterrence.
- Given the nuclear postures of potential adversaries, simulations and gaming can help the US and its Allies understand better the dynamics of limited nuclear use.
- Different factors influence different players (adversary, allies, US), and understanding these asymmetries is important because differences in culture, organizations, and other human factors may impact deterrence significantly. These factors, which have become highly noticeable in on-line gaming, can be identified and assessed in realistic deterrence gaming as well.
- Gaming can improve presidential decision support, particularly in understanding nuclear effects on infrastructure and populations.
- Concerns over the implications of cyber or space war on C4ISR and especially NC2 may be better understood by the effective use of new tools for analysis, modeling, simulation, and war gaming. Scenarios used for war gaming must go beyond immediate operational planning needs to address "What if?" possibilities such as are mentioned above.

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UNDERLYING ANALYSIS

Problem statement: The US effort to modernize and sustain its aging nuclear forces faces three central challenges that create significant risk for the US nuclear deterrent:

1. Over the next two to three decades that today's modernization activities will play out, **successive Presidential administrations must persuade successive Congresses to continue the necessary bipartisan political and financial support for modernization programs.** This will be no small feat. In the past, failure to sustain sufficient bipartisan commitment has often led to delays resulting in block aging of forces and then the necessity for larger funding bow waves later to restore capability.
2. **Delays in replacement, early retirement of legacy systems, or a combination of both can create significant gaps in capability.** DoD and DOE must manage great technical and programmatic risk in delivering these complex programs on time and within cost projections. Previous delays in initiating programs have left no margin for error in fielding these systems on current schedules. Slips in programs, coupled with serious shortfalls in DOE's aging uranium and plutonium infrastructure, risk degraded deterrence from not having forces available sufficient to meet combatant command requirements. In addition, some legacy systems may unexpectedly age out before their replacements come online.
3. **US nuclear forces in development today, and with Initial Operating Capabilities (IOCs) in the next 10 to 12 years, will face a spectrum of threats that will evolve over the many decades that these forces are expected to remain in the field.** Will modernizing existing forces be sufficient or suited to address the threats of such a landscape? If not, what else should be done? Future force capabilities and the capabilities of the R&D and industrial base that sustain and modernize those forces must enable timely adjustments responsive to evolving technological and geostrategic threats.

The Task Force assesses that the above three central challenges should receive greater attention at senior levels in the Department. It also assesses that, while certain DoD elements have begun to examine the associated out-year risks, the requisite comprehensive information and analysis are not yet available to best support decisions on how to manage and mitigate them in the years ahead. The Task Force notes a lack of an empirical basis for use in gaming, simulation, and modeling in order to determine how best to address these challenges. Improved analysis, modeling, simulations and gaming are not the solutions to the challenges facing the American nuclear deterrent in the years ahead, but they can make options chosen more effective and less expensive.

Recommendations: The Task Force recommends that the USD(A&S) take steps to strengthen analytic efforts to develop a firmer, more rigorously grounded understanding of potential futures and options for managing the risks posed by the resulting uncertainty. The analytic effort must be rigorous and replicable in order to isolate with high confidence key variables and risks in ongoing modernization programs in the decades ahead. Rigor will also ensure that this analytic work is credible and compelling to a wide range of key audiences across the government. **In**

particular, the Task Force believes that there is great value in the creation of a Roadmap for modeling, simulation, and gaming of the nuclear deterrence challenge that systematically integrates analytic tools to generate high-quality, statistically significant data to support strategic-level decision making to optimize the deterrent; such a Roadmap would also guide cost-effective acquisition of modeling and simulation.

With regard to tools for analysis of deterrence. Using analytic tools to gain insight into the dynamics of deterrence has a rich history including the development of the mathematics of game theory by some of the world's most brilliant analysts. Since the end of the Cold War, the intensity of the attention to the operation of deterrence has atrophied. As an introduction to the topic, and to illustrate some of the relevant factors and measures of merit, we provide a short primer in Annex A. The complexity of 21st century geopolitics requires high-quality analytic attention that parallels that of the early Cold War years.

Specifically, extensive analytical efforts are needed that cut across all aspects of US nuclear forces and their ongoing sustainment and modernization programs with an integrated approach to addressing the challenges identified earlier, and their associated risks. Modern simulation, modeling, and gaming can add greatly to current assessments. In addition to modeling efforts, validation using data from past exercises and system acquisitions coupled with more traditional analytical studies continues to be valuable and should be expanded. Often, advanced and traditional approaches can be integrated. For example, war gaming can be employed in an iterative way to inform ongoing analytical efforts and evaluate key attributes of deterrence, as well as to educate senior leaders in the Department about risks and their mitigation.

With regard to war gaming. Our review of existing war gaming efforts indicates that, while quite useful in providing experiential learning for participants from the policy and military communities, they fall short of providing reliable data for structured, rigorous analysis regarding force posture and structure, or to inform acquisition programs. Shortcomings in gaming include sample sizes that are too small to provide statistical significance, outcomes that appear to be highly dependent on the characteristics of both individual players and adjudicators, and limited explorations of alternate force structure and warhead configurations to understand their role in producing both deterrence of adversaries and assurance of allies.

War games exploring the nuclear dimension should be updated to allow many more iterations with a wider range of players. This might be done economically with machine-learning techniques both for adjudication and decision support. Updates should include input from social scientists who can help provide statistically significant data on human decision making in contexts relevant to future nuclear scenarios.

Using these instrumented games, significant alternate futures can be explored. Modeling efforts are already being designed to probe risks within the program-of-record that could lead to gaps in capability. War gaming can be used to examine risk mitigation approaches should gaps be identified. In addition, games can explore technological innovations being introduced by potential adversaries and help to identify a range of US and allied capabilities and countermeasures that could guide acquisition decisions, even as they help explore different adversary "values" and thresholds for deterrence and/or escalation.

Finally, acquisition of modeling, simulation, and gaming capabilities must be geared to provide highly leveraged means to enhance evidence-based decision making that can:

- Be integrated functionally or digitally to provide a broader, coherent picture relevant at each level of command,
- Be used for multiple purposes such as training, planning, red teaming, intelligence evaluations, assessments of existing or desired weapons or support systems, procurement planning, and testing performance and readiness of units and personnel,
- Provide sufficient data to support better evidence-based decisions on policy, plans, development, acquisition, and logistics,
- Examine multi-domain interactions involving air, sea, land, space, and cyber capabilities as they relate to conventional, nuclear, and hybrid operations at the same time,
- Break down barriers and overcome gaps created between DoD organizations and also between regional and functional commands and examine "whole of government" interactions, and
- Help inform development and acquisition strategies, investment decisions, and policymaking.

In short, a Roadmap to deliberately integrate modeling, simulation, and gaming of US forces, including both nuclear and conventional, across all domains, at every phase of confrontation and hostilities, can break down "stovepipes," enhance policy, strategy, and assessments, and provide greater capability per dollar for the forces the US acquires and for the analytical capabilities (both hardware and software) that are required.

Because other efforts are underway to improve and exploit modeling and simulations of NC2, the Task Force did not specifically address these tools in detail. Nevertheless, the Task Force emphasizes that any tools to assess the capabilities and performance of nuclear deterrence forces must go beyond the traditional Triad delivery systems and warheads to include DCA, air and missile defenses, space operations, and the associated NC2 and C4ISR capabilities.

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SUPPORTING LOGIC

HISTORICAL BACKGROUND

The basic principles of military strategy, planning, logistics, leadership, intelligence gathering, training, and implementation have shown great continuity over the ages. The application of these principles to specific conflicts, however, has differed significantly in detail and grown more complex over time. Organizational specialization and diverse defense technologies give modern military forces many more options than were available to their predecessors.

From Sun Tzu through Clausewitz, the mantra has been to know the enemy and know yourself. Creating and promulgating such knowledge over time required ever more sophisticated analysis, planning, and training. Readiness inspections and field exercises were increasingly supplemented by the introduction of modeling, simulations, and war games. By the time of the industrial revolution, map and sand board exercises had become useful complements to field exercises. With the arrival of the nuclear and digital ages, both the need and the prospects for advancing modeling, simulation, and war gaming to new levels of realism and validity increased.

The overwhelming destructive power of nuclear weapons seemed, at first, to simplify strategy. With prevention of nuclear attack through nuclear deterrence as the driving priority, basic nuclear deterrence theory emerged from the blending of classical economics and early game theory. Over time, however, diversified nuclear forces under the control of multiple actors operating in multiple scenarios in multiple domains across the expanded spectrum of escalation possibilities highlighted the importance of being able to incorporate more data to understand more contingencies.

IMPACT OF ADVANCED INFORMATION TECHNOLOGIES

The rise of electronic computers aided the operations research, modeling, and simulations that informed the weapons effects and stability analysis that characterized the Cold War debates. Today, as state of the art computations approach the exascale milestone, high performance computers (HPC) that were recently the world's fastest are becoming widespread and affordable. Thus, more dimensions of deterrence can be modeled with greater realism. More permutations of significant factors can be explored, and more complex dynamics analyzed. Relationships among nuclear, conventional military signaling and operations, and even unconventional operations, now involve more domains including cyber and space. More state actors, and even non-state actors, located in diverse regions of the world, with their own weapons of mass destruction (WMD) or aligned with nation states that have such weapons, add to the landscape of concern and present more complex organizational, cultural, and psychological behaviors. New weapon delivery systems present different timelines of concern, and new sensors combined with machine learning and artificial intelligence transform what we may know or not know in a crisis. Moreover, connectivity that may be instantaneous and secure in peacetime may be fragile, unreliable, or even non-existent in a crisis or conflict. That certain particular conditions might lead down different paths to nuclear use may not be evident to all or any of the antagonists involved, especially early on in the confrontation.

No modeling, simulations, or gaming can perfectly recreate reality no matter how powerful the processing and vivid the images. None can offer exact predictions of the future. Nevertheless, the advance of information technology and analytics offers the possibility of major improvements in understanding the dynamics of escalation of conflicts. Much of this comes from the ability to model the greater number of contributing factors more accurately. Still more improvement comes from the ability to give decision makers more detailed and accurate pictures of developments, more realistic experiences of the dynamics, and more data from many war games and exercises such that statistical analysis becomes meaningful.

UTILIZATION OF ADVANCED TECHNOLOGIES

Over the years, DoD has undertaken many efforts to acquire more advanced capabilities for modeling, simulations, and gaming. The most successful have been with stand-alone programs focused on systems design and technical weapons effects. Acquiring large networked and integrated systems has been problematic, often for understandable reasons such as stove piped organizations, differing requirements, lack of common standards, asynchronous development and acquisition schedules, lower funding priority, and lack of confidence in security. In addition, many programs fell short of expectations. Advanced hardware often had difficult-to-support software with weak applications that seemed more artificial even than traditional sand board planning and field exercises.

Vital training and planning are achieved in many exercises without the use of sophisticated technology. Likewise, some of the most insightful analysis comes from simple logic, mathematics, or spreadsheets. Still modeling, simulation, and gaming of military operations has benefited from computer applications ranging from the portable, consumer level computers to HPCs with some very useful results. Some DoD tools still lag the private entertainment industry at the desktop/laptop/mobile level, but the cost effectiveness of what already exists is often high. Whether entry level or advanced, DoD conventional and small unit models, simulations, and games, in general, have far more fidelity than their nuclear counterparts. Bridging the conventional and the nuclear elements, however, is often not available. Ultimately, the most realistic modeling, simulations, and war gaming of both conventional and nuclear operations, with rapid visualization that could significantly augment some or all field exercises, requires high performance computing, often with “hardware-in-the-loop.”

In today’s world, circumstances different from those of the Cold War have emerged. Simply engaging diverse scenarios is valuable experience but modern technology might permit more iterations that produce statistically significant data. Yet there are barriers to full exploitation of the new technology. Among the most volatile variables in war gaming seems to be the knowledge base and proclivity of the players. Fear of controversy is also a significant inhibitor of gathering and integrating data on nuclear scenario simulations, models, games, and exercises.

ATTRIBUTES OF DETERRENCE

US NUCLEAR MODERNIZATION PROGRAM

The US has embarked on a generational recapitalization of its nuclear deterrent. It last modernized its nuclear forces in the late 1970s through the mid-1980s and largely deferred planned modernization through the 1990s and 2000s. With the nuclear weapons build up in an assertive China, an aggressive Russia, and a provocative North Korea, *en bloc* modernization of the US nuclear deterrent is now necessary. Administrations of both political parties have recognized this need to recapitalize US nuclear forces and the infrastructure that supports them; indeed, both the Obama and Trump Administrations have placed nuclear modernization of each leg of the Triad at the top of their defense priorities.

The 2018 Nuclear Posture Review and its 2010 predecessor make clear that the US nuclear deterrent, centered on the strategic nuclear Triad, should exhibit certain key features across multiple platforms and without single points of failure. Each leg has strengths and weaknesses, but synergism among the legs complicates attacker planning and provides hedges that enhance deterrence. A robust Triad has been a central feature of US nuclear policy for well over half a century, and it is reasonable to assume that it will remain so.

Accordingly, the US has set a course to refurbish or replace nearly all major elements of its nuclear enterprise. It is developing a modern ballistic missile submarine (SSBN), intercontinental ballistic missile (ICBM), long-range heavy bomber, air-launched cruise missile, and dual-capable regional strike aircraft. The DOE is fielding a life-extended gravity bomb and plans to adapt other warheads for all these delivery systems in addition to recapitalizing aging infrastructure. These modern systems will replace aging legacy nuclear systems that are well beyond their original design lives and must be sustained until their modern replacements are fielded. Together, these modernization and sustainment efforts are extraordinarily complex and interconnected.

ASPECTS OF NUCLEAR DETERRENCE

Many factors can impact nuclear deterrence, and not all of these are nuclear and not all of them are weapons. Conventional, unconventional, cyber, and space operations along with command, control, communications, intelligence, and surveillance systems are vital to overall deterrence. Moreover, the perspectives and behavior of different organizations and personalities in various crisis scenarios may play an equally important role in determining outcomes. Thus, understanding the dynamics of comprehensive deterrence requires an understanding of what attributes of alternative deterrent forces influence different players – not only adversaries and allies but also ourselves. These attributes may involve concepts of stability, sufficiency, cost effectiveness, collateral damage, and the like. They may involve more specific attributes such as weapons effects, the probability of success against given targets, or the ability to penetrate defenses. They may be qualitative or quantitative.

Attributes of deterrence are most commonly expressed in qualitative terms. Sometimes in public debate, qualitative labels such as superior, equivalent, countervailing, sufficient, minimal, and the like are used that reflect the goals of a deterrent strategy or a general assessment of the nuclear balance. Underpinning these evaluations, however, are more operational qualitative judgements about what nuclear deterrent strategies and forces are supposed to do (such as limit damage), the ways in which they might do this (such as discourage escalation), and the means by which they might do this (such as maintaining survivable second strike forces). Thus, the attributes of deterrence frequently are evaluated in terms of general characteristics (e.g., effectiveness, flexibility, reliability, adaptability, survivability, sustainability) that support objectives such as deterring aggressors, assuring allies, maintaining stability, discouraging arms races, managing escalation, or responding to surprise. These in turn lead to metrics that invite quantitative analysis such as target coverage, timeliness of response, minimizing collateral damage, and the ability to hedge.

The most common quantitative measures in public discourse are numbers of weapons and delivery systems. These simple static measures are often elaborated according to whether the warheads are carried by fast flying ballistic missiles or by slow flying air delivered systems. The alert status of systems, the explosive yields of the warheads they carry, and the accuracy of their delivery are more complicated static measures. These data inevitably generate more complex quantitative measures such as the probability of surviving an attack or the probability of destroying a target. These measures in turn lead to more dynamic measures such as force exchange calculations. A survey of the various qualitative and quantitative attributes of deterrence favored by different governments, organizations, and individuals (both friendly and hostile), can constitute something of a primer on deterrence (reference Annex A: A Deterrence Primer). Whether qualitative or quantitative and no matter how useful, deterrence metrics are not the same as deterrence itself and the strategies that promote it. Comparing metrics under different circumstances, however, can give a more objective measure of deterrence.

The most complete dynamic understanding of the significance of qualitative and quantitative measures of nuclear capability, however, requires that multiple attributes of deterrent forces be examined in context. Scenario planning is a valuable means for understanding these situational dynamics of deterrence. Most scenarios used in defense planning involve best estimates of immediate military threats. The classic scenarios are geo-centric – Korea, Taiwan, the Baltics, etc. And yet more speculative, “what if” scenario planning has become essential to exploring how to cope with change and overcome surprise. Because geopolitical and technological change can alter basic assumptions, challenging the ability of different nuclear forces with their different strengths and weakness in the context of “what if” scenarios can be very valuable. What if air or missile defenses vastly improve? What if we lose our Global Positioning Systems (GPS)? What if an ally switches sides? What if we have a serious accident with a leg of the Triad? How might economic or demographic collapse impact nuclear armed states or governments that might seek them?

CHALLENGING SCENARIOS

The geographical and functional combatant commands prepare war plans to address threats that seem most likely. They have some flexibility in their exercises, but the time and resources necessary to train for the most likely scenarios are already large. Exploring more excursions to evaluate different aggressors, tactics, equipment, and leadership may be valuable, but unaffordable. Nuclear scenarios in particular create problems. Nuclear use is a great fear; actual military detonation of nuclear weapons in war has not happened since the end of World War II. Just the decision to include nuclear weapons in a war game can be controversial. Initiating even the most limited nuclear use is often the end of the game. Scenarios in which nuclear use has happened and may be continued are seen as very challenging, but also as less likely than conventional war and unconventional conflict. Sensitivity over what actions individual or institutional players may take provides further disincentives to explore alternative scenarios, especially those involving the actual detonation of nuclear weapons.

BENEFITS OF TECHNOLOGY-ENABLED MODELING, SIMULATION, AND GAMING

The potential availability of technology-enabled modeling, simulation, and gaming can help overcome obstacles to using these tools to expand our understanding of deterrence, including its nuclear components. Some modeling, simulations, and gaming options offer low cost, adaptable means to explore more permutations. Some of these can be done without putting players in a controversial decision making role. The scenario can be pre-scripted as a "what if?" excursion. At the other end of the spectrum, extremely high fidelity capabilities can give decision makers new challenges to test their doctrine, equipment, and leadership.

Scenarios that are relevant to nuclear deterrence are often described along various spectra such as from regional to global, from pre-conflict to full scale war, from unconventional to WMD, and the like. Clearly, the circumstances in which nuclear weapons are detonated are shaped by the broader strategic environment and the particular actors and events in action. Modeling, simulations, and games can be tailored to focus on one scale, or they can integrate actions taking place at many levels –for example from a national decision maker down to the pilot in a plane. The largest current gap in the use of these tools appears to be at the strategic level, which is precisely where deterrent capabilities can be stressed and valuable insights about nuclear decision-making can be captured.

Unfortunately, today's world offers many worrisome developments that can inform both the broader strategic environment of a scenario and the specific choices to be tested. Strategic competition with nuclear-armed regional powers is now a reality on a day-to-day basis. Potential adversaries are developing new, and more diverse capabilities. Indeed, several near-peers and pariah states have placed an increased emphasis on nuclear weapons. In some cases, threats are aimed at specific allies or friends of the US, sometimes outside the well understood alliance security zones. Some of these adversaries invoke nuclear weapons in smaller scenarios than the Western democracies had ever believed could be nuclear. On the other hand, rhetoric often presents the specter of "doomsday" threats. These threats seem aimed at dividing Western democracies and alliances, but they reinforce influence operations designed to advance alternative approaches to international order, norms, and structures. The actual use of chemical weapons, both in war and for assassinations, violates treaties, laws, and norms in part as a means of signaling that may have implications for nuclear deterrence. Likewise, cyber, space, and hybrid operations continue to blur the boundaries between pre-crisis and actual conflict.

Traditionally, modeling, simulations, and war games have focused on testing the US responses to attack. The scenarios may scale from small unit tactics to presidential decisions. Increasingly it will be important to understand what allies and friends including their publics may do under various scenarios. Of course, a better understanding of what adversaries do under different circumstances in our scenarios – and even more importantly in their scenarios – would be valuable to intelligence assessments. In some cases, potential adversaries are growing in economic strength. In other cases, their economies are weakening. These may have domestic and international political implications. Scenarios involving growing military cooperation among potential near-peer adversaries or covert aid to other dangerous actors on the international scene are increasingly important. Again, strategic-level games that test our capabilities and national decision-making in such scenarios appear to be most needed.

All technology has some military implications, but not all will be significant. Still, the advance and spread of technology around the world today means that not all of the centers of excellence in important technologies with international security implications will be in the US or perhaps even in an allied nation. The same can be said of the sources of certain strategic raw materials. All of this has implications for the distribution around the globe of advanced military capabilities including autonomous air, sea, land, and underwater vehicles, enhanced cyber warfare capabilities, anti-satellite weapons, exotic sensors, artificial intelligence enabled weapon systems and support capabilities, advanced manufacturing, and new chemical and biological weapons. The advance and proliferation of weapons potential--nuclear, advanced conventional, unconventional, and even illegal--coincides with a greater awareness of the systemic vulnerabilities of modern, interconnected, just-in-time societies. Communications, transportation, and energy vulnerabilities expose both civilian and military targets to highly leveraged disruption or destruction. Scenarios range from long-term economic warfare to the imposition of an immediate crisis in critical infrastructure or communications.

TECHNOLOGICAL DEVELOPMENTS AND NUCLEAR DETERRENCE

In the military realm, nuclear deterrence futures may be impacted by many technological developments. Some could involve enemy nuclear weapons capabilities such as tailored weapons effects or electromagnetic pulse (EMP) attacks. Others might involve ultra-precision accuracy, coordinated swarms of autonomous systems, or extraordinary sensors with machine learning to pick out otherwise undetectable signals from background noise. Potential leaps forward in stealth and counter-stealth technologies, whether air or missile defense or possibly anti-submarine warfare, may be on the horizon. Certainly, more government and non-government entities are active in space operations. Concerns over anonymous attacks or catalytic warfare are exacerbated by the prospect that cyber operations, electronic warfare, and other techniques could result in the functional kill or degradation of military systems by nonkinetic means. Many scenarios, such as attacks on space assets, which were once seen as unlikely because of international norms and certain symmetrical interests, no longer seem unlikely. Cultural differences and different security perspectives among potential adversaries must be considered more carefully when looking at the likelihood of different scenarios.

To test our comprehensive deterrent including its nuclear components, we may find it valuable to posit developments we hope never to see. We need to explore how stressful certain attacks might be. Traditionally, we have looked across battle lines such as the Demilitarized Zone (DMZ) between the two Koreas. We then look to see how to best bring our own strengths to bear to get the outcomes we want. And yet, we may learn more by asking what happens when we are deprived of some of our strengths. What if we lose local air superiority? What if we lose key logistics hubs? What if we lose an aircraft carrier? What if there is an attack on a key forward base such as in Guam? Nuclear scenarios that adversaries might create may not follow what we would expect. Early nuclear use well before a decisive moment is an example of concern. Alternatively, what about conventional attack on nuclear deterrent forces such as submarines in port? Or nuclear use against a non-ally?

KEY VARIABLES IMPACTING US NUCLEAR STRATEGY

Today, concern has increased about the implications for nuclear deterrence of multi-domain warfare, conventional attack on nuclear forces, and other capabilities whose implications are magnified if the number of nuclear weapons is reduced or the remaining weapons are concentrated on fewer delivery systems with less diversity and fewer bases. Concerns over the implications of cyber or space war on C4ISR and especially NC2 amplify these fears about instabilities that could emerge. The best solutions to these challenges may emerge from the effective use of new tools for analysis, modeling, simulation, and war gaming.

To date, scenarios used for war gaming have been dominated by immediate operational planning needs, typically region by region. Important though these are, they need to be supplemented by challenges to deterrence itself. "What if?" examples include:

- Unexpected technological challenges affecting the survivability or effective functioning of the various elements of the Triad, DCA, and NC3/C4ISR,
- Significant geopolitical change,
- Opponents who make decisions based on different assumptions, rules, or values,
- Loss of a major weapon system because of a systemic problem or accident,
- Fact-of-life delays in completing nuclear modernization, and
- Future negative growth in the DoD and DOE budgets.

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TOOLS: ANALYSIS, MODELS, SIMULATIONS, GAMES

QUANTITATIVE METHODS AND NUCLEAR DETERRENCE ANALYSIS

Bringing together quantitative analysis to assess effectiveness of various forces and policies in meeting qualitative goals could prove very valuable in the years ahead given the challenges we will face and the new tools that may be available. An examination of the current capabilities and opportunities in modeling, simulations, gaming, exercises, and analysis suggests the following:

- Most nuclear deterrence analysis today continues classic techniques using simple data and traditional scenarios with little ability to explore more than a few parameters.
- As new techniques and technologies to generate and analyze data explode in the private sector through high performance computing, ubiquitous sensors, digital visualization, artificial intelligence and the like, DoD is moving to exploit these capabilities, but primarily for general purpose forces and common support organizations.
- These modern tools could add great value to the nuclear deterrence missions, not only for deterrence analysis and planning, but also for training and evaluation and acquisition program management.
- Exploitation of the most advanced modern techniques for nuclear deterrence analysis is complicated by the already stressed budgets required for block modernization, the different scenarios facing Commands and other users, and a fear of provoking controversy through nuclear war gaming.
- Very useful analytical tools and games can operate at laptop level, but state of the art analysis, simulations, and gaming with rapid visualization can require massive data and high-performance computing, often with "hardware-in-the-loop."
- What is missing most for fidelity in deterrence analysis is a sample size of data sufficient to understand the interactions of diverse actors and complex systems across a range of challenging scenarios.
- In some areas such as systems development and weapons effects, extensive data exist, although keeping the data and models current as systems change, age, and modernize is vital. Still, the best integrated nuclear analysis requires that new, more extensive data be generated through multiple iterations of simulations, games, and exercises with different players to capture more parameters and more decision-making situations where nuclear use may have to be considered.
- Repositories for such data are needed that can be accessed more widely and with modern IT tools.
- The Department must use care in designing these approaches because:
    - At best, analytic tools will only answer questions that are asked; asking the right questions is more important than the tools used to generate answers. Thus, it is essential that analysts who understand deterrence and military strategy writ large partner with tool developers to ensure that analytic tools are designed to answer the most important questions.

- A number of measurable measures of merit are important to deterrence, assurance, stability, sufficiency, etc. but no single commensurate measure of merit has yet been found that captures all the essential variables.
- Scenario-based planning built upon prediction of the future is often less valuable than scenarios that explore surprise and involve plausible game changers and diverse human and organizational reactions to them, especially because personal and cultural differences may weigh heavily.
- Stereotyping and mirror imaging of adversaries can distort fidelity, but understanding and replicating or emulating adversary war gaming could be of tremendous value to the intelligence community.

- The period in which modern tools for deterrence analysis may be most important coincides with a period in which ML and AI are expected to become widely available for multiple applications. These developments should be exploited.
- If modern tools for deterrence analysis were put in place for use during the next decade, DoD would benefit greatly as the bloc modernization of nuclear deterrence forces now underway transitions from legacy systems to replacement systems, with a particular emphasis on examining the FY29-FY39 time period.

While not all analysis of deterrence need be state of the art, the value of cutting edge developments could be very great. In post-World War II military strategy, nuclear weapons and information technology dominated analysis of peace and war. In nuclear deterrence studies, game theory and simulations emerged as powerful decision making tools. In the 21st Century, however, ML and AI may become the cutting edge of that process. AI has been developed to give machines the ability to do things that would normally require human intelligence. Some AI may actually exceed human performance in recognizing patterns and making predictions. Although key decision making must always have a human in the loop for making judgments and decisions, AI support for analysis is very powerful.

USE OF ADVANCED TECHNOLOGIES FOR QUALITATIVE ANALYSIS

Combined with modern HPC, ML, and AI are beginning to transform every aspect of modern societies including military operations. Investments are massive. And in the DoD, sound ethical guidelines and organizational structure for the application of AI are emerging. These technologies can enhance the performance of existing American forces, provide analysis to improve those forces, and enable better assessments of threats. In the years ahead, however, the US could find itself at a disadvantage as adversaries exploit ML and AI to identify and exploit gaps in Western deterrence and defense postures.

AI is at the forefront of game theoretic analysis today in many fields. Given the historic contributions of game theory to deterrence, it is reasonable to ask whether recent advances in AI may make corresponding contributions. AI systems that dominate human players in games of perfect information such as chess or Go are of less interest to deterrence than are the recent advances in games of imperfect information – in particular poker [see for example, N. Brown and T. Sandholm, Science 10.1126/science.aay2400 (2019)]. The current AI system for poker has dominated human players at the championship level by adapting to the behavior of multiple human competitors as well as bluffing to win, game traits that appear in today's competitive geopolitical environment. However, caution is necessary. Unlike poker, deterrence lacks a well-defined, universally agreed set of rules. Thus, it may be much more difficult to train and test the validity of an AI system for deterrence. In addition, the insertion of an AI-enabled game theoretic must be guided by thoughtful questions posed by experienced deterrence thinkers. Nevertheless, the time is now to invest in exploratory research to examine whether recent advances in game theory can inform our understanding of deterrence including the ability to test how adversaries might behave in different scenarios.

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ANNEX A: A DETERRENCE PRIMER

INTRODUCTION

The United States (US) has embarked on a generational recapitalization of its nuclear deterrent. It last modernized its nuclear forces in the late 1970s through the mid-1980s and largely deferred planned modernization through the 1990s and 2000s. With the nuclear weapons build up in an assertive China, an aggressive Russia, and a provocative North Korea, *en bloc* modernization of the US nuclear deterrent is now necessary. Administrations of both political parties have recognized this need to recapitalize US nuclear forces and the infrastructure that supports them; indeed, both the Obama and Trump Administrations have placed nuclear modernization of each leg of the Triad at the top of their defense priorities.

The 2018 Nuclear Posture Review (NPR) and its 2010 predecessor make clear that the US nuclear deterrent, centered on the strategic nuclear Triad, should exhibit certain key features across multiple platforms and be without single points of failure. Each leg has strengths and weaknesses, but synergism among the legs complicates attacker planning and provides hedges that enhance deterrence. A robust Triad has been a central feature of US nuclear policy for well over half a century, and it is reasonable to assume that it will remain so.

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Many factors can impact nuclear deterrence, and not all of these are nuclear and not all of them are weapons. Conventional, unconventional, cyber, and space operations along with command, control, communications, intelligence, and surveillance systems are vital to overall deterrence. Moreover, the perspectives and behavior of different organizations and personalities in various crisis scenarios may play an equally important role in determining outcomes. Thus, understanding the dynamics of comprehensive deterrence requires an understanding of what attributes of alternative deterrent forces influence different players – not only adversaries and allies but also ourselves. These attributes may involve concepts of stability, sufficiency, cost effectiveness, collateral damage, and the like. They may involve more specific attributes such as weapons effects, the probability of success against given targets, or the ability to penetrate defenses. They may be qualitative or quantitative.

Attributes of deterrence are most commonly expressed in qualitative terms. Sometimes in public debate, qualitative labels such as superior, equivalent, countervailing, sufficient, minimal, and the like are used that reflect the goals of a deterrent strategy or a general assessment of the nuclear balance. Underpinning these evaluations, however, are more operational qualitative judgements about what nuclear deterrent strategies and forces are supposed to do (such as limit damage), the ways in which they might do this (such as discourage escalation), and the means by which they might do this (such as maintaining survivable second strike forces). Thus, the attributes of deterrence frequently are evaluated in terms of general characteristics (effectiveness, flexibility, reliability, adaptability, survivability, sustainability, etc.) that support objectives such as deterring aggressors, assuring allies, maintaining stability, discouraging arms races, managing escalation, responding to surprise, restoring deterrence, or bringing a conflict to an end. These in turn lead to metrics that invite quantitative analysis such as target coverage, timeliness of response, minimizing collateral damage, reconstitution, and the ability to hedge.

The most common quantitative measures in public discourse are numbers of weapons and delivery systems. These simple static measures are often elaborated according to whether the warheads are carried by fast flying ballistic missiles or by slow flying air delivered systems. The alert status of systems, the explosive yields of the warheads they carry, the accuracy of their delivery are more complicated static measures. These data inevitably generate more complex quantitative measures such as the probability of surviving an attack or the probability of destroying a target. These measures in turn lead to more dynamic measures such as force exchange calculations. A survey of the various qualitative and quantitative attributes of deterrence favored by different governments, organizations, and individuals (both friendly and hostile), can constitute something of a primer on deterrence. These different attributes also guide the development of qualitative and quantitative measures of merit for analysis.

QUALITATIVE MEASURES OF MERIT

Strategic Modernization of Near-Peer Competitors

For the US Strategic Command (USSTRATCOM) – and its Cold War predecessor, the Strategic Air Command (SAC) – the American nuclear deterrent is linked to the motto: “Peace is our Profession.” After two world wars and especially during the Cold War, an extensive US nuclear deterrent was widely accepted as vital to prevent large wars and to end them if they began. The measure of merit was keeping the “Big Peace.” That Big Peace has been sustained thus far. The last world war ended about three-quarters of a century ago. The Cold War ended nearly three decades ago. After the breakup of the Soviet Union, however, the specter of total war and thermonuclear strikes faded leading to decades of intellectual and operational neglect of things nuclear – including in the uniformed services. Unfortunately, current events remind us that the old dangers can return, requiring us to think again about how we keep the “Big Peace.”

Despite years of scarce resources, Russia has modernized all its traditional strategic forces, upgraded its non-strategic nuclear forces, and developed new and exotic systems. Russian leaders routinely invoke nuclear saber-rattling rhetoric even in small scenarios and publicize their participation in nuclear exercises. The once slow, but steady Chinese strategic nuclear modernization has blossomed into a more diverse force with significant theater capabilities emerging. Both Russia and China appear to have theories of success in regional contexts for which nuclear means are integrated as tools of influence and coercion. Even smaller nuclear actors such as Pakistan and North Korea are diversifying their nuclear capabilities.

The 2018 NPR highlights the growing nuclear capabilities of China and Russia and their increasingly belligerent language and actions. The NPR expressed concern that, as the nuclear deterrence mission resumed its central importance, the security of the US and its Allies might be undermined by current and evolving geopolitical and technological challenges. These include important differences from the past such as more players, a more dynamic strategic setting, and a wider range of leveraging capabilities including cyber, space, hybrid, and advanced conventional. These developments stress both delivery systems and Nuclear Command, Control, and Communication (NC3). In the years ahead, these challenges will continue to morph and could present the US with strategic surprises leading to weakened or failed deterrence.

U.S Nuclear Strategy Response to the Evolving Nuclear Threat

Changed circumstances require that the Department of Defense (DoD) examine both what has changed and what is enduring. Successful deterrence, both nuclear and comprehensive, cannot be separated from the broader national security strategy and capabilities including conventional military capabilities, multi-domain activities, intelligence assessments, National Nuclear Security Administration (NNSA)/DOE support, our military alliances, and American diplomatic efforts. This interacting complexity continues to grow, underscored by concerns over cyber and space and "hybrid" operations on conflict escalation and the possibility of nuclear weapons use.

US policy emphasizes that nuclear weapons are not just another munition and that crossing the nuclear threshold is a fundamental phase change in risk calculations. Traditionally, US and allied commentaries focus on an "escalatory ladder" for which nuclear forces are kept ready to dissuade aggression, but, if use becomes necessary, every attempt is made to control escalation and bring hostilities to an end at the lowest level of destruction. Having the appropriate weapons for dangerous, but plausible scenarios helps prevent attack in the first place and, if use should become necessary, provides for proportionate responses. Both offensive forces and air and missile defenses must be included in the calculations.

US efforts to prevent conflict and control escalation inevitably involve command, control, communications, and situational awareness as well as modern cyber and space capabilities, sometimes called an "escalatory lattice." The dimensions added by the "lattice" are often contrasted these days with the linear "ladder." A spatial dimension, geography, plays heavily among our allies and in those broader regions where conflict and escalation might begin or spread. Where we can deploy our forces matters to our allies and should matter to us. The possibility of "horizontal escalation" out of region is a factor for both Blue and Red. There is also a temporal dimension. Much of the effectiveness of our deterrent is time dependent. How much time do we have to decide? Can we intercept? Can we disrupt? Can we avoid the "fait accompli?" Perhaps we should highlight additional dimensions. For example, the greatest uncertainty about deterrence may be found in cultural, organizational, and even personal differences. Today, we must deal with the behavior of more players from different cultures with alternative versions of history. We must recognize that their approach to things nuclear may differ in important ways from ours. We need to understand better our adversaries, and our friends, and ourselves as well.

Enduring principles in US deterrence policy recognize complex dynamics and the inevitability of surprises. How these surprises might play out today can vary greatly. For example, the US wants to deploy forces such that any aggressor would be very uncertain that that aggressor could conduct a successful attack by that aggressor's standard. This has led to an emphasis on the collective survivability of our deterrence forces, with an emphasis on the synergy of diverse forces that complicates any aggressor's attack planning. In today's world deterrence must be assured with fewer forces, at lower readiness, and possibly with less warning. At the same time, the US wants to make certain that any potential aggressor knows with great certainty that the price of even a highly successful attack would be too high. The US emphasizes that this means the US would, after an attack, have the capability and credibility to attack and destroy targets most valued by the aggressor, again by that aggressor's standards. Today, we are perhaps faced with greater uncertainty as to how different adversaries make these calculations.

Even though the US considers nuclear weapons to be weapons of last resort, this does not mean that the US would wait until all is lost and when retribution might become the only option left. US policy requires that our responses be militarily effective, attempt to limit further escalation, and terminate any conflict on terms acceptable to the US. A central challenge to deterrence is the danger that an attacker might believe that they could accomplish a *fait accompli* that leaves American leadership unable to act in a relevant timeframe. For that reason, the US retains forces for prompt and timely response that can disrupt the implementation of the attacker's plan even as it is underway.

In US nuclear strategy, resolve must be reinforced by considered restraint. As a matter of strategy, law, and doctrine, the US does not target enemy populations per se. Indeed, in American nuclear strategy, civilian casualties are a negative measure of merit. Written guidance shapes US nuclear and conventional targeting to minimize collateral damage in accordance with the laws of war and to ensure that no aggressor believes that the US will be self-deterred. Likewise, the US seeks options that would encourage potential aggressors to go down less dangerous paths, perhaps to cooperate on enhancing mutual security, restraining arms and reducing defense spending. Understanding how this can be done with potential adversaries while maintaining a strong deterrent requires operational professionalism and the sustainment of high-quality forces, infrastructure, and people.

US Nuclear Capabilities

To ensure the "Big Peace" and in particular the nuclear peace, the US maintains diverse nuclear forces. Often, reference is made to the nuclear Triad of bomber weapons and missiles at sea and on land. Others would include American dual-capable aircraft overseas as a fourth leg of the US deterrent, and nearly everyone sees NC3 as a vital, integral component of the deterrent. Multiple legs of the deterrent provide a number of advantages. Competition between the legs and their providers can provide options for more cost effective acquisition and operations. Options to change the mix help address changes in the threat. Indeed, a failure in one leg of the deterrent or a new threat against it can be compensated for by the existence of the others. Each leg has its own strengths, but each also has its own very real weaknesses.

Bombers and their weapons remain the most flexible of the nuclear forces. While they are expensive to procure and operate, they primarily conduct conventional missions. In a crisis, they are usually the weapon selected for strategic signaling and a show of force. Aircraft are often the weapon of choice against mobile and deeply buried targets. Their bombs and long-range missiles, including air launched cruise missiles, provide a wide range of conventional munitions and nuclear yields. As reflected in the START I and New START bomber discount rules, they are favored in arms control for their contributions to stability as "slow-flyers" that can be recalled. Unfortunately, our current bomber systems are aging and face advanced air defense systems. Increasingly they need to add modern standoff capability for many of their missions. Our B-52 and B-2 bombers operate out of very few bases and currently do not stand day-to-day nuclear alert. A limited attack without warning could take out the US bomber bases and any aircraft still there, but this would involve attacking the sovereign territory of the US itself, a major escalation.

The ICBM provides the lowest cost, highest readiness leg of the nuclear deterrent. Although the heavily MIRVed (Multiple Independent Reentry Vehicle) ICBM is favored by Moscow to deliver many warheads quickly, the US has moved to the single warhead ICBM to enhance stability and provide greater targeting flexibility. De-MIRVed ICBMs are stabilizing because each target by itself is of low value, especially when to attack even a few ICBMs would require an attack on the territory of the US itself. Moreover, an attack on all the singlet ICBMs would require a massive attack across great areas of the US with more warheads than are destroyed in the attack. The force exchange ratio does not favor the attacker. Even then, if the circumstances warranted, the US missiles might have already been launched leaving only empty silos to be destroyed. Weaknesses include the fact that each launch silo may be individually vulnerable and that launching against some targets may require undesirable overflight of other countries. Also, because the ICBM is the system with the most prompt response capability, it has also been the lightning rod for public debate over theoretical unauthorized launch or "use it or lose it" decision making pressures, although similar concerns are also expressed about Sea Launched Ballistic Missiles (SLBMs) and were once the focus of the "fail-safe" debate over bombers.

American SLBMs deployed on SSBNs in the open ocean currently provide a highly survivable force deployed away from the sovereign territory of the US. The SSBNs can be relocated to reach more targets and avoid overflight of certain countries. With a modified warhead added to the current nuclear modernization program, the SLBMs join the bombers in offering a lower yield option. As long as the total number of submarines is not greatly reduced, a number of submarines can be maintained on continuous patrol. The weakness of the SLBM forces are to be found in their high cost and the concentration of many warheads on very few delivery platforms. The submarines in port are highly vulnerable to very small, even non-nuclear attacks and if nuclear forces are significantly reduced, only a small number of submarines may be at sea. The British and French – who need four submarines to keep one at sea – recently experienced a scare associated with so few submarines. In February 2009, the single French SSBN at sea, *Le Triomphant*, collided with the lone British SSBN at sea, *H.M.S. Vanguard*. Had both sunk, this would have disarmed two independent nuclear deterrents instantly and would have raised questions about the future of all sea-based deterrent forces including those of the US.

Now and in the years immediately ahead, under the limits of the New START Treaty, the US plans to have 60 strategic bombers and 400 ICBMs counted as strategic delivery vehicles. Under the Treaty ceilings, this would in theory leave room for a maximum of 1090 strategic operationally deployed warheads on about a dozen submarines. Approximately half of these might routinely be at sea. Although great advances are likely in anti-submarine weapons (ASW), when these advances might impact the viability of any number of submarines on patrol remains uncertain. Some have criticized even highly survivable SLBMs as destabilizing arguing that with movement closer to targets, fast flight times, and depressed trajectories, they threaten decapitation attacks and disarming first strikes. Ironically, some question the reliability of NC3 with submarines in global, multi-domain warfare and argue that SLBMs are thus dependable only for massive pre-planned strikes. Such images plus concerns that at-sea nuclear weapons might be drawn into conventional conflicts have led to arms control proposals to de-nuclearize the open ocean. Thus far, however, the Nuclear Weapon Free Zones in place do not limit the transit of SSBNs.

The US has set aside a limited number of nuclear weapons for American or allied dual-capable fighter-bomber aircraft (DCA) in the North Atlantic Treaty Organization (NATO). Alliance DCA are vastly outnumbered by the non-strategic nuclear aircraft and missiles of the Russian Federation. Nevertheless, these DCA delivered weapons are highly valued by allies as symbols of coupling to the American nuclear umbrella through the use of aircraft that can also perform conventional missions. Their presence in Europe places an escalation burden on any aggressor. They may also have more credibility in some low level and regional deterrence scenarios than strategic systems. Nevertheless, NATO's DCA have limited range from their current bases, are not on alert, and would take some time to activate. Support for DCA is not universal with questions being asked about the cost of security as well as the survivability of the aircraft and bases.

Diversity of US Nuclear Systems

In looking at the diverse nuclear and dual capable delivery systems, some analysis emphasizes the strengths of each leg. Other assessments emphasize the weaknesses of each. A more complex analytical approach focuses on the synergism between the deterrent legs that can provide a total deterrent greater than the sum of the parts. An attack on subs at sea or on regional DCA provides warning to forces in the US. Attacks on submarines in port and bomber bases, which requires few warheads, would provide warning to the ICBM force and the SSBNs at sea. To attack all ICBMs, however, would require a massive strike deep into sovereign American territory.

The diversity in the deterrent force permits more than synergism. Diversity is a major antidote to surprise. The technologies and strategies necessary to undermine each delivery system in the deterrent are not all the same although they often benefit from similar advances and ideas. For example, optimal defenses against low flying, course changing cruise missiles are different from those that are optimal against ballistic missiles. Active electronic countermeasures on bombers present yet another problem to overcome and presents different challenges than the ASW operations and technologies aimed at tracking submarines at sea. To have high confidence in a disarming attack, an aggressor must look for more than a single “silver bullet.” A comprehensive approach requiring the development of many different “silver bullets” would be necessary.

If there is one greatest risk of a common mode of failure, however, it is associated with NC3. Although different means of communications can be associated with different delivery systems, ultimately, they come together at the top of the decision tree. For this reason, special attention is being paid to a replacement for the legacy NC3 systems. Trade-offs between dedicated, “strong back” communications and exploitation of multi-path, redundant systems of systems are being explored. Central to such decisions are questions of reliability, survivability, and security made more complex in the cyber age with its dependence on the fragility of space-based nodes.

QUANTITATIVE MEASURES OF MERIT

Numbers of Nuclear Weapons

Despite these many complex, qualitative considerations, objectives, interactions, and measures of merit, most discussions of nuclear deterrence and disarmament obsess with numbers: How much is enough? How many are too few? Is even one too many? Each year the President signs a memorandum indicating what weapons and how many should be retained at various levels of readiness. The total number of nuclear weapons is a crude measure of merit, but it is watched closely. The official total stockpile number made public in 2017 was 3822 – about 12% of the Cold War peak. Some weapons awaiting dismantlement and some nuclear explosive “pits” for nuclear weapons are not included in this total stockpile number.

At the same time, the number of weapons in the official stockpile total exceeds the number of weapons for which there are delivery systems. Many of these weapons in the stockpile do not have limited life components and could not be readied quickly even if extra delivery systems were available. This is true even of some weapons in the subset of the total nuclear weapons stockpile known as the “active stockpile.” The active stockpile includes spare weapons to be examined for aging, backup weapons to replace any weapons found to be of uncertain reliability, and hedge weapons to be available if more weapons should be needed. These weapons are more readily available then new production, especially given the current challenges associated with any production of new pits.

In arms control and in most analytical assessments of deterrence, the focus is on nuclear weapons that are “operationally deployed,” meaning warheads actually on sea-based and land-based missiles and bombs and cruise missiles deployed at bases with strategic bombers and DCA. For the US, the DCA number is small. Thus, the primary focus is on “strategic operationally deployed.” Of these, for the US, bombers are not on alert and, like submarines in port, would take some time to go on alert or patrol. Day to day, the US relies on its submarines at sea and its ICBMs. Thus, the nuclear weapons potentially available to the US can be categorized by the time necessary to be mission ready. For new production or rebuilds, this might take years. For some weapons in the Total and Active Stockpiles, this might take many months. For bombers and submarines in port or overhaul this might take days or even weeks. For some submarines at sea, this may take hours. For submarines on station, it could be minutes. Perhaps the fastest response could be from the ICBMs, although some brief additional time may be required to re-target them. No American weapons are currently targeted on potential adversaries, although some systems are targeted at open ocean areas because with current technology they must always be targeted on something to stay on alert.

To put this in numerical perspective, in 2009 the total nuclear weapons stockpile of the US was 5113. Only 1968 of these weapons (38%) were strategically operationally deployed. Less than 10% were on the approximately 500 ICBMs. Under the New START Treaty, in which bomber weapons are discounted, the planned 60 strategic bomber force would leave headroom for about 1490 SLBM and ICBM warheads. The planned operationally deployed ICBM force would consist of 400 warheads operationally deployed at well over 90% availability. This would, in theory, leave headroom for up to 1090 SLBM accountable warheads, of which perhaps half would be at sea. Thus, the day-to-day total of SLBM warheads at sea and ready ICBMs might normally total less than one thousand.

Yield of Nuclear Weapons

Of course, not all nuclear weapons have the same nuclear explosive yield as measured in tons, thousands of tons, and millions of tons – tons (t), kilotons (kt), and megatons (mt). Historically, the largest nuclear weapon ever tested, the Soviet Tsar Bombe at 50 megatons, was some 5 million times larger than the smallest weapon known to have been tested. At the height of the Cold War, the average yield of a nuclear weapon in the American stockpile was over 3 megatons. By the end of the Cold War, it was a bit over 200 kilotons, less than 7 percent of what it had been. Over time, a stockpile based on a smaller number of very high yield weapons was replaced by a stockpile with a larger number of much lower yield weapons. Then, with the breakup of the Soviet Union, the total number, total megatons, and average warhead yield all declined greatly from Cold War levels. Indeed, the reduction in the total megatons in the stockpile was far greater than the reduction in numbers of weapons. Warheads eliminated included both the largest and the smallest.

These reductions reflect the exploitation of technical advances to: (1) improve accuracy, (2) reduce collateral damage, (3) improve targeting efficiency, (4) cut costs, (5) reduce requirements for Special Nuclear Material (SNM), and (6) minimize aggressor incentives to attack by increasing the dispersion, hardening, stealth, and mobility of different parts of the US deterrent. Thus, the nuclear stockpile has changed greatly over time because of: (1) dramatic responses to world events, (2) cyclical bow waves of modernization, (3) periods of consolidation or stasis, (4) quality versus quantity trade-offs, and (5) the increasing caution that is displayed as available weapons and delivery systems go to lower levels. This last factor is driven by concerns that small qualitative and quantitative changes can be particularly destabilizing at low numbers of deterrent systems.

Deterrence Considerations

The logic of deterrence is driven by both simplicity and complexity. The simple truth is that a massive nuclear weapons exchange could bring the catastrophe of total war in a fraction of the time associated with the two 20th Century world wars. Preventing nuclear war is more complex. As long as nuclear weapons remain essential to the security of the US and its allies, US policy continues to maintain that diverse options are necessary to help deter both high-level conflicts and certain lower level conflicts that could escalate including those threatening US forces and Allies in dangerous regions abroad. This has become even more important as the Russian Federation under Vladimir Putin invokes nuclear weapons in contexts that the West thought were no longer nuclear or had never been nuclear.

This continuing US nuclear policy of prevent and restrain has enduring principles that require diverse capabilities that are credible to adversaries whose views may differ from ours, but also credible to our allies, and especially to ourselves. The needed capabilities must be able to avoid any adverse *fait accompli*, while being proportionate, discriminate, and legal. They are required to be militarily effective, have a rational purpose and be suitable to control escalation and limit damage. The goal, if deterrence fails, is to bring conflict to an end and re-establish deterrence. All of this is meant to strengthen prevention of conflict in the first place. Having diverse capabilities can help mitigate self-inflicted problems with the legs of the Triad such as aging, or accidents, or obsolescence, but more importantly, diversity complicates attack planning by adversaries who think, and plan, and test, and probe our weaknesses.

The US must maintain nuclear diversity, but not unlimited diversity. Compared to today's forces, the US once had many more types of nuclear weapons and delivery systems deployed for many more missions including air defense, missile defense, anti-submarine warfare, artillery, anti-armor, atomic demolition, and many more. For the US military, nearly all the missions that were once nuclear have been replaced by conventional capabilities. This is not true of the Russian Federation today, which retains many systems we thought were made irrelevant with the end of the Cold War, including a system we believe was banned by the Intermediate-Range Nuclear Forces (INF) Treaty.

The total number of weapons in the nuclear stockpile and their total megatons over time are often compared to show trends, but even when readiness distinctions are made between active weapons, hedge weapons, operationally deployed weapons, alert weapons, and the like, total numbers and yield alone are very crude measures of nuclear deterrence. Still, when broken down by specific weapons against specific targets, numbers and yield are the most often used measures of merit in both static and dynamic comparisons.

US Nuclear Arsenal Effects

The number of weapons at various states of readiness are inputs into how many point targets can be covered under different scenarios. Yield is an important factor in determining the probability of destroying a hard target such as an ICBM silo or missile command post, but also in any assessment of area destruction against soft targets such as a military production facility. Caution in referencing or focusing on any specific measure of merit such as yield is warranted, however. For example, accuracy of the delivery system is a greater factor than yield of a weapon in calculating effectiveness against hardened targets. Equivalent megatons (EMT=Y 2/3) is a better measure against area targets than megatons because of the way the sphere of an explosion interacts with the generally flat plane of the earth. Weapons above one megaton become continuously less efficient against area targets, whereas those below one megaton become more efficient.

Calculating weapons effects for individual weapons and for forces in actual scenarios quickly becomes very complex. At different yields and heights of burst, different nuclear weapon effects are dominant including blast, heat, prompt radiation, residual radiation, fallout, fire effects, electromagnetic impulse (EMP) and the like. Although the destructive effect of any attack is ultimately a product of the weapon's interaction with its target or targets, a major determinant of the outcome rests with the ability of the delivery system, be it missile or bomber or other, to get the weapon to its aim point. In realistic scenarios, models must consider many factors such as the pre-launch survivability of the delivery system and sub-factors such as the pre-launch hardness of the delivery systems and/or its alert status.

Modeling and simulations have become more sophisticated at looking at many such factors. Some of these still produce essentially static comparisons, for example, the total prompt hard target capability inherent in a given force. Others are more dynamic looking at force exchange models with assumptions about whether the exchanges are sequential or simultaneous. Still others push the complexity to include the selection of alternative force structures or targeting options by different decision makers.

Static measures do have an important impact on decision makers. Comparisons of numbers and capabilities of the weapons and delivery systems of antagonists is a common currency of debate and signaling. Static measures can show trends, but they also highlight asymmetries in choices made. Comparing the capabilities of different force structures guided by different strategies under different circumstances becomes more complex. Even when the goal of arms control agreements is to influence dynamic measures such as crisis stability, the limits imposed are on static numbers of launchers, missiles, aircraft, and attributed weapons.

Applying New Analytical Techniques/Advanced Technologies

The US does not need to do all that others do, but it must have capabilities to dissuade and deter anyone thinking about nuclear aggression, whatever their thought processes. The current US air, land, and sea program provides a sound foundation for today's world and for future developments, both positive and negative. Nevertheless, circumstances change, threats are transformed, and resources are limited. Can we take advantage of new analytical techniques and advanced technologies to better address questions such as?

- Where is comprehensive deterrence to be found?
- What are the deterrence measures of merit?
- How do numbers and force structure relate to real deterrence requirements?
- How should combatant command deterrent requirements be calculated?

Key Attributes of Deterrence

To illustrate the number of attributes of a sound deterrent force that are important to any assessment, consider the following list, produced at the Institute for Defense Analyses, focusing on just "survivability "and "diverse and graduated options:"

Survivability – The force and NC3 resilience needed to survive any potential adversary attack and endure throughout crises and conflict.

1. *Prelaunch survivability* – delivery systems and onboard nuclear weapons can survive any adversary's first strike and launch successfully against designated and authorized targets.
2. *Prelaunch connectivity* – combat crews can receive prelaunch emergency retargeting and/or execution orders despite adversary efforts to deny NC3 connectivity.
3. *Penetrating defenses* – the capacity to counter active and passive defenses, including hardened and buried facilities, to pose credible deterrent threats and achieve military objectives with high confidence.
4. *Post-conflict endurance* – the capability to retain and maintain sufficient survivable nuclear forces to deter potential adversaries from miscalculating that gains can be made by restarting nuclear war.

Diverse and Graduated Options – The availability of forces with the spectrum of yield options, weapon types, and delivery options necessary to support the most effective tailoring of strategies across a range of adversaries and contingencies.

1. *Weapons Yield Options* – the availability of forces with the spectrum of yield options.
2. *Accurate Delivery* – the precision needed to hold adversary assets at risk while minimizing unintended effects.
3. *Forward deployable* – the ability and range needed to temporarily or permanently relocate some US nuclear capability to allied or partner territory for needed political or military effect.
4. *Diversity of Ranges* – the availability of forces with a spectrum of range options necessary to support the most effective tailoring of strategies.
5. *Diversity of Trajectories* – the capacity to locate forces at multiple geographical locations and with multiple flight profiles to complicate adversary active and passive defense planning.
6. *Responsive* –the capacity to deploy and employ forces as promptly as necessary to pose credible threats.
7. *Visible* – the capacity to display national will and capabilities as desired for signaling purposes throughout crisis and conflict.
8. *Weapons Reallocation* – the capacity to change target information quickly to enable adaptive planning and effective employment.

Just as no single measure of merit can comprehensively gauge the strength of a deterrence strategy and posture, no combination of such metrics substitutes for the goal of achieving a sound deterrent. Such metrics are, however, valuable tools for analysis and signaling. This brief discussion of deterrence principles and diverse measures of merit is but an introduction to the deterrence of the future. Ensuring nuclear deterrence in the coming decades will be more complex than it has been in the past. Cold War deterrence analysis was predominantly bipolar; in the 21st century, it is increasingly multi-polar. The pace of technological change affecting proliferation and deterrence has accelerated in the 21st century. Because there are more participants in the deterrence equation, it is probable that they will bring different values as well as different perceptions of the norms of international behavior. Taken together, these require renewed attention to the analytic work supporting deterrence using the best, modern analytic tools.

ANNEX B: TERMS OF REFERENCE

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION AND SUSTAINMENT

SEP - 4 2019

MEMORANDUM FOR CHAIRMAN, THREAT REDUCTION ADVISORY COMMITTEE

SUBJECT: Terms of Reference –Threat Reduction Advisory Committee Task Force on Scenario-Based Planning to Maintain the Credibility of the U.S. Nuclear Deterrent Against Emerging Threats

The 2018 Nuclear Posture Review (NPR) notes that despite decades of concerted U.S. efforts to reduce the role of nuclear weapons in international affairs and to negotiate reductions in the number of nuclear weapons, potential adversaries, namely Russia and China, have not reduced either the role of nuclear weapons in their national security strategies or shown interest in negotiating reductions in the number of nuclear weapons they field. Rather, they have moved decidedly in the opposite direction. Russia is modernizing these weapons as well as its other strategic systems. Even more troubling has been Russia's adoption of military strategies and capabilities that threaten nuclear use in regional scenarios. China, too, is modernizing and expanding its already considerable nuclear forces. Like Russia, China is pursuing entirely new nuclear capabilities tailored to achieve particular national security objectives while also modernizing its conventional military, challenging traditional U.S. military superiority in the Western Pacific.

What has emerged is an unprecedented range and mix of threats, including major conventional, chemical, biological, nuclear, space, and cyber threats, which have produced increased uncertainty and risk, demanding a renewed seriousness of purpose in deterring threats and assuring allies and partners.

The 2018 NPR further assessed that nuclear weapons have, and will continue to play, a critical role in deterring nuclear attack and in preventing large-scale conventional warfare between nuclear-armed states for the foreseeable future. In turn, it focuses on identifying the nuclear policies, strategy, and corresponding capabilities needed to protect the United States, its allies, and partners in a deteriorating threat environment, and ultimately applies a tailored approach to effectively deter across a spectrum of adversaries, threats, and contexts.

However, U.S. future force requirements for deterrence cannot prudently be considered fixed. The United States must be capable of developing and deploying new capabilities, if necessary, to deter, assure, achieve U.S. objectives if deterrence fails, and hedge against uncertainty. An iterative, evidenced-based analytical framework, which integrates diverse perspectives from the intelligence community, academic theoreticians, policy makers and operators, is needed to better inform modeling and simulation capabilities and assessments in order to optimize capability investments.

Toward this end, the task force should consider analytic and data-driven frameworks for evaluating the current strategic environment and assessing emergent challenges to the U.S. ability to deter threats from peer and near-peer competitors (primarily Russia and China). The Threat Reduction Advisory Committee (TRAC) should evaluate available methodologies—including war gaming, modeling and simulation—as well as realistic scenarios for planning purposes to identify gaps and opportunities in the process and execution of integrated, comprehensive planning to identify the requirements for ensuring the credibility of the U.S. nuclear deterrent over the next ten-to-twenty-five years. Further, the TRAC should identify options on how to more rapidly integrate a data-driven approach into a decision framework to maintain flexibility and decision space to optimize future investments of the Office of the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs.

I will sponsor the study. Ambassador Ronald F. Lehman and Maj Gen William A. Chambers, (USAF, *Ret.*) will serve as co-chairs of this study. Mr. Christopher S. Grisafe will serve as the Executive Secretary. The co-chairs are encouraged to recruit government advisors from stakeholder organizations.

The study members are granted access to the Department of Defense (DoD) officials and data necessary for the appropriate conduct of their study. The nominal start date of the study period will be within three months of signing this Terms of Reference, and the study period will be between nine to twelve months. The final report will be completed within 3 months from the end of the study period. Extensions for unforeseen circumstances will be handled accordingly.

The study will operate in accordance with the provisions of Public Law 92-463, the "Federal Advisory Committee Act," and DoD Directive 5105.04, "DoD Federal Advisory Committee Management Program." It is not anticipated that this study 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 action as a procurement official.

Ellen M Lord

Ellen M. Lord

ANNEX C: MEMBERS AND ADVISORS

Major General William A. Chambers, USAF (Ret) (Co Chair)*
The Honorable Ronald F. Lehman, Ph.D. (Co-Chair)*
Joseph V. Braddock, Ph.D.* **
Miriam E. John, Ph.D.*
Charles F. McMillan, Ph.D.*
Michael Nacht, Ph.D.*
Ms. Joan B. Rohlfing*
Mr. Elbridge A. Colby, J.D.
John R. Harvey, Ph.D.
The Honorable W. Bruce Weinrod, J.D.

Executive Director: Drew Walter, Senior Advisor DUSD(A&S)

*Member of TRAC
** Stepped down from TRAC May 27, 2019

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ANNEX D: THREAT REDUCTION ADVISORY COMMITTEE CHARTER

1. Committee's Official Designation: The Committee shall be known as the Threat Reduction Advisory Committee ("the Committee").
2. Authority: The Secretary of Defense, in accordance with the provisions of the Federal Advisory Committee Act (FACA) of 1972 (5 U.S.C., Appendix, as amended) and 41 C.F.R. § 102-3.50(d), established this discretionary Committee.
3. Objectives and Scope of Activities: The Committee shall provide independent advice and recommendations on matters relating to combating Weapons of Mass Destruction (WMD), as set forth in paragraph 4 below.
4. Description of Duties: The Committee shall provide the Secretary of Defense, and the deputy Secretary of Defense, through the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)) and the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs (ASD(NCB)), independent advice and recommendations on:
Reducing the threat to the US, its military forces, and its allies and partners posed by nuclear, biological, chemical, conventional, and special weapons;
Combating WMD to include non-proliferation, counterproliferation, and consequence management;
Nuclear deterrence transformation, nuclear material lockdown and accountability;
Nuclear weapons effects;
The nexus of counterproliferation and counter WMD terrorism; and
Other AT&L, NCB, and Defense Threat Reduction Agency (DTRA) mission-related matters, as requested by the USD(AT&L).
5. Agency or Official to Whom the Committee Reports: The Committee shall report to the Secretary of Defense and the Deputy Secretary of Defense, through the USD(AT&L). The USD(AT&L), pursuant to Department of Defense (DoD) policies and procedures, may act upon the Committee's advice and recommendations.
6. Support: The DoD, through the Office of the USD(AT&L), the Office of the ASD(NCB) Defense Programs, and DTRA, shall provide support, as deemed necessary, for the Committee's performance, and shall ensure compliance with the requirements of the FACA, the Government in the Sunshine Act of 1976 (5 U.S.C. § 552b, as amended) ("the Sunshine Act"), governing Federal statutes and regulations, and established DoD policies and procedures.
7. Estimated Annual Operating Costs and Staff Years: The estimated annual operating cost, to include travel, meetings, and contract support, is approximately $758,000. The estimated annual personnel costs to the DoD are 1.65 full-time equivalents.
8. Designated Federal Officer: The Committee's Designated Federal Officer (DFO), pursuant to DoD policy, shall be a full-time or permanent part-time DoD employee, designated in accordance with established DoD policies and procedures.
The Committee's DFO is required to attend all Committee and subcommittee meetings for the entire duration of each and every meeting. However, in the absence of the Committee's DFO, a properly approved Alternate DFO, duly designated to the Committee, according to the DoD policies and procedures, will attend the entire duration of the Committee or subcommittee meetings.

The DFO, or the Alternate DFO, shall open all of the Committee's and subcommittee's meetings; prepare and approve all meeting agendas; and adjourn any meeting when the DFO, or the Alternate DFO, determines adjournment to be in the public interest or required by governing regulations or DoD policies and procedures.

9. Estimated Number and Frequency of Meetings: The Committee shall meet at the call of the Committee's DFO, in consultation with the Committee's Chair. The estimated number of Committee meetings is four per year.

10. Duration of the Committee: The need for this advisory function is on a continuing basis; however, it is subject to renewal every two years.

11. Termination Date: The Committee shall terminate upon completion of its mission or two years from the date this charter is filed, whichever is sooner, unless the Secretary of Defense or Deputy Secretary of Defense renews its charter.

12. Membership and Designation: The Committee shall be composed of no more than 25 members who are eminent authorities in the fields of national defense, geopolitical and national security affairs, WMD, nuclear physics, chemistry, and biology.

The appointment of Committee members will be authorized by the Secretary of Defense or the Deputy Secretary of Defense, and administratively certified by the USD(AT&L), for a term of service of one-to-four years, with annual renewals, in accordance with DoD policies and procedures. Members of the Committee who are not full-time or permanent part-time Federal officers or employees will be appointed as experts or consultants pursuant to 5 U.S.C. § 3109 to serve as special government employee (SGE) members. Committee members who are full-time or permanent part-time Federal officers or employees will be appointed pursuant to 41 C.F.R. §102-3.130(a) to serve as regular government employee (RGE) members. No member, unless authorized by the Secretary of Defense or the Deputy Secretary of Defense, may serve more than two consecutive terms of service on the Committee, to include its subcommittees, or serve on more than two DoD federal advisory committees at one time.

The USD(AT&L) has the delegated authority to appoint the Committee's chair and vice chair from among the membership previously appointed according to DoD policies and procedures and, in doing so, will determine the term of service for each, which will not exceed the member's approved term of service.

Each member is appointed to provide advice on behalf of the Government on the basis of his or her best judgment without representing any particular point of view and in a manner that is free from conflict of interest.

Committee members shall, with the exception of reimbursement for official Committee-related travel and per diem, serve without compensation.

13. Subcommittees: The DoD, when necessary and consistent with the Committee's mission and DoD policies and procedures, may establish subcommittees, task forces, or working groups to support the Committee. Establishment of subcommittees will be based upon written determination, to include terms of reference, by the Secretary of Defense, the Deputy Secretary of Defense, or the USD(AT&L), as the DoD Sponsor.

Such subcommittees shall not work independently of the Committee and shall report their recommendations and advice solely to the Committee for full deliberation and discussion. Subcommittees, task forces, or working groups have no authority to make decisions and recommendations, verbally or in writing, on behalf of the Committee. No subcommittee or any of its members can update or report, verbally or in writing, directly to the DoD or any Federal officers or employees. If a majority of Committee members are appointed to a particular subcommittee, then that subcommittee may be required to operate pursuant to the same notice and openness requirements of FACA which govern the Committee's operations.

Pursuant to Secretary of Defense policy, the USD(AT&L) is authorized to administratively certify the appointment of subcommittee members if the Secretary of Defense or the Deputy Secretary of Defense has previously authorized the individual's appointment to the Committee or another DoD advisory committee. If this prior authorization has not occurred, then the individual's subcommittee appointment must first be authorized by the Secretary of Defense or the Deputy Secretary of Defense and subsequently administratively certified by the USD(AT&L).

Subcommittee members will be appointed for a term of service or one-to-four years, subject to annual renewals; however, no member shall serve more than two consecutive terms of service on the subcommittee. Subcommittee members, if not full-time or permanent part-time Federal officers or employees, will be appointed as experts or consultants pursuant to 5 U.S.C. § 3109 to serve as SGE members. Subcommittee members who are full-time or permanent part-time Federal officers or employees will be appointed pursuant to 41 C.F.R. §102-3.130(a) to serve as RGE members.

The USD(AT&L) has the delegated authority to appoint the chair and vice chair of any appropriately approved subcommittees from among the subcommittee membership previously appointed according to DoD policies and procedures and, in doing so, will determine the term of service for each, which will not exceed the subcommittee member's approved term of service.

Each subcommittee member is appointed to provide advice on behalf of the Government on the basis of his or her best judgment without representing any particular point of view and in a manner that is free from conflict of interest.

With the exception of reimbursement for travel and per diem as it pertains to official travel related to the Committee or its subcommittees, Committee subcommittee members shall serve without compensation.

All subcommittees operate under the provisions of the FACA, the Sunshine Act, governing Federal statutes and regulations, and established DoD policies and procedures.

14. Recordkeeping: The records of the Committee and its subcommittees shall be managed in accordance with General Records Schedule 6.2, Federal Advisory Committee Records, or other approved agency records disposition schedule, and the appropriate DoD policies and procedures. These records shall be available for public inspection and copying, subject to the Freedom of Information Act of 1966 (U.S.C. § 552, as amended).

15. Filing Date: May 31, 2016

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ANNEX E: THREAT REDUCTION ADVISORY COMMITTEE MEMBERSHIP

Chair
The Honorable Ronald Lehman
Vice-Chair
Dr. Miriam John
Members
The Honorable Joseph Benkert
Rear Admiral Kenneth Bernard, USPHS, Retired
Dr. Joseph Braddock*
Major General William Chambers, USAF (Ret.)
Dr. Melissa Choi
Colonel David Franz, DVM, USA (Ret.)
Ms. Donna Gregg
Dr. Gigi Gronvall
Vice Admiral Robert Harward, USN (Ret.)
The Honorable Susan Koch
Dr. John Lauder
The Honorable Michael Leiter
Dr. Charles McMillan
The Honorable Michael Nacht
Ms. Joan Rohlfing
Dr. Jeffrey Starr
Dr. George Whitesides

* Stepped down from TRAC May 27, 2019

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ANNEX F: STAFF AND DESIGNATED FEDERAL OFFICERS

STAFF
ANSER (www.anser.org)
Kate Zander – Program Manager (ANSER), Office of the Deputy Assistant Secretary of Defense (Threat Reduction and Arms Control)
Georgia Holko – TRAC(TRAC) Senior Coordinator
Elvera (Vera) Nelson – TRAC Administrative Support
Martha Lopez – TRAC Administrative Support

DESIGNATED FEDERAL OFFICERS (DFOs)
Mr. Stephen J. Polchek
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Mr. Kevin McCall
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