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# Stockpile Stewardship in the United States: A Primer

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## I. A brief history of stockpile stewardship

### *A. Prologue: Stockpile stewardship in the age of nuclear testing*

For as long as a nuclear stockpile has existed in the United States, a technical program has existed dedicated to maintaining the stockpile. During the Cold War, the work of stockpile stewardship was performed under the Stockpile Evaluation[1] or Stockpile Surveillance programs. Today, the program is known formally as Stockpile Stewardship, and is overseen by the National Nuclear Security Administration, a semi-autonomous agency within the Department of Energy. The two main technical goals of the program have not changed since the days of the Cold War, however: now, as then, the program is responsible for making sure that the weapons in the stockpile are both reliable (certain to detonate when needed) and safe (certain not to detonate when not needed).

During the Cold War, yield-producing nuclear tests were, for obvious reasons, the most familiar tool of stockpile stewardship.[2] They were never the only tool, however, nor were they necessarily the most important one. A National Academy of Sciences study on the Comprehensive Test Ban Treaty concluded that "stockpile stewardship by means other than nuclear testing… has always been the mainstay of the U.S. approach to maintaining confidence in stockpile safety and reliability."[3]

### *B. The origins of the Stockpile Stewardship Program*

During the Cold War, maintaining existing warheads consumed far less of the nuclear weapons complex's energies than designing and building new weapons. The high rate of stockpile turnover caused by the constant stream of well-tested new designs made stockpile stewardship less of a challenge than it is today. The post-Cold War emphasis on maintaining existing weapons without testing constitutes a major programmatic transformation in the nuclear weapons complex even though it builds on a half-century of technical experience.[4]

This transformation is the result of three events which took place around the time of the end of the Cold War. In 1989 the Rocky Flats site in Colorado, which for several decades had produced the plutonium pit for every weapon in the stockpile, was closed down in the wake of a long series of severe health, safety and environmental problems.[5] The loss of

Rocky Flats severely curtailed the nuclear complex's ability to manufacture new warheads. Then, in 1992, after the Soviet Union had suspended nuclear testing and later dissolved, Congress mandated a one-year moratorium on nuclear testing, which eventually grew into an indefinite but voluntary moratorium.[6] These two events led to the third and most critical development, the closing of the nuclear stockpile to new weapons. Together, these three events shaped the task of stockpile stewardship as it exists today.

At the same time, lawmakers and laboratory heads began to worry that the human capital which powered the nuclear complex would be lost as retirement thinned the ranks of the last generation of Cold War weapons-builders and the lack of new weapons projects made younger scientists and technicians harder to recruit.

These changes created an unprecedented challenge for the nuclear weapons complex: an arsenal of aging weapons would have to be maintained indefinitely, without yield-producing tests, and with diminishing involvement by the people who had crafted the weapons in the first place. Furthermore, the skills and resources needed to design, build and test new weapons would have to be maintained in case the nation one day found itself in a new nuclear arms race.

These various concerns led Congress to establish the Stockpile Stewardship Program in the fiscal year 1994 National Defense Authorization Act.[7] In the words of the Department of Energy, the mandate of the Stockpile Stewardship Program is to:

"1. …Increase the understanding of the enduring stockpile;
2. Predict, detect, and evaluate potential problems of the aging of the stockpile;
3. Refurbish and re-manufacture weapons and components, as required; and
4. Maintain the science and engineering institutions needed to support the nation's nuclear deterrent, now and in the future."[8]

Three years later Congress emphasized that the "sense of Congress" regarding stockpile stewardship included a firm commitment to "maintaining nuclear weapons production capabilities and capacities."[9]

The ensuing years have witnessed a struggle to organize the different activities of the nuclear weapons complex into a coordinated stewardship effort. In recent years, the technical and political debates surrounding stockpile stewardship have culminated in the debate over the Reliable Replacement Warhead program, which some believe offers an entirely new strategy for maintaining the nuclear stockpile. This primer will outline the form which stewardship has taken over the last decade, as an evolved form of the stewardship activities of the Cold War era, and introduce some of the issues involved in the debate over the Reliable Replacement Warhead program.

## II. The elements of stewardship

### *A. The Stockpile Stewardship Program: Structure and budget*

Any stockpile stewardship effort must include three basic activities: developing an understanding of the effects which can impair the performance of nuclear weapons, observing the stockpile for signs of these effects, and correcting the problems which have been detected.[10] In the context of U.S. stockpile stewardship activities, these three activities are commonly respectively referred to as stockpile science, stockpile surveillance, and warhead life extension.[11]

In principle, the interactions between these three activities should obey a simple set of relationships. Stockpile science should investigate how potential age-related changes might affect warhead performance; stockpile surveillance should look for evidence in real weapons of the potential problems identified by stockpile science; and life extension should correct the problems identified by the other two programs.

In practice, however, integrating these three activities – making sure that each plans its work according to the needs and findings of the others – has proven to be a great challenge.[12] The Secretary of Energy Advisory Board Nuclear Weapons Complex Infrastructure Task Force concluded that at present "there is not a unified interdependent nuclear weapons enterprise vision or set of mission priorities."[13] Some of the inefficiencies which led to this assessment will be discussed in this paper.

The Stockpile Stewardship Program does not appear as a named item in the Department of Energy's budget. Instead, the program's budget is commonly identified today with the DOE Office of Defense Programs' "weapons activities" program element,[14] the traditional category for nuclear weapons development and maintenance. The "weapons activities" element, however, still includes a range of activities other than the stewardship activities considered here, including weapon storage, security and transportation, retired weapon dismantlement, nuclear weapons incident response, and environmental work.[15] The total "weapons activities" budget was $6.6 billion in fiscal year 2005; the budget for core stewardship activities, as described here, was no more than $5.4 billion.[16]

### *B. Stockpile science: the science campaigns*

Since 1999, the stockpile science component of the Stockpile Stewardship Program has been organized into a number of "technically challenging, multiyear, multifunctional" campaigns. While some of these campaigns are directly involved in the "development and improvement of… scientific knowledge" regarding nuclear weapons, others develop the major tools which support research in warhead science.[17] The former group consists chiefly of the Primary Assessment Technologies and Secondary Assessment Technologies campaigns, which "analyze and understand the different scientific phenomena that occur in the primary and secondary stages of a nuclear weapon during detonation."[18] The latter group includes the Advanced Simulation and Computing (formerly Accelerated Strategic Computing) campaign, the Advanced Radiography campaign, the Dynamic Materials Properties campaign, and the Inertial Confinement Fusion campaign, which includes the National Ignition Facility.[19]

Some of these latter campaigns have been challenged over the degree of their relevance to preserving the stockpile and the human capital behind it.[20] The National Ignition Facility has come under particularly sharp attack,[21] though it is prominently featured in the Stockpile Stewardship Program's original mandating legislation.[22] Some analysts, while not questioning the value of these latter four campaigns, emphasize the distinction between actual warhead science and long-term investment in research capability by describing them as "infrastructure initiatives," rather than as "stewardship campaigns."[23]

The total budget for the six campaigns was $1.5 billion in fiscal year 2005. More than half of this total went to the Advanced Simulation and Computing campaign, and a further third of the total went to Inertial Confinement Fusion. Each of the remaining campaigns received between $40 million and $90 million.[24]

### *C. Stockpile surveillance: history and techniques*

Because of the unique visibility of a yield-producing nuclear test as a tool for demonstrating the health of the nuclear stockpile, surveillance is often assumed to be the element of the stewardship triad which suffers most from the testing moratorium. The actual role of yield-producing nuclear testing in stockpile surveillance, as compared with the roles of physical inspection of warheads and of non-yield-producing tests, is discussed in the National Academy of Sciences study quoted above.

Yield-producing nuclear tests of weapons drawn from the stockpile were conducted for surveillance purposes during the Cold War, but these "stockpile confidence tests" made up a small part of the overall American nuclear testing program. There were two reasons for the limited program of surveillance-related testing: first, given limited resources for testing, the complex preferred to focus on exploring design concepts and validating production-representative units rather than on checking up on older systems, and second, it was never possible to perform enough tests to provide statistically meaningful estimates of reliability across all warhead variants, stockpile conditions and usage scenarios.[25]

Furthermore, even these stockpile confidence tests, which took place over the last two decades of US nuclear testing, involved relatively young warheads; only one such test involved a warhead even approaching 30 years old.[26]

Nuclear testing also contributed to stockpile confidence in another way, however: primaries from the stockpile were often used in preliminary tests of new weapons concepts. The reliability which these primaries demonstrated contributed to overall stockpile confidence[27] (The difference between assessing the reliability of the stockpile and establishing confidence in it is an important one, which will be examined in Part III.)

Today, surveillance of the U.S. nuclear stockpile follows a schedule according to which "21 warheads of each type with a population under 500 and 22 warheads of each type with a population of 500 or more are withdrawn randomly from the stockpile every 2 years for examination."[28] This schedule is designed to produce a particular likelihood that a problem in the stockpile will be detected within a given period of time. This criterion is often expressed, misleadingly, in statistical terms: the schedule is said to ensure, to a level of confidence of 90 percent, that a flaw in any warhead type will be discovered within two years if it exists in at least 10 percent of warheads of that type.[29] This statistical criterion is not actually met, however, since the inspected warheads do not all undergo the same set of tests, and not all tests are equally likely to reveal a given flaw.[30] The statistical criterion should therefore be thought of as a ballpark figure only.

Most of the warheads inspected undergo any of a range of non-destructive tests, while a small number each year are destructively disassembled. The nuclear and non-nuclear subsystems of the warheads are tested separately.

Non-nuclear components can be tested exhaustively, since their performance does not directly initiate a nuclear chain reaction. The most complete form of testing for all non-nuclear subsystems is Joint Test Assembly flight-testing, in which the nuclear subsystem is replaced with a dummy payload (generally including a sensor suite) and the warhead is launched with its typical delivery system in order to test the integrated performance of all non-nuclear systems.[31]

A far more significant challenge lies in assessing the nuclear subsystem. Surveillance of the nuclear subsystem emphasizes physical inspection of the components under static conditions and analysis of their performance under test conditions which do not produce a sustained nuclear chain reaction or a significant nuclear yield.

Physical inspection includes checking every piece of the warhead for signs of corrosion and other imperfections. Of particular importance is the inspection of the plutonium metal in the pit of the primary stage. Many of the known effects of aging on plutonium have signatures which can be detected by physical inspection of either dissected or intact pits,[32] using high-resolution imaging techniques including transmission electron microscopy[33] and static radiography (x-ray photography).[34] Magnetic eddy current imaging (a technique similar to the one used in metal detectors) and ultrasound imaging have also at least been considered for imaging the interiors of intact pits.[35]

The high explosives used to initiate the pit implosion are also subject to deterioration over time, and are the subject of a surveillance and science program at least as urgent as that devoted to the plutonium metal.[36]

Surveillance of plutonium and high-explosive aging is supported by a stockpile science program of non-yield-producing tests whose purpose is to establish the relationship between physically observable aging effects and primary performance – that is, whether aging, as observed by surveillance, is liable to cause the primary yield to fall below the minimum necessary to initiate the secondary.[37]

These tests generally fall into two types: either an inert material is used in place of the plutonium or the plutonium configuration is modified so as to prevent a nuclear chain reaction from being sustained. Tests using inert materials are sometimes referred to as hydrotests (and should not be confused with hydronuclear tests, which do produce a measurable yield and are banned under the CTBT), while tests using plutonium are known as subscale or sub-critical tests.[38] The commonly-used term “hydrodynamic test” is sometimes used in reference to tests involving plutonium[39] and at other times to tests not involving plutonium.[40] Both types of tests are performed regularly in the United Statesand are permitted under the Comprehensive Test Ban Treaty.[41]

The non-yield-producing testing program is a key consumer of the tools being developed by the Advanced Radiography campaign mentioned above. This campaign develops flash radiography (high-speed x-ray) tools for imaging assemblages as they undergo implosion. The campaign’s main projects are the Dual-Axis Radiographic Hydrodynamic Test Facility (DARHT) at Los Alamos National Laboratory and the Advanced Hydrotest Facility at Lawrence Livermore National Laboratory.[42] While sub-critical tests are generally performed at the Nevada Test Site,[43] the Department of Energy has planned in the past to perform tests involving plutonium at DARHT.[44]

In the fall of 2006, several years of intensive stockpile science and surveillance efforts are expected to culminate in a much-anticipated update of the National Nuclear Security Administration’s estimates of the reliable lifetimes of the various pits in the U.S. stockpile.[45] Because a number of major decisions regarding the future of the nuclear weapons stockpile and its associated complex hinge on the reliable lifetimes of these components, the new estimates, if they differ substantially from the current estimates of 45-60 years, are likely to have a profound effect in the political arena.[46]

### *D. Life extension*

The current Stockpile Life Extension Program was organized within the Department of Energy’s Office of Defense Programs in the mid-1990s. The fiscal year 2000 National Defense Authorization Act specified that the Stockpile Life Extension Program address individually “each weapon design designated by the Secretary [of Energy] for inclusion in the enduring nuclear weapons stockpile” and stipulated that a detailed plan for carrying out this program be submitted to Congress by January 1, 2000.[47]

In a separate title (known as the National Nuclear Security Administration Act) the 2000 National Defense Authorization Act also created the National Nuclear Security Administration and transferred into it the Office of Defense Programs.[48]

A series of Government Accountability Office investigations and reports by the JASON defense advisory group has found that in spite of these congressional interventions the nuclear complex’s life extension activities still suffer from organizational deficiencies. Most worryingly, life extension appears to be taking place without regard for the results of the other stewardship activities. A 1999 study by JASON found that schedules and priorities for remanufacturing were being set largely according to arbitrary, and very conservative, notions of “design lives,” rather than aging data being produced by stockpile surveillance.[49]

Another JASON study found that “it is difficult in hindsight to identify why certain SLEP decisions were made and who takes responsibility for them…. Moreover, it appears difficult if not impossible to modify planned Life-Extension activities as new developments arise, often more for institutional reasons… than for technical reasons.”[50]

The detailed roadmap for future life extension activities required by Congress in the 2000 National Defense Authorization Act was presumably intended to address these questions; unfortunately, according to the Government Accountability Office, this document was never produced.[51] In 2003, another GAO report again criticized the management and accounting practices of the Stockpile Life Extension Program.[52]

Nonetheless, considerable life extension work has been done. In 2004, the W87 intercontinental ballistic missile warhead became the first warhead type to complete its life extension program. The W87 was originally mated to the MX or Peacekeeper ICBM, which was retired in September 2005, and will now replace the older W62 warhead onboard the nation’s Minuteman ICBMs.[53] Each W87 warhead in the U.S. arsenal is now nominally expected to remain functional for 30 years past its (nominal) original design lifetime.[54] The B61 bomb warhead, W76 submarine-launched ballistic missile warhead and the W80 cruise-missile warhead are the subjects of current life extension programs.[55]

The activity of “refurbish[ing] warheads through the Life Extension Program” takes place within the Office of Defense Programs’ broad “Directed Stockpile Work” program element, along with such non-stewardship activities as retired weapons dismantlement. At the same time, the actual manufacturing of replacement components and related research takes place under several other program elements, including the “Pit Certification and Manufacturing Campaign” and the “Readiness Campaign.”[56] The total budget for “Directed Stockpile Work,” the “Pit Manufacturing and Certification Campaign,” and the “Readiness Campaign” was about $1.8 billion in fiscal year 2005.[57]

### *E. The Reliable Replacement Warhead program*

Since life extension is the stewardship activity most directly implicated in setting the future course of the stockpile, it is also the element most immersed in both technical and political controversy. At present, the political controversy centers on a program known as the Reliable Replacement Warhead program, which was introduced in the fiscal year 2005 Consolidated Appropriations Act.[58]

As a Congressional Research Service (CRS) report observes, “many find RRW to be confusing because it is a new program and descriptions of it have changed.”[59] RRW has been described as everything from a technical program to improve the manufacturing of replacement components for warheads to a program for designing the next generation of U.S. nuclear weapons. A comprehensive examination of RRW, its various incarnations, and its advantages and disadvantages is beyond the scope of this primer. Instead, we will examine briefly the perceived shortcomings of the Stockpile Life Extension Program which have given impetus to the Reliable Replacement Warhead program.

In an ideal world, life extension could proceed by replacing any unacceptably aged component with an identical component, manufactured according to the original specifications.[60] Unfortunately, this is often impracticable. Nuclear weapons were "essentially handmade,"[61] and in the ensuing years, technicians have retired, manufacturing lines have shut down, suppliers have gone out of business or cancelled products, and health and environmental regulations have grown more stringent. Minor modifications to the original specifications may be harmless, and may even offer an improvement in component performance.

On the other hand, in the absence of nuclear testing, the accumulation of minor modifications to warhead components could cause public confidence in the stockpile, and possibly the real reliability of the stockpile, to decline. For this reason, a conservative philosophy of "change discipline,"[62] or "change-control discipline,"[63] has guided the Stockpile Life Extension Program in its decisions regarding modifications.

In its most modest form, the Reliable Replacement Warhead plan calls for replacing change-control discipline with a new philosophy which would value ease of reliable remanufacture over fidelity to original component specifications.[64] Rather than struggling to resurrect archaic manufacturing methods, this approach would design new components which would incorporate improved manufacturing techniques while adhering as closely as possible to the original specifications. According to the Congressional Research Service, "the main difference between RRW and the current approach to stockpile maintenance, the Life Extension Program (LEP), is one of an underlying philosophy…. Most of the changes under RRW probably could be made under LEP. However, they probably would not be because LEP strives to hold changes to a minimum."[65]

The debate over RRW has become much more than a technical debate over the best strategy for sustaining the current stockpile, however. The keyhole through which broader strategic considerations entered the RRW debate has been the assertion that if warhead designs can be updated to meet current priorities in stability and manufacturability, then perhaps they can also be modified to reflect changes in military priorities (such as yield and penetrative ability) as well.[66]

While the sustainability arguments for RRW involve primarily changes to the nuclear subsystem (which the life extension programs tend not to modify),[67] the strategic arguments may also require modifications to the non-nuclear subsystems.[68] For example the ability of a nuclear weapon to penetrate hardened structures is largely a function of the warhead casing and of the fuzing system. The prospect of such wide-ranging modifications raises the question of where modifications to existing warhead components end and the introduction of new weapons begins.[69] It is for this reason that "many find RRW to be confusing."[70] A struggle is still being waged to define what exactly the Reliable Replacement Warhead program will entail, if it is to proceed beyond the planning stages, and this debate implicates an array of technical, political, budgetary, and international considerations.

The Nuclear Weapons Council has begun to implement the Reliable Replacement Warhead program by initiating a competition between teams from Los Alamos and Lawrence Livermore National Laboratories to design new warheads for the nation's submarine-launched ballistic missiles.[71] The budget for the program was $9 million in 2005 and $25 million in 2006,[72] funded through "Directed Stockpile Work."[73]

**III. Between "reliability" and "confidence"**

One of the greatest challenges to sustaining the aging stockpile is not a technical one: this challenge arises from the difference between "reliability" and "confidence."

While some treatments use these terms interchangeably, we define the former as a quantifiable technological parameter and the latter as a psychological state. In a 1992 chapter titled "Reasons for Nuclear Testing," Steve Fetter writes,

> Stockpile confidence is not the same as stockpile reliability. Reliability is an objective measure of warhead performance, and can be measured to any degree of accuracy by performing enough [non-yield-producing] tests. Confidence, on the other hand, is the belief of those responsible for the stockpile that the weapons are reliable.[74]

Fetter further argues that maintaining confidence, rather than reliability, is the true metric for the performance of a stockpile stewardship program. A stockpile stewardship program is worthless if it cannot communicate its own confidence in the stockpile to the outside world – to the political leadership, to the electorate, and to potential adversaries.[75]

How reliability can be translated into confidence is a subject beyond the scope of this primer. The relationship between the two concepts is non-trivial, however and may ultimately prove to be the greatest challenge in maintaining the testing moratorium.

Some nuclear weapons analysts have speculated that budgetary considerations, especially those surrounding major programs such as the Reliable Replacement Warhead and the major infrastructure initiatives, provide incentive for public officials to undermine confidence as a way of encouraging investment in stockpile activities. A recent study by the Congressional Research Service identified what may have been a case of this dynamic at work. The CRS study quotes a House Appropriations Committee report according to which "Congressional testimony by NNSA officials is beginning to erode the confidence of the Committee that … Stockpile Stewardship is performing as advertised."[76] If the testimony in question was in fact intended to produce increased funding by undermining confidence in existing programs, however, it appears to have backfired: the Committee responded by cutting $160 million from the Advanced Simulation and Computing budget to pay for life extension work.[77]

Without citing any such specific testimony, the National Academy of Sciences appears to have intended to warn of a similar dynamic in stating that "it would be very unfortunate if confidence in the safety and reliability of the stockpile… were made to appear conditional on the major-tool initiatives [ASC and the NIF] having met their specified performance goals."[78]

In a report on techniques for quantifying warhead reliability, JASON also recognized the distinction between confidence and reliability, emphasizing that "confidence is what the Secretary of Energy and the President need from the weapons labs; it is not a number…. Reliability may be the concept used by the labs to express certain … findings quantitatively, and as part of their own process of building confidence internally, but confidence is what they must pass on to higher authority outside NNSA."[79] The JASON report also predicted that the skepticism regarding "expert assessments" of reliability which has been nurtured by such incidents as the two Space Shuttle disasters will significantly inhibit the transmission of confidence from the professional community to the political community.[80]

The political debate over the Reliable Replacement Warhead program has exposed a bimodal split in public expressions of stockpile confidence: supporters of RRW have tended to emphasize threats to the reliability of the current stockpile, while the program's opponents have tended to emphasize evidence of its long-term viability. This fact has led some opponents of the program to accuse its proponents of intentionally undermining public confidence in the stockpile, without justification in the form of real evidence of declining reliability.

If this accusation is true, the implications are extremely serious: not only would such a tactic be both unethical and dangerous, but, as the committee report cited by the Congressional Research Service suggests, it could have unintended consequences in the form of reduced funding for important programs. It is vital that both sides of this highly consequential debate bear in mind the fact that, as the experience of NASA cited by JASON illustrates, public confidence in a national program is a resource which, once lost, is not easily regained.

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[1] Kent Johnson, *et al.*, "Stockpile Surveillance: Past and Future," Sandia National Laboratories, January 1996, 2. <http://www.fas.org/sgp/othergov/doe/lanl/osti/197796.pdf>.

[2] Various terminologies are used in the literature to distinguish between experiments with fissionable materials which produce a sustained nuclear chain reaction, and therefore a nuclear explosive yield, and those which do not. This primer will refer to the former, which are prohibited under a nuclear testing moratorium, as yield-producing tests, and to the latter, which are permitted, as sub-critical tests. Many sources label the two types of tests "underground tests" and "aboveground tests," respectively, even though sub-critical tests are generally performed subterraneously.

[3] Holdren, John P., *et al.*, *Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty*. Washington, DC: National Academy Press (2002), 34.

[4] Johnson, *et al*., "Stockpile Surveillance: Past and Future," 1.

[5] The nuclear subsystem of a thermonuclear weapon, also known as the nuclear explosives package or the physics package, consists of a primary (fission) stage, a secondary (fusion) stage initiated by the primary, and elements which channel the energy of the primary to the secondary. The primary consists, in turn, of a plutonium "pit" and the high explosives required to initiate it by implosion. The non-nuclear subsystems include all other components of the warhead, such as safing and fuzing mechanisms and power supplies. See Jonathan Medalia, "Nuclear Weapons: The Reliable Replacement Warhead Program," Congressional Research Service report RL32929, March 9, 2006, 54. <http://www.fas.org/sgp/crs/nuke/RL32929.pdf >.

[6] Jonathan Medalia, "Nuclear Weapons: Comprehensive Test Ban Treaty," Congressional Research Service report IB92099, Nov. 5, 2002, 1. <http://ncseonline.org/nle/crsreports/02Dec/IB92099.pdf>.

[7] National Defense Authorization Act for Fiscal Year 1994 (H.R.2401), Jan. 5, 1993, U.S. Congress.
[8] "Stockpile Stewardship," *Nevada Site Office*, Department of Energy, April 20, 2006. <http://www.nv.doe.gov/nationalsecurity/stewardship/default.htm>.
[9] National Defense Authorization Act for Fiscal Year 1997 (H.R.3230), Jan. 3, 1996, U.S. Congress.
[10] Raymond Jeanloz, "Science-Based Stockpile Stewardship," *Physics Today*, **53**.12, 44-50, December 2000. <http://www.physicstoday.org/pt/vol-53/iss-12/p44.html>.
[11] Again, the terminology used in the wider literature is not entirely consistent. In particular, terms such as "manufacturing" or "remanufacturing" often substitute for "life extension," even though life extension refers to a broader set of activities. See, for example, Holdren *et al.*, *Technical Issues*, 19.
[12] Regarding research coordination issues in stockpile science, see D. Eardley, *et al*., "Quantifications of Margins and Uncertainties (QMU)," JASON report 04-330, The MITRE Corporation, March 2005, <http://www.fas.org/irp/agency/dod/jason/margins.pdf>; regarding life extension, see R. Jeanloz, *et al*., "Science and Technology in the Stockpile Stewardship Program," JASON report, The MITRE Corporation, October 2001, 6, <http://www.fas.org/resource/08062004161721.pdf >.
[13] David Overskei, *et al*., "Recommendations for the Nuclear Weapons Complex of the Future," Secretary of Energy Advisory Board Nuclear Weapons Complex Infrastructure Task Force, July 2005, vi.
[14] Medalia, "Nuclear Weapons: Comprehensive Test Ban Treaty," i.
[15] "Department of Energy FY 2006 Congressional Budget Request," vol. 1, U.S. Department of Energy. <http://www.mbe.doe.gov/budget/06budget/Content/Volumes/Vol_1_NNSA.pdf>.
[16] "Department of Energy FY 2006 Statistical Table by Appropriation," U.S. Department of Energy, 10-14. <http://www.mbe.doe.gov/budget/06budget/Content/appstat_cd.pdf>.
[17] "NNSA Needs to Refine and More Effectively Manage Its New Approach for Assessing and Certifying Nuclear Weapons," Government Accountability Office report 06-261, February 2006, 9.
[18] "NNSA Needs to Refine…," Government Accountability Office, 2.
[19] "NNSA Needs to Refine…," Government Accountability Office, 9-10.
[20] See, for example, Ray E. Kidder, "Problems with Stockpile Stewardship," *Nature*, 386, 645 – 647, Apr. 17, 1997. <http://web.mit.edu/sts/SSBS/kidder.html>.
[21] Richard L. Garwin, "The Future of Nuclear Weapons Without Nuclear Testing," *Arms Control Today*, **27**.8, 3-11, November/December 1997. <http://www.armscontrol.org/act/1997_11-12/garwin.asp>; see also Kidder, "Problems with Stockpile Stewardship."
[22] 1994 National Defense Authorization Act.
[23] Raymond Jeanloz, "The Stockpile Stewardship Program," *Physics Today*, **53**.12, December 2000. <http://www.physicstoday.org/pt/vol-53/iss-12/captions/p44box1.html>.
[24] "NNSA Needs to Refine…," Government Accountability Office, 11.
[25] Holdren, *et al.*, *Technical Issues*, 21.
[26] Holdren, *et al.*, *Technical Issues*, 20-1 and Kidder, "Problems with Stockpile Stewardship."
[27] Holdren, *et al.*, *Technical Issues*, 20.
[28] Holdren, *et al.*, *Technical Issues*, 26.
[29] Holdren, *et al.*, *Technical Issues*, 26.
[30] "Stockpile Surveillance: Past and Future," Sandia National Laboratories, 6.
[31] Holdren, *et al.*, *Technical Issues*, 26.
[32] S. Drell, *et al*., "Signatures of Aging," JASON report 97-320, The MITRE Corporation, January 1998, 20-1. <http://www.fas.org/resource/08062004173235.pdf>.
[33] Brian D. Wirth, *et al*., "Fundamental Studies of Plutonium Aging," *MRS Bulletin*, **26**.9, 679-683, September 2001. <http://iron.nuc.berkeley.edu/~bdwirth/Public/WRG/publications/BDW.F3.pdf>.
[34] Garwin, "The Future of Nuclear Weapons Without Nuclear Testing."
[35] S. Drell, *et al*., "Signatures of Aging," 27.
[36] S. Drell, *et al*., "Remanufacture," JASON report 99-300, The MITRE Corporation, October 1999, 8. <http://www.fas.org/rlg/JSR-99-300.pdf>, 11-2 and S. Drell, *et al*., "Signatures of Aging," 13-4.
[37] Jeanloz, "Science-Based Stockpile Stewardship"; see also Garwin, "The Future of Nuclear Weapons Without Nuclear Testing"; Eardley *et al*., "Quantifications of Margins and Uncertainties," 29; Medalia, "The Reliable Replacement Warhead Program," 54.
[38] Garwin, "The Future of Nuclear Weapons Without Nuclear Testing."
[39] Garwin, "The Future of Nuclear Weapons Without Nuclear Testing."

[40] "Record of Decision Dual Axis Radiographic Hydrodynamic Test Facility," Department of Energy, Oct. 16, 1995. <http://www.epa.gov/fedrgstr/EPA-IMPACT/1995/October/Day-16/pr-1395.html>.
[41] Garwin, "The Future of Nuclear Weapons Without Nuclear Testing"; see also Holdren, *et al.*, *Technical Issues*, 14.
[42] Garwin, "The Future of Nuclear Weapons Without Nuclear Testing."
[43] "Subcritical Testing," *LANL: National Security: Nuclear*, Los Alamos National Laboratory. <http://www.lanl.gov/natlsecurity/nuclear/current/subcritical.shtml>.
[44] "Record of Decision Dual Axis Radiographic Hydrodynamic Test Facility," Department of Energy.
[45] "Department of Energy FY 2006 Congressional Budget Request," vol. 1, 109 and Jonathan Medalia, "Nuclear Warhead 'Pit' Production: Background and Issues for Congress," Congressional Research Service report RL31993, March 29, 2004, 9. <http://www.aps.org/public_affairs/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=58209>.
[46] Medalia, "Nuclear Warhead 'Pit' Production: Background and Issues for Congress," 9.
[47] National Defense Authorization Act for Fiscal Year 2000 (S.1059), Jan. 6, 1999, U.S. Congress.
[48] 2000 National Defense Authorization Act.
[49] S. Drell, *et al*., "Remanufacture," 8.
[50] Jeanloz, *et al*., "Science and Technology in the Stockpile Stewardship Program," 6.
[51] "Status of Planning for Warhead Life Extension," Government Accountability Office report 02-146R, December 2001, 2.
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[61] "NNSA Needs to Refine…," Government Accountability Office, 9.
[62] Jeanloz, *et al*., "Science and Technology in the Stockpile Stewardship Program," 8.
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[65] Medalia, "The Reliable Replacement Warhead Program," 4.
[66] Medalia, "The Reliable Replacement Warhead Program," 11.
[67] Medalia, "The Reliable Replacement Warhead Program," 4.
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[70] Medalia, "The Reliable Replacement Warhead Program," 1.
[71] Medalia, "The Reliable Replacement Warhead Program," 51.
[72] Medalia, "The Reliable Replacement Warhead Program," summary.
[73] "Department of Energy FY 2006 Congressional Budget Request," vol. 1, 67.
[74] Fetter, Steve, "Reasons for Nuclear Testing ," *Towards a Comprehensive Test Ban Treaty*. Oslo: Royal Norwegian Ministry of Foreign Affairs (1992), 13. <http://www.publicpolicy.umd.edu/Fetter/1992-Norway-CTB.pdf>. This terminology suffers from the unfortunate coincidence that in the parlance of statistics and engineering, "confidence" is actually a quantifiable concept more closely akin to what we here call "reliability." We will follow Fetter and the others cited, however, in using "confidence" to label a non-quantitative dimension.
[75] Fetter, "Reasons for Nuclear Testing ," 13.

[76] House Appropriations Committee report accompanying the FY2006 Energy and Water Development Appropriations Bill, May 18, 2005 (H.Rept. 109-86), as cited in Medalia, "The Reliable Replacement Warhead Program," 45.
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[78] Holdren, *et al.*, *Technical Issues*, 29.
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