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The Reliability and Safety of U.S. Nuclear Weapons

by

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Abstract

More than 16 years of experience with the Science-Based Stockpile Stewardship Program and its successors show that U.S. nuclear weapons can be maintained safe and reliable without nuclear explosion testing. Contributing to this conclusion are reports and statements from NNSA, from the JASON group of consultants to NNSA, and announcements from the British nuclear weapons program--the Atomic Weapons Establishment (AWE) at Aldermaston.

This discussion covers the Executive Summary of the JASON Report on "Life Extension Programs," October 2009, and will address concerns to the extent that classification allows.

A U.S. nuclear weapon system (or "nuclear weapon" for short) consists not only of the nuclear warhead or bomb for delivery by missile or aircraft respectively, but also the delivery vehicle, personnel, command and control, and the like. Reliability (or lack thereof) is dominated by failures of the delivery system and not by the warhead or bomb itself. In fact, not only reliability but also safety is strongly affected by the delivery vehicle, which in the case of aircraft may be (and have been) subject to fires on the runway while nuclear weapons are attached. In the case of the submarine-launched Trident ballistic missiles (SLBMs) the third rocket stage has a propellant that is capable of detonation and would then likely detonate the explosive of the nuclear weapons.[1]

That said, this talk will focus on the NNSA responsibility within the nuclear warhead or bomb. To save space, at the risk of some confusion, we will call this the "warhead."

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[1] "Report of the Panel on Nuclear Weapons Safety," Committee on Armed Services of the U.S. House of Representatives, Sidney D. Drell, chair, John S. Foster, Jr., Charles H. Townes, December 2000. (http://www.plrc.org/docs/Drell_Report_1990.pdf. See also Drell testimony of 2002 at http://www.plrc.org/docs/Drell_Testimony_1992.pdf)

A modern U.S. nuclear warhead consists of a "primary" nuclear explosive and a "secondary" explosive package, both enclosed by a single radiation case. The primary obtains its yield from the total fission of a fraction of a kilogram of its plutonium, which energy is used to compress the secondary which consists of uranium of various enrichments, together with solid thermonuclear fuel, often containing the light isotope lithium (Li-6) and a heavy isotope of hydrogen (deuterium) in the form of lithium deuteride—LiD. The secondary is in the form of a Canned Secondary Assembly (CSA) for ease of handling and storage and to reduce environmental influences on the materials of the secondary.

The primary nuclear explosive, in turn, contains a hollow metal shell of steel or other sturdy and heat-resistant material, containing a shell of plutonium-- the whole metal object is known as a "pit." The pit itself is made to produce nuclear yield by its implosion by means of conventional explosive surrounding the pit, which in turn is detonated by (what else?) electrically or optically fired detonators. At least two simultaneous detonators are required so that accidental detonation of the high explosive ("HE") at a single point will not provide a nuclear yield. In order to obtain adequate yield in light weight and confined space, sufficient to compress and ignite the secondary charge, the primary explosion is "boosted" by having the hollow pit filled with some grams of deuterium-tritium mixture, which provides neutrons at a rate approximately 100 times that of the D-D reaction, at the temperatures achieved in a fission bomb. Since the tritium has a half-life of about 12 years, the tritium is stored externally to the "physics package" in a steel "bottle" with automatic valves that allow the D and T to be injected in flight into the pit.

Beyond the nuclear-explosive package—NEP-- containing the primary and secondary within the radiation case, there are other elements within the bomb's "ballistic case" or the warhead's "aeroshell". Among these elements are the Arming Firing and Fuzing System—AFFS—incorporating various types of fuze that might include radar altimeter, barometric fuze, path-length fuze, or even a contact fuze or laser fuze. There may also be special batteries among these elements. For Air Force missiles, these elements outside the NEP are largely the Air Force responsibility.

In addition to the elements designed, manufactured, and tested to ensure that the nuclear weapon will detonate when called upon, there are other elements that ensure with high probability that it will not detonate when it has not been commanded to do so. These include Environmental Sensing Devices—ESD—that, for instance, will prevent arming of the nuclear weapon if it has not experienced normal rocket boost, coast, and sufficient travel in the case of warheads. In the case of bombs, there are requirements for safe separation from the delivery aircraft, and the like. Despite several having been dropped accidentally from aircraft, and some of those having had the high explosive detonate, there has never been an accidental nuclear explosion.

In addition to the requirements for reliability and safety, there is increasing emphasis on Security. Ideal security implies that a nuclear weapon could be captured by a knowledgeable group, and, somehow, could never be made to provide a nuclear yield.[2]

For the most part, such absolute security is not achieved or even designed. Adequate security might be taken to require that even with the capture of several U.S. nuclear weapons and the opening of the weapon case with access to the pit, the plutonium could not be extracted for use in a less sophisticated nuclear weapon. Alternatively, instead of providing weeks of protection against a nuclear explosion after a weapon is captured, it might be regarded as adequate to provide hours of protection. One hypothetical possibility, for instance, would be for the security package intentionally to detonate the high explosive at a single point (which for all U.S. nuclear weapons is now guaranteed to provide no significant nuclear yield) so as to disperse the plutonium, substituting a massive radiological mess for the possibility of a later terrorist nuclear explosion. Usually, less extreme security options are chosen.

With the basis now provided for the discussion, I refer to a UK document of 2002[3]. In addition to sketching the program on which the UK relies to address nuclear warhead assurance without nuclear test explosions, the document defines safety and reliability as follows:

- A safe warhead is benign in all situations other than deliberate detonation.
- A reliable warhead will act in the prescribed manner when detonated.

Now to discuss in sequence: reliability, safety, and security.

1. Reliability.

Things degrade. Therefore it is entirely reasonable to expect that individual nuclear weapons will gradually or suddenly become less reliable as they age. Some nuclear weapon parts are routinely reset to zero age, as I have indicated is the case with the substitution of refilled tritium bottles. Other parts outside the physics package (outside the radiation case) can be thoroughly tested without destroying them, or in some cases, samples are tested to destruction, with retrofit to be made if the reliability does not continue to be adequate. That is the case with the AFFS, and there is also the opportunity, carefully, to install elements of new design if they can be thoroughly demonstrated by independent groups within NNSA and by actual test not involving a nuclear explosion to be, in turn, highly reliable. The fact that this can be done, of course, does not ensure that it will be done, and there have been and probably are now deficiencies in carrying out this entirely feasible activity.

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[2] In a speech of January 31, 2008, US STRATCOM Commander General Kevin P. Chilton expressed the need for a nuclear weapon so secure that in terrorist possession “it would be a doorstop.”

[3] “The Science of Nuclear Warhead Assurance, AWE Aldermaston. (http://tinyurl.com/ydt4cnf)

Serious concerns have been evinced about the behavior of elements within the radiation case, particularly the primary nuclear explosive, and especially the plutonium in the metal pit. Plutonium is a particularly serious concern because it is radioactive to the extent that half of it decays in 24,000 years, meaning that about 0.1% of it decays in 40 years. The loss of 0.1% of plutonium would not be significant, but the radioactive decay in itself is a problem in the sense that the energetic helium nucleus ("alpha particle") produced gives substantial recoil to the U-235 that is the other product of the radioactive decay. This recoil moves the U-235 many atomic positions in the plutonium metal crystal and in the process displaces about 2300 plutonium atoms from their positions. Furthermore, the alpha particle instantly acquires two electrons from its surroundings and becomes a helium atom, and the helium atoms can agglomerate into high-pressure micro-bubbles of helium.[4] It was therefore a matter of some surprise and great relief when the NNSA announced in 2006[5]:

> "Overall, the weapons laboratories studies assessed that the majority of plutonium pits from most nuclear weapons have minimum lifetimes of at least 85 years."

and

> "The JASON Study concludes that most plutonium pit types have credible lifetimes of at least 100 years, while other pit types with less than 100 years of projected stability have mitigations either proposed or being implemented."

The other metals of the pit—steel, perhaps beryllium, etc., do not have the special aging problem and are not a concern for aging for the 85 or 100 years for which the Pu is expected to remain viable.

But the metal pit is not the primary explosive, by far. The high-explosive shell itself is not a single compound but a mixture, usually including plasticizer, and can, with time, crack, become inhomogeneous, emit vapors, and the like. The crucial detonators can, fortunately, be tested and are, initially, and identical detonators to those used in the nuclear weapons are routinely tested as they age. The ones in the nuclear weapons, within the physics package, are exposed to a somewhat different environment, and those can be assessed by the detailed stockpile surveillance—the SSP.

The SSP has long been designed to detect with 90% probability the potential failure of 10% of the nuclear weapons in a time less than two years. To do so, 11 samples of each type of nuclear explosive are temporarily removed from the inventory and brought back for inspection by radiography and partial disassembly. One example of each type is totally disassembled, so that the detonators and the high explosive and other parts can be assessed and even fired.

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[4] "Radiation Effects in Plutonium: What is known? Where should we go from here?" by Wilhelm G. Wolfer, Los Alamos Science, No. 26, 2000. (http://www.fas.org/sgp/othergov/doe/lanl/pubs/00818033.pdf)

[5] "Studies Show Plutonium Degradation in U.S. Nuclear Weapons Will Not Affect Reliability Soon," November 29, 2006. (http://www.nnsa.energy.gov/news/999.htm)

As might be expected, there have been many Significant Finding Investigations—SFI—most of them not within the physics package; about one-third of these become Actionable Findings. But there have been some SFIs within the physics package itself that, uncorrected, could have prevented proper operation of the nuclear explosive. Most of these have been design flaws, some discovered late in life, which contributed unreliability from the time the weapons were put into service.

Specifically, from a very useful 1996 Sandia Report (it is puzzling that a more recent summary is not available), from 1958 – 1995 some 13,800 weapons were tested, yielding 1,200 SFIs, from which there came 416 actionable findings (3% of the weapons tested. Of these, 306 related to the non-nuclear components and 110 related to the nuclear explosive package (13 secondary, 97 primary). Overall, some 118 of the actionable findings resulted in retrofits and major design changes.[6]

Finally, from GAO report http://www.gao.gov/archive/1996/rc96216.pdf , p 2 footnote 1: 1.3% of the 13,800 weapons had failures that would have prevented the weapon from "operating as intended."

2. Safety.

It has long been the criterion for U.S. nuclear weapons that under ordinary operation the probability of an unintended detonation should be less, per year and per weapon, than one part per billion. And in an accident, such as a fuel fire, the probability of detonation should be less than one in one million. Nuclear weapon design is strongly constrained by such requirements, and nuclear weapon concepts have sometimes involved the separation of the plutonium core from the high explosive until the weapon is about to be used, as was the case with the Nagasaki plutonium implosion bomb. Alternatively, the explosive could be extruded into place after the weapon is launched.

The scattering of plutonium in an accident, although serious, is a far lesser concern than is the prevention of unintended nuclear yield. To this end, U.S. nuclear weapons have long been fitted with enhanced nuclear detonation systems—ENDS, designed so that even a lightning strike cannot produce nuclear yield. Evidently contributing to safety is the substitution of insensitive high explosive—IHE—for conventional high explosive in order to prevent detonation by a normal bullet, if the weapon is fired upon in transit.

Since the late 1950s much effort has been expended in tests and analysis to ensure that U.S. nuclear weapons are one-point safe against detonation of the high explosive at the most unfavorable point. It would be desirable, though, to ensure that the weapon is "multi-point safe," so that even several points of simultaneous detonation in the high explosive could not produce nuclear yield. In the extreme, it is, of course, feasible to make a nuclear weapon that will not produce yield even against precision and

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[6] NUCLEAR WEAPONS, Improvements Needed to DOE's Nuclear Weapons Stockpile Surveillance Program, July 1996. (http://www.gao.gov/archive/1996/rc96216.pdf)

simultaneous firing of the detonators, which could be done (and has been done) by filling the pit with enough inert material such as wire or pellets to keep the system even from reaching nuclear criticality. This is not done universally because of the tradeoff among risk mitigation, reliability, and operational constraints.

Nuclear weapon safety is a primary responsibility of the weapon laboratories—Los Alamos, Livermore, and the Sandia National Laboratories at Albuquerque and at Livermore.

3. Security.

Public discussion of nuclear weaponry is limited by the necessity to inhibit proliferation of nuclear weapons to additional states and even, now, to non-state groups such as terrorists. Certainly there is a lot that "people" don't know about nuclear weapons, but there is both a sensible and an official distinction between information that is unknown to most people and that which is classified and cannot be publicly discussed by those with knowledge of nuclear weapon programs. Much of the first category is akin to college courses that are published in text books and yet unfamiliar to class after class of students who then learn the material. If it is publicly and reliably available, then it must be assumed that any would-be nuclear weapon state will be able to find it, particularly with the search capabilities of the Internet. Other material is unofficially and unreliably available but still classified. We can't discuss that here.

Discussions of weapon security are even more difficult than discussions of weapon principles or reliability or safety, because they involve what has been done or could be done to make weapons secure against unauthorized detonation, penetration, acquisition, or the like. The benefits of public discussion must be balanced against the increased risk to weapons from the availability of such details.

In this category fall details of the Permissive Action Links—PAL—introduced in the 1960s into U.S. nuclear weapons, and other means to prevent unauthorized access to nuclear weapons or to prevent unauthorized detonation or even, in the extreme, use of the plutonium or highly enriched uranium in fabricating improvised nuclear weapons.

Building a weapon primary with insensitive high explosive—IHE—evidently facilitates and expands the range of security features that could be implemented to prevent nuclear yield without scattering plutonium. In general it is not feasible to substitute IHE for conventional explosives without redesign and validation by nuclear testing.

- Technical features in current warheads counter the most important threats
- Introducing new surety features may be possible but there are costs and risks
- Significant surety gains can be achieved, and soon, by attention to the entire life cycle of the nuclear weapons.

What can be said about weapon security is that the most secure weapon design imaginable (and they don't come more secure than that) which, in the words of

STRATCOM Commander, General Kevin P. Chilton, would be nothing but a "doorstop" if terrorists acquired it, would not soon solve or even reduce our security problems.

This is due to the thoroughly unclassified fact that a new weapon concept would probably take five years to put into production, and if it could be produced in a form that would replace eventually all current nuclear weapon types at a rate of 100 weapons per year (which is about the maximum capability under discussion), it would take 50 years of production to acquire 5000 such perfectly secure weapons. And that is about how many strategic weapons the United States has, although only about half are currently "operationally deployed."

And it is not as if after 30 years, when half the nuclear weapons had been replaced by the hypothetical perfectly secure weapons—PSW—that the security threat would have been reduced by 50%. It is probably not possible to eliminate public knowledge that this or that weapon system or location still has legacy weapons. Hence, terrorists (who are not going to acquire all 5000 nuclear weapons) could concentrate on a few of the legacy weapons.

Furthermore, striving for perfect security of some future nuclear weapon ignores the threat to world security (ant to the United States) from stocks of nuclear weapon and of plutonium and highly enriched uranium abroad. It is likely easier for a terrorist to acquire one or more of those weapons than it is to gain control over a U.S. nuclear weapon—one difference, however, being that some U.S. weapons are in a location where a nuclear explosion could cause a lot of immediate damage—for instance at a U.S. base for Trident submarines.

Even massive reductions in nuclear weaponry (whether accompanied by production of the hypothetical PSW or not) do not eliminate the terrorist threat, for the same reason—terrorists can concentrate on the remaining weapons. Only when the remaining weapons are more heavily protected than the average weapon is now, is there a great benefit to security.

But probably long before major reductions can be achieved, and surely long before a PSW could replace even a residual force of 1000 nuclear weapons (15 years at a 100/yr production rate), targeted measures could reduce security exposures of nuclear weapons.

This would come from a detailed analysis of the nuclear weapons system, writ large, from the weapon-usable material itself to the weapon assembly/disassembly plant at Pantex (Texas), to the shipment and installation of nuclear weapons and to their routine maintenance and eventual disassembly. That is the urgent work for those responsible for U.S. nuclear weaponry—STRATCOM, NNSA, and the military services.

4. The Health of the Nuclear Weapon Infrastructure at the Nuclear Weapon Laboratories.

All of these attributes of nuclear weapons—reliability, safety, security—can only be achieved if there are people and organizations up to the task. Routine is not good enough, as demonstrated by Secretary of Defense Robert Gates's dismissal of the Air Force Secretary and Chief of Staff for an egregious security lapse involving six nuclear-armed advanced cruise missiles. And this is something that much concerns me because in the work of the Executive and the Congress, essential details perforce get lost in the big picture of budgets and numbers of employees.

For instance, all these weapon attributes depend on knowledgeable people in the weapon laboratories and in the weapon complex. Maintaining this expertise needs interesting and important work, the right equipment, and a good, supportive work environment.

Weapon experts are motivated to learn and understand and to contribute to a very complex and important domain of science and technology. There remains much important work to be done and new tools to do it with. The United States conducted over 1000 nuclear explosive tests , many with extensive diagnostic instrumentation. The entire record of instrumentation of all the nuclear explosion tests carried out by the United States, has now been preserved and is an invaluable resource for advancing our understanding of nuclear explosives through analysis, simulation and modeling, including comparison with laboratory experiments.l

An essential part of the work of weapon experts is to increase their understanding of their field, in the light of advancing tools of science and technology. For example, computers at the labs are a million times faster (from the gigaflop to the petaflop class) than those used in the design of the most modern nuclear weapon in the U.S. stockpile—the W-88, but also increased understanding has come from the effort to more closely "predict" the observations of the past weapons tests. This is exciting work, and it is a team effort. It is essential to have teams that seriously compete, so that results and claims by one team at Los Alamos, for instance, can be replicated or challenged by another team at Livermore, using, in all probability, different tools and approaches.

In addition to computing capabilities at the National Labs, it is essential to model results from experiments regularly performed on the high-energy-physics facilities there__ the National Ignition Facility—NIF—at Livermore, the Dual Axis Radiographic Hydrodynamic Test facility--DARHT at Los Alamos, and the Z-R pulsed power machine at Sandia National Laboratories, Albuquerque. These machines were built at great cost since 1997, but there is little money for actually using them to advance the Labs' mission in maintaining U.S. nuclear weapons reliable, safe, and secure. It makes no sense to have spent the money for these tools without providing funds for using them in an experimental program that would go hand-in-hand with simulation and modeling.

To maintain expertise, it is also necessary to maintain high morale. First, it is necessary to make clear that this work is valued and will be supported into the future as a priority so long as there are nuclear weapons.

U.S. nuclear weapon experts at the National Labs play an important role is assessing foreign nuclear weapon capabilities and the potential for improvised nuclear explosives, and in developing means to counter such weapons, including serving on the Nuclear Emergency Support Teams—NEST.

Scientists and weapon experts were seriously demoralized—however unintentionally—by the transfer of Los Alamos and Livermore to corporate management, with no prior recognition that for each Laboratory there would be a $100 million management fee and a similar further program budget reduction because Laboratory activities would no longer be exempt from tax. This lack of foresight and the apparent valuation of bureaucratic milestones over technical performance has been a substantial problem in recent years. Furthermore, micromanagement by NNSA, DOE in the field of safety and management, and even by the Congress has impaired morale.

It is helpful for the U.S. effort to have close contact with the Atomic Weapons Establishment—AWE—of the UK, with significant interchange of personnel with this much smaller British program. The UK nuclear weapons effort benefits from an "eyes on, hands off" description of the role of the parent Ministry of Defence that provides funds and supervision for the AWE. The idea is that MOD is kept fully and currently informed, but that AWE itself takes the decisions. Although the UK has now only a single warhead type (in its Trident missiles), AWE staff are directed to engage in new weapon design tasks, even though it is recognized that such will never be deployed. I think that the United States nuclear weapons effort has much to learn from the AWE approach, even though it may not be possible to implement it fully here.

It would expand the knowledge base and the ability to analyze problems and predict performance of current weapons, if the National Labs (Los Alamos, Sandia, and Livermore) conducted general design studies of new thermonuclear weapons to obtain a better understanding of potential cost, reliability, safety and security. This should not be a substitute for specific existing warheads or be considered for production or deployment. One needs a far more reliable means of determining program costs, and opportunity costs, and I don't believe that we have yet the ability to deploy with acceptable risk new-design weapons that have never had a nuclear explosion test.

Harold Agnew, a longtime leader of the nuclear weapons effort at Los Alamos and who was in charge of development of the first stockpiled hydrogen bombs, later served 10 years as Director of the Los Alamos Scientific Laboratory. He has been steadfast in his advice, to the present day, that no nuclear weapon should be deployed that has not had a nuclear explosion test in the stockpiled configuration.

Another element of maintaining and enhancing technical excellence would be to institutionalize a summer school taught by lab nuclear-weapon experts, perhaps alternately at Los Alamos and Livermore, to which graduate students or people working in allied fields of computation, simulation, hydrodynamics, astrophysics, and the like could be immersed in the nuclear weapon program, after receiving the necessary security clearance. The teaching staff from the Laboratories would learn as much as the students.

I am persuaded that we do not need actually to build new-design nuclear weapons in order to maintain and modernize the capability to do so. And I return to the Finding of the JASON study of Life-Extension Programs that the LEPs have been successful in maintaining the reliability and safety of U.S. nuclear weapons, and that similar approaches will do continue to do so for decades in the future, with no anticipated loss in confidence.

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