OPINION

Does nuclear stockpile stewardship's science diminish global security?

The answer is relevant to the physics community, especially for scientists who are choosing their research paths.

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Under broad pressure for a global moratorium on nuclear weapons tests, the US in 1994 initiated a new nuclear weapons R&D initiative: the science-based Stockpile Stewardship Program (SSP). The purpose of the SSP is to ensure the "safety, security, and reliability" of the US nuclear arsenal without the need to detonate nuclear weapons.[1] Many policy analysts have argued that the program is sensible: "Safe" bombs will have a minimal likelihood of detonating from accidents, unauthorized actions, errors, and acts of nature; "secure" bombs won't be accessed by unauthorized personnel; and "reliable" bombs will detonate with the desired explosive energy at the specified time and place.

Usually, discussions of the SSP's merits end there, and the conclusion is that the program is unambiguously beneficial for global security. A full assessment of the program, however, involves several other factors.

That the SSP allows the US to obtain information comparable to that accrued by testing raises many questions. Does the SSP encourage a proliferative response from other nations? Does it reinforce US adherence to nuclear weapons as tools of geopolitics and warfare? Is certifying the technical reliability of the US nuclear arsenal through a program like the SSP essential? Would such reliability ever be seriously doubted by an adversary? Does the SSP spur the development of new, destabilizing nuclear weapons? Does the net effect of the SSP decrease the threat from nuclear weapons? In this article, we discuss the factors underlying those questions and conclude that the SSP contributes to a nuclear arms race.

We argue that the existence of the SSP and the technical advances that it yields could have destabilizing implications for the geopolitics of nuclear weapons. The SSP, therefore, violates the intent of the 1996 multilateral Comprehensive Nuclear-Test-Ban Treaty (CTBT), the goal of which is to prevent "the proliferation of nuclear weapons in all its aspects." A public consideration of both the merits and dangers of the SSP is needed. Discussions are particularly important in the physics community, given the large number of physicists who are employed by the SSP.

Today, the danger from nuclear weapons is growing as arms control treaties are abandoned, states with such weapons are engaged in conventional war, new risks emerge from cyberattacks, nuclear threats from leaders are issued more regularly, and the US and other states modernize their nuclear weapons systems. The massive modernization programs signal a commitment to nuclear weapons for much of the century. Assessing the role of the SSP in the deepening crisis is as critical now as similar discussions were at the beginning of the nuclear era when many physicists—including Niels Bohr, Albert Einstein, Enrico Fermi, James Franck, and Leo Szilard—considered the consequences and ethics of nuclear weapons research.

The core argument

Before 1997, about 2000 nuclear weapons tests were carried out aboveground, underground, and underwater; more than half of those were by the US.[2,3] Nations that conducted testing largely did so to advance weapons science, ensure the reliability of existing weapons, and validate new designs.

After several decades of efforts to limit nuclear weapons testing, the United Nations General Assembly adopted the CTBT and opened it for signature in September 1996. Since then, it has been signed by 187 nations and ratified by 178 of them. The CTBT is derived from two earlier treaties: the Limited Test Ban Treaty of 1963, which prohibited testing everywhere except underground, and the Threshold Test Ban Treaty of

The Minuteman III intercontinental ballistic missile (ICBM) was first designed in the 1960s to launch nuclear warheads. To modernize the US nuclear stockpile, including developing new warheads that could replace those in the existing 400 ICBMs, researchers conduct various physics experiments at the National Ignition Facility and elsewhere as part of the US Stockpile Stewardship Program. (Photo by Staff Sgt Alan R. Wycheck, North Dakota/National Archives photo no. 6461659.)

1974, which banned tests with yields that exceeded 150 kilotons. Those treaties were driven by public concern over the arms race and radioactive fallout from testing.

The US signed the CTBT in 1996 but never ratified it. The congressional vote to ratify in 1999 failed because of partisan politics and concerns about whether the substitution of US testing by the SSP would be sufficient and how the absence of testing by other nations would be verified. Nonetheless, as a signatory, the US is obligated to not test any nuclear weapon,[4] and other nations have adhered to the ban. No tests have been conducted since 1996 except by India and Pakistan in 1998[5] and North Korea as late as 2017.[6]

US policymakers have advanced an additional argument in support of the test ban: It freezes the technological lead that the US secured through past nuclear tests. The US previously conducted 1030 nuclear tests; Russia, 715; France, 210; the UK and China, 45 each; and the others, less than 10 each.[2] The enormous success of the ban has slowed the spread of nuclear weapons to new states and the further development of weapons in existing nuclear states.

The US agreement to the CTBT is facilitated by the SSP, which supplies information on nuclear weapons science and technology. The SSP supports a broad-based scientific program that's relevant to the primary and secondary components of nuclear warheads. Examples include the study of materials under extreme compression, subcritical nuclear tests of imploding materials, and inertial confinement fusion experiments to elucidate the physics of fusion burn and matter at high-energy densities.[7] Experiments are complemented by computational modeling with supercomputers.[1] Indeed, the military value of supercomputers has led to export controls on their distribution.[8]

The SSP employs about 8100 scientists and 13 200 engineers.[1] Research and technology funding for the program has escalated from $2 billion in 2019 to $4.2 billion in the fiscal year 2026 federal budget request. Overall, expenditures on nuclear weapons have similarly surged.

Given the intent of the CTBT, however, the conclusion seems inescapable that the SSP violates the spirit of the treaty. The main purpose of the test ban is to slow the advance and spread of nuclear weapons by limiting the knowledge that is gained through testing. The preamble of the CTBT states that "the cessation of all nuclear weapon test explosions and all other nuclear explosions, by constraining the development and qualitative improvement of nuclear weapons and ending the development of advanced new types of nuclear weapons, constitutes an effective measure of nuclear disarmament and non-proliferation in all its aspects."

Yet the US gleans more knowledge of nuclear explosions through SSP science than through actual detonations. "We've progressed from observing high explosives being blown up to carefully studying their chemistry, morphology, crystallinity, and aging characteristics," says Jon Maienschein, former director of the Energetic Materials Center at Lawrence Livermore National Laboratory (LLNL).[9]

The SSP is a test-ban workaround that affords the US the advantages of testing without actually testing. Russia, France, the UK, and China have programs similar to the SSP. Other countries that neither test nor have a science-based stewardship program could create geopolitical instability as they seek to reduce the disparity. Indeed, India has not signed the CTBT on account of nuclear power imbalances. In a 20 June 1996 statement at the Conference on Disarmament, Arundhati Ghose, India's UN ambassador and permanent representative, said that the country "cannot accept any restraints on its capability if other countries remain unwilling to accept the obligation to eliminate their nuclear weapons."

Reliability, new designs, and the arms race

Before the SSP, nuclear tests were not essential for the certification of reliability of nuclear weapons. George Miller, former director of LLNL, states that "nuclear weapons were never certified by nuclear tests; nuclear tests were important, but frequently not even the most important part of the process because there were never enough nuclear tests over the full range of conditions to provide certification."[10]

Nonetheless, a critical goal of the SSP is to certify annually that nuclear warheads are technically reliable, a responsibility carried out by the three national security laboratories: LLNL, Los Alamos National Laboratory, and Sandia National Laboratories. Unclassified reports from the national security laboratories indicate that a typical technical metric for reliability is 90% confidence that the warhead yield will be within 10% of that specified. Historically, US nuclear subsystems have, with 100% success, performed at the specified yield; the National Academy of Sciences reports that the "reliability of existing systems is determined entirely by the 'non-nuclear' subsystems," which includes the delivery system.[11]

Technical metrics of reliability, although sensible for most technological systems, become meaningless when they're applied to the unique case of nuclear weapons. Reliability for nuclear weapons ultimately refers to a measure of psychological deterrence of a potential adversary. It seems inconceivable that a hostile state would ever doubt that the thousands of US nuclear weapons are anything less than assuredly lethal and an ever-present threat to the existence of other nations. It seems similarly unlikely that the US would act in a conflict based on the assumption that the weapons of other states are unreliable.

At the inception of the SSP, the geopolitical landscape was one of negotiated nuclear arms reduction. As stated in the *Stockpile Stewardship Program Strategy* of 1994, "No new weapons are being designed." The strategy, however, also called for "breakthroughs in unexplored areas of science and technology," which, if needed in the future, could provide the knowledge base for new design ideas.[12]

▲ Inside the metal case shown here are weapons-grade plutonium samples. To better understand the effect that a hostile environment, such as a missile defense system, may have on US nuclear weapons, researchers at the National Ignition Facility exposed the plutonium to intense pulses of neutrons in 2025. The radiation was generated by the implosion and heating of nuclear fusion fuel by incident lasers. (Photo by Jason Laurea/LLNL.)

The lack of emphasis on new weapons designs was consistent with the reduction of the number of nuclear warheads in the US and Russia and persisted through the Nuclear Posture Review of 2002, which recognized the "reduced threat posed by the former Soviet Union," and the one in 2010, which stated that the "most immediate and extreme danger is nuclear terrorism" and that the "other pressing threat is nuclear proliferation."

In 2018, as nuclear competition among nation-states began to grow, so, too, did the emphasis of the SSP on new weapons designs. Indeed, the main purpose of US nuclear weapons tests before the CTBT was not to certify reliability but to develop new designs. The 2018 Nuclear Posture Review states that the "need for flexibility to tailor U.S. capabilities and strategies to meet future requirements and unanticipated developments runs contrary to a rigid continuing policy of 'no new nuclear capabilities.'" Similarly, one aim of the 2025 Stockpile Stewardship and Management Plan is "to define the appropriate warheads to support anticipated future threats."[1]

Another nation may well fear new nuclear designs derived from the SSP and respond in an escalatory fashion. A 1994 JASON report, written by an independent group of scientists that advises the government on sensitive scientific and technological matters, expressed that concern. The report states that the SSP "may be perceived by other nations as part of an attempt by the U.S. to continue the development of ever more sophisticated nuclear weapons."[7]

The development of new concepts or significant design changes could also lead to internal pressure for the US to resume nuclear testing to ensure their validity. Currently, the Trump administration and some members of Congress have called for the resumption of nuclear testing.

Nations without a current SSP and without nuclear weapons could use unclassified published research for weapons development, according to Robert Goldston and Alexander Glaser of the Program on Science and Global Security at Princeton University. They note that "success in … the National Ignition Facility … could lead to greatly increased R&D in inertial confinement fusion worldwide, along with increased proliferation risks."[13]

Indeed, recent satellite observations reveal that China is constructing an inertial confinement fusion facility, which is viewed as a military asset, in Mianyang in Sichuan Province.[14] The size of the experimental bay is about 50% larger than that of the National Ignition Facility (NIF), which might indicate a superior scientific capability. The project, which can have collateral benefit for the development of fusion energy, has not been announced by the Chinese government and highlights the potential for the SSP to contribute to a nuclear arms race. France's Laser Megajoule facility, which opened in 2014, has capabilities that are comparable to NIF.

The net effect

As stated in the annual Stockpile Stewardship and Management Plan, the program must be "capable of servicing the stockpile for 50 years or more."[1] Thus, the SSP advances the salience of nuclear weapons as geopolitical tools and thereby moves the world further from arms control and disarmament.

We consider three possible scenarios involving the SSP, nuclear testing in the US, and their effects on the stability of the nuclear world order. In the first, the US has an SSP but no testing. As we've discussed, this current scenario contributes to a nuclear arms race and the spread of SSPs in other nations. In the second, the US has no, or a reduced, SSP but returns to nuclear testing. That situation is likely worse than the first one because nuclear testing would strongly incentivize other nations to test. In the third scenario, the US maintains neither an SSP nor testing. We believe that scenario would be the most stabilizing approach and would dampen rather than stimulate an arms race.

A nuclear stewardship model of reduced activity, although it would sacrifice a small amount of reliability assurance, would continue to ensure stockpile safety and security while being consistent with the intent of the CTBT. We recognize that such an approach would face strong challenges from many of the people working in the nuclear weapons complex.

For physicists and the physics community, the SSP's effect on global well-being is especially relevant, particularly for early-career physicists, and can influence whether one chooses to work on advancing nuclear weapons—a consideration with technical, policy, and ethical dimensions. Perhaps the most visible and exciting component of the SSP, at least from a physicist's viewpoint, is NIF, a technological and scientific marvel at LLNL. NIF research advances progress toward the goal of carbon-free fusion energy and enhances understanding of matter under extreme conditions.

Many of the physicists and engineers who work at NIF may be motivated by those goals, but the primary purpose of the experiment and the reason for funding it is to enhance the understanding of the nuclear fusion process that occurs in a nuclear warhead.[7] We urge each of our colleagues who work at NIF and on other aspects of the SSP to do their own self-assessment of the net effect of their creative work. A full discussion in the broader scientific community on the net effect of the SSP has not been had, to our knowledge, and is overdue.

In the 20th century, many revered physicists struggled with similar issues. Some chose to build US national security labs. Others—such as Hans Bethe, a Nobel laureate and the former director of the theoretical division of the Manhattan Project—eventually opted out of nuclear-arms research. In 1995, he wrote in an open letter that “individual scientists” can influence the national debate on weapons development “by withholding their skills.”[15] He called on “all scientists in all countries to cease and desist from work creating, developing, improving and manufacturing further nuclear weapons.” PT

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