Technical Considerations for the Evolving U.S. Nuclear-Weapons Stockpile

Executive Summary

Contact: D. McMorrow - dmcmorrow@mitre.org

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JASON
The MITRE Corporation
7515 Colshire Drive
McLean, Virginia 22102-7508
(703) 983-6997

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7515 Colshire Drive
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In view of the reduction in the number of re-entry system NEP designs called for by the 3+2 hedge strategy and NNSA's desire to use common non-nuclear components in producing future warheads, JASON is tasked in the present study to consider questions of possible common-mode failures that could impact effectiveness of active-stockpile segments. More specifically, JASON was asked to examine these questions at the design, component, and system levels and to provide guidance to the NNSA and DoD on how to mitigate and manage possible new technical risks associated with the 3+2 strategy to ensure the safety, security, and effectiveness of the nation's nuclear deterrent.

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1 EXECUTIVE SUMMARY

JASON was asked by NNSA to provide an assessment of technical issues associated with the nuclear warheads to be employed on submarine-launched ballistic missiles and land-based intercontinental ballistic missiles in the context of the Nuclear Weapon Council's (NWC) approved "3+2 Strategic Vision" for the future of the US nuclear deterrent. The present study is complementary to a concurrent DoD-chartered JASON study, JSR-14-Task-016, *Military Requirements for the Evolving U.S. Nuclear-Weapons Stockpile*.

While the "3+2" strategy was the framework in which the two studies were conducted, the majority of the findings, analyses, and recommendations apply to stockpile strategies in general.

1.1 The 3+2 Strategic Vision

The US nuclear-weapon Triad comprises three legs: one "air-carried" leg and two ballistic-missile or "re-entry" legs (land-based and sea-based). The "3+2" strategy looks toward a future U.S. nuclear weapon stockpile with three warhead types for each re-entry leg (the "3" in "3+2") and two warhead types for the air-carried leg (the "2" in "3+2"). In this report, "warhead" is defined as the nuclear explosive package (NEP) and all additional components (fuzing systems, neutron generators, etc.) required to make the NEP function. The NEP is defined as the radiation case and everything inside it. In re-entry systems, the warhead is carried by a re-entry vehicle (RV,the Air Force terminology) or re-entry body (RB, the Navy terminology). The "warhead system" comprises the warhead and its RV or RB.

The “3+2” strategy calls for “interoperable” NEPs for the re-entry legs—common NEP designs for both submarine-launched ballistic missiles (SLBMs) and land-based intercontinental ballistic missiles (ICBMs)—and for some common non-NEP components as well. Upon full implementation of the “3+2” strategy, each of the three interoperable NEPs, along with many associated non-NEP components, is to be packaged into both an Air Force RV and a Navy RB. Each interoperable NEP must satisfy military characteristics (MC) and stockpile-to-target-sequence (STS) requirements for both the ICBM and SLBM systems. To date, Air Force RVs have never operated on SLBMs and Navy RBs have never operated on ICBMS; thus, while some warhead components are intended to be interoperable, the RVs and RBs will not be (although this could change by the time the third interoperable NEP is deployed).

In this report, “commonality” refers to employment in both an Air Force RV and a Navy RB. The “3+2” strategy’s feature of interoperable NEPs means that each NEP is a “common” component in the language of this report. The same “common component” terminology applies to any non-NEP warhead component that is intended for both an Air Force and a Navy delivery platform.

The term “IW1” refers to the first pair of re-entry warheads (ICBM and SLBM) to be developed under the “3+2” strategy. These two warheads are to contain a common NEP and are likely to contain some common non-NEP components. The strategy also calls for an “IW2” warhead pair and an “IW3” pair. Designs for the NEPs to be employed in IW1,2,3 warhead pairs are not yet specified. For the purposes of this study, JASON accepts NNSA’s working hypothesis that the NEP for the IW1 pair will employ a W87 pit. We also assume, as a basis for our technical considerations, that the common IW2 NEP will have a primary that reuses an existing stockpile pit designed for a conventional high explosive (CHE) implosion system, but with a preference for an implosion system that uses insensitive high explosive (IHE). These assumptions provide concrete examples for development and discussion of study results but do not presume which stockpile options will actually be selected in the future.

1.2 Study Charge

In view of the reduction in the number of re-entry system NEP designs called for by the 3+2 hedge strategy and NNSA's desire to use common non-nuclear components in producing future warheads, JASON is tasked in the present study to consider questions of possible common-mode failures that could impact effectiveness of active-stockpile segments. More specifically, JASON was asked to examine these questions at the design, component, and system levels and to provide guidance to the NNSA and DoD on how to mitigate and manage possible new technical risks associated with the 3+2 strategy to ensure the safety, security, and effectiveness of the nation's nuclear deterrent through the following set of tasks:

- *As requested in congressional reports associated with fiscal year 2014 appropriations, assess emerging frameworks for understanding and quantifying risks that may inform the "technical hedge." In addition, provide recommendations for strengthening these frameworks, if necessary.*
- *As requested in congressional reports associated with fiscal year 2014 appropriations, assess the technical feasibility and science-based stockpile stewardship challenges associated with implementing an all insensitive high explosive-based stockpile. This shall be evaluated in the context of pit production limitations and the timelines associated with executing the 3+2 Strategy.*

- *Assess emerging frameworks and methodologies for characterizing and quantifying (where possible) design, component, and system-level diversity as a cost-effective, practical, and/or necessary means to reduce the likelihood or consequences of common-mode failures for both nuclear and non-nuclear components. When is diversity favored and when is it not? Provide advice on tradeoffs between the complexity and effort associated with single-purpose components and individual multi-purpose components. When do gains from commonality offset the costs of additional complexity and the likelihood of common-mode failures, in the context of a 3+2 stockpile?*

- *Looking toward the full implementation of 3+2, identify gaps in the existing science-based stockpile stewardship program that maintains technical credibility of warhead/bomb assessments/certifications in absence of new nuclear testing. What issues are key to managing integral weapon certification while implementing the 3+2 strategic vision?*

- *Coordinate and reconcile the JASON input to the NNSA with that in response to the closely related study tasking by the DoD.*

1.3 Findings and Recommendations

The "3+2" strategy presumes choices for features in a technical trade-space usually explored as part of system optimization. These features are 1) three warhead types for each re-entry leg (land and sea), 2) interoperable NEPs, and 3) insensitive high explosive (IHE) as a goal for every stockpile NEP. JASON observes that the benefits of each feature are independent of whether either of the other two features is employed. While this is not listed as a formal finding, it informs some findings and our main recommendation.

The complete set of findings and recommendations described in this report is given below:

1. **NNSA capabilities are critical to the nations's nuclear deterrent.** NNSA's primary assets for conducting stockpile stewardship and executing the "3+2" strategy are its unique capabilities in areas of: design, engineering, and assessment (including experimentation, modeling, and simulation) for understanding and extending lifetimes of stockpile systems; science and surveillance for providing long-range and short-term assessments of the health of the stockpile; and production, assembly, and dismantlement for weapon components and systems. Well-trained, experienced, motivated, and engaged people in NNSA's capability organizations are critical to the success of its mission.

2. **Program instability poses a significant threat to NNSA's mission-critical capabilities.** Ensuring and sustaining the vitality—productivity, safety, responsiveness, and efficiency—of NNSA's capabilities depends on continuous application of skills and continuous improvement of approaches. As presented to JASON, the applications of NNSA capabilities to the "3+2" strategic vision to date and in future planning scenarios is erratic. Stopping and re-starting efforts is wasteful of limited resources and introduces risk. Capabilities that are not continuously exercised will degrade or be lost.

3. **The best mitigation of a well-understood failure scenario is a combination of a design that performs well in that scenario, quality assurance during production, and surveillance after deployment.** In such a hypothetical "well-understood" scenario, multiple diverse designs that meet the same requirements provide little benefit over a single high-confidence design, but would likely require additional effort in design, production, and surveillance.

4. **In less-understood or unanticipated failure scenarios, where the knowledge base is more limited, diversity can provide benefits.** Simplified statistical analyses indicate benefits from deploying a second weapon type even if it is assessed to be less reliable than the first.

5. **Diversity in deployed weapon types mitigates risks of as-yet undiscovered flaws.** The hedge stockpile would come into play only after a flaw has been discovered. The deployment of multiple weapon types provides some insurance against undetected flaws, provided the flaws are not in the common components or design principles of these weapon types.

6. **Choices regarding commonality, performance, diversity, and intrinsic safety and security features are in a competitive design trade space.** A choice of NEP interoperability or of an all-IHE stockpile may force a reduction in primary yield margins, for example.

7. **JASON is not aware of a compelling analysis of the net impact of commonality requirements on cost, schedule, or risk associated with NNSA's tasks under a "3+2" strategy.** It is more difficult to design and qualify an NEP or a non-NEP component for two delivery platforms than for one. The resulting common design may be sub-optimal for each platform, for example with lower margins than those achieved by platform-specific designs. Commonality does lead to fewer total component types, which provides advantages during development, qualification, production, and potentially, surveillance. These advantages must be weighed against increased complexity and potentially sub-optimal performance. There are cases in which the advantages have been judged to outweigh the disadvantages, as with the common fuze components for the W88 and W87 warheads, but each case is different and requires its own analysis.

For completeness, we list below selected findings from the companion study, JSR-14-Task-016 *Military Requirements for the "3+2" Stockpile Strategy*, that are directly relevant to the present study:

- **Commonality of components between Air Force RVs and Navy RBs (including NEP interoperability) does not provide intra-leg hedge benefits, but may provide marginal benefit for hedging against significant loss of SLBM capability.** The intra-leg hedge benefits of the "3+2" strategy derive from the *number of warhead types on a given Triad leg* (three for re-entry legs) and are unrelated to components on other legs. Hedging against the loss of SLBMs by uploading ICBMs could potentially benefit from interoperability, via transfer of Navy warhead components into Air Force RVs at Pantex. However, the first choice would be to upload the ICBM leg's intra-leg hedge warheads, with component transfer providing benefit only to the extent that there were not enough ICBM intra-leg hedge warheads for a full ICBM upload. See the companion study, JSR-14-Task-016 *Military Requirements for the "3+2" Stockpile Strategy*, for details.

- **The "3+2" strategy specifies three types of re-entry NEPs, each deployed in two types of aeroshells, which translates to six types of re-entry systems. It also calls for two types of air-carried warheads. Each system type requires system-level testing and qualification, including flight tests.** The "3+2" strategy includes a substantial reduction in the number of types of air-carried warheads. For the re-entry legs the strategy leads to fewer types of NEPs but more types of warhead assemblies. Even if the ICBM and SLBM warheads share many common components, the "3+2" strategy results in six (not three) total types of RV and RB warhead assemblies. Commonality of components can reduce component-level testing, but each of the six RV/RB types must be qualified and tested independently as an integrated warhead assembly.

- **Matching properties that affect RV/RB flight dynamics may pose challenges under "3+2", especially if IHE and interoperability are required.** Employing an IW1 warhead in the Mk5 RB or the Mk21 RV would change the details of mass distribution, flexure modes, and dissipative properties from those of the well-tested W88/Mk5 and W87/Mk21 re-entry systems, even if mass, center of gravity, and moments of inertia are matched. This could change the details of re-entry flight dynamics and could alter reliability or targeting accuracy.

JASON recommends:

1. **NNSA, working with its capability organizations—the national labs and production facilities—and with Congress, must maintain stable and predictable execution of program elements and work flow while sustaining essential mission capabilities within expected budget levels.** The principal capability tasks to be executed under NNSA's responsibility to maintain a safe, secure, and reliable U.S. nuclear weapons stockpile without nuclear-explosion testing are cyclic in nature, matched to various time scales: 1) decadal aging rates of stockpile components and advances in applicable knowledge and technology; 2) multi-year production/assembly/testing cycles; 3) annual assessment, surveillance, and dismantlement activities; and 4) rapid response to significant finding investigations, or international events. To remain effective, any capability organization must be regularly challenged, exercised, and tested on time scales commensurate with its tasks. While choices must be made to determine how much improvement is necessary and can be afforded in a given process or

design at each cycle, high priority should be assigned to establishing baseline activities for every capability organization that exercise its responsibilities and demonstrate continuing ability to fulfill its mission.

2. **Starting as soon as possible, pursue trade studies regarding surety, component commonality, and the number of warhead types on each Triad leg to better inform "3+2" decisions without delaying schedules.** The complexity and potential effects of these studies are large enough that they should not wait until LEPs are underway. Three issues illustrate the need for these studies: 1) component commonality introduces both complexities and simplifications, the net effect of which has not yet been assessed; 2) the effects on flight dynamics of the introduction of an IHE-based IW1 into the Mk21 and Mk5 aeroshells are not yet understood, and 3) the benefit of the hedge reduction obtained by having a third warhead type in a leg with a small number of deployed warheads is quantitatively small and should be weighed against the costs—which include flight tests—of qualifying and maintaining the third type.

1.4 Responses to Requests from Congressional Reports

Assess emerging frameworks for understanding and quantifying risks that may inform the "technical hedge."

Our response to this request forms much of the substance of this report, particularly material presented in section 3 of the full report; Findings 3–7, listed above, and the findings quoted above from the companion study, JSR-14-Task-016 *Military Requirements for the "3+2" Stockpile Strategy.*

Frameworks presented to us include well-established engineering approaches, such as fault-tree analyses of nuclear and non-nuclear components, which do not directly inform the technical hedge. Because answers to stockpile questions depend intimately on scientific and engineering detail, abstract concepts in risk management are generally insufficient to provide guidance. In the course of the study, JASON developed a simplified statistical framework, described in our report, which was found useful for analyzing questions related to stockpile diversity and technical hedge.

Assess the technical feasibility and science-based stockpile stewardship challenges associated with implementing an all-insensitive high explosive-based stockpile.

JASON reviewed concepts for reusing existing pits designed for conventional high explosives (CHE) with implosion systems that use insensitive high explosives (IHE). In the context of the "3+2" strategy examined in this report, such a primary is a possible choice for the IW2 NEP. The candidate IW1 NEP uses a W87 pit; the W87 is the only IHE primary ever certified for U.S. re-entry systems. Reuse of CHE pits in IW2 is logical because limited numbers of W87 pits are available and because of uncertainties associated with pit production.

Design challenges for primaries assembled from CHE-based pits with IHE implosion systems stem from the lower energy density of IHE materials relative to CHE and from other differences that are discussed in the main report. The design space for IHE to successfully implode a CHE-design pit is more constrained than those for either a CHE- or IHE-designed primary, and the relevant UGT experience base is much smaller. Both factors suggest that uncertainties in primary performance for such hybrid designs may be larger than current stockpile primary design uncertainties.

LLNL and LANL recently engaged in "120-day" studies to consider pit-reuse design options. The design laboratories also considered pit-reuse options as part of their formal 6.2 feasibility and down-select study for IW1, before IW1 design activities were postponed for ≈ 5 years as part of PB2015 budget decisions. This work on pit reuse began to address technical issues involved with implementing an all-IHE stockpile under limitations in pit production capacity that indicate the need for reuse of CHE pits. Preliminary designs are characterized by different values of various metrics used by designers to assess primary performance. While no consensus pit-reuse design has emerged to date, JASON finds these early steps to be encouraging. It is premature today to project this progress into an ultimate assessment of technical feasibility or certifiability of an IHE primary with a reused CHE-designed pit. Despite the nation's large stores of retired CHE pits and uncertainties surrounding pit production capabilities, the possible surety advantages of IHE implosion systems warrant further design-laboratory effort to address the feasibility of employing IHE implosion systems on surplus pits originally designed for CHE primaries.