

The Artisanal Nuke

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Abstract

In the post-Cold War era, preservation of the nation's nuclear deterrent has become the provenance of the Stockpile Stewardship Program (SSP). The United States does not design, build, or test new nuclear weapons, but is required to maintain the safety, security, and reliability of those weapons remaining in the active deterrent stockpile. How to do that without nuclear testing is a “grand challenge” considered by many to be as difficult, if not more so, than were the challenges of the original Manhattan Project. It has led to the development of new experimental scientific and computing capabilities as well as expanded use of technologies used during the Cold War test and build program. In contrast to the image most people have of a massive industrial effort, it is very much an artisanal preservation effort by teams who work at detailed levels to maintain a product everyone hopes will never be used.

This thesis examines the artisanal scientific and engineering challenges inherent in such an effort, and makes clear what is and is not part of SSP. The method of investigation was to review relevant literature on the development of the overall approach to the SSP grand challenge to include program milestones met, scientific and engineering breakthroughs and technological improvements, the value of the intellectual capacity needed in the program, the difficulty of retaining highly educated and trained staff, costs, problems, criticisms, and value of the overall science and engineering represented in such large, costly government programs.

The results are impressive in terms of achievements many of which have far ranging implications for the U.S. economy beyond national security goals. The results are mixed in terms of the program's ability to manage costs effectively. The problems associated with obtaining sustained federal funding are seen. The conclusion is that SSP is a reasonable solution to the continued need for a nuclear deterrent, and that there is a continued need for a deterrent. It is worth the dollars being spent but could be more cost-effective.

CHAPTER 1

Introduction

There have been many words written about the value and importance of nuclear disarmament. There have also been many words written about the value and importance to the U.S. defense posture of nuclear weapons. This thesis will not be about either one of those points of view. The commentary will not purport to tell anyone that there is or is not a need for one nuclear weapon or thousands of nuclear weapons. This study is more about, “well, they are here – now what?”

The title of this study is “The Artisanal Nuke.” Yet, ordinarily no one thinks of nuclear weapons as highly sophisticated, craft made artisanal items. Why not? It could be because there were estimates that the United States and the Soviet Union had in the neighborhood of 25,000 or more nuclear weapons at one time.

What is an artisanal product? Films are highly sophisticated works that represent a team effort. They, too, are produced by the thousands, but when we think of the “film industry,” we never think that films are a mass-production kind of item. They would always be recognized on some level as “artisanal.”

Craft brewed beers are also considered artisanal items, though even a small brewery probably produces 30,000 bottles of beer in much less time than it took to have the nuclear weapons stockpile add up to anything remotely close to that number.

In a very real sense, all nuclear weapons developed by and since the original World War II Manhattan Project weapons are artisanal creations. The designs were always very carefully, individually crafted by the most advanced scientific and engineering methods employed by highly educated, experienced, and trained people. These artisans of nuclear knowledge operated in a small, elite community. The individual designs they created were not mass-produced, though at the height of the arms

race there was much more of a large industrial production complex atmosphere associated with the program.

New designs were always being developed. Old designs were always being replaced. Designs incorporated increasingly sophisticated new requirements that were dictated by the customer. Elaborate safety and security requirements surrounded all processes, and were part of every step of each process. Nothing went forward on autopilot. These weapons were carefully considered and handled from beginning to end point.

That process continues under the Stockpile Stewardship Program. The Godfather of Stockpile Stewardship, Dr. Victor Reis, has said that the work of Stockpile Stewardship might be harder than the work of the original Manhattan Project in terms of the challenge involved.

As nuclear weapons age, they change. Stockpile Stewardship, the process of maintaining them, is a complete reinvention of the science, engineering, and subjective judgment applied during the days of nuclear testing, but it is also a passing on of knowledge from artisan to artisan. SSP was planned to replace underground nuclear testing and to keep the existing stockpile safe, secure, and reliable/effective in the absence of underground testing. Testing has been replaced by experimentation and computation in SSP. However, subjective artisanal judgments have had to be passed on from test experienced veterans of the days of design, build, and test to young scientists and engineers who will never, it is expected, have to plan, execute, and evaluate a weapon based on a new underground nuclear test.

Extending the life spans of these highly sophisticated artisanal products has been largely a process of entering terra incognita. It hasn't been done before, and while some twenty years into the program, success has been good, there remain some questions about whether or not it can be done successfully long-term.

Not everything was written down during the days of design, build, and test, anymore than a good auto mechanic writes down the subjective diagnostic and repair judgments that have been gained from years of trial and error working on many different models of cars. Nor do recipes from a favorite family member have everything written down to get a perfect result. There is always subtle knowledge involved that comes with experience and is a result of knowing the craft well. It is artisanal.

This thesis presents the story of the Stockpile Stewardship Program and the artisanal craft of how it maintains the nuclear weapons of the enduring stockpile. A case can be made that the nation has gained incalculable benefits beyond any military gains in terms of the total national security package. Education, economic benefits, and creative growth gained through solutions to hard problems have always led the United States toward security and prosperity. The urgency of this kind of challenge has always offered a framework for great leaps forward in knowledge and technology.

The fact is that the decision to have nuclear weapons was made before most Americans now living were born. The Cold War nuclear weapons build-up between the United States and USSR was part of childhood, the teenage years, college years, and beyond for many Americans. This thesis will not be about whether the Cold War could have been avoided. Those decisions were made, the Cold War came and went, and there were and are consequences that came out of the more than half century since the atom was split and fused, setting in motion the process that led to the Cold War arms race.

Those who grew up during the Cold War nuclear arms race have memories made up of varying degrees of knowledge and fear about the nuclear threat under which America lived. For some there were “duck and cover” exercises that certainly would have been futile in the face of the kind of nuclear attacks envisioned under Cold War policies.

For children of those who served in the U.S. Air Force (USAF), there are memories of special sections of Air Force bases that were off-limits, even to other Air Force personnel. There were bright lights, tall fences, and armed guards in addition to the usual base gate guards. There was the late night roar of B-52 engines being tested for readiness for the mission that everyone hoped would never come. Living on or near base, no one expected to survive such an attack, and wondered what the point was of all those people building fallout shelters? What would be left to those people who might survive, hidden underground?

The usually cited negative consequences of the decision to move ahead with nuclear weapons focus on radioactive fallout from above ground nuclear testing that had the potential to raise occurrence rates of some types of cancer; the need for expensive cleanups to former nuclear production facilities; and the dollars spent on what became the Cold War

arms race between the United States and USSR – dollars that many believed would have been better spent otherwise.

Another consequence not always mentioned is the development of nuclear medicine, which has been, and remains, key to medical diagnostics and to many medical treatments.

There have been other consequences of the nuclear weapons program that should be mentioned. As Dr. Victor H. Reis, the father of today's nuclear weapons program to maintain the safety, security, and reliability of the existing weapons, known as the Stockpile Stewardship Program (SSP), pointed out in his acceptance of the Schlesinger Award in 2009.¹

Examples of how nuclear weapons have changed the way we live include:

- U.S. Department of Energy (DOE) labs started and continue to play a critical role in the human genome project because the nuclear weapons scientists needed to understand the effects of radiation on the survivors of Hiroshima and Nagasaki.
- The U.S. space satellite program was developed to spy on the Soviet nuclear arsenal, and to provide strategic communications in the event of a Soviet nuclear attack.
- Packet switching, the technology that lets computers communicate with other computers, was developed to ensure that the communications to our nuclear forces would survive a surprise Soviet attack. The first major application of packet switching, the Arpanet, grew into the Internet.
- Packet switching was central to the development of parallel computer processing, which driven by DOE's stockpile stewardship program has led to a factor of 10,000 improvement in supercomputing (since 1994).
- Thus, while the genome project, the Internet, petaflop² computing and the space program might have happened without the atomic bomb and the Cold War, certainly urgency and shape of those programs were driven in large part by nuclear weapons and the Cold War.

It should be noted that these developments were made possible because the nation was willing to spend the large sums of money on the science and engineering needed in a concentrated effort to accomplish certain kinds of tasks.

Dr. Reis pointed out that since the end of the Cold War, the Department of Energy laboratories have:

- Completed – or almost completed – some seven world leading science installations.
- Created a stockpile stewardship program that has deepened our knowledge of the nuclear explosive process. Some 13 certifications of the safety, security, and reliability of the existing stockpile have been completed without further nuclear underground testing and stockpile stewardship has driven the world's supercomputing capability.
- Safely dismantled more than 13,000 U.S. nuclear weapons and converted some 350 tons of Russian weapons grade uranium into nuclear fuel to produce electricity in the United States.
- Created with our Russian colleagues, a first class materials control and accounting program in Russian, and the United States is involved in materials protection and security in some 108 nations.
- Become the major supplier of safeguard technology to the International Atomic Energy Agency (IAEA), and leads international efforts to safely expand nuclear power worldwide with minimal proliferation risk.
- Transformed the Rocky Flats plutonium pit production complex into a National Wildlife Refuge.
- Submitted the Yucca Mountain Repository to the Nuclear Regulatory Commission for a license, and have been permanently storing actinide waste at the Waste Isolation Pilot Plant in Carlsbad, New Mexico for more than 10 years.

Reis further noted that the DOE laboratories have more than 12,000 PhDs and host some 25,000 visiting scientists each year, making the lab

system probably the world's largest collection of scientific talent – possibly in the history of the world.

It is wise to consider all sides of a situation before characterizing it entirely in positive or negative terms. The science and engineering associated with the nuclear weapons program was, however, most often shrouded in national security secrecy, or the scientific achievements were made public completely disconnected from their weapons roots, in the service of security for the overall program.

This meant that particularly after the end of above ground nuclear testing in 1962, the public perception of the deterrent was almost entirely characterized by the negative views of those who opposed the basic idea of nuclear weapons and possibly conventional weapons as well. The paradox of this was that the nuclear deterrent may have been perceived as more effective because its opponents made it seem bigger, darker, more powerful than might otherwise have been the case. In short, efforts to undermine the existence of nuclear weapons may have made them a more effective deterrent. Of course that being possibly the case, it might also be that one reason the nuclear deterrent remains central to national defense is because of the success of opponents in demonizing the deterrent into something more than it might otherwise be perceived to be.

While it would be difficult to underestimate the negative potential of mutually assured destruction (MAD), the political policy associated with Cold War nuclear weapons, there also developed fears of any and all things named “nuclear” in the minds of many that far exceeded the actual risks associated with that particular area of science and technology. Even today, when nuclear weapons are no longer being designed and built, and the size of the stockpile continues to decline, there is a requirement for the DOE to spend incredible amounts of public money to try to clean legacy weapons materials production sites at Hanford, Washington, and the Savannah River Site in South Carolina.

Given current budget debates and choices, might it be better for now just to put a fence around those sites with guards and cameras to keep people from the toxic brews still there? Perhaps in future there will be more understanding of affordable, effective ways to clean those sites. Due to long-time public perception, however, this relatively inexpensive option is not on the table as an interim measure. Risk associated with nuclear anything is viewed differently from risk associated with the rest of modern

life. This is in part because nuclear things came of age in the post-World War II era when it seemed to Americans that the world could be made risk-free and that it should be made so at all costs.

It is not a good thing that these toxic nuclear sites exist, but the nation has lived with toxic chemicals of all kinds on a daily basis in many communities since the beginning of the Industrial Revolution. The occasional train or truck wreck producing a chemical spill reminds the community that the substances and cleaners used to keep communities healthy and to ease the path of modern life have an unhealthy side to them that entails risk. The toxic side effects of the coal industry and the dangerous conditions that have killed thousands of coal miners and polluted the air and water for all have long been known, yet coal use goes on.

When commercial nuclear power proposals are evaluated, however, “zero risk” is the standard against which they are most often judged. Zero risk is impossible in any human endeavor, but when nuclear is in the name, zero risk is the standard. A half-century of proactive, effective anti-nuclear messages have led to a view that no nuclear risk is acceptable. Meanwhile, coal mine accidents kill, and air pollution from coal burning causes lung disease. Oil platforms explode and burn, killing humans and animals and polluting fragile marine life for decades.

A contrasting view is provided by the space program, which has been highly publicized and highly romanticized over time. The National Space and Aeronautics Administration (NASA) proactively controlled the narrative and incorporated strategic communications into its work at very basic levels of activity from the first days of the agency. NASA was assertive, proactive, and creative about the mission, the spinoffs and benefits of the space program that came from tax dollars it received.

The nuclear weapons program was always in the position of reacting to negative characterizations by others. While the space program is inherently more romantic, it also remains a fact that nature abhors a vacuum. Nature will put something in the vacuum over which it is not necessarily possible to have positive control. A game cannot be won only by playing defense. Some solid offense is required.

There were no stories from NASA about dealing with the radiation associated with space travel, yet that is a very real limitation to human exploration of space. There have been some protests about plutonium

batteries used to power some space vehicles, but most Americans do not worry that plutonium will rain down on their neighborhoods if space vehicles somehow crash in the vicinity. In other words, the drama and romance of space travel have overshadowed the risks associated with it.

The narrative, again, was controlled by the space program rather than by anyone associated with opposition to the program. While nuclear weapons are not inherently appealing, this paper will point out that there are many things that might never have come or might have come far more slowly were it not for the imperatives associated with the nuclear weapons program.

There are those who believe that the development of nuclear weapons has prevented World Wars III and IV and so on. This is not to say that no wars have occurred since then, but nothing on the scale of that seen in World Wars I and II has been experienced since the discovery of nuclear weapons.

A somewhat tongue-in-cheek view of the usefulness of the Cold War appeared in “Duck and Cover,” from the online *Daily Kos* blog by Dark Syde, posted July 21, 2013.

Consider WW2, most of the old industrial world along with half of the new locked in combat, factories churning out planes and bombs and ships furiously, to hit their factories making the same stuff. Whole populations rounded up and murdered on an industrial scale using pretty much every means we had been busily perfecting since Moonwatcher symbolically cracked that other, incredibly annoying alpha ape upside his screeching head with a knobby antelope femur. Then, at the very, very end, a group of the wisest quantum sorcerers cast their mysterious spells on the rarest of earths to produce a technological super weapon working on whole new principles capable of leveling entire cities in one stroke. Which was then used to level not one but two cities in the fanatical enemy nation thus ending the war.

If aliens were watching from orbit, they surely realized they could not have written a better script. Except for the sequel, which promised to be literally apocalyptic. For the first time earth’s presumably only intelligent species had the

power to destroy its own biosphere. This was new, up to then we could put everything we had into it and still leave a healthy population and industrial base standing, enough that a whole new set of all out wars could be waged in a few years if not immediately. We basically existed in a state of perpetual warfare for at least five millennia. There was certainly no reason to think we would stop now. Nor at any time over the next several decades as we lurched from one proxy war to another with plenty of perilous saber rattling and chances for honestly mistaken Armageddons along the way.

Another great thing about the Cold War was we enjoyed all the benefits of being on a war footing. We couldn't really afford to humor know-nothings and corrupt woosayers on a mass scale. Our weapons had to actually work for the deterrent to be effective, the spillover onto scientific progress was astonishing. To this day the United States, falling behind in so many other fields of study, remains the undisputed leader in aerospace and communications. A couple of the crowning achievements therein include walking on the moon and the network you are reading this post on. The economic benefits surpassed the fondest hopes of our original cold warrior-leaders, notably Ike and JFK. As a nation the Cold War forged us, it defined us, it became our collective political operating system we ran on for decades. The politics of division were cast aside, briefly, more so than ever before anyway, clearing the way for women and minorities to begin an epic, long overdue march to legal equality.

In fact, wars in general and the Cold War specifically were so damn useful in so many ways that we almost needed it. Or, something like it. The "good" exists in contrast to the "bad," much like blue stands out best on a field of red and white. It didn't escape anyone's notice that having a feared enemy has a huge upside, be it in a democracy or

totalitarian state. Terrified people tend to make snap decisions, offer them a well-defined set of alternatives and they can even be stampeded in the desired direction.

The *Daily Kos* blog is home to very liberal bloggers, so the excerpt would be surprising to some readers of the blog. It helps to illustrate that there really are many points of view across the political spectrum about nuclear weapons and their role as a scientific facilitator in addition to their role as the end all and be all of weapons. Take for example, the following phrase "...a group of the wisest quantum sorcerers cast their mysterious spells on the rarest of earths to produce a technological super weapon working on whole new principles capable of leveling entire cities in one stroke."

This quote sums up the essence of the Manhattan Project succinctly but does not demonize the scientists and engineers who were part of it. On the contrary, it alludes to the brainpower and achievement that nuclear weapons represented. Look at the phrase, "the spillover onto scientific progress was astonishing." It acknowledges and highlights the fact of incredible scientific achievements associated with the science and engineering of nuclear weapons. This work, that had such a dark side, also made the United States a world science leader.

Hungarian born, U.S. physicist Leo Szilard was singled out by Richard Rhodes in *The Making of the Atomic Bomb*, as being perhaps the first person to fully realize the potential for making a nuclear weapon: "What Szilard saw before others did was that if one bombarded a nucleus with neutrons, one might institute a nuclear chain reaction."³

Throughout the 1920's, Szilard, a prodigious and energetic student and thinker, had an interest in nuclear physics. It was a new field at that time, and he found in science patterns that seemed to him to be in some ways analogous to then emerging philosophical and artistic movements. He saw all of these areas of endeavor as ways in which he might, were he to study and work hard enough, benefit society. Szilard's reading of H.G. Wells' *The World Set Free* inspired him in this direction, seeing the "liberation of atomic energy as a means to allow humans to leave earth and the solar system to satisfy the human need for danger and heroism often associated with war."⁴ It was as if he sought to replace war with scientific advances as an alternative path toward the kind of excitement

and challenge so important to humans that seemed to be represented by warfare. He believed his work would contribute to excitement for human progress instead, and he believed such a thing was possible.

Szilard was not unique in his view, particularly among well-educated young people of his time. Felix Frankfurter, later to become a Supreme Court Justice, was a young man in the early years of the 20th century, who also believed that the social sciences and other areas of study could be relied on to provide concrete, well-reasoned solutions to problems in society.

In the late 19th and early 20th centuries, the newly developing social sciences appeared to offer approaches to some social issues that might improve society in a number of ways. There were also movements for better worker protections, an end to child labor, and so forth. Most educated Americans, which Justice Frankfurter certainly was, embraced these new ideas.

Unfortunately, sometimes these new ideas were not grounded as solidly in real science as would be the physics of nuclear weapons. For example, eugenics was one such philosophy that held interest for a number of Americans during the early years of the century, but there was a dark side to eugenics as was later observed in Nazi Germany.

Still, at that time, Frankfurter, and many others believed that ‘experts’ were always to be relied on to know what would be best for all. “His conviction (was) that the proper study of enough facts would produce inevitable conclusions about societal goals...” that “good motives and diligent care would inevitably produce happy human relationships.”⁵

According to Rhodes, Szilard had his thought about a nuclear chain reaction while stepping off a curb in London to cross the street as the traffic light changed. By the time he reached the other side of the street, his idea was in place.

He thought it would be analogous to a chemical process involving chemically unstable systems that used oxygen atoms to produce via chain reaction, a two-for-one molecule product, each of which could also produce two-for-one more. If he could find an element that could be split by neutrons, emitting two for every one absorbed, it would be possible to create a sustained chain reaction (using

nuclear fission) in contrast to self-limiting chemical chain reactions.⁶

Szilard's thought was an elegant one that would indeed be realized in the creation of the ultimate artisanal product: the first nuclear weapon, a one of a kind, handmade and painstakingly crafted object. Szilard would eventually, post-Hiroshima and post-Nagasaki, be part of efforts by other Manhattan Project scientists to control or stop the production and use of the nuclear weapons they had created. Even J. Robert Oppenheimer was often described as conflicted and ambivalent about the project he had so brilliantly led.

The 'genie' was out of the bottle, however, and indeed, Oppenheimer himself understood that it would have happened no matter what. Oppenheimer once said, "It is a profound and necessary truth that the deep things in science are not found because they are useful; they are found because it was possible to find them."⁷ It is not possible to know what may come from any given discovery. It is only possible to know what has been found and perhaps understand something about how a discovery may affect human kind in the short term.

The vocabulary of nuclear weapons has become part of everyday conversation. *Ground Zero*, *nuclear option*, *fallout*, and other terms are used to characterize events and situations that have nothing to do with nuclear weapons. These terms as used, however, do indicate extreme events and situations. For example, *Ground Zero* is used to refer to the location of the attacks by terrorists on the World Trade Center on September 11, 2001, in New York City. Most recently, the term "nuclear option" has been used to refer to the desire to reform rules on the floor of the U.S. Senate in order to move presidential appointments to a vote in a timely fashion. *Fallout* can be anything from embarrassing consequences for a misstep by a public figure to unfortunate business results that might come from bad financial decisions.

Discoveries are rarely all good or all bad. They are just additions to the sum total of knowledge. They exist in a time and context that has to be understood and acknowledged by succeeding generations who are seeking to measure that worth and will find purposes that were never envisioned by the discoverers.

This thesis is not about whether or not nuclear weapons are or were inherently moral or immoral. As an example of the fact that it is not

possible today to second-guess the historical context in which decisions about them were made, several years ago a very liberal Member of Congress, always reticent about supporting any kind of military action by the United States, talked about his own experience.

He was a young man in the military near the end of World War II. He had been sent to England to fight, but Germany's surrender ended the war in Europe. He knew that he was probably headed for the Pacific next. An invasion of Japan was being planned. Casualties associated with such an undertaking were expected to be somewhere around one million. By the Congressman's own reckoning, President Harry Truman saved his life and the lives of many young American service personnel among others when he decided to use nuclear weapons to end the war with Japan.⁸

After reading about firestorms initiated by allied bombing over Germany and Japan and the ghastly kinds of deaths suffered by civilians in those locations, it is clearer why at that time it might have seemed that a nuclear weapon would not be worse. Considering that many things were still unknown about these new weapons, including the full extent of their raw power and effects, it is easier to understand why the choice to use them might have seemed entirely reasonable.

A modern nuclear weapon has about 6,500 parts. Something like 80 percent of those parts are non-nuclear. The story of how nuclear weapons were invented how and the Cold War began has been recounted many times, most comprehensively and memorably by Richard Rhodes in *The Making of the Atomic Bomb* (1986) and *Dark Sun* (1995).

This study is about how the United States has decided to manage the nuclear weapons still in the nuclear weapons stockpile; how to keep them safe, secure, and reliable/effective without further need for underground nuclear testing and without a need to design and build new nuclear weapons. The commentary focuses on the hard challenges in science and engineering of the kind that, throughout history, have stimulated intellectual and technological advancements in the United States.

Meeting these challenges has brought unprecedented economic growth as a byproduct of the mission and changed the world in ways no one could have anticipated at the outset. It is about the artisanal nature of the work being done to maintain the stockpile. It will also be about some of the benefits already realized across the U.S. economy from this program.

In stories about the costs of the nuclear weapons program, those costs are often estimated at \$30 billion per year. It is useful to remember that this is not the cost for nuclear weapons alone. Numbers this high always include costs of nuclear submarines, missiles, and the aircraft that deliver a nuclear weapon to a target. The higher numbers also may include military operational support provided in the form of submarine crews, missile control crews, and aircraft maintenance and flight crews.

It is not widely understood that the actual nuclear weapons program has never been part of the military or Department of Defense. Since the nuclear weapons program has always been under civilian control and kept separate from the Department of Defense, it is more appropriate to view the cost of the weapons themselves as separate from the other items. The billions of dollars for missile defense, or new missiles, submarines, and aircraft do not maintain the weapons. The requirements that the weapons must meet in terms of the job they must do are set by the Department of Defense, however, as part of military strategy.

When the Berlin Wall fell and the USSR fell apart, many Americans thought it meant the absolute end of nuclear weapons. There was no more “enemy” like the USSR for the United States to deter and build against with nuclear weapons. There were stories of the peace dividend that would be available through massively reduced military expenditures on nuclear weapons, associated delivery systems, and the operational support provided by the military.

In 1992, President George H.W. Bush declared a nuclear testing moratorium. The name of the last underground nuclear test, interestingly enough, was *Divider*. The moratorium was extended by President Bill Clinton and is still in place today.

The costs of the Manhattan Project offer food for thought with regard to today’s Stockpile Stewardship Program. As reductions in the numbers of nuclear weapons in the enduring active stockpile are made via treaty or other agreements, there are some who view this as a major dollar savings opportunity. Looking back at the costs of the Manhattan Project, it is estimated by The U.S. Nuclear Weapons Cost Study Project, completed in August 1998, that the four atomic devices/bombs developed cost on average \$5 billion each in constant 1996 dollars.

This estimate includes infrastructure development to produce the bombs, but not for initiatives including the \$76 million spent on Project

Silverplate, covering the modifications of bombers in support of the Manhattan Project and personnel training associated with the bombers that would deliver the atomic bombs to Japan.⁹

Compared to other World War II expenditures, this cost was very economical, given the effectiveness of atomic weapons. For example, all bombs, mines, and grenades cost \$31.5 billion, while small arms materiel (not including ammunition) cost \$24 billion. WWII's tanks cost \$64 billion, while heavy field artillery cost \$4 billion and all other artillery costs were \$33.6 billion.¹⁰

Although deaths in Hiroshima and Nagasaki were estimated to range somewhere between 100,000 and 200,000 – counting both immediate deaths and deaths from injuries received – overall deaths for World War II are often estimated at 55 million.¹¹ In addition, no airplanes or crew members were lost in the two nuclear attacks.

It may be that to some, the basic efficiency associated with results available from use of nuclear weapons seemed more frightening than the less well-understood radiation effects. If nuclear weapons were so “cheap” and efficient, perhaps there would be an inclination to use them more often. It should have been clear that just a few nukes could do what General Curtis LeMay needed thousands of pounds of conventional bombs, the lives of hundreds of bomber crews and their costly planes to do with massive bombings that produced firestorms in Japanese and German cities. Firestorms in Tokyo and Dresden killed and maimed the same numbers that suffered and died as a result of nuclear bombs at Hiroshima and Nagasaki.

In recent current events, similar questions have arisen about the public concern over use of chemical weapons in Syria, when thousands of Syrians were already being murdered by their leader using conventional means. How is it that those deaths are less meaningful, less awful, than the ones caused by chemical weapons?

Nuclear weapons obtained the same or better results with far less cost in personnel and materiel. They were efficient and effective at doing some very dirty business, but given the events of the World War II years, maybe nukes didn't seem that bad in comparison to what had gone before. The deaths of non-military non-combatants did not seem unduly unfair when measured against the treatment meted out against such populations by the enemy in Asia and in Europe. Simply stated, the whole concept of nuclear

weapons did not seem unreasonable, even with what was then known about risks and effects, given what had been going on in the war.

The problem with talking about cost is that “capabilities cost whatever they cost.”¹² The truth about cuts in numbers of nuclear weapons and the work of Stockpile Stewardship is that while the overall numbers of weapons go down, the costs of the science and engineering needed to maintain the existing weapons do not decline noticeably and probably increase over time.

Whether the nuclear weapons stockpile consists of the four original bombs, the 20,000 plus that existed at the height of the Cold War, or the 1,550 weapons the United States has agreed to retain under the New START Treaty, capabilities to maintain those weapons do not change in cost. The cost of maintaining the weapons per unit goes up but, to repeat, the costs of the kinds of capabilities that must be in place to maintain the weapons do not decline much, if at all, as the size of the stockpile is reduced.

It may be that those who oppose this program believe that public dollars would be better spent in other ways. That is not an argument this study can assess. As was stated early on, the decisions to move toward nuclear weapons were made long ago. The present decisions have to do with how best to move ahead, given the realities of today’s world.

An example of how urgency led to gains is, once again, the space program. Sputnik propelled the United States to the moon and beyond as part of the Cold War. Today, NASA is not driven by the threat of a competitor nation. Budgets and a sense of purpose are lagging for NASA.

The nuclear weapons program is also not threatened by a peer competitor such as the Soviet Union was during the Cold War. The United States is not under the gun in a nuclear arms race today. But there is a race against time to keep the leading edge of nuclear knowledge in the United States.

Even in a post-Cold War world, where the United States is arguably the only superpower, the United States cannot afford to have any other nation know more than it does about nuclear weapons, nuclear forensics, treaty verification, and related science and technologies. The only way to be sure the United States always has that knowledge is to be sure that U.S. nuclear experts know everything necessary and possible to know about the country’s nuclear stockpile.

The Stockpile Stewardship Program can continue to bolster our intellectual achievements and contribute to economic growth and security, as it has been doing for some twenty years.

Notes

1. The Schlesinger Award is a DOE award named for James Schlesinger, the first Secretary of Energy.
2. A petaflop is a measure of computing speed and equals a thousand trillion floating point operations per second.
3. Richard Rhodes, *The Making of the Atomic Bomb*, (New York: Simon and Shuster, 1986), 28.
4. Ibid., 23-25.
5. Mary Dixon, *Felix Frankfurter: A Study in Contrasts*, (Washington D.C.: Georgetown University, 2012), 79.
6. Rhodes, *Atomic Bomb*, 28.
7. Ibid., 12.
8. U.S. Rep. Robert W. Kastenmeier (D-WI), conversation with author, Washington, D.C., ca. 1989.
9. *The Costs of the Manhattan Project*, historical project page, On-line, Internet, 8 July 2013, available from <http://www.brookings.edu/about/projects/archive/nucweapons/manhattan>.
10. Ibid.
11. Richard Rhodes, *Dark Sun*, (New York: Simon and Shuster, 1995), 17.
12. General Larry Welch, former U.S. Air Force Chief of Staff and former USSTRATCOM commander, remarks at SW21 Conference, January 2013.

CHAPTER 2

Background

After the Manhattan Project but before Stockpile Stewardship, there was a nuclear weapons program that included facilities from coast to coast made up of design laboratories, engineering laboratories, industrial capabilities, production plants, and nuclear testing locations. Not only was the complex widely dispersed geographically – for security and safety concerns facilities were often originally remotely located – but also the locations were no doubt in part aimed to please congressional funders across the nation. Over time, these locations became less remote, as workers settled nearby and communities grew up around facilities.

When testing was above ground at the Nevada Test Site (NTS) (later renamed the National Nuclear Security Site (NNSS)) (hereafter referred to as NNSS/NTS), mushroom clouds could sometimes be seen sixty-five miles away in Las Vegas, but after testing went underground, it was almost as if the entire enterprise disappeared from view.

There were still the routine anti-nuclear protesters outside the NNSS/NTS entry, other locations associated with the program, and around the White House. There were still news stories and opinion columns about the possibility of nuclear war between the United States and USSR. There was the Cuban missile crisis. There were other, less frightening confrontations. There were signs directing people to basements in emergencies. There were underground home fallout shelters being constructed in back yards across the country. There was evidence that the Strategic Air Command was on the scene with a nuclear mission. There was a general understanding that something called MAD (mutually assured destruction) existed. After above ground testing ceased, however, these were the only daily reminders of the Cold War in progress and the existence of a nuclear weapons program that included underground nuclear testing.

The laboratories and plants of the Atomic Energy Commission, signed into law by President Harry S Truman in 1946, were numerous and widespread; most were part of the nuclear weapons program but some focused on other defense or civilian research. There were thirty-four laboratories and seventeen production, development, and fabrication plants.¹ From Pinellas in Florida, to Hanford in Washington State, to Mound in Ohio, to Pantex in Texas, and Paducah, Kentucky there were more than thirty laboratories and production facilities that contributed materials, parts, and expertise to the Cold War nuclear program.

As the stockpile numbers began to be reduced, after Rocky Flats (Colorado) was closed down, after the Berlin Wall fell, signaling the end of the Cold War, those facilities were being phased out. By the time that Stockpile Stewardship came along, the nuclear weapons complex consisted of three laboratories: Los Alamos, Lawrence Livermore, and Sandia National Laboratories; plants at Kansas City (Missouri), Pantex (Texas), Y-12 at Oak Ridge (Tennessee), the Savannah River Site (South Carolina), and the NNSS/NTS.

Since the first nuclear weapons were designed and built by the Manhattan Project, there have always been questions. Those questions focused on expectations, effectiveness, and safety:

- Will it work?
- Will it work as expected?
- How effective is this design?
- Will it go exactly where it is expected to go?
- How safe is the weapon when not needed?

The answers to these and other questions have been ascertained in a variety of ways over the half-century of the nuclear weapons program. Central to every answer to every question was the issue of confidence. Confidence was never defined by one measure of proof – let me repeat – confidence was never defined by only one measure of proof. Confidence was always partly based on the expert judgment of experienced scientists and engineers, i.e., confidence of the artisans in the artisanal product. It was something that went beyond testing, beyond physics, beyond engineering. It represented the judgment of highly trained, educated, and

experienced teams. It was truly an artisanal approach to confidence. That was true when weapons were tested – it remains true with Stockpile Stewardship.

Since 1958, warhead/bomb reliability has always, in part, been determined through the Stockpile Evaluation Program. Typically, several random samples of each weapon type are taken from the stockpile each year. These samples are partially disassembled and inspected prior to being subjected to various types of tests. The non-nuclear components are given system level testing or flight testing. Generally, one nuclear explosive package has been destroyed as part of an examination for dimension and material composition changes. This sample is then retired from the stockpile. The remaining ten samples, along with non-nuclear components, might be reused, replaced, or reassembled with the nuclear explosive package, and returned to the stockpile.

The sampling rate provides a ninety percent confidence that within two years, a defect affecting the ability to function of ten percent or more of the weapons of a given type will be found, if it falls within the scope of this program of evaluation.

Underground nuclear tests were never part of the formal Stockpile Evaluation Program. If that was the case, what was the role of nuclear testing? The United States has not conducted a sufficient number of nuclear tests for any one weapon type to provide a statistical assessment of reliability for nuclear explosive performance.

- Nuclear tests were important in maintaining the safety and reliability of stockpile weapons.
- Nuclear tests were important in development of new weapon designs. Tests that dealt with elements of the new designs were also used to eliminate potential safety problems. In some cases, nuclear testing during development of one weapon type uncovered a problem that was pertinent to a previous design already in the stockpile.
- Nuclear tests identified certain classes of stockpile problems not observable in the surveillance program, such as whether a particular corrosion problem might affect yield.

- Nuclear tests have been used to verify the efficacy of design changes. For example, the adequacy of certain mechanical safety techniques was determined with nuclear testing. In the case of a catastrophic defect, nuclear tests have been used to certify totally new designs to replace an existing design. And in some cases, nuclear testing proved that a potential problem was not significant, thus obviating the need for an expensive fix.

A series of formal Stockpile Confidence Tests was initiated in the 1970's. They were different from weapon development tests in that the weapon had come off the actual production line, most often had experienced stockpile conditions, and had minimal changes made to either nuclear or non-nuclear components prior to the test.

Of more than 1,000 U.S. nuclear tests, seventeen were Stockpile Confidence Tests conducted on war reserve units that had been through the military and returned to DOE, or were fresh from the production line before being sent to the military.

Four additional tests were on assemblies close to war reserve configuration.

At least fifty-one tests were on significant war reserve component configurations, including primaries and secondaries.² These tests had objectives that included weapon effects, weapon R&D, confirmation of a fix or investigation of safety or reliability.

Three of these tests revealed or confirmed a problem that required corrective action.

Four tests confirmed a fix to an identified problem.

Five tests were performed to provide additional data on the one-point safety properties of three different warhead types and they confirmed that a problem did not exist.

During the nuclear testing program years, there was no requirement that the stockpile be annually certified to the President.

Weapons were constantly being developed and replaced in the stockpile. There was no need to ensure that weapons would continue to be safe, secure, and reliable/effective far beyond their design lifetimes because they were never going to be in the stockpile long enough to reach that date. There was little need to be concerned about the effect of a problem affecting a "batch" of weapons in a large stockpile because such a

problem would pose fewer negative consequences than the same problem in a more limited stockpile.

Certainly, a nuclear test was a very dramatic demonstration. But it was only one element in making a decision about whether any given weapon system would be safe and reliable because even in the days of testing, confidence was ultimately a subjective judgment based on a variety of factors.

Even during design and testing days there were experiments in materials science, hydrodynamics, and high energy density physics using X-rays, lasers and other sophisticated equipment as well as computational capabilities. There was surveillance of weapons drawn from the stockpile. There were computer codes. There were flight and non-nuclear system tests. But the tools of those times were much less sophisticated than those developed for the 21st century Stockpile Stewardship Program.

There was the expertise and judgment of people who had been part of the program and had in-depth experience with underground nuclear testing regimes and the experimental program. There was data from previous underground tests.

Confidence was based on limited knowledge, statistical significance, and dramatic demonstration. But that confidence in the safety, security, and reliability of existing and newly designed and produced nuclear weapons came from analysis and judgment of all the different kinds of work being done, not just from underground testing.

With nuclear testing there was a solid understanding of “how” to make a nuclear weapon from scratch. The United States was in the Cold War arms race. New weapons were being developed and the stockpile was turned over with new weapons coming in every few years. Weapons rarely stayed in the stockpile for the entire length of the design lifespan, let alone beyond. In a time when new weapons were being designed and an adequate production complex existed to produce required numbers of any given weapon type, that was all that was needed.

The constant changing out and updating of the stockpile was a function of requirements from the military and advances in nuclear weapons technologies.

In other words, the triad of air, land, and sea delivery methods dictated what the weapons designers worked toward. Bombs couldn’t be too large and heavy or the airplanes couldn’t haul them. Warheads had to

fit on an ICBM, a missile, or inside a nuclear submarine. These constraints dictated what types of advances in technology nuclear designers were working toward. Smaller, lighter, and more compact without sacrificing capability to hold targets at risk were the goals.

Targeting was, and remains, a military responsibility, but targets tell designers what a given weapon must be able to defeat.

Nuclear weapons were not in the inventory long enough for any questions to arise regarding the age of components and materials.

With nuclear testing, there was a broad understanding that designs and various features of nuclear weapons did work, but there was less direct knowledge of why and how things worked. Thus, it was necessary to be updating the stockpile with new designs and new models to be sure they would function properly within their design lifespan and then to replace them.

All of that came to a halt with the shutdown of Rocky Flats in 1989 and with the institution of the testing moratorium by President George H.W. Bush in 1992. In 1995 when the French announced a return to nuclear testing for a series of tests in the Pacific that would then be followed by adherence to a zero yield Comprehensive Test Ban Treaty (CTBT), President Bill Clinton announced that the United States would also abide by the zero-yield standard.³

Clinton's submission of the CTBT to the Senate for ratification, however, rested on several safeguards.

Safeguard A: The conduct of a Science Based Stockpile Stewardship program to ensure a high level of confidence in the safety and reliability of nuclear weapons in the active stockpile, including the conduct of a broad range of effective and continuing experimental programs.

Safeguard B: The maintenance of modern nuclear laboratory facilities and programs in theoretical and exploratory nuclear technology which will attract, retain, and ensure the continued application of our human scientific resources to those programs on which continued progress in nuclear technology depends.

Safeguard C: The maintenance of the basic capability to resume nuclear test activities prohibited by the CTBT

should the United States cease to be bound to adhere to this treaty.

Safeguard D: Continuation of a comprehensive research and development program to improve our treaty monitoring capabilities and operations.

Safeguard E: The continuing development of a broad range of intelligence gathering and analytical capabilities and operations to ensure accurate and comprehensive information on worldwide nuclear arsenals, nuclear weapons development programs, and related nuclear programs.

Safeguard F: The understanding that if the President of the United States is informed by the Secretary of Defense and the Secretary of Energy (DOE) – advised by the Nuclear Weapons Council, the Directors of DOE’s nuclear weapons laboratories and the Commander of the U.S. Strategic Command – that a high level of confidence in the safety or reliability of a nuclear weapon type which the two Secretaries consider to be critical to our nuclear deterrent could no longer be certified, the President, in consultation with Congress, would be prepared to withdraw from the CTBT under the standard “supreme national interests” clause in order to conduct whatever testing might be required.⁴

With Stockpile Stewardship, there would be broad and deep understanding of the physics and engineering of nuclear weapons and an elegant environment in which to make and keep them viable for an indefinite period of time, but without having to design and build new weapons and without having to test them.

Testing and Stockpile Stewardship have never been and were never meant to be the same program by any means, but a natural congruence exists between them and a compatibility with the ultimate goal – to maintain the safety, security, and reliability of our nation’s nuclear deterrent.

Notes

1. Alice Buck, *The Atomic Energy Commission*, (Washington, D.C.: U.S. Department of Energy), 36-38.
2. NOTE: A modern nuclear weapon consists of a primary stage and a secondary stage.
3. Victor H. Reis, *Personal papers*, "A Personal Perspective on the Stockpile Stewardship Program Strategy," 20 April 2010, 1-5.
4. Ibid., 1-5.

CHAPTER 3

Stockpile Stewardship

World War II and the Cold War provided the urgency behind the Manhattan Project and the nuclear arms race. It is difficult for anyone with no memory of those days as a child or as an adult to understand exactly how scary the world often looked to American eyes in those times. The PBS television series *Foyle's War* provides glimpses of how, coming victorious out of World War II, England confronted new fears and moved directly into what could be termed the paranoia of a shadow war, the Cold War.

When the Cold War ended with the fall of the USSR, a different sense of urgency arose about the disposition and care of the existing nuclear weapons. That urgency which manifested itself in the desire to sign onto a Comprehensive Test Ban Treaty drove creation of the Stockpile Stewardship Program.

Stockpile Stewardship is a one-of-a-kind endeavor. It is responsible for a product that everyone hopes will never be used. It is artisanal in the same way that the Manhattan Project and Apollo moon program were: providing innovative, highly crafted approaches to something new under the sun with no margin for error. To quote retired Air Force General Frank Klotz and Obama nominee to be Undersecretary of Energy for Nuclear Security at his September 19, 2013, confirmation hearing, "...there needs to be scientific work and an awful lot of tough labor to ensure that those nuclear weapons that we retain are still fully safe, fully secure, and fully effective."

No new nuclear weapons are being made, but the existing inventory must be maintained in tiptop working order. Current models that were designed for a limited life span must be maintained until further notice without total system testing. At the same time preparations must be in place to return to design, production, and testing if directed to do so by the President.

Every year, success on the job must be reported to the President as per the following from a State Department 2012 Fact Sheet, “Annual Assessment of the U.S. Nuclear Weapons Stockpile”:

In 1995, President Clinton established an annual reporting and certification requirement that ensures the nation’s nuclear weapons remain safe and reliable without underground nuclear explosive testing. [The requirement for annual stockpile assessments was made law in Section 3141 of the National Defense Authorization Act for Fiscal Year 2003.]¹

The Directors of the three DOE nuclear weapons laboratories (Los Alamos (LANL), Lawrence Livermore (LLNL) and Sandia National Laboratories (SNL)] are required to complete annual assessments of the safety, reliability, and performance of each weapon type in the nuclear weapons stockpile. In addition, the Commander of U.S. Strategic Command provides an assessment of the military effectiveness of the stockpile. These assessments also include a determination as to whether it is necessary to conduct an underground nuclear test to resolve any identified issues. The Secretaries of Energy and Defense are required to submit these reports unaltered to the President, along with any conclusions the Secretaries consider appropriate.

Program responsibilities and capabilities are often the focus of heated, emotional public debate and occupy a unique position in the formulation of foreign and defense policy. What exactly is Stockpile Stewardship and how did it get started? The man who led the formulation and implementation of SSP, Dr. Reis, recalled as follows:

- There was a specific time urgent vision elucidated by the President of the United States (Bill Clinton) on an important international issue.
- That vision was transformed into a Department of Energy (DOE)

program with goals and a schedule that fit DOE expert skills; it was a very difficult “big science and simulation” challenge.

- We created an aligned and complete DOE team of government, laboratory, industrial and academic players that strongly (obsessively) focused on the program.
- The DOE owned the assets and could “lead” the interagency (process).
- There was sufficient, sustained funding and bipartisan political support.
- Dr. Reis called SSP “as hard to do, or maybe harder to do” than the Manhattan Project.²

Presidential questions/taskings for Reis, who was nominated to be Assistant Secretary for Defense Programs in the Department of Energy, came from the situation at hand. A testing moratorium was in force. There was a desire to move the United States toward signature and ratification of a Comprehensive Test Ban Treaty.

The testing moratorium was put in place (1992) before nuclear weapons scientists and engineers had time to execute a planned test. That test was eventually cancelled, leaving cables for diagnostics still trailing on the ground from abandoned trailers to the hole where the test device would have been placed for detonation.

There had been some discussion about whether the testing moratorium might be temporary or what making the moratorium permanent might mean. There was the Hatfield Amendment passed in 1992 for a one-year testing moratorium to be followed by a resumption of testing for a limited time period with limited objectives. There was a need to think in-depth about what might be needed in terms of additional diagnostics if a small number of further nuclear tests would be allowed as final tests before a test ban treaty went into effect. The following questions arose:

- How many nuclear tests should the nation carry out (before ending the testing program entirely)?
- Should the Clinton Administration support a CTBT?³

Considerable difference of opinion existed about whether more tests should be conducted and how many. President Clinton ended that debate in a radio address on July 3, 1993, when he said:

I have therefore decided to extend the current moratorium on United States nuclear testing at least through September of next year (1994). I therefore expect the (DOE) to maintain a capability to resume testing. To assure that our nuclear deterrent remains unquestioned under a test ban, we will explore other means of maintaining our confidence in the safety, reliability, and the performance of our own weapons.⁴

Dr. Reis was confirmed as Assistant Secretary of Energy for Defense Programs in August 1993. His career had not been in the nuclear weapons program, although he had served as chair of the Nuclear Weapons Council and had served with line responsibility for the Defense Nuclear Agency and as the Assistant to the Secretary of Defense for Atomic Energy. He had also headed up both the Department of Defense Research and Engineering Enterprise (DDRE) and the Defense Advanced Research Projects Agency (DARPA). He was, and is, a rare combination of a person with vision, technical knowledge, and a well-developed understanding of how politics and policy work in Washington.

The Department of Defense (DoD) establishes the military requirements for nuclear weapons such as what kind of targets they must be able to destroy and what delivery vehicles will carry them. Those requirements must be presidentially approved. The DoD is also responsible for development and operation of complete weapon systems, personnel training, and maintenance of nuclear employment (use) plans. This means that delivery systems such as submarine launched missiles, intercontinental ballistic missiles that are housed in land-based silos, and aircraft that can deliver nuclear weapons are all part of the DoD responsibility.

The DOE has responsibility for the conduct of nuclear weapons research and development of nuclear warheads; production of nuclear warheads; surveillance of the stockpile; management of nuclear materials; dismantlement of retired weapons; maintenance of critical capabilities across the weapons complex made up of the national laboratories,

production plants, and the NNSS/NTS; conduct of subcritical and other experiments; and advanced simulation capabilities in support of SSP.⁵

Currently, the nuclear weapons complex consists of the following:

Laboratories	Plants and Test Sites
Lawrence Livermore National Laboratory (LLNL)	Kansas City Plant (KCP)
Los Alamos National Laboratory (LANL)	Pantex Plant (PTX)
Sandia National Laboratories (SNL)	Savannah River Site (SRS)
	Y-12 (Y-12)
	Nevada National Security Site/Nevada Test Site (NNSS/NTS)

Under Stockpile Stewardship, DOE and DoD share responsibility for the identification and resolution of health and safety problems connected with stockpile weapons and for the prevention of unauthorized use of nuclear weapons. Positive controls to restrict weapon use and physical security for the weapons are included under this requirement.⁶

The requirements that Stockpile Stewardship had to meet were originally laid out in the 1994 Nuclear Posture Review (NPR) as developed by the weapons program customer, the Department of Defense. The NPR recognized the challenge of maintaining high confidence in the stockpile. The NPR assumed that there would be no nuclear testing or fissile material production in the future. The NPR further stated that the DOE was to do the following:

- Maintain the capability to design, fabricate, and certify new warheads.
- Develop a stockpile surveillance engineering base.
- Demonstrate a capability to refabricate and certify weapon types in the stockpile.
- Maintain a nuclear weapons science and technology base.
- Ensure tritium availability.⁷

Stockpile Stewardship would have to include operations associated with manufacturing, maintaining, refurbishing, assessing, surveillance, and dismantlement of the nuclear weapons stockpile; the activities associated with the research, design, development, simulation, modeling, and non-nuclear testing of nuclear weapons components; and the assessment of safety, reliability, and certification of the stockpile.⁸

In the past, nuclear testing and the continuous development and production of new nuclear weapons were essential elements for preserving high confidence in the stockpile. With the imposition of the testing moratorium, however, improved experimental capabilities combined with advanced simulation and surveillance tools would guide the path forward.

With the end of designing, building, and testing new nuclear weapons, a program that was always somewhat artisanal in nature became decidedly more so.

To illustrate more simply the artisanal nature of Stockpile Stewardship, artisanal cheese comes to mind by way of comparison. Hundreds of cheeses of one kind may be produced over time. There may be several types of cheeses produced. But artisanal cheese is never mass-produced. It is crafted with great care by individuals with expertise and experience working in teams.

The basic processes are labor-intensive, requiring experience, education, training, and time. Before the older generation of cheese makers retires, they must recruit and train the next generation of cheese makers transferring to them all of the tips and techniques of artisanal cheese production developed over the years.

Cheese making is a delicate kind of work that does not entirely depend on following instructions written down in a recipe. With cheese making experience there comes subtle subjective knowledge that helps an artisan to know when things are going right and when they are not. Of course, with cheese ultimately there is a test – a taste test.

The story of Myron Knapp and the pork ribs, which came from Bruce T. Goodwin of Livermore, makes clear how artisanal the weapons program always was. Bruce was the Associate Director for Weapons Complex Integration for many years at Livermore and is now Associate Director-at-Large, National Security Policy & Research and Director, Center for Global Security Research. Myron Knapp was the father of the interim director of Livermore lab as of November 1, 2013, Brett Knapp, as

if to illustrate the generational and sometimes familial nature of the program. Bruce states:

Myron Knapp was a leading engineer in the development of innovative very small primaries (the first stage of a modern nuclear weapon) invented by the young Johnny Foster (a storied nuclear scientist and former LLNL director) during the mid-1950's. Computation was primitive at the time and so issues of nuclear criticality (whether a chain reaction could be successfully created) had to be determined experimentally. Myron was worried that the water in a human hand might be enough to moderate the components of the new design and cause a criticality event during hand assembly. He very cleverly did a simple, safe experiment to verify that this would not be a problem by buying a few pounds of pork ribs at the butcher shop and then placed the ribs on the components to be assembled, "one finger's worth" at a time while monitoring criticality signals carefully. After having placed many times the amount of human hand equivalent pork ribs on the components, step by step, he demonstrated that there was no danger in assembling the parts by hand and so the devices could be put together safely by the technicians.⁹

In August 1995, the Knowledge Preservation Project to capture these and other kinds of personal knowledge and experience was the subject of a *Los Angeles Times* article by Ralph Vartabedian, a reporter who has covered the weapons complex for many years:

The black art of nuclear weaponry – handed down from scientist to scientist since World War II – would be lost to history without the archive, leaving the nation unable to maintain in 10 or 20 years its powerful stockpile of nuclear weapons or to restart nuclear arms production...We don't want to push the erase button on our memory and go back to where we were 50 years ago...You have to have the intellectual capability to respond to future developments.

This lets our adversaries know that we still know what to do.¹⁰

Even in the days of Cold War design/testing, nuclear weaponry was not simply a matter of physics and engineering formulas, and it was not a situation where massive numbers of a single weapon were mass produced. While eventually during those years there might be a total of tens of thousands of nuclear weapons in the stockpile, the numbers of any given model or type were not massive. They were changed out of the stockpile frequently as well. New military requirements led to new designs. Older models or types were retired long before their “sell by dates” arrived.

Development of new weapons always involved many small, lesser processes and tests, but underground testing was always there to confirm that the work was on track. Various subtleties became familiar to those who spent careers creating these delicate, stunningly complex, and advanced weapons.

Under SSP, this knowledge, this ability to sense subtleties, to know when something might be wrong, or if things were on track must be passed on to a new generation, this time without benefit of the final proof test that was once available. In the absence of underground testing and as the weapons age, the questions have been and still are the following: how long before the parts and materials that make the weapon what it is change to the point beyond which the weapon can no longer meet the military requirement; and how to address those looming changes before they disable a weapon system.

Scientists and engineers knew that there were limited life components that would have to be replaced at intervals and that certain materials might not age well and would have to be replaced. What they did not know was exactly when and how those changes might occur. Nor was it known what might be suitable replacements for limited life components made years in the past for which the same materials and crafting processes were no longer available – so-called “sunset technologies.” Eventually, SSP was refined into three focus areas:

- **Directed Stockpile Work (DSW)** is work done on the weapons, such as current maintenance and day-to-day care of the stockpile, as well as planned refurbishments. This category also includes

research, development, and certification activities in direct support of each weapon system and long-term, future oriented research and development to solve either current or projected stockpile problems. LEPs, or life extension programs, done on the weapons comes under DSW.¹¹

- **Campaigns** focus on the science and engineering that underpins the work done on the weapons. They are focused scientific and technical efforts to develop and maintain critical capabilities needed to enable continued certification of the stockpile for the long term. Campaigns are technically challenging, multi-function efforts that have definitive milestones, specific work plans, and specific end dates. The campaign approach was begun during the 1990s as part of planning and executing the new stewardship program, with the following examples:
 - Enhanced Surveillance Campaign to identify precursors of aging-related defects that could affect warhead safety or reliability.
 - Primary Certification Campaign to be able to qualify and continue certification of rebuilt and aged weapon primaries [Modern nuclear weapons all have a primary stage and a secondary stage.]
 - Secondary Certification and Nuclear Systems Margins Campaign to determine the minimum primary performance needed to produce a militarily effective weapon for each system in the stockpile.
 - Certification in Hostile Environments Campaign to deal with weapon survival in various environments by using radiation-hardened technologies.
 - Inertial Confinement Fusion (ICF) and High Yield Campaign to validate codes from testing days in the absence of the ability to test.
 - Pit Readiness Campaign to reconstitute the ability to produce a limited number of pits that could be certified for use in the stockpile.

- Non-nuclear Readiness Campaign to deal with how best to replace outdated non-nuclear components that make up some 80 percent of a weapon and to do so at lower cost.
- Enhanced Surety Campaign to provide the most modern safety, security, and use controls for nuclear weapons that remain in the stockpile.

Integrating the work from campaigns and directed stockpile work with archived nuclear testing data would be the supercomputing capabilities that would come from the Accelerated Strategic Computing Initiative (ASCI).¹²

- **Readiness in Technical Base and Facilities (RTBF)** deals with keeping plant, lab, and test site infrastructure in operating condition and updated. RTBF includes ensuring that facilities are operational, safe, secure, in compliance with standards, and sustaining a defined level of readiness. No weapons work or other activities can take place unless infrastructure is in place and ready for business, providing a modern, appropriately equipped workplace with modern safety measures.¹³

To understand the scope of the nuclear weapons complex infrastructure that would need to be either preserved, and updated, put into cold storage, or otherwise decontaminated and decommissioned, consider that at the NNSS/NTS the infrastructure left from nuclear testing days included the following:

- 700 miles of copper and fiber optic communications lines
- 14 communications sites
- 532 miles of power lines
- 214 distribution substations/transformers
- 11 transmission substations and switching stations
- 340 miles of maintained paved roads
- 300 miles of maintained unpaved roads

- 160 miles of underground water distribution pipeline
- 26 water storage tanks
- 10 producing water wells
- 10 booster pump stations
- 11 pressure reducing stations
- 6 heliports
- 2 airstrip
- 7000 buildings (2.6 million square feet)¹⁴

At Los Alamos National Laboratory, the infrastructure included:

- 43 square miles of land
- 2000 buildings (approximately 8 million square feet)
- 85 miles of paved roads
- 22 miles of unpaved roads
- 19 miles of steam and condensate lines
- 36,000 drains
- 30 miles of 115kV power transmission lines
- 120 miles of gas transmission lines
- 59 cooling towers
- 260,000 light fixtures
- 54 miles of sewage collection lines
- 39 water storage tanks (capacity of 41 million gallons)¹⁵

Facilities built during World War II for the Manhattan Project had often not been updated or upgraded since then, while safety and security standards had increased. A new replacement facility at the NNSS/NTS, built at the end of the testing era, and repurposed for SSP, came under fire as being costly and lacking a mission. The 100,000 square foot (9,000 square meter) Device Assembly Facility (DAF) was originally designed to

serve as the location for assembly, disassembly, and characterization operations for experimental nuclear test devices and nuclear weapons for the United States underground nuclear test program.¹⁶

The DAF was constructed in response to Congressional and Departmental concerns regarding the safety and security of nuclear explosive operations that were being conducted at the Area 27 facilities on the NTS. It was designed to address those concerns by incorporating modern safety features to protect workers and advanced security to prevent unauthorized access to nuclear explosives.¹⁷

The DAF has always had a mission. Today the original mission of supporting nuclear tests has since been modified, to conform with the Comprehensive Test Ban Treaty, as the United States no longer conducts underground nuclear tests. The present missions support Stockpile Stewardship: readiness to provide a staging area for test assemblies in the event that the President directs the resumption of underground testing; disassembly and associated operations on a damaged nuclear weapon or unauthorized nuclear explosive device; assembly of non-nuclear explosive test devices for use in the subcritical experiments planned at the NNSS/NTS and for certain stockpile surveillance operations.¹⁸

Each of the three categories – DSW, campaigns, and RTBF – covered work at all of the weapons laboratories, the plants, and the NNSS/NTS, as well as work done at other major research facilities.¹⁹

Eventually, the campaigns morphed into broader categories of science, engineering, inertial confinement fusion, ASCI, pit manufacturing/certification, and readiness.²⁰

Basics of a Nuclear Weapon

A nuclear weapon has about 6,500 parts. More than 90 percent of those parts are non-nuclear. That means that about 90 percent of the 6,500 parts can still be tested exactly as they always have been throughout the history of the weapons program – and because of concerns about the effects of aging, more modern, more in-depth methods are needed to study those parts and to replace them as needed. The basic parts of a modern nuclear weapon are:

- Primary (Pit) (fission trigger for secondary)

- Secondary (fusion/fission)
- Neutron generators (starter)
- Tritium (turbo)
- Non-nuclear parts – more than 90 percent of weapon – gears, safety measures, electronics, explosives²¹

The enduring stockpile is not static and SSP scientists and engineers were prepared for certain kinds of problems such as:

- Limited life component exchanges – such as tritium replacement.
- Defect discovery – were there pre-existing problems not previously discovered, or new problems that appeared over time?
- Weapons and component aging – what would occur to materials over time?
- Spare part inventory depletion – parts would continue to be destroyed as part of the assessment process. Would that cause inventories to run too low?
- Conformance to military characteristics and surety requirements – would the weapons still perform according to military requirements and would there be new safety or security issues to arise?
- New or modified requirements – what about new military requirements? Could they be met with existing weapons?²²

Facilities and capabilities that support SSP

In the case of experimental facilities such as the National Ignition Facility (NIF), the Dual Axis Radiographic Hydrodynamic Facility (DARHT), and the subcritical experiments, the ability to see and understand weapons behavior has been far superior to any type of experimental studies and analysis that could be done in the past. The scientific knowledge gained exceeds anything that was possible from diagnostics and experiments performed during the underground nuclear testing era. Each of the three laboratories would have new experimental

and engineering responsibilities. New facilities would be associated with those responsibilities.

The NIF in California at Lawrence Livermore National Laboratory is the world's largest, most powerful laser assembly and is able to reproduce for the first time in a laboratory setting, conditions of temperature and pressure found only on the sun, or inside a detonating nuclear weapon. No comparable diagnostic exists from the past history of the weapons program: NIF can look at boost and the secondary, or nuclear fusion, portion of the detonation, and assist in validation of other experimental and computational studies.²³

The DARHT in New Mexico at Los Alamos National Laboratory is an extremely advanced X-ray machine that allows scientists to look at what happens when a mock nuclear weapon primary implodes with levels of clarity, detail, and depth never before possible in the weapons program. DARHT is part of the hydrodynamic science needed to examine the primary phase of detonation.²⁴

Advanced Simulation and Computing (ASC) – (formerly the Accelerated Strategic Computing Initiative (ASCI), hereafter referred to as ASC/ASCI) (all three labs) – Stockpile Stewardship has set the gold standard for computing in the 21st century. The computers use experimental data from the subcritical experiments, NIF, DARHT, and other non-nuclear tests, surveillance activities, and experiments, combined with archived data from United States nuclear tests, in simulations that assess and certify the safety and reliability of the nuclear weapons stockpile without further nuclear testing. ASC/ASCI integrates the information, allowing modeling and simulation of the explosion and assists in validating experimental information.²⁵

Microsystems & Engineering Sciences Applications (MESA) at Sandia National Laboratories) – Sandia is the engineering lab for SSP and must develop and design the electronic non-nuclear systems that operate nuclear warheads. The MESA facility “combines the most advanced design and simulation tools with the most advanced micro systems and nano-technologies.”²⁶ MESA is where microsystems for SSP and other national security tasks can be made in small quantities and/or under stringent security requirements.²⁷

How Exactly Does SSP work?

Each year random samples of each type of weapon are returned from the active force and are disassembled, examined, tested, and analyzed for defects. As defects are found, their effect on reliability and safety is assessed. Some parts, for example, neutron generators and gas reservoirs, require replacement at regular intervals, as limited life components. Plans are made based on what is found to decide on changes needed based on changes observed in the weapons.²⁸

Other parts of a nuclear weapon are made from radioactive materials that decay and as they decay both their own properties and the properties of other materials within the weapon may change and affect the safety, security, and reliability of the weapon. Tritium is an example of such material. Tritium decays at a rate of 5.5 percent per year. This means that periodically it has to be replenished.

Remanufacturing replacement parts for nuclear weapons sounds simple enough, but since the time that the current weapons in the stockpile were originally manufactured, production plants have been closed and manufacturing processes, techniques, and standards have changed. There is more awareness of health and safety, and more concern about waste.²⁹

Today, replacement parts require even tighter production process controls than the extraordinarily rigid standards under which the original parts were designed and manufactured. A nuclear weapon that may be smaller than a small desk has enough explosive power to completely destroy a modern city, yet it must be able to survive extraordinary accidents with less than a one-in-a-million chance of exploding.³⁰

Industrial materials advancements and new manufacturing processes make it difficult, if not impossible, to get exact replacement parts. Yet the nuclear weapons program must produce replacement parts using modern materials and processes that will still maintain the safety and reliability of the weapons while certifying safety, security, and reliability without underground nuclear testing.³¹ As stockpile weapons continue to age, even more parts will require replacement. Because new warheads have not been produced since 1989, old weapons have not been replaced with new ones as they were in the past.

By 2010, most nuclear weapons designers with nuclear test experience had retired. This means that when the newest weapon system,

the W88, reaches the end of its original design life in 2014, there might not be anyone with the test-based job experience to help evaluate modifications required due to aging at that time. Successfully dealing with this kind of time factor has been critical to the success of the Stockpile Stewardship Program.³²

Instead of an underground nuclear test, the explosion sequence is conceptually divided into each of its parts; each of these is tested and analyzed separately. All of the data are put together into a computer calculation – a simulation – to see if the resulting performance falls within original performance specifications. Each part of the simulation must predict the results of each of the separate tests, and where the information exists, the results must be consistent with archived underground nuclear test data and research. A nuclear weapon detonates in the following sequence:

- high explosive detonation
- implosion in the primary
- fission burn of the primary
- boosted burn
- radiation flow to the secondary
- implosion in the secondary
- burn/explosion in the secondary
- effects
- yield³³

The supercomputer simulations are validated using the state of the art experimental tools of DARHT and NIF and other experiments done or observations made at the laboratories or plants or in Nevada. The grand challenge of Stockpile Stewardship, as well as the opportunity to develop these modern codes and experimental tools, also offers the way to attract and maintain a cadre of outstanding scientists and engineers.

THE SCIENCE

Experimental Programs

It is at the DOE's Los Alamos, Sandia, and Lawrence Livermore National Laboratories and at the NNSS/NTS that the science base of the Stockpile Stewardship Program is developed and applied. In the absence of nuclear testing, the physics of the explosive sequence is divided into each of its parts, and analyzed separately in the experimental program. Information from the production and surveillance activities, both past and present help to focus the experiments. Data from more than 1,000 United States nuclear tests also make clear what is not known and where there are knowledge gaps that can be addressed through experiment and observation. Thousands of experiments, large and small, are performed each year in support of Stockpile Stewardship.

With adequate tools, it is possible to do a thorough job of investigating the first part of the nuclear explosion; that is, the implosion of the plutonium pit by high explosive, with non-nuclear experiments. A number of important features can be measured by taking X-ray pictures during critical parts of the experiment. The time evolution of the implosion can be measured with arrays of contact sensors (called pins). These pictures and time histories can be compared with calculations and with previous data from the more than 1,000 underground nuclear tests and 14,000 surveillance tests.

During FY1999, for example, some 14 non-nuclear hydrotests were conducted at the Pulsed High Energy Radiographic Machine Emitting X-rays (PHERMEX) and related facilities at LANL, and about 15 tests at the Flash X-Ray (FXR) and B851 Site 300 facilities at LLNL.

In addition, there have been up to 1,000 less complex experiments per year aimed at preparing for larger tests and subcritical experiments, and for understanding high-explosives behavior and explosive effects on materials. A similar number of experiments have been conducted with major radiography shots, primarily at DARHT. Ultimately, better pictures are required at multiple times to certify rebuilt pits and 3-D simulations of weapon performance.

DARHT

DARHT, the massive, double-axis advanced X-ray facility, examines an imploding pit model from two different directions at greatly improved resolution. Although it might sound like something everyone has to walk through at the airport, the facility is far more delicate and sophisticated. DARHT actually makes freeze-frame high-powered X-ray images of materials as they are being imploded at more than 10,000 miles per hour. DARHT replaced an older machine at Los Alamos to provide the higher resolution images and information needed in the post nuclear testing environment.

As an example of the delicacy and power of DARHT, on the first axis, a five-centimeter cathode covered with velvet cloth is used. Velvet is used because the properties of the velvet nap make electron transmission more effective. On the second axis, the much more powerful cathode must be maintained typically at 1,150 degrees centigrade so that it can produce a 17-million-volt electron beam that lasts for 1.5 millionth of a second.³⁴

NIF

The Inertial Confinement Fusion (ICF) experimental program, in conjunction with the other stewardship campaigns, has moved ever closer to achieving ignition and has successfully addressed a number of stewardship issues at the NIF.

Think of something like a light saber from the film *Star Wars*. (In fact, the NIF has been used as a movie set background in one of the *Star Trek* films.) However, think of 192 light beams in a building the size of several football fields, rather than a single beam hand-held tool. The NIF is the world's most powerful laser, with 50 times more energy than any other laser on earth. Consisting of 192 laser beams, the NIF has been designed and built to produce, for the first time in a laboratory setting, conditions of matter close to those that occur in nuclear weapons. NIF is capable of compressing a tiny – about the size of a buckshot – capsule of hydrogen isotopes to pressures 100 billion times earth's atmosphere and at temperatures hotter than the center of the sun. Nuclear fusion occurs both in stars, such as the sun, and in nuclear weapons, and in short bursts in the tiny NIF target. When used with other data and advanced computational

capability, results from this work support assessment of the reliability of the nation's nuclear stockpile as it ages.

Civilian applications such as fusion energy research and astrophysics may also benefit from access to the NIF laser. The goal of ignition in NIF has been to attain a tiny controlled fusion reaction wherein output of energy would exceed input. Such a reaction would represent an unparalleled and unprecedented scientific achievement that would offer unique capability for SSP while providing a beginning to the development of fusion energy power.

Meanwhile, NIF provides unmatched input to SSP even without attaining ignition. Demonstrations of how aged or changed materials behave under these highly specialized conditions provide data essential to validate computer-based predictions. Challenges associated with bringing NIF online included demonstration of laser glass production; and development of coatings for the glass that would not sustain damage at the laser energy levels required for ignition. The NIF began operations that also marked the beginning of the ignition campaign in 2009.

Integration, schedule, and cost problems associated with the construction of the NIF were identified in 1999. Secretary of Energy Bill Richardson announced a series of actions to address these specific problems that had more to do with the experimental nature of the facility than with the underlying science. Because NIF was a "first ever" kind of facility, the materials and requirements involved had to be checked, rechecked, and adjusted as construction proceeded. One important challenge in the building of NIF was that construction had to be done in clean room conditions for a building the size of a sports arena. The time frame was extended because short term budgets would not allow for needed cost increases. In 2010, NIF won the Project Management Institute's Project of the Year Award recognizing "the accomplishments of a project team for superior performance, exemplary project management, execution, innovation..."³⁵

Subcritical experiments

One of the most "touch labor" intense experimental programs goes on in an existing underground facility at the NNSS/NTS. Known as subcritical experiments, because no sustained nuclear chain reaction or

“critical mass” is associated with them, they are small-scaled experiments to study the material properties of plutonium.

For the subcritical experiments sponsored by Lawrence Livermore National Laboratory, instead of a deep bore hole for an underground nuclear test, a series of underground clean rooms were built by LLNL scientists. Clean rooms are not exactly the usual kind of laboratory facility found underground, being more often associated with, for example, production of sensitive computer parts, but for LLNL subcritical experiments a clean room was needed. Los Alamos National Laboratory scientists and engineers built similarly small scaled capabilities in other rooms located nearby in the same underground facility.

The subcritical experiments are among the materials properties studies needed to understand detonation of the primary. They have provided a wealth of new information that is key to development of advanced 3D computer codes. The conduct of these experiments at the NNSS/NTS also supports twelve of the fourteen Nuclear Test Readiness functions required to be maintained in case the President ever directs that a nuclear test be performed again.

Subcritical experiments are very small-scaled efforts helping to fill in gaps in empirical data on the high pressure behavior of plutonium; realistically benchmarking data on the dynamic, non-nuclear behavior of components in today’s stockpile; analyzing the effects of remanufacturing techniques; understanding the effects of aging materials; and addressing other technical issues.

Information from these experiments has been key to qualifying the pit production capability at LANL, as well as certifying the performance of those weapons that will contain replacement pits. These experiments also contribute significantly to the maintenance of the critical infrastructure and educational base of skilled personnel at the NNSS/NTS. Besides addressing the effects of aging on plutonium, subcritical experiments are key to the test readiness program, a condition for United States adherence to the CTBT.³⁶

Advanced Simulation and Computing (ASC) formerly Accelerated Strategic Computing Initiative (ASCI)

Directed Stockpile Work includes assessments, surveillance, the crafting of replacement parts, and substitutions of alternative parts into the weapons. The science experimental program supports campaigns and DSW with science and engineering results providing data to supplement data from archived testing records.

What then pulls together all of the information that comes from DSW, the campaigns, and archived data? What is the integrating mechanism that allows the information to be used to certify the stockpile in the absence of an underground nuclear test?

The integrating mechanism for all of the information is computing. From the earliest days of nuclear weapons, some of the earliest, most rudimentary computers were used to make calculations and predictions. Some of those old computers are on view in the basement of the Smithsonian Institution's Museum of American History. When Stockpile Stewardship was under discussion and in the process of being created, it was clear to those involved in creating the program that the computing power and speed required would be prodigious. It was also true that such computing power and speed did not exist at that time.

At the same time, Stockpile Stewardship could never be a "simulation only" program. To maintain the United States world-class nuclear weapons program and provide data to the computers, results would come from hydrodynamic experiments and high energy density physics studies – the most advanced of which would be done at NIF – plus there would need to be micro-electronic systems engineering to verify computational results and provide more detailed data for programming the computers.

There are surveillance and manufacturing and life extension programs and archived data from the more than 1,000 nuclear tests. All of these things are vital to the program. No one element can get the job done. All are needed. Computing, however, has always been central to the requirement not to conduct nuclear tests.

Dr. Gilbert Weigand was asked by Dr. Reis to come from DARPA (Defense Advanced Research Projects Agency) to DOE to head up the ASC/ASCI program. His meetings at the nuclear weapons laboratories and with companies in the United States commercial computing industry

indicated that the requirement for computing power and speed to handle the types of problems involved would be about 100 teraFLOP/s or TeraOps. This was a factor of about 10,000 times more computing power than was available at the time SSP was getting underway. The goal was to reach the performance level of 100 teraflops by 2004 when at least some test experienced weapons designers would still be on the job.³⁷

The ASC/ASCI Program Plan of 1996 spelled out the vision and goals of the program. The vision was to “shift promptly from nuclear test based methods to computation based methods” and “create leading edge computational modeling and simulation capabilities.” To realize that vision ASC/ASCI would:

- Create virtual testing and prototyping capabilities based on advanced weapon codes and high-performance computing.
- Use predictive simulation based on experimental data, to assess and certify the safety, performance, and reliability of nuclear systems.
- Understand aging weapons, predict when components would have to be replaced, and evaluate the implications of changes in materials and fabrication processes to the design life of the aging weapon systems.³⁸

To meet SSP needs by the year 2010, ASC/ASCI would have to be able to solve ever more difficult problems as the weapons age and the date of the last underground tests moved further into the past. Applications would have to achieve higher resolution, higher fidelity, three-dimensional, full-physics, and full system modeling capabilities.³⁹

Additionally, SSP, relying heavily on ASC/ASCI, would have to respond to the loss of nuclear testing, deal with constraints on non-nuclear testing, and allow for the downsizing of production capabilities and the fact that no new weapons would be designed to replace aging weapons.⁴⁰

ASC/ASCI would also support the Stockpile Life Extension Program (SLEP) to predict what had to be done to replace limited life components that would need to be changed out over time.

ASC/ASCI had the following objectives:

- Performance: Create predictive simulations of nuclear weapon systems to analyze behavior and assess performance in an environment without nuclear testing.
- Safety: Predict with high certainty the behavior of full weapon systems in complex accident scenarios.
- Reliability: Achieve sufficient, validated predictive simulations to extend the lifetime of the stockpile, predict failure mechanisms, and reduce routine maintenance.
- Renewal: Use virtual prototyping and modeling to understand how new production processes and materials affect performance, safety, reliability, and aging issues.⁴¹

Strategies to accomplish this ambitious program were to create one computing program across the laboratories and plants that would focus on advanced applications, high end computing, and problem solving environments, and do this via strategic alliances and collaborations with industry and academia.⁴²

ASC/ASCI successfully developed the high-performance computational modeling and numerical simulation capabilities necessary to integrate theory, existing data, and new experimental data to predict results that could be verified and validated. The program, a collaborative effort between the U.S. Government, U.S. industry and academia brought the world's fastest, most powerful computational and advanced simulation and modeling capabilities to the SSP laboratories. These advanced supercomputers are used to fully implement science-based methods and to assess and certify the safety, security, and reliability of the stockpile, without underground nuclear testing.⁴³

Advanced computational capabilities that include application codes, computing platforms, and various tools and techniques, were developed at about twice the rate of commercial computing speed and power advances. ASC has been highly successful in meeting and beating milestones as well as providing new tools to support Stockpile Stewardship.

Information developed from other elements of SSP, such as NIF and the subcritical experiments, have continued to provide the basic physics models and data for ASC/ASCI simulations.⁴⁴

By the end of FY1998, ASC/ASCI unveiled its second generation of computing systems. Two major systems capable of running in excess of three trillion operations per second (3 TeraOps) peak speed were delivered ahead of schedule and within budget. Blue Pacific, developed by IBM, was located at LLNL, and Blue Mountain, developed by Silicon Graphics, Inc. (SGI), was located at LANL. These systems were each 15,000 times faster, with roughly 80,000 times the memory of the average personal desktop computer of that time. Under the Blue Pacific program, a world record 1.2 TeraOps was achieved on a hydrodynamics benchmark while a second benchmark run set a world record with 70.8 billion zones.⁴⁵

Earlier in 1998, DOE had announced the selection of IBM to partner with ASC/ASCI on the Option White 10 TeraOps supercomputer eventually to be located at LLNL. Building upon the experience and knowledge gained with the 3 TeraOps Blue Mountain system, LANL procured its own computational system that achieved a peak performance level of 30 TeraOps by mid-year 2001.⁴⁶

According to Secretary of Energy Federico Pena at the announcement, “to put this in context, we will be able to do in less than a day, all of the calculations that were performed at the weapons laboratories in the first fifty years of the nuclear weapons program.”⁴⁷

The Department’s first generation Option Red Intel computer system, installed at Sandia National Laboratories in 1996, was upgraded with faster processors and more memory to operate in production mode at a peak speed of more than 3 TeraOps.⁴⁸

The ASCI Defense Applications and Modeling Campaign completed the first three-dimensional simulation of a nuclear weapon primary explosion and compared the results with the data from an underground test. This calculation, an important first step toward simulating a complete nuclear weapon, was performed by LLNL during December 1999.⁴⁹

On the supercomputer, this calculation ran for more than 20 days. A desktop computer would have taken 30 years to accomplish the task. Modern nuclear weapons consist of two main components: the *primary*, or trigger, and the *secondary*, which produces most of the energy of a nuclear weapon. The ability to “see and understand” the action of the primary is a critically important step in simulating the entire weapon detonation in three dimensions.⁵⁰

Completion of the prototype ASC/ASCI burn code was the first of an ambitious series of mileposts required to achieve a high-fidelity simulation of a full nuclear weapon system by 2004. At the same time, other mileposts addressed the advanced physics and materials models required to achieve the highly accurate simulations needed in the absence of underground nuclear tests.⁵¹

Weapons designers used the new three-dimensional codes and the ASC/ASCI computer systems to support assessment of the stockpile. For example, they ran simulations to support the certifications of the B61 (bomb) modification and the W76 (warhead) neutron generator. These simulations would not have been possible without the capability provided by the computer platforms performing at the TeraOPs level. However, three-dimensional, high-fidelity simulation of a full weapon system and its performance, would require a minimum of 100 TeraOPs of computing capability.⁵²

Then-director of LANL, Dr. Siegfried Hecker, testified before Congress on March 12, 1996, that, “In general, future stockpile assessments will require three-dimensional calculations, which in turn need 1,000 times the computing memory and would take 100 years to perform on current machines.”⁵³

By 2005, ASC/ASCI had arrived at the point of success. In October 2005, the IBM 100 teraFLOP/s Purple system at LLNL was commissioned. The designation “TeraFLOP” versus teraOps and other iterations of the term had been used at various times, coming to rest in 2005 at teraFLOP/s. The acronym, however it is structured, stands for thousands of “floating point operations per second.”⁵⁴

Another landmark for ASC/ASCI in 2005 was that the program name and logo were officially changed. ASC/ASCI had become the Advanced Simulation and Computing program in 2002, so in 2005, to emphasize its evolving objectives a new logo was made up to go with the changed name.⁵⁵

The 100 teraFLOP/s goal was soon met and exceeded. A machine with possibly a more familiar name to many people was also installed at LLNL in 2005: the BlueGene/L. BlueGene/L “represented a new approach to high-performance architecture and used more than 131,000 low-power processors to deliver a peak of 360 teraFLOP/s.”⁵⁶ This, of course, was three times the speed and power originally described by Dr. Hecker as what was needed for SSP.

The real item of general interest about BlueGene/L might have been that this machine was designed to use “larger numbers of cheaper, simpler, and smaller components” to “reduce systems cost, size, and energy consumption” while increasing computing power at the same time.⁵⁷

Not only was BlueGene/L meeting program goals, but it was also available for work immediately upon delivery. This represented a major advance in computing user environments. One can readily see how these advances might be of value to commercial computing firms.

In 2006, the 100-TeraFLOPs ASC/ASCI Purple machine at LLNL delivered the first ever three-dimensional full-detail nuclear weapons simulation. Today, Sequoia, the most recent machine located at LLNL, provides a “peak performance of twenty petaflops (quadrillion floating-point operations per second).” Sequoia is the “bridge between supercomputers of the past fifteen years” and future exascale machines that will be some 100 times faster.⁵⁸

In the earliest days of ASC/ASCI, neither the laboratories, nor the U.S. commercial computing industry, had current plans to invest in the capabilities that were being proposed to meet SSP’s projected requirements. By the end of the 1990s, ASC/ASCI was leading the business plans of the U.S. computer industry.

While the earliest computers were built for use by the nuclear weapons program, and while it was known what those computers could do, and perhaps imagined by others some things that they might do in future, it is hard to believe anyone ever thought that a paper such as this thesis could possibly be researched, written, edited, shared, and submitted from a home based laptop computer, nor that it might be possible, also using that home laptop, to incorporate in some fashion video materials from interviews videotaped using an iPad.

Alex Larzelere has written a comprehensive history of the ASCI program. From this history the story can jump from the 1999-2000 time-frame to the following in 2009:

Since their invention, computers have become increasingly important supplemental tools in scientific discovery. Computer modeling is used both to interpret experimental results and to design experiments that address theories. New simulation capabilities were under development at laboratories and academia even as ASCI began, but much of the success of this approach is directly attributable to the

ASCI effort. It was the Initiative that provided the urgency, the money, and the unified approach to developing simulation by advancing applications, platforms, and environments together.

With the sophisticated simulation capabilities growing out of the ASCI era, scientists now can set up a simulation with the appropriate dimensionality, resolution, physics, time span, and size to replicate a physical event with great accuracy. The resulting data are then studied in detail by scientists, who can freeze the time variable and explore the physical realm in detail. Fleeting phenomena can be halted for examination, and the nearly invisible can be made visible. With accurate underlying physics inputs, much is revealed, sometimes including surprising events not predicted by theory.

Somewhat suddenly, scientists have a new approach to discovery, one that enables them to attain new insight into the world around them. This results in new theories to explain the simulation results and new experiments to validate the simulations. In a 2005 interview, LLNL's Dona Crawford said, "The world is starting to understand how we [the National Laboratories] go about, and what we do with, simulation. It has changed the scientific discovery process and at this point we couldn't do it [science] any other way."

It is impossible to predict just how far computational simulation can go in predictive science. We do know that it is already providing weapons scientists with information at resolutions never before possible and facilitating insights about how physical systems behave under the hostile conditions of nuclear weapon operations. We also know from the ASCI Alliance Centers that simulations can lead to insights about how energetic materials react to shocks, how explosives operate in fires, how turbulence flows in jet

engines, how solid rockets burn, and how neutron flashes are generated on the surface of stars.

Other government scientific programs are also using simulations to develop scientific insights, including efforts by the DOE's Office of Science, the National Science Foundation, and others such as NASA, NIST, NOAA, and DARPA. The challenge, posed by SBSS (Science Based Stockpile Stewardship), of how to understand the complex physical systems of nuclear weapons without full-scale experimentation, was taken on and met by ASCI. The legacy of that work, however, will benefit people far beyond the nuclear weapons complex. Computational simulation has now been established as a fundamental part of science.⁵⁹

Early on in the program, the unprecedented computational power of ASCI was made available to selected groups in the university community through the Academic Strategic Alliances Program. In 1997, the Department awarded contracts to five major U.S. universities – Stanford University, California Institute of Technology, the University of Chicago, the University of Utah, and the University of Illinois. The work of the university teams is of similar difficulty and complexity to that needed for Stockpile Stewardship and will provide benchmarks by which the accuracy of SSP work can be assessed. These projects have led to advances in computer simulation technologies as well as to discoveries in basic and applied science, areas important to ASCI, the broader Stockpile Stewardship Program, and other application areas.⁶⁰

Bruce T. Goodwin, of LLNL put it as follows:

Supercomputing reduces the investment in time and testing needed to bring a product to market...The industrial facet of computing matters because computational excellence is both a national and economic security issue, and countries such as China are offering intense competition on both fronts...wider adoption of HPC (high performance computing) simulation in product development is essential if our nation wishes to prevail in this competition.⁶¹

Stockpile Life Extension and Surveillance

DOE works closely with the DoD to finalize detailed plans to indefinitely extend the lifetime of each weapon system in the stockpile. The Stockpile Life Extension Program is the planning framework for proactive management of system maintenance activities. Under SLEP, LEP options are developed to address potential refurbishment actions.

These life extension options address things that must be done to correct known problems; things that should be done to prevent foreseeable problems; and things that could be done to improve safety, use control and other items given the opportunity while working “musts” and “shoulds.” The life extension options allow the DOE and DoD to anticipate and plan for future resource requirements such as workforce, skill mix, equipment, and facilities.

The requirements provide the framework for surveillance of the stockpile and stockpile research and development activities at the nuclear weapons laboratories, for guiding the production plants in validation of new materials, and development and certification of new manufacturing processes. The cycle is continuous and is closely integrated. Data and information from surveillance programs and from the hundreds of experiments and simulations being performed help to identify which parts of a weapon are aging gracefully, and which parts present current and potential future problems.

Stockpile surveillance has been a major element of the U.S. nuclear weapons program ever since the first weapons were put into service. Approximately 100 stockpile weapons are thoroughly examined each year. The results provide data not only for assessing the current safety and reliability of the stockpile, but also for developing predictive models and age-focused diagnostics required to anticipate weapons refurbishment requirements.

The Enhanced Surveillance Program (ESP), one of the campaigns, develops the technologies and methods, as well as a fundamental understanding of materials properties and weapons science, to significantly improve detection and predictive capabilities. For example, the ESP identified an aging mechanism in a stockpile high explosive, ultimately concluding that the changes actually improved the stability of the explosive.

The assessment permits reuse of the high explosives during the W87 life extension program, thus avoiding significant costs. There was also a novel strategy to accelerate the aging process in plutonium. The capability to predict the lifetime of components made from plutonium permits the more accurate identification of when pit replacements are needed and when the significant facility investments must be made in order to support pit replacement.

THE CRAFT

Manufacturing Capabilities

Manufacturing continues to play a critical role in the Stockpile Stewardship Program. During FY1999, almost 1,300 Limited Life Components (LLCs) were produced. Plans called for the production of over 2,000 LLCs in FY2000. These product deliveries signaled the successful transfer of production activities from plants which have been closed. The weapons complex also has plans to perform major refurbishment actions on several weapon types, most currently the B61.

Advanced Manufacturing, Design, and Production Technologies (ADAPT)

The Advanced Manufacturing, Design, and Production Technologies Campaign (ADAPT) was developed to provide advanced capabilities for: designing, developing, and certifying components and systems; and for producing, assembling, and delivering weapons components and products for systems. ADAPT infused new product and process technologies, and adopted state-of-the-art business and engineering practices. For example, the use of a “paperless” product realization system allows for quick design and evaluation of components prior to release for production. Once released for production, the same paperless designs (computer models) can be used to develop and drive manufacturing operations. This approach has already cutting cost and time while improving the ability to deliver extremely high quality parts.⁶²

In one instance, removal of a bottleneck in certain dismantlement operations allowed time needed for a warhead dismantlement process to be cut by half, with no compromise in safety and security.⁶³

The robust and world-class microsystems engineering capability at Sandia National Laboratories allows for development and exploitation of emerging technologies that show great promise for miniaturizing weapon components, improving their reliability, and for maintaining a critical capability in radiation-hardened electronics needed to address potential safety, security, and hostile radiation threat environments of the future.⁶⁴

Tritium

Every U.S. nuclear weapon requires tritium to function as designed. Because tritium, a radioactive isotope of hydrogen, decays at a rate of 5.5 percent per year, it must be periodically replenished. DOE had not produced tritium since 1988 and the START I inventory was expected to be sufficient only until about 2005, after which the five-year tritium reserve would be reduced. Therefore, a new source of tritium would be needed.⁶⁵

The nation's tritium production capability was lost when the last heavy water reactor at the Savannah River Site (SRS) shut down in 1988. Interim stockpile requirements were met through recycling, which involved recovering and purifying the gas from dismantled nuclear weapons and from routine tritium reservoir exchanges from the existing nuclear stockpile.⁶⁶

In December 1998, DOE announced that commercial reactors would be the source for new tritium production. The Tennessee Valley Authority's (TVA) Watts Bar Unit 1 and Sequoyah Unit 1 and Unit 2 reactors were selected for irradiation of the DOE-supplied Tritium Producing Burnable Absorber Rods (TPBARs).

An interagency agreement between DOE and the TVA to allow tritium absorbing rods to be inserted into designated TVA commercial reactors went into effect on January 1, 2000.⁶⁷ The TPBARs could be irradiated in the Watts Bar reactor and then transported to SRS, where the tritium would be safely and efficiently extracted in the new Tritium Extraction Facility (TEF).⁶⁸

The new TEF's operating capacity was to be such that the five-year reserve would be fully replenished in two to three years. The tritium could then be piped to the existing Tritium Loading Facility at SRS for further purification and can then be loaded into reservoirs for shipment to the DoD.⁶⁹

An additional issue with regard to a source of tritium is that tritium for use in nuclear weapons must be "unencumbered" – it must be indigenous and domestically produced, and cannot come from facilities established in the United States using foreign technology or from a foreign owned facility (for example from Canada).⁷⁰ This requirement has caused some to complain about the use of TVA reactors for tritium production.

Fortunately, tritium can be recycled from existing warheads as well as extracted from nuclear power reactors.⁷¹ Recycling tritium allows the United States to stretch its tritium supplies. Tritium is most familiar to most people as the gas that produces the glow in emergency exit signs.

In 2011, plans were announced to consolidate facilities and install new processing equipment to lower business costs associated with tritium production.⁷²

The size of the U.S. nuclear weapons stockpile has been greatly reduced since TEF was designed, which means the required tritium supply can be met via recycling of gas from unloaded reservoirs.⁷³

In October 2003, the first TPBARs were inserted into TVA's Watts Bar reactor for irradiation. The first shipment of irradiated TPBARs arrived at SRS in August 2005.⁷⁴

In November 2006, NNSA approved radioactive startup of TEF. The first tritium was extracted at SRS from TPBARs in January 2007 and transferred via underground piping to the Tritium Loading Facility in February 2007.⁷⁵

Technology Partnerships Programs

Stockpile Stewardship involves many industrial processes common to private industry. Replacement parts must continue to be available, and it must be certain that new materials and processes are compatible with maintaining the existing stockpile inventory in perfect working order, without underground nuclear testing. To get the job done right, advanced scientific expertise, complex experimental capabilities, historic product

data, and highly sophisticated computer calculations – bottom line – more high tech and labor intensive than many private corporations today, provide the artisanal tools needed.⁷⁶

The Defense Programs Technology Partnerships Program, which was restructured and directly integrated into Stockpile Stewardship activities, represented an important investment in near-term and future capabilities. For example, a partnership between SNL and General Electric Company improved SNL's capability in the production of neutron generators, a critical weapons component.⁷⁷

Another example has been the LANL collaborations with Dow Chemical and PPG Industries on predictive modeling of materials aging. The ability to predict accurately material lifetimes and reliability has paramount consequences for SSP and for major industrial challenges like aging effects on an array of materials from car frames and engine parts to medical implants. Measured progress in these partnerships remains beneficial to Stockpile Stewardship and to other national concerns.⁷⁸

Additive Manufacturing

Additive Manufacturing at LLNL is a new approach that holds great potential to make major contributions to the processes associated with replacement parts in SSP. The name “additive” indicates the nature of the production process, which consists of layers being created using a computer and 3D printer that then form a three-dimensional product. The product can be made of paper, plastic, metal and possibly, for medical use, of human tissue.⁷⁹

In the SSP, where hands-on work by small teams is key to success, being able to design and produce needed parts can be a cost-effective way to replace parts that can no longer be made using traditional manufacturing methods. Suppliers have gone out of business. New technologies are needed for modernization of systems. Processes have changed. Old materials are no longer available. Security concerns are key. Relatively small numbers of items are required.⁸⁰

Most people who have any familiarity with additive manufacturing may have seen it used by architects to produce heavy 3D models of designs. The prototypes or the actual products can be made.⁸¹

Pit Manufacturing

Think of the historic cast iron buildings in downtown Manhattan. Then, think of decorative wrought iron stair railings to be seen, for example, around Washington, D.C. What do they have in common with the plutonium pits that make up the “primary” stage of a nuclear weapon?

According to Robert Putnam, former director of LANL’s Plutonium Sustainment Program, “Pit manufacturing is an art.” While there will never be a plutonium pit railing anywhere, the processes for making plutonium pits are much the same as those used in the railings and cast iron building fronts. Plutonium is a metal as is iron. Metals can be cast or wrought.⁸²

From 1952 to 1989, when all pits for nuclear weapons were made at Rocky Flats in Colorado, they were wrought. Rocky Flats was closed in 1989, and for some 19 years the United States had no ability to build a pit and put it into a weapon.⁸³

Today replacement pits for the SSP are made at Los Alamos using a metal casting process. Some 700 scientists, administrators, technical and clerical support employees are involved in the pit replacement process, 300 of whom work full time on pit manufacturing. More than 100 crafting processes were involved in being able to reconstitute pit manufacturing.⁸⁴ In August 2011, the 29th and final replacement pit for the W88 warhead to be deployed on a Navy Trident II submarine was presented to the NNSA by Los Alamos.⁸⁵

SSP research and experiments have discovered that plutonium ages well, so the need for replacement pits will be manageable, although military requirements control the actual number of pits that LANL must be prepared to produce per year. Indeed, the reason that replacement pits were needed for the W88 was because of the numbers of pits destroyed during the annual surveillance process which is also part of SSP. The W88 will remain in the stockpile for the future and will eventually be the subject of a life extension. Meanwhile, SSP has rebuilt the ability to make whatever replacement pits may be needed.

THE ARTISANS

People

At the heart of Stockpile Stewardship are the people who make it work. They really are rocket scientists. Los Alamos, New Mexico, has the highest proportion of Ph.D.'s per capita of any community in the nation, and Livermore, California, has the second highest.⁸⁶

During the 1990s when Stockpile Stewardship was coming together, it was very much a team effort – and it was fun. There was an energy in the air that the work being done mattered to the nation. There was the shared camaraderie of people who worked intensely toward shared goals – much like working in a political campaign, or playing on a sports team. It was a special time in life with a sense of belonging to a team, of trusting the other members of the team, of solving tough problems, and of achievement.

The leadership of Dr. Vic Reis, Dr. Gil Weigand, Brigadier General Tom Gioconda (USAF, ret.), Dr. Dave Crandall and others on the federal side set the goals, provided guidelines, and encouragement – then let the members of the team get to work. Often at the end of the day there was a time to decompress and reflect. The atmosphere was one in which good work and good humor flourished. That is a rare thing, but it is so valuable to any endeavor. When the atmosphere encourages thought and creativity, then creativity and thought are likely to result. In the case of SSP, the fact that the program got off to a roaring, successful start was certainly due to the people who were the founders on both the federal side and those who were the contractors of the laboratory, plant, and test site side of the equation.

It was clear, however, that over time, recruitment and retention of future stockpile stewards would not be easy. The Chiles Commission on Maintaining U.S. Nuclear Weapons Expertise offered twelve specific recommendations for action under four broad categories: national commitment, program management, personnel policies, and oversight. A key driver in the time frames for SSP planning and executing the program was the fact that scientists and engineers with nuclear test experience were nearing retirement age and would be leaving the program in large numbers within the first 10 to 15 years of the program. To transfer the knowledge

they had to a new generation was vital so that the role of testing in the process of maintaining the stockpile would be well understood in all its dimensions.⁸⁷

It had been recognized since the days of the Atomic Energy Commission (AEC) that scientists and engineers responded well to opportunities to learn and grow in their professional disciplines. Provision of such opportunities was always considered an important recruiting and retention tool.

The DOE points out:⁸⁸

The AEC recognized that to maintain the laboratories' intellectual vitality, their ability to respond immediately to developments at the cutting edge of science and technology, and their ability to retain the best scientific, technological and managerial talent, a certain amount of work must be left to the laboratories' discretion. Thus, from its inception (1946), the AEC and its successor agencies made allowable certain amounts of research derived from the ideas of the national laboratory researchers themselves.

In 1985, and in response to the recommendations of prestigious national panels and commissions, the Department established the Exploratory Research and Development Program (ER&D) to formalize the practice of providing its national laboratories with the means to conduct laboratory initiated R&D. Six years later, DOE renamed the program Laboratory Directed Research and Development (LDRD) and formally established it at the DOE national laboratories. Today, the LDRD Program at the DOE national laboratories and analogous programs at the Department's nuclear weapons production plants (Plant Directed Research and Development, or PDRD) and Nevada National Security Site (NNSS) Site Directed Research and Development, (or SDRD) are active components of DOE mission to promote scientific and technical (S&T) innovation that advances the economic, energy, and national security of the United States.

The skill mix at the laboratories would have to shift away from nuclear test-based expertise toward a more science-based expertise for maintaining the nuclear weapons stockpile. At the production plants, there would of necessity be more emphasis on computer and network based design tools and advanced manufacturing techniques. These changes in skill mix would be major recruiting and retention challenges, and they came into existence immediately with the advent of SSP.

When Lawrence Livermore National Laboratory was founded in 1952, lab director Herbert York was 31; Harold Brown, in charge of thermonuclear design was 24, and John Foster, in charge of fission weapon design was 29.⁸⁹ By July 2000, at Los Alamos, in X Division, the weapons design division, the average age was 54.⁹⁰

Today there are fewer opportunities to conduct exploratory research at the laboratories due to limits on LDRD (in January 2014 the most recent budget Omnibus bill for FY14, caps LDRD spending at six percent, a reduction from the eight percent previously allowed), LDRD has been a key vehicle to attract new talent to the laboratories and to hone their skills. Reductions like this affect the workforce pipeline, and yet the need for highly talented young scientists and engineers to make a commitment to careers in SSP continues.⁹¹

In what is admittedly a unique setting, there have been high level security and safety concerns, environmental responsibilities, downsizing requirements, workforce and training issues, cost-benefit trade-offs to consider, as well as other problems similar to those faced by private businesses. All of these concerns also affect how long experienced scientists and engineers will stay on the job as well as how easily the next generation can be recruited and retained.

When problems arose regarding lab security and other issues during the late 1990s and early years of the next decade, departures and retirements soared at LANL and LLNL. During the first half of 2000, Los Alamos lost 96 scientists and engineers, compared to 137 for all of 1999 and 139 for the entire year of 1998. At Livermore, by the same date, 130 scientists and engineers had left compared to a total of 102 in 1999 before and 71 during all of 1998.⁹²

The departures came amid very public retellings of various security issues discovered at the labs, so that anyone seeking to work there had to ask themselves what would be the requirements of working in a

government program as opposed to working for a private sector company where money and flexibility in the workplace might be better.

Despite those concerns, SSP has been and continues to be successful. A further discussion of problems and opposition to SSP follows this section, but the science, the craft, and the artisans have prevailed. With nuclear testing, there was a gross understanding that designs and various features of nuclear weapons did work, but there was less direct knowledge of why and how things worked. Thus, updating the stockpile with new designs and new models was necessary to be sure they would function properly within their design lifespan and then to replace them.

Once again, with Stockpile Stewardship, there is a broad and deep understanding of the physics and engineering of nuclear weapons and an elegant environment in which to make and keep them viable for an indefinite period of time without having to design and build new weapons and without having to test them.

Testing and Stockpile Stewardship are not the same program by any means, but there is congruence between them and a compatibility with the ultimate goal – to maintain the safety, security and reliability of our nation’s nuclear deterrent.

Notes

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CHAPTER 4

Opposition & Problems

The biggest fear about nuclear weapons has always been associated with radiation. Regardless of the fact that Hiroshima and Nagasaki have been rebuilt and reoccupied since the end of World War II, a disproportionate fear is associated with anything nuclear, in direct contradiction of evidence found in the years since by expert epidemiologists and radiation biologists. It was recently addressed in an article in *The New York Times* online from the *International New York Times*, written by David Ropeik, an instructor at the Harvard Extension School:

Beginning shortly after World War II...researchers have followed roughly 112,600 Japanese...The most current analysis estimates that, out of 10,929 people in the exposed population who have died of cancer, only 527 of those deaths were caused by radiation from the atomic bombs. For the entire population exposed (112,600), in many cases to extremely high levels of radiation, that's an excess cancer mortality rate of about two-thirds of 1 percent...The robust evidence that ionizing radiation is a relatively low health risk dramatically contradicts common fears...But nuclear accidents have provided strong evidence that those fears have dramatic health consequences of their own. The World Health Organization's 20-year review of the Chernobyl disaster found that its psychological impacts did more health damage than radiation exposure did."¹

Think for a moment of the thousands of coal miners killed over the decades in mine accidents, and coal miners now facing the same very real risks every day. Think also for a moment of those killed in Dresden or Tokyo by firebombing during World War II. Or, consider those being

killed by chemical weapons most recently in Syria. None of these situations are good, but there has always been such intense focus on the potential for radiation associated with nuclear weapons. That intense fear helps stoke opposition to the Stockpile Stewardship Program, regardless of the need for the program, or the scientific and engineering achievements that are associated with it.

Spend a few hours looking at public writing in newspapers, publications and online sites of non-governmental organizations, and government reports about SSP. In doing such a review, several strains of argument appear:

- SSP is too expensive – the money could be better spent elsewhere;
- SSP has been badly managed and continues to be problematic; or
- SSP is a bargain for the deterrent value provided.

The NNSA website offers several facts necessary to evaluate those arguments:

The U.S. nuclear stockpile includes both active and inactive warheads. Active warheads include strategic and non-strategic weapons maintained in an operational, ready-for-use configuration, warheads that must be ready for possible deployment within a short timeframe. Inactive warheads are maintained in a non-operational status at depots.

Although the current number of nuclear weapons is classified, the Department of Defense released the historical stockpile quantities. As of September 30, 2009, the U.S. stockpile of nuclear weapons consisted of 5,113 warheads. This number represents an 84 percent reduction from the stockpile's maximum (31,255) at the end of fiscal year 1967, and over a 75 percent reduction from its level (22,217) when the Berlin Wall fell in late 1989.

The following chart illustrates the makeup of the current nuclear weapons stockpile.²

Current U.S. Nuclear Weapons and Associated Delivery Systems

Warheads – Strategic Ballistic Missile Platforms					
Type	Description	Carrier	Laboratories	Mission	Military
W78	Re-entry vehicle warhead	Minuteman III intercontinental ballistic missile	LANL/SNL	Surface to surface	U.S. Air Force
W87	Re-entry vehicle warhead	Minuteman III intercontinental ballistic missile	LLNL/SNL	Surface to surface	U.S. Air Force
W76-0/1 ^a	Re-entry body warhead	D5 submarine-launched ballistic missile Trident submarine	LANL/SNL	Underwater to surface	U.S. Navy
W88	Re-entry body warhead	D5 submarine-launched ballistic missile Trident submarine	LANL/SNL	Underwater to surface	U.S. Navy
Bombs – Aircraft Platforms					
B61-3/4/10	Non-strategic bomb	F-15, F-16, certified NATO aircraft	LANL/SNL	Air to surface	U.S. Air Force
B61-7	Strategic bomb	B-52 and B-2 bombers ^b	LANL/SNL	Air to surface	U.S. Air Force
B61-11	Strategic bomb	B-2 bomber	LANL/SNL	Air to surface	U.S. Air Force
B83-1	Strategic bomb	B-52 and B-2 bombers ^c	LLNL/SNL	Air to surface	U.S. Air Force
Warheads – Cruise Missile Platforms					
W80-1	Air-launched cruise missile strategic weapons	B-52 bomber	LLNL/SNL	Air to surface	U.S. Air Force

LANL = Los Alamos National Laboratory

LLNL = Lawrence Livermore National Laboratory

NATO = North Atlantic Treaty Organization

SNL = Sandia National Laboratories

^a The suffix associated with each warhead or bomb type (e.g., “-0/1” for the W76) represents the modification associated with the respective weapon.

^b The strategic B61 bomb is currently planned for delivery solely on the B-2 bomber.

^c The B83-1 bomb is currently planned for delivery solely on the B-2 bomber.

The Defense Department also offers an accounting of the weapons stockpile. Concerning warhead dismantlement: “From fiscal years 1994 through 2009, the United States dismantled 8,748 warheads. Several thousand additional nuclear weapons are currently retired and awaiting dismantlement.”³ In addition, “the number of non-strategic nuclear weapons declined by approximately ninety percent from September 30, 1991, to September 30, 2009.”⁴

Under the 2010 New START Treaty, the nation is expected to reduce the deployed strategic weapon stockpile to 1,550 bombs and warheads by 2018.⁵

It bears repeating that even with these lower numbers of actual weapons that will need to be maintained via life extension programs, the updating of limited life components, replacement of tritium, and capabilities that support those fewer weapons cannot really shrink, nor do they get cheaper over time.

General Larry Welch, former U.S. Air Force Chief of Staff and former USSTRATCOM commander summed the situation up succinctly when he said that "...capabilities cost what they cost."⁶

The nuclear weapons complex has certainly shrunk over time, to its current three labs (Los Alamos and Lawrence Livermore for nuclear design expertise and Sandia for engineering), the NNSS (for subcritical experiments and other R&D), and four plants: Y-12 (for uranium and other components), Kansas City (non-nuclear components), Savannah River (tritium extraction and processing) and Pantex (warhead assembly, disassembly, disposal, and high explosive components).

The Kansas City Plant once occupied a space some 1.2 million square feet in size that very much resembled a large warehouse.⁷ It is currently moving to a new, modern facility that is a Leadership in Energy and Environmental Design (LEED) certified building. The new KCP expects savings of an estimated \$100 million in operating costs from the combination of overhead reduction and sustainable strategies to cut energy consumption by more than 50 percent.⁸ The KCP footprint will be about the same, but the more modern facility allows work to be done under 21st century working conditions. Given the age and condition of most program facilities, updates, downsizing where possible, and new more modern, safer facilities allow for the program to move into the future on a more sound basis.

At Los Alamos, the WWII era CMR (Chemical and Metallurgy Research) facility was to be replaced with the CMRR (Chemical and Metallurgy Research Replacement) facility. The old building had come to be the scene of problems such as fires from outdated wiring. Certain experiments could no longer be performed there. It was not up to modern safety standards or modern workplace standards. A new facility had been sought for many years, but the need was not considered urgent enough to undertake the cost involved until recent times.

A plan was developed to move ahead on the new CMRR. Budget constraints, however, have dictated that LANL will have to defer the

replacement building once again and the lab has come up with a workaround plan. The capabilities of the new CMRR in full were deferred several years into the future to focus current dollars on a site with even more urgent need for modernization: the Y-12 plant in Oak Ridge, Tennessee.

At Y-12, a new Uranium Processing Facility (UPF) has been planned for construction. Cost estimates for the building have ranged from \$600 million to more recent projections of more than \$10 billion. At an embarrassingly late stage of the process to design and build the new facility, the building design was discovered not to have included ceilings high enough to accommodate the equipment that would be located inside. This meant that more time would be needed to update the design before construction could begin. Any time delay means costs rise. Now alternatives are being sought for this project.

Outside opposition to the costs associated with SSP generally comes from groups that oppose the entire notion of nuclear weapons and have always done so. These are often also the sources of the information that lump in the cost of new submarines, missiles and bombers, and associated operational costs for the military with the cost of maintaining the weapons themselves.

The estimated cost of the planned B61 LEP (Life Extension Plan) is somewhere in the neighborhood of \$25 million per bomb or \$10.4 billion total, according to the Arms Control Association.⁹ This amount and estimates by the NNSA are much higher than earlier estimates of costs. Groups such as the Arms Control Association oppose this expenditure based on several hypothetical projections about what the European allies may want done about this particular weapon that has been key to the defense of NATO in nuclear planning.

Four former U.S. Strategic Command leaders were reported to be in strong support of the B61 LEP in the Weapons Complex Morning Briefing, October 29, 2013:

Cuts to the NNSA's B61 life extension program could imperil the airborne leg of the nation's nuclear deterrent, four former leaders of US Strategic Command (and its Air Force predecessor, Strategic Air Command) said in a letter last month to key leaders on the Senate Appropriations and Armed Services committees. The B61 will be the subject of

a House Armed Services Strategic Forces Subcommittee hearing today as lawmakers consider the massive price tag of the bomb refurbishment, but retired Air Force Gen. Larry Welch and Kevin Chilton and retired Navy Adms. Henry Chiles and Richard Mies suggested in their Sept. 10 letter to Sens. Barbara Mikulski (D-Md.), Richard Shelby (R-Ala.), Carl Levin (D-Mich.) and Richard Inhofe (R-Okla.) that the effort was well worth the cost. According to the most recent estimate from the NNSA the cost will be \$8.1 billion, but a Department of Defense estimate set the price tag in excess of \$10 billion.¹⁰

The NIF, originally budgeted construction costs at \$1.2 billion in the 1990s. The final construction cost was \$2.4 billion. Total program costs also increased due to early technical challenges. These challenges were readily addressed, but concerns about these issues led to a complete overhaul of the schedule and budget led to higher costs. DARHT also had technological glitches that added to cost.

It would seem that criticisms of cost and management might be justified even from those who support SSP. Why is it so hard to have accurate cost estimates? Was it unreasonable to expect the designers of the new UPF at Y-12 to have noticed that the ceilings they were designing were too low to fit the necessary equipment in the building, for example? Why are costs so high?

Britain's former Prime Minister John Major told the *Financial Times* that "Britain maintained its (nuclear) arsenal partly for industrial and employment reasons and mainly for prestige," calling it a "tremendous waste of money."¹¹

On the other hand, there are advocates such as Robert Spalding, a military fellow at the Council on Foreign Relations. In a recent op/ed for *The Washington Post* he recalled his days as a bomber pilot in the waning days of the Cold War. He believed that nuclear weapons were irrelevant to the future. More recently however, he has adopted a different view and now sees nuclear weapons as a war deterrent. Spalding believes that nuclear weapons have supported development of a post-WWII world community that "always de-escalated back to dialogue" when tensions among nuclear powers became too threatening.¹² According to Spalding:

Since August 9, 1945, approximately 7 million to 10 million people have died from conflict. Before the introduction of nuclear weapons, two world wars alone led to the deaths of 70 million to 100 million – a difference of a decimal point.

Nuclear weapons are an affordable deterrent. The cost of the triad (air/land/sea delivery ability) represents less than 3 percent of the \$526 billion Defense Department budget.

As conventional forces modernize, nuclear weapons funding dwindles, and weapons systems age. The irony is distressing. We are funding weapons that kill on a daily basis to the detriment of the weapons that exist to prevent war.¹³

Spalding is succinctly stating a position that is representative of views widely shared among those who support funding for SSP. By this line of thinking, the approximately \$7 billion budgeted for SSP in recent years is a bargain in terms of lives saved and wars prevented. Of course, deterrence was the original purpose of the nuclear arms race. Historically, the United States and USSR have wanted to remain as close to parity as possible in terms of nuclear weapons capabilities in order to keep some type of balance that would deter either side from taking the nuclear leap, knowing their own destruction would result as surely as that of the opposition.

With more nations than ever having become nuclear powers – such as China, India, and Pakistan – the question remains about the value of SSP. Other nations are modernizing their nuclear forces, while the United States is doing SSP to maintain current capabilities only.

Whatever the costs for SSP are, are they unreasonable? They may be unreasonable in the case of not being able to get accurate cost estimates for the UPF at Y-12. The review of the discovery that the building size would not hold the necessary equipment found clear procedural reasons for what appeared to be an almost Keystone Kops-like error being made by people that most Americans think of as being almost rocket scientists.

Dana Priest, writing “Aging U.S. Nuclear Arsenal Slated for costly and Long-delayed Modernization,” in *The Washington Post* in September 2012, pointed out that the numbers of weapons in the stockpile had been

cut by both Presidents Bush, but that renovations of facilities in the weapons complex had been deferred, adding to costs.¹⁴

It is clear that the situation at Y-12 with regard to the old building where uranium has been processed since Manhattan Project days is acutely in need of remediation. Citing “rust and corrosion on interior walls,” a manager is quoted as saying the walls and roof leak during rain storms, “If water hits the floor, we treat it like a contaminated spill.” Work is stopped for extended periods when minor safety problems arise in order to avoid bigger problems.¹⁵

And as it turns out, the Government Accountability Office (GAO) had reviewed the NNSA’s work on planning for the new UPF, and had said that six of ten critical technologies that were to be part of the project were not expected to be “ready by the time construction began.”¹⁶ It cannot be surprising that cost estimates were wrong, given the fact that nuclear facilities are most often “one-of-a-kind” facilities requiring a variety of considerations to be factored in to cost estimates and decision-making processes. The GAO was critical of the NNSA’s management of the process, but it is wise to consider that a lack of sustained funding over time due to congressional budgeting processes in the past decade or so have also contributed to confusion, stops, starts, and cost escalation problems.

Cost escalation may be somewhat more understandable in terms of the NIF, which was a first-of-a-kind, large-scale experimental facility for which the building/creation was a kind of experiment as much as the science NIF would encompass upon completion would be. When engineering problems arose during the construction period, it was not surprising, but the time frame for completion of the gigantic laser facility was extended. This meant that costs would increase as well. It was essentially an exercise in figuring out how to spread a larger cost over a longer time frame while working through the immediate problems. That problem was solved and NIF eventually won the 2010 Project of the Year Award from the Project Management Institute (PMI).¹⁷

It may be understandable how and why costs went up, but it is not a comfortable thing for those who appropriate funds for SSP. To some degree that discomfort may be associated, particularly on the appropriations side, with the fact that appropriations for NNSA and SSP come through the Energy and Water Subcommittee of the Appropriations

Committees in both the House and Senate, while the authorization of monies comes through House and Senate Armed Services Committees. This division of responsibilities is not necessarily unique, but it is unusual. In addition, the Energy and Water appropriators do not generally deal with the kinds of expenditures that the Armed Services authorizers do.

In the House Energy and Water Appropriations Bill Report (Report 113-135) the Department of Energy appropriation was almost \$25 billion, of which some \$11 billion went to NNSA programs. The U.S. Army Corps of Engineers appropriation is less than \$5 billion while the Department of Interior and Bureau of Reclamation appropriation is closer to \$104 million.

The House Defense Appropriations for Fiscal Year 2014 totaled \$512.5 billion. It is easy to see that the dollars for NNSA equal about one-third of the total Energy and Water Appropriation, but represent only .02 percent of Defense dollars. Everything in the nuclear weapons program looks large in the overall context of Energy and Water Appropriations activities.

There is no reasonable comparison between the complex science, engineering and computing required for SSP, and the less-complex work of the water agencies that come under the same appropriations subcommittees, but looking at the numbers side by side, the first thing that comes to mind is probably not Mr. Spalding's view of what is affordable. Thus, the SSP programs are often on defense.

When those who oppose the SSP program for philosophical or political reasons join in talking about costs of submarines, etc., as part of an expensive defense proposition – in order to seek to undermine it – SSP begins to seem much more costly than might actually be the case given the complexity of the task at hand.

An article in *The New York Times* on the costs of asthma medications offers a rough point of comparison:

The Centers for Disease Control and Prevention puts the annual cost of asthma in the United States at more than \$56 billion....the United States spends far more per capita on medicines than other developed countries. Drugs account for 10 percent of the country's \$2.7 trillion annual health bill, even though the average American takes fewer prescription medicines than people in France or Canada,

said Gerard Anderson, who studies medical pricing at the Bloomberg School of Public Health at Johns Hopkins University...In 2012, generics increased in price an average of 5.3 percent, and brand-name medicines by more than 25 percent, according to a recent study by the Health Care Cost Institute...

Our regulatory and approval system seems constructed to achieve high-priced outcomes,” said Dr. Peter Bach, the director of the Center for Health Policy and Outcomes at Memorial Sloan-Kettering Cancer Center.¹⁸

While one may disapprove of the way in which the United States approaches various health care issues such as costs of drugs to consumers and drug development cost sharing, and one may think these costs represent excessive wasteful spending, drug manufacturing is a costly field of advanced medicine and science. It is also a private industry with some government regulation. There certainly are ways in which cost saving changes could be made, but absent the public or political will to insist on such changes, prices will not improve. The profit motive will continue to drive health care outcomes.

Opponents of waste in health care do not criticize the science and engineering that produces the drugs, nor the costs of the infrastructure needed to produce those drugs as part of efforts to make changes in the health care system. Scientists and experts made clear early on that the challenge of SSP was perhaps more difficult than the original Manhattan Project was, so at no time should SSP have been regarded as an inexpensive enterprise.

Recall that the four original weapons developed by the Manhattan Project cost on the order of \$5 billion each, according to the U.S. Nuclear Weapons Cost Study Project. The Arms Control Association criticizes the cost of the B61 LEP at \$25 million per bomb (no note was provided as to whether this amount was in constant 1996 dollars or current 2013 dollars). Using that standard of comparison, the cost per unit for modernizing a weapon to maintain the same capability has fallen significantly and on that basis alone it is a reasonable cost, without factoring in any indirect potential value of deterrence.

It is also useful to remember, again, that modern nuclear weapons are highly sophisticated examples of science and engineering, the artisanal products of years of work and refinement. There are reasons that the United States might not choose to proceed with a LEP of the B61, including costs, but to say that the cost is unreasonable per se is not one of them.

Several advisory and expert panels over the past decade and more have looked at problems associated with management by the NNSA, which was established in 2000 as a way potentially to avoid management problems. During the early 2000's, the contracts to manage both Los Alamos and Lawrence Livermore were recompeted for the first time since World War II and were moved from the non-profit sponsorship of the University of California to a private sector based corporate sponsor team for each lab – Bechtel LLNS at Livermore and Bechtel LANS at Los Alamos.

Many believe that moving the labs to private sector contract status has created more problems than it might have solved, for example, increasing costs because there is now a profit making opportunity associated with the contracts whereas previously there was not.

The National Research Council was tasked in the Fiscal Year 2010 Defense Authorization Bill to review the quality and management of science and engineering at the three nuclear weapons laboratories. Phase One of their report makes several recommendations backed up by findings of their investigation:

- Congress “needs to recognize that because the nuclear weapons core function of the labs has changed the role of the labs, that the labs overall need to evolve toward broader national security missions.”
- Congress and the NNSA need to “strongly, consistently support both funding and flexibility for Laboratory Directed Research and Development (LDRD).” It is key to the future of the laboratories because it has been key to recruiting and retaining high caliber key staff.
- The study also “recommends restrictive reporting requirements be reduced and/or simplified and standardized to benefit health and safety among other issues; that managerial and governance

relationships and trust between NNSA and the laboratories be repaired and restored; and that roles and responsibilities be clearly stated and boundaries respected.”¹⁹

The possibility exists that more layers and confusing layers of reporting requirements may actually lead to more safety problems rather than fewer. The same problem may lead to completely missing out on something as obvious as the fact that the ceiling on a building will not accommodate needed equipment and will have to be redesigned at a significant increase in costs.

Another problem identified by the NNSA lab directors is the need for budgetary consistency, for sustained funding for SSP. Even at lower levels of funding, if the program can plan ahead over time, progress can be made.

An example of the concern over sustained funding was captured in the Weapons Complex Morning Briefing an online report of comments from retired Generals Welch and Chilton, and Admirals Mies and Chiles, all former heads of the U.S. Strategic Command, October 29, 2013:

The Administration requested \$537 million in Fiscal Year 2014 for the (B61) refurbishment, but appropriators on the Senate Energy and Water Appropriations Subcommittee provided only \$369 million in an effort to prod the Administration to narrow the scope of the project. Senate appropriators did include a provision that would free up the rest of the \$168 million as long as the Secretaries of Energy and Defense certify that the life extension program will stay within its \$8.2 billion cost estimate, though it’s unclear when – or if – the certification could be achieved, or where additional money would come from for such a reprogramming. The cuts “would impact the future of the airborne leg of the U.S. nuclear deterrent, it would imperil our commitment to the security of our NATO allies, and, it would preclude significant reductions in the large non-deployed nuclear weapons stockpile that the United States maintains to hedge against technical and geopolitical risk.”

When agency or program funding becomes a political policy football, and stops and starts with situations such as government shutdowns, the

cost of completing the program when things are reopened is always higher than it would have been had government not shut down, or if there had been appropriations passed instead of continuing resolutions that cause disruptions and cuts.

According to the Congressional Research Service, between Fiscal Year 1998 and Fiscal Year 2011, there have been a total of eighty-seven Continuing Resolutions (CR) lasting an average of almost thirty days each – that’s an annual average of just over six CR’s. During that period there were two full-year CR’s for FY2007 and FY2011.²⁰ For FY2012 and FY2013, there were CR’s, and for FY2014, as of October 29, 2013, almost a month into the new fiscal year, the CR that is in place expires December 15.²¹

Under a CR, no new work may be started and funding levels and priorities from the previous year are in place. In the long run when this goes on, government costs more, not less, as timelines slip and necessary work is put on hold until a regular appropriation is in place.

During FY2013, sequestration to require across-the-board cuts in all agencies and across all programs, and not allowing for any management flexibility to choose what cuts to make and when, was voted into place as being so awful it would keep the Congress from letting it happen. The idea was that the threat of sequestration would drive Congress to the negotiating table and that appropriations would be passed. Sequestration is now in operation because it wasn’t effective as part of the budget process, but government programs and workers are paying the price, as is the public.

In October 2013, there was a sixteen day shutdown of most U.S. Government operations over funding issues and policy disputes in Congress. Stopping and starting work, not knowing whether a project begun in one fiscal year will receive needed funding the next year, and working at levels required by CR’s rather than regular appropriations bills, do not allow for consistent progress. Nothing that government does saves money using this approach.

In 2000, the National Nuclear Security Administration was created within the Department of Energy. The new agency was supposed to set the nuclear weapons enterprise, including nonproliferation work and naval reactors, apart from the rest of DOE. The idea was to simplify lines of authority and reporting in order to facilitate work and reduce confusion.

Since 2000 there has been a great deal of criticism about the way the relationship between NNSA and the labs has been working, or has not been working. There have been a number of studies and recommendations. A February 16, 2012, hearing of the House Armed Services Committee Subcommittee on Strategic Forces on the Nuclear Security Enterprise heard testimony from former lab directors, the GAO, and two members of the study panel responsible for the report entitled *Managing for High Quality Science and Engineering at the NNSA National Security Laboratories*. Summing up the varying views are the following excerpts from testimony at that hearing:

From Gene Aloise, Director: Natural Resources and Environment, GAO:

With regard to the concerns that DOE's and NNSA's oversight of the laboratories' activities have been excessive and that safety and security requirements are overly prescriptive and burdensome, we agree that excessive oversight and micromanagement of contractors' activities is not an efficient use of scarce federal resources. Nevertheless, in our view, the problems we continue to identify in the nuclear security enterprise are not caused by excessive oversight, but instead result from ineffective oversight. Given the critical nature of the work the nuclear security enterprise performs and the high-hazard operations it conducts – often involving extremely hazardous materials, such as plutonium and highly enriched uranium, that must be stored under high security to protect them from theft – careful oversight and stringent safety and security requirements will always be required at these sites.

From Mike Anastasio, former Director of both Lawrence Livermore National Laboratory and Los Alamos National Laboratory:

...because of the large number of external entities peering into NNSA and its inner workings, with disproportionate attention relative to that seen in other parts of the government, a significant risk aversion has developed within the bureaucracy at NNSA. This risk aversion has

manifested itself in a growing focus on compliance at the expense of delivering the mission.

I was heartened by the bipartisan commitment to the 2010 NPR (Nuclear Posture Review) and accompanying budget outline...there are already changes in the making, amplified by the financial challenges faced by the country. This drives inefficiencies. Inconsistent priorities will arise and will be exacerbated when there is a gap between expectations and fiscal realities...

My experience at LANL is instructive...We were able to increase the effectiveness of the Laboratory in delivering on our missions over the last five years while absorbing new costs of approximately \$225 million per year and simultaneously confronting a new contract structure, security and safety concerns, and an aging infrastructure. Because of the new contract, LANL's costs rose by approximately \$150 million per year overnight due to substantial increases in available fee, in gross receipts tax to the state of New Mexico and in a pay-as-you-go defined contribution pension system...it will be difficult for my successor to make further efficiency and effectiveness gains due to the growth in unfunded requirements and from transactional oversight. For example, the NNSA site office has grown from approximately 100 employees to over 130 now. Their focus is oversight of safety, security, and business operations where the inexorable trend is toward ever-deeper involvement and direction of how specific activities are executed rather than evaluating whether the outcomes meet expectations...new requirements and reinterpretations are promulgated continuously from NNSA and/or the DNFSB (Defense Nuclear Facilities Safety Board) to drive down operational risks and demand more and more paperwork to demonstrate compliance. Usually those who establish and interpret the requirements do not have direct responsibilities for program. And those that are responsible do not fully understand what goes on in the

field...safety and security are paramount...a hallmark of an efficient and effective organization is that it achieves a balance across all the competing demands from mission accomplishment to operational excellence...Priorities can change in the 18 months between budget formulation and the start of the new fiscal year. Our ability to reallocate funding within our overall budget to meet changed priorities is restricted by...congressionally directed control levels and the way they are managed at DOE/NNSA headquarters.

Unless dramatic progress can be made on these issues, the inevitable response to financial pressures will be to modify the program...If past history is a guide, these program impacts will fall disproportionately on the science and engineering base...It is very difficult to convince top quality technical staff to join an organization where they are told how to do their work and left wondering if there is going to be an opportunity to discover and innovate. This has already resulted in the loss of some of the best mid-career scientists from the Laboratories...A deepened and vital science and engineering base that is advancing with the state of the art was a key premise of the Stockpile Stewardship Program and has been responsible for our success over the last two decades. Failure to remedy the oversight/requirements...and...avoid the squeeze on science can have irreparable harm – once we lose the capabilities we may not be able to recover them.²²

While there is always some degree of tension between the federal managers and the laboratories who execute the SSP program, this testimony from both the GAO and a former lab director sums up the depths to which the situation has deteriorated.

A new Secretary of Energy, Ernest Moniz, along with Vic Reis and others are seeking to make changes that will start the process of remedying these rifts. Meanwhile, the budget situation goes on and work gets pushed further out, thus costing more.

The push and pull goes on. The missteps that seem like ridiculous self-inflicted wounds at first glance look different when context is considered. The science goes on. The accomplishments go on in spite of it all, so far.

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CHAPTER 5

Milestones & Accomplishments

From the earliest days of the Stockpile Stewardship Program, it has been keeping the stockpile viable, while preparing to solve even more complex problems expected to arise as the weapons age. Ultimately, Stockpile Stewardship will allow weapons designers unparalleled opportunities to simulate and learn about weapon behavior in levels of detail and in time frames that previously *would not have been possible at all even with nuclear testing*. The following are a few examples of milestones and accomplishments.

1998

In 1998, the W87 was a key component of the U.S. land-based ballistic missile element of the U.S. nuclear deterrent triad and the Y-12 plant at Oak Ridge completed and shipped to Pantex the first refurbished canned sub-assembly for the life extension program of the W87 under the Stockpile Life Extension Program.

1999

Early in 1999, the first deliveries of electronic and mechanical parts for the W87 life extension were shipped to Pantex from the Kansas City plant. The first W87 life extension unit was delivered to the Air Force in May 1999, becoming the first production unit completed under the life extension program. This was a major milestone in meeting a DOE commitment made to the Air Force.¹

Also in 1999, the first lot of twenty-four War Reserve, W76 neutron generators were placed in inventory by Sandia National Laboratories (SNL), reconstituting a capability lost when the Pinellas County Florida

plant was closed in 1994. Neutron generators are limited life components that help to initiate a fission reaction.²

Also, the first successful hydrodynamic test at the DARHT facility provided a freeze-frame photo of materials imploding at speeds of more than 10,000 miles an hour, allowing scientists to study solids and metals as they flow like liquids, thus become hydrodynamic, when driven by the detonation of high explosives.³

2000

In 2000, tests key to certification of the W76 Acorn gas transfer system were conducted in the Annular Core Research Reactor (ACRR) at Sandia National Laboratories. Initial tests indicated good results for Acorn certification to the stockpile.⁴

2002

In 2002, Los Alamos and Livermore labs, combining data analyses from archived nuclear tests, examining key physics issues both ran the first three-dimensional simulations of a nuclear weapon secondary and a nuclear weapon primary. The Los Alamos simulation was run on a machine at Livermore, a thousand miles away.⁵

2005

In 2005, IBM Blue Gene, then the fastest computer in the world, located at LLNL, allowed the study of the “effects of voids in metal failure” involving simulation of more than 2.1 billion atoms.⁶

Also, the First TPBARs from the TVA Watts Bar reactor arrived at the Savannah River Site.⁷ [First tritium produced in United States since 1992].

2007

In 2007, the first replacement pit in 18 years was produced at Los Alamos ahead of schedule and under budget for the W88. The work

included the development and qualification of more than one hundred crafting processes. LLNL and Kansas City Plant contributed expertise, and the pit will be installed in the W88 at Pantex.⁸

Rebuilt W88 warhead, using the replacement pit and replacement gas transfer system, was formally accepted into the stockpile.⁹

2009

In 2009, the refurbished W76 warhead returned to the stockpile,¹⁰ the National Ignition Facility at LLNL was completed,¹¹ and DARHT's first double-viewpoint test at LANL was conducted.¹²

2012

In 2012, the stockpile was certified as safe, secure, and reliable for the twentieth year without the need for underground nuclear testing.¹³

Noted Accomplishments

On the Tenth Anniversary of the NNSA the agency published a long list of accomplishments.¹⁴ Here are just a few excerpts:

- Completed one-of-a-kind construction projects like the National Ignition Facility, Highly Enriched Uranium Materials Facility (HEUMF), and the Microsystems and Engineering Sciences application (MESA) facility.
- Eliminated three million square feet of excess buildings and structures.
- Assessed the safety, security, and effectiveness of the nuclear stockpile without underground nuclear testing for fifteen consecutive years.
- Developed three of the ten fastest computers in the world and two of the world's most energy efficient supercomputers that use the most advanced simulation and modeling capabilities in the world.

- Designed, built, and delivered all U.S. space-based sensors to detect nuclear detonations.
- Deployed field teams of nuclear experts from the laboratories around the world in response to radiological or nuclear emergencies forty-nine times.

Other tenth anniversary milestones:

- Lawrence Livermore, Los Alamos, and Sandia National Laboratories won more than ninety-three *R&D100* Awards since 2000. (*R&D100* Awards are given by *R&D Magazine* and are typically given for important technical innovations).
- The nuclear weapons labs were home to one Nobel Prize and three Enrico Fermi Award winners.
- Laboratory-Directed Research and Development (LDRD) dollars supported nearly 4,000 postdoctoral researchers since 2000.
- The Secure Transportation Asset provided 100 million miles of service moving sensitive cargo without incident of loss or release.

Notes

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CHAPTER 6

Conclusion

Nuclear weapons are an appropriate topic for a Liberal Studies thesis because they sit at the heart of the modern world. Writings, studies, and analyses of nuclear weapons and their role in modern life are part of history, current events, law, philosophy, medicine, politics, international relations, the arts, religion, science, technology, the environment, and so on. There is no human endeavor of the past almost seventy years that has not been affected in one way or another by the existence of nuclear weapons.

In many ways, they represent a major crossroads in civilization, regardless of whether they are viewed as tools of damnation, or tools of deterrence. That is what liberal studies is all about: how all of the various fields of endeavor in the world blend into one to create the world we live in. These weapons represent the challenge of managing great risks for longer term benefit. They represent the question of whether humankind can live together in at least a semblance of peace and cooperation even in the face of temptation to exert power and control. They represent the striving of some nations to gain parity and respect with other nations, as a sort of badge of political adulthood.

The United States cannot ever afford to know less about nuclear weapons than any other nation in the world and, until the day comes when the weapons are no longer a factor, the Stockpile Stewardship Program is a reasonable and valid way to manage this knowledge. The cost of the program, when considered in the context of both direct and indirect benefits to the nation and to the world, is reasonable. As political currents shift in the United States, however, budgetary issues will increasingly affect the laboratories and plants of SSP, most probably resulting in limited capability to perform work and possibly, limited ability to recruit the finest scientists and engineers to the work.

There are only two nuclear design laboratories: Los Alamos National Laboratory and Lawrence Livermore National Laboratory. While the engineering and other work of Sandia National Laboratories might be replicated by private sector firms, there are no counterparts to LANL and LLNL. Some ask why one design lab is not “enough.” Can’t we, they say, just consolidate all design related knowledge and activities in one location? The answer is that LANL and LLNL are a check and balance on one another that cannot be duplicated elsewhere. In the military this process of checks and balances is known as “red teaming.” One set of experts develop answers to problems and then the other set of experts review and critique the work of one another. It is sort of like getting a second opinion about a serious medical problem. The question becomes, for the next fifty years and more, can the United States afford to have only one point of view about whether the nation’s nuclear stockpile is safe, secure, reliable, and effective? Is this the best way to be sure the United States leads the world in nuclear knowledge in the future? Does that sound like it would be a smart path to the kind of peaceful world the nation has deemed to be a long term objective?

In the case of LLNL, the conclusion to this thesis includes a suggestion for a path forward to the ultimate future of the lab. The reason for this is that LLNL has been in the past, and may well be again, particularly vulnerable to calls for funding cuts in SSP.

In order to be sure that LLNL remains intact, providing the kind of unrivaled scientific expertise on nuclear weapons that has been a hallmark throughout the lab’s history it might be wise to begin to rethink funding mechanisms.

Given current federal budget constraints and the very real prospect that things will not improve in the foreseeable future, LLNL could look at the possibility of developing more diverse funding sources with an eventual goal of shifting from all government dollars to sustained self-funding. Sustained self-funding would mean that the laboratory would be financed by something other than federal appropriations, although federal money would still be a part of funding. This would mean that the lab would need a completely new model for governance and operations.

There are at least three organizational models to consider when thinking about this kind of path forward for LLNL. Two of those presented here are government based non-profit models. The third is a

private sector model but has been perhaps unique in having a long term programmatic focus rather than a focus on development of profit potential.

Port Authority of New York and New Jersey

One model to consider would be something like the public-private bi-state agency Port Authority of New York and New Jersey (PANYNJ). PANYNJ is an agency entirely funded by revenues from the projects the agency undertakes, and/or bonds used to develop new projects. The PANYNJ was formed as a bi-state compact between New Jersey and New York. These types of organizations are provided for in the Constitution, and the Port Authority, formed in 1921, has been extraordinarily successful at accomplishing its mission. Originally formed to build and operate the Holland Tunnel between lower Manhattan and New Jersey, the agency expanded from building/owning/operating tunnels, to bridges, to other types of transportation such as the bus terminal in midtown Manhattan. Ultimately, the agency took on the task of building, owning, and operating the World Trade Center by classifying the need for the office space as part of agency responsibility for international trade facilities associated with traffic (i.e., transportation) in the New York/New Jersey harbor. Tolls, fares, and fees pay for operation and maintenance and bonds are issued when needed for new projects. All new projects must be able to demonstrate that returns on the project will exceed the hurdle rate of 3 percent in order to be approved.

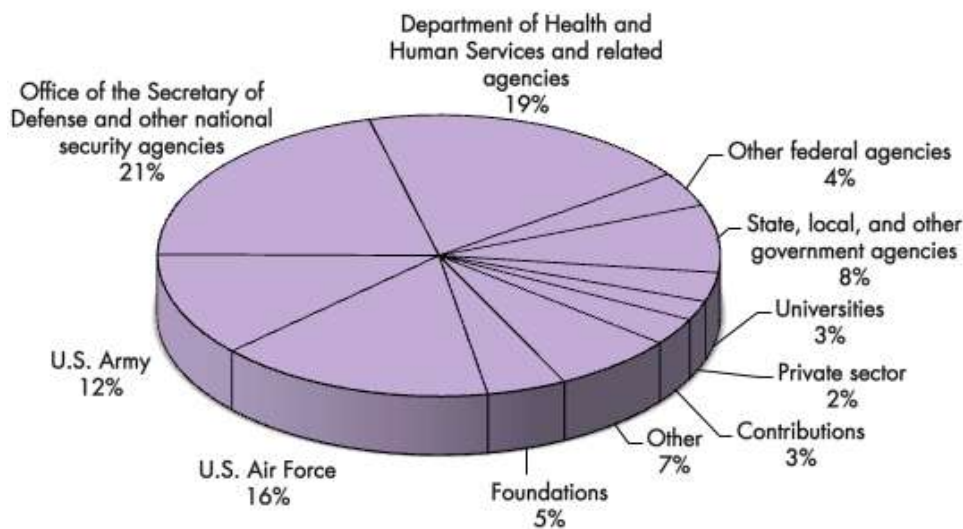
There are legitimate criticisms of the Port Authority to be made, but historically the management has been fiscally responsible and the funding mechanism has been successful. Current agency budgets are in the \$7 billion annual range. State and federal dollars are not part of the equation.

The RAND Corporation

Another organizational option that could be used to structure a free-standing LLNL includes the RAND model. RAND's research is commissioned by a wide range of sources. Federal, state, and local government agencies provide the largest share of the funding; however, RAND also conducts projects for foundations, foreign governments, and

private-sector firms. Contributions from individuals, charitable foundations, and private firms, as well as earnings from RAND's endowment, offer a steadily growing pool of funds that allow RAND to address problems not yet on the policy agenda. RAND's revenue in FY12 was \$264.9 million. While 50 percent of RAND's current \$223 million budget still comes from federal funding, much of that goes toward non-defense work.¹

RAND Fiscal Year 2012 Research Activity • 264.77 million*
(*Net of subcontracts and RAND-initiated research).²



The RAND model represents a hybrid system of some public funding with opportunities to develop diverse sources of additional funding. RAND is an FFRDC (Federally Funded Research and Development Center).

Project RAND began after World War II as a special initiative within the Douglas Aircraft Company of Santa Monica, California. The purpose was to continue in peacetime the advances in knowledge that civilian research scientists had been recruited to develop during the war.

Early research was conducted for only one client – the U.S. Army Air Forces – and focused exclusively on U.S. national security. In 1948, Project RAND separated from Douglas Aircraft and became the RAND Corporation, an independent, nonprofit organization dedicated to promoting scientific, educational, and charitable purposes for the public welfare. RAND diversified its research focus and for more than six decades has used scientific analysis to help individuals, families, and communities throughout the world.³

Bell Laboratories

The third option is a Bell Laboratories model. Bell Labs was a private sector creation. It was owned by AT&T (American Telephone and Telegraph) in the days when that company had a telephone service and equipment monopoly in the United States. Why look at Bell Labs? From an Op/Ed in *The New York Times*, by Jon Gertner, published on February 25, 2012:

It (Bell Labs) offers a number of lessons about how our country's technology companies – and our country's longstanding innovative edge – actually came about. Yet Bell Labs also presents a more encompassing and ambitious approach to innovation than what prevails today. Its staff worked on the incremental improvements necessary for a complex national communications network while simultaneously thinking far ahead, toward the most revolutionary inventions imaginable...The teams at Bell Labs that invented the laser, transistor and solar cell were not seeking profits. They were seeking understanding. Yet in the process they created not only new products but entirely new – and lucrative – industries.

Thus, the philosophy that guided Bell Labs is very much in tune with the philosophy that has guided LLNL for sixty years. The idea of complicated mission needs spawning unimagined ancillary benefits seems common to both as well.

For LLNL to replicate any such system, or to appropriate particular pieces from several choices to create a new system, many changes would be required. Those changes would involve both the U.S. Congress and the DOE. A good way to approach the idea is to insist that saving the brain power, the laser power and the computing power of LLNL must be sustained for the nation's future both in national security and economic security.

Another fact is that California has a House delegation (fifty-three) almost the same as the total House delegations for New Mexico, South Carolina, Tennessee, and Texas (fifty-five) combined. That may be a good reason to keep LLNL under the NNSA umbrella but perhaps also makes a case for change. NNSA does not want to find the weapons laboratory program support limited to one state with five House members. California's fifty-three votes represent twelve percent of the House, and that total is likely to rise. Politics in California, however, probably lean in favor of moving LLNL away from nuclear missions but keeping it intact as a premier scientific institution.

If a mostly self-sustaining model could be created by LLNL, it might become a model for all of the DOE labs. The DOE and the Congress might not care for that for a number of reasons involving loss of control, dealing with regulatory responsibilities, and reduced oversight opportunities. The PANYNJ, for example, maintains its own standards that are neither federal nor state standards. In the case of fabrics used in facilities for example, after 9/11 there was early criticism that the PANYNJ had not met New York City fire retardant standards in fabrics in the World Trade Center. The fact is that the PA uses a higher flame retardant standard than New York City.

LLNL would have to work incrementally toward a more diverse, more independent status. It is unlikely that new status would be created all at once, and as long as the nuclear weapons mission remains a core competency needed by the federal government, there will always be a sizeable segment of federal funding for that mission.

It would not be necessary to be part of a bi-state compact, although there might be advantages to such an arrangement and if such an arrangement were contemplated, the suggestion is that Idaho laboratory would be a good choice for California as the other party to such an agreement.

Self-funding would have to be developed over time and would involve such strategies as those recently highlighted in news about small modular nuclear reactors being developed in Oregon by the NuScale company.

The basic design is based on the MASLWR (Multi-Application Small Light Water Reactor) developed at Oregon State University (OSU) in the early 2000s, in cooperation with the Idaho National Laboratory. OSU licensed the technology to NuScale, and owns 1 to 3 percent of the private company as of 2011.⁴

Making part ownership of new companies a source of revenue back to LLNL is a way to build a revenue stream independent of federal funding. Revenues from licensing of technologies and patents would be another source.

LLNL has consistently, over time, been involved in scientific advancements that came from the nuclear weapons program, or were associated with LDRD that supported the weapons program and also provided far ranging scientific achievements. Over time these things could provide revenue to the lab.

Examples of some achievements that might yield revenues were LLNL allowed to operate in one of the models cited include the following:

- LLNL currently has active commercial licenses with more than 100 companies as well as dozens of active CRADAs, a type of cooperative research agreement. Licensing and royalty income in recent years has topped \$8 million annually, representing more than \$300 million in annual sales of products based on Laboratory technologies.
- On September 19, 1957, LLNL conducted the first contained underground nuclear explosion, the Rainier Event, in a tunnel at the NNSS/NTS. The detonation provided the information necessary to establish systems such as an international array of seismic detectors for monitoring nuclear test activities worldwide.
- In 1990, the Energy Department joined with the National Institutes of Health and other laboratories around the world to kick off the Human Genome Project, an international collaboration to map the

human genome. The Department's expertise and ability to support this effort arose from research conducted at a number of the National Laboratories, including research on chromosome 19 conducted by Livermore biomedical researchers.

- At the forefront in materials science, the Laboratory has produced aerogels, one of the lightest solids ever made, since 1985. Aerogels, also known as frozen smoke, have the highest heat resistance of any material tested. They are also fireproof and extraordinarily strong, able to support more than a thousand times their own weight. As a result of their heat resistance, aerogels are outstanding candidates for insulation in buildings, vehicles, filters, and appliances. They are already found in such high performance autos as Corvette.⁵

The latest National Defense Authorization Act mentions several areas of potential interest to LLNL when thinking about the future of the lab:

- Establishment of a “five-year pilot program to allow DoD laboratories to license department-owned intellectual property that may or may not be patented, and to retain associated royalties consistent with existing statutes on patent licensing.”⁶
- The environmental provisions work addresses the impacts of higher sea levels and more intense natural disasters on military installations, readiness and long term planning for humanitarian missions.⁷
- Areas of interest for the DoD in future included several topics that LLNL has some background and/or expertise in and could provide future defense related, but also possibly commercially viable work: Electromagnetic Pulse & Spectrum Management; Rare Earth Materials; and Environmental Provisions.⁸

A couple of specific LLNL examples of 2013 accomplishments illustrate weapons expertise applied to broader national security issues.

Twenty-first Century Energy systems (CES-21) project – in December 2013, LLNL agreed to use its “supercomputing and related domain expertise in engineering and applied science” to improve the “efficiency, security and safety of the state’s utility systems.”⁹

Critical Materials Institute – LLNL is part of a multi-laboratory team led by Ames Laboratory in Iowa, addressing shortages of metals and materials “critical to U.S. energy security.” Aside from the national security implications associated with critical materials that are of vital interest to the lab’s core mission of SSP, this work allows LLNL to share expertise gained over sixty years for a purpose that complements that mission and extends beyond traditional lab parameters. Critical materials are vital to the future of energy development, communications technologies, and other drivers of economic growth. SSP built the specialized expertise needed, from knowledge needed to determine such things as the mechanisms and speed at which plutonium ages, to the ability to understand the unique electron bonding of nuclear actinides with atomic profiles similar to rare earth materials. LLNL’s nuclear weapons knowledge applies directly to these types of problems.¹⁰

Beyond this, the plain fact is that nuclear weapons exist and as long as they do, the United States cannot ever be in a position not to know as much as, or more than, any other nuclear nation. Period. For the United States to abandon the stockpile and the weapons knowledge and capabilities developed over the past 80 years would be unwise and counterproductive.

In his article *Deterrence in the post-Cold War era: Five myths of the nuclear nonproliferation agenda*, Al Mauroni comments on the Fifth Edition of the Truman Security Briefing book. He points out the idea that “if only the world would give up nuclear weapons, all nations would be safer” as representing the liberal internationalist point of view, rather than representing a realistic approach to sound national security policies.¹¹

Mauroni’s myth number five is: “New programs to modernize weapons are unnecessary and out of touch with the current security climate.” Mr. Mauroni sees this myth as a way to say that the nonproliferation community views ICBMs as Cold War relics of a relationship with the Soviet Union that is no longer applicable in today’s security climate. He points out that the “current security climate is one in which nearly every other nuclear-weapon state is modernizing its nuclear weapons” except the United States.¹²

He concludes that “There does not have to be, and should not be, such an adversarial relationship” between the nonproliferation community and

the proponents of SSP. “Both nonproliferation activities and a modern, credible nuclear deterrent are required in this post-Cold War era.”¹³

Keeping the weapons safe, secure, and reliable/effective is not cheap because high quality artisanal work is not a bargain in any field of endeavor. Cost-effectiveness is a reasonable requirement, but the weapons of the nuclear stockpile are highly sophisticated and require unique security and safety measures in addition to the life extension plans and other required processes.

Keeping the artisanal nukes in good condition through SSP remains the best way to deal with the nuclear weapons world that exists today. For those who would like there to be no more nuclear weapons right now, or who think there are big savings to be gained if the United States moves to minimal stockpile numbers right now, the reality is far more complex.

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