Stockpile Stewardship Without Nuclear Explosion Testing

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I am glad to have the opportunity to discuss here the mechanism for maintaining the reliability, safety, and security of U.S. nuclear weapons without nuclear explosion testing. President Obama has stressed his dedication to this goal, and to the eventual elimination of nuclear weapons, which latter he did not expect to see accomplished during his lifetime or perhaps even the lifetime of his children. As this image of the destruction at Hiroshima reminds us, the avoidance of not only nuclear war, but of accidental or terrorist nuclear explosions is of critical importance.

Hiroshima, October 1945

In this presentation I rely heavily upon a paper of January 28, 2010 posted on my website, "The Reliability and Safety of U.S. Nuclear Weapons." The points I make in this talk are developed more thoroughly in that paper, with references. The goals of stockpile stewardship may be summarized by a United Kingdom document of 2002 which in addition to sketching the program on which the UK relies to address nuclear warhead assurance without nuclear test explosions, 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.**

A modern U.S. nuclear warhead consists of a "primary" nuclear explosive and a "secondary" explosive package, enclosed in 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 of lithium (Li-6) and a heavy isotope of hydrogen (deuterium) in the form of lithium deuteride—LiD—dubbed "salt". The secondary is in the form of a Canned Secondary

Assembly for ease of handling and storage and to reduce environmental influences on the materials of the secondary. The secondary provides almost all the yield of the weapon, e.g., 100 kilotons or 350 kilotons.

The primary nuclear explosive, in turn, contains a hollow metal shell of steel or other sturdy and heat-resistant material, encasing a shell of plutonium-- the whole metal object is known as a "pit." The pit itself is induced to provide nuclear yield by its implosion by means of high explosive surrounding the pit, which in turn is detonated by 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. The design of the primary must ensure this single-point safety. The plutonium content of U.S. weapons averages about 4 kg.

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 only about 12 years, tritium gas is stored externally to the "physics package" in a steel "bottle" with automatic valves that allow the in-flight injection of D and T into the pit, and also the scheduled replacement of the tritium bottles.

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

1. Reliability.

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 implied 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 is not assured.

For instance, the Arming Firing and Fuzing System can be thoroughly tested without nuclear explosion (and, in fact, was not ordinarily exercised in the case of underground nuclear explosions) 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.

Plutonium metal is highly reactive chemically, avidly combining with water, air, or hydrogen, but in U.S. nuclear weapons it is well protected in the welded-metal sealed pit. The pit, however, does not protect the plutonium against its inherent radioactive decay; half of it converts in 24,000 years to uranium-235 or about 0.1% of the plutonium in 40 years. The loss of 0.1% of plutonium would not be significant, but the radioactive decay in itself is a problem because 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.[1] It was therefore a matter of some surprise and great relief when the NNSA announced in 2006[2]:

> "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; 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.

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. Some SFIs within the physics package itself, 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

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[1] "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)
[2] "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)

non-nuclear components and 110 to the nuclear explosive package (13 secondary, 97 primaries). Overall, some 118 of the actionable findings resulted in retrofits and major design changes.[3]

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." Since 1996 the scientific basis for stockpile stewardship has been much strengthened with focused experiment, analyses and computer simulation, so that it is clear that the Stockpile Stewardship Program, of which we now have 17 years of experience in pretty much its current form, is doing a good job in maintaining the reliability of the nuclear weapons.

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 than one part per billion, per weapon lifetime,. 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—CHE--in order to prevent detonation by shrapnel or a 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 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. Surety of U.S. nuclear weapons.

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

Nuclear weapon "surety" is a term used to encompass both safety and security. Although the design and manufacture of nuclear weapons is the responsibility of the U.S. Department of Energy and more specifically the National Nuclear Security Administration (NNSA), the actual use of nuclear weapons is the responsibility of STRATCOM, under a chain of command from the President. Indeed, physical control over nuclear weapons is transferred to the Department of Defense and its agencies until weapons are returned to NNSA control for refurbishing or dismantlement.

NNSA and DOD have highly capable people involved in the planning and execution of nuclear weapon security tasks, about which there is even more than the usual tension over public discussion. The introduction of the Permissive Action Link (PAL) to U.S. weapons in the 1960s is an example of a major improvement that could be implemented, evidently without nuclear testing, but as the threat evolves, naturally security measures must also change. Evidently, theft of U.S. nuclear weapons by the Soviet Union is no longer a leading concern for U.S. security measures. But the demonstrated willingness and goal of terrorist groups to inflict enormous damage on society, including the use of suicide as an enabler, has evidently demanded a response.

Over the years, weapon safety has been improved by the substitution of insensitive high explosive (IHE) for the "conventional" plastic-bonded explosives (PBX) that have been the mainstay in nuclear weapon primaries. IHE has also enabled improved security, in principle allowing energetic measures to defeat attacks on the nuclear weapon itself.

Serious evaluation of the weapon security situation compels a look at not only external but internal threats, including threats to kill or torture family members of those with legitimate access to nuclear weapons; there are examples in the "Irish troubles" over the years. And responses to security analyses must take into account the enormous range of consequences of terrorist access to a U.S. (or other) nuclear weapon—ranging from full-yield detonation in a city at a time and place of terrorist choice through detonation in place of a weapon in transit, perhaps resulting in a small fraction of the explosive yield, to damage that might be done by security measures that successfully prevent terrorist access to an intact weapon.

4. The Future of U.S. Stockpile Stewardship.

That reliability, safety, and security of U.S. nuclear weapons is satisfactory, is evidenced by the annual assessment letters of the heads of the U.S. nuclear weapon laboratories and the Commander of STRATCOM. But to carry this forward in the future requires competent and dedicated personnel and facilities. This system can be imperiled in many ways, from being a political football, to demands for ever increasing capabilities that, paradoxically, might lead to less safe nuclear weapons. As has happened in other major government programs, over-promising and over-commitment can imperil the more mundane goals of reliability, safety, and security. To argue that enormous investments are required just because we know how to make nuclear weapons safer and more secure than they are now is to ignore not only the enormous marginal costs per unit of improvement in weapons safety and security, but also ignores feasible options for obtaining improved safety and security without significant modification of existing weapons.

It is just such an analysis that is an essential responsibility of both the Department of Defense and of NNSA, to which they seem to be committed.

Thus far I have discussed stockpile stewardship in the light of the four goals of reliability, safety, security, and preserving the capability. It is also instructive to take a cross-cutting view and to illustrate some of the tools that may contribute to several of the goals. For instance, Livermore has built the National Ignition Facility—NIF; Los Alamos has developed and deployed the dual-axis Radiographic Hydrotest Facility—DARHT; and Sandia has built, used, and upgraded the Z-pinch machine—Z-R.

The U.S. nuclear weapons program benefited from the very first by a capability to use short-pulse high-voltage electron accelerators serving as x-ray machines to image explosively driven plates and shapes. Of course, for a full-size plutonium pit driven by high explosive, laboratory imaging is impossible because the experiment will yield a full-scale nuclear explosion. To image sectors of a pit or small-scale plates or shapes driven by high explosive involves no risk of nuclear yield, but if done with plutonium must confidently contain the plutonium so that it is not scattered to produce a radiological hazard.

The proton radiography facility—P-RAD-- at the Los Alamos Neutron Science Center—LANSCE—can provide multiple x-ray-like images during a single implosion, and is capable of using plutonium. Together with bench scale experiments, these major facilities give valuable information on the properties of materials at the extreme conditions found only in nuclear weapons, and also lead to understanding the difficult but crucial questions of the mixing of adjacent materials in the weapon.   Many P-RAD and DARHT images are of explosively driven implosions that use lead or other heavy metal such as uranium as a simulant for plutonium.

The most powerful and flexible tool for stockpile stewardship, aside from the human mind, intuition, and spirit, is advanced computer simulation. However, experiment, peer review, and images in particular, help to keep both simulation and humans honest, and contribute to the store of both information and humility in the program.