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In Brief: Options to Help Meet a Congressional Requirement for Nuclear Weapon "Pit" Production

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Summary

A pit is the plutonium core of a thermonuclear weapon. Imploding it with conventional explosives provides the energy to detonate the rest of the weapon. The Rocky Flats Plant made up to 2,000 pits per year (ppy) through 1989; since then, the United States has made 29 pits for the stockpile. Yet the FY2015 National Defense Authorization Act requires the National Nuclear Security Administration (NNSA), which manages the nuclear weapons program, to produce at a rate of 80 ppy for 90 days in 2027. How can that requirement be met?

Pits are to be made at Los Alamos National Laboratory's main plutonium facility, PF-4. To manufacture pits, a facility must have enough laboratory floor space and a high enough limit for Material At Risk (MAR), the amount of radioactive material a worst-case accident could release. Producing 80 ppy requires enough "margin," the space or MAR available to produce pits minus space or MAR required for that production rate. While space and MAR available have been calculated, amounts required to produce 80 ppy have never been calculated rigorously, leaving space and MAR needs undefined. Although CRS cannot address whether certain options could meet the 2027 date because time to implement them cannot be determined, this report presents 16 options that seek to increase the feasibility of producing 80 ppy by 2027, including:

- The radiation dose an individual would receive from a worst-case accident determines MAR permitted in PF-4. A ten-factor equation calculates dose as a function of MAR. NNSA uses worst-case values in this equation, yet median values may provide sufficient conservatism. Median values reduce calculated dose by orders of magnitude, permitting a large increase in PF-4 MAR. Yet merely doubling permitted MAR might suffice for producing 80 ppy. Providing this increase through construction at PF-4 could be costly and take years.
- In determining MAR for PF-4, the closest offsite individual is at a nearby trailer park. Relocating it would place the next closest individual farther away. The added distance would reduce dose, permitting increased MAR in PF-4.
- Using a different meteorological model and different assumptions would greatly reduce the currently calculated dose, perhaps permitting doubling PF-4 MAR.
- Plutonium decays radioactively, creating elements that various processes remove to purify plutonium. One process generates byproducts; plutonium is recovered from them with processes that take space and MAR. Since the United States has tons of plutonium surplus to defense needs, byproducts could be dispositioned as waste.
- Pits use weapons-grade plutonium (WGPu). U.S. WGPu is about 50 years old. About nine-tenths of plutonium-241, a WGPu isotope, decays to americium-241 in that time. Since plutonium-241 is the source of americium-241 in WGPu, removing the current americium-241 would prevent WGPu from ever reaching its americium-241 limit, permitting reduction in equipment for that process and reducing worker radiation exposure.
- A plutonium isotope used in space probes, plutonium-238, is extremely radioactive. It accounts for a small quantity of PF-4 plutonium but a quarter of PF-4's MAR. Building a "module" near PF-4 for plutonium-238 work would free MAR and space in PF-4, so one module might suffice instead of two or three.

- To reduce risk of collapse, loss of life, and radiation release from an earthquake, NNSA increased the seismic resilience of PF-4. More steps are planned; more could be taken.

Many options may boost U.S. pit production capacity, but none by itself could meet capacity and schedule requirements. NNSA therefore faces the prospect of assembling a package of options, and Congress faces the prospect of evaluating, perhaps amending, and approving it. Arriving at a satisfactory package will require complex analyses to optimize among such goals as margin, cost, worker safety, and throughput. At issue for Congress: What are the risks, costs, and benefits of the options? What is the optimum package?

This report is a condensed version of CRS Report R44033, *Nuclear Weapon "Pit" Production: Options to Help Meet a Congressional Requirement*, by Jonathan E. Medalia.

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Introduction

A "pit" is the core of the primary stage of a thermonuclear weapon. Its key ingredient is weapons-grade plutonium (WGPu), which is composed mainly of the fissile isotope plutonium-239 (Pu-239). Detonating the pit provides the energy to detonate a weapon's secondary stage. During the Cold War, the Rocky Flats Plant (CO) made up to 2,000 pits accepted for use in the stockpile per year. Production at Rocky Flats halted in 1989. Since then, the United States has made 29 such pits in total. Yet the Department of Defense (DOD) stated it needed the National Nuclear Security Administration (NNSA), the separately organized agency within the Department of Energy (DOE) that maintains the U.S. nuclear stockpile, to have the capacity to produce 50 to 80 pits per year (ppy). Pits are to be made at Los Alamos National Laboratory (LANL, NM) in the PF-4 building, potentially in proposed smaller structures called modules connected to PF-4 by tunnels, or in both. Pits are made by casting two hemishells, or half-pits, then welding them together. In Section 3112 of P.L. 113-291, the Carl Levin and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015, Congress directed NNSA to demonstrate the capacity to produce at a rate of 80 ppy for at least a 90-day period in 2027. Accordingly, this report takes as its focus how to move toward that requirement.

Producing 80 ppy requires enough "Material At Risk" (MAR) and space. DOE defines MAR as "the amount of radioactive materials … available to be acted on by a given physical stress," such as an earthquake. It is measured in units of Pu-239 equivalent (PE). Space is laboratory floor space available for plutonium operations. This report uses "margin" to measure "enough." Margin is space available for pit production and supporting tasks minus space required for them to be able to produce at a specified rate, and MAR available for pit production and supporting tasks minus MAR required for them to do so. Space and MAR margins are separate; both must be greater than zero to produce pits at the specified rate. MAR and space also figure in analytical chemistry (AC), a production support function. AC determines the composition of very small samples of plutonium. The Radiological Laboratory-Utility-Office Building (RLUOB), which was completed in 2010 and is near PF-4, is to house most AC.

There are figures for available space and MAR, but *figures for space and MAR required to produce 80 ppy have never been calculated rigorously,* so this report cannot determine what options would provide *enough* margin for producing 80 ppy. Nor can it address whether certain options could meet the 2027 date because time to implement them cannot be determined. Instead, the report presents 16 options that increase the feasibility of producing at a rate of 80 ppy rate by 2027. A decision will likely weigh such factors as margin, cost, schedule, throughput, and safety.

Sixteen Options

Options Not Involving Process Modifications

Install Equipment with a Single-Shift Capacity of 50 ppy

DOD stated a need for NNSA to have a capacity to manufacture 50 to 80 ppy, and Los Alamos "estimates that a second shift would increase pit-manufacturing capacity by 60% so that establishing a 50-ppy capacity could supply 80 ppy using a second shift." Further, NNSA deferred to FY2030 the projected delivery of the first production unit of the warhead that might be the first to use a newly manufactured pit since 2011; certain retired pits might prove suitable for reuse, reducing the number of newly manufactured pits needed; and pit lifetime might be longer than currently expected. Thus equipment to produce 50 ppy with a single shift might meet the 80-ppy requirement with less cost and space than equipment to manufacture 80 ppy with a single shift because less equipment would be needed. On the other hand, a higher operating tempo would place more strain on the equipment while allowing less time to maintain and repair it, though this disadvantage would occur only with double-shift operations. A few production processes run continuously for more than one shift, so adding a shift would not increase their capacity. It would be harder to surge production beyond 80 ppy if necessary.

Relocate a Trailer Park at Los Alamos

LANL is on one side of Los Alamos Canyon; the city of Los Alamos is located on the other side. The Royal Crest trailer park, with several dozen trailers, is on the lab side. It contains the non-lab publicly accessible structures closest to PF-4, about 3,500 feet away. The next closest structures accessible by the public are in the city of Los Alamos, about 6,000 feet from PF-4, and the next closest such structures after those in Los Alamos are in White Rock, about five miles from PF-4.

Royal Crest is the location of the maximally-exposed offsite individual (MEOI), the hypothetical person outside the lab boundary who would receive the highest radiation dose from an accident in PF-4 that released plutonium. If Royal Crest were no longer the location of the MEOI, and the road it is on were controlled by the lab so the MEOI was not on that road, the next closest accessible structure would be farther away. Typically, fewer radioactive particles are deposited per unit of area as distance increases, so dose to an MEOI would be expected to be less in Los Alamos than Royal Crest. Since the MAR ceiling in PF-4 depends on dose to the MEOI, reducing the dose to the MEOI would permit increasing MAR in PF-4. Relocating Royal Crest could permit an increase in MAR at PF-4 faster, and probably at less cost, than new construction.

Improve Modeling of Atmospheric Dispersion of Plutonium

NNSA calculates dose to an MEOI from an accident at PF-4 using computer models. The models use assumptions on the amount and form of plutonium released into the atmosphere, mechanisms for releasing it from PF-4, wind direction and speed, temperature, humidity, and the like. Three changes to accident modeling might be made. First, use a different atmospheric transport and dispersion model. Second, assume, based on historical data during drills, that the doors to PF-4 are open for less time during an evacuation, permitting less plutonium to escape in an accident. Third, change time-of-day assumptions in the model. Particles disperse less at night, when winds are calmer. More dispersion occurs in the day, reducing dose to an MEOI at any spot. Yet more plutonium is at risk during the day, when technicians are working with it; at night, it is stored in a less vulnerable state. At present, the model assumes daytime MAR and nighttime dispersion. Harmonizing MAR and time of day would reduce calculated dose.

Such changes in PF-4 accident modeling could reduce the calculated dose to the MEOI by several orders of magnitude. That reduction, if incorporated into PF-4's safety documents, would permit more than doubling the MAR permitted in PF-4. It would surely be faster and less costly to change the model and assumptions than to build a new plutonium building. At issue for Congress: would a change made to PF-4's MAR allowance by using the more realistic model increase risk to the public? If so, would the benefits obtained by using that model be worth the added risk?

Remove Contaminated Equipment

The Defense Nuclear Facilities Safety Board (DNFSB) monitors health and safety issues at DOE defense nuclear facilities. A DNFSB report of October 2014 stated in regard to PF-4, "an entire wall of legacy gloveboxes … contains degraded conditions that workers suspect has contributed to multiple contamination events during the past few years. LANL management does not currently have a plan to remove these gloveboxes in order to both eliminate the hazard and free up the considerable space for new programmatic work." Removing the gloveboxes would reduce the risk of a contamination accident, which would remove a room from service until the contamination was cleaned up, and would free up space. The gloveboxes will have to be removed eventually at the end of PF-4's life; there is a tradeoff between the advantages of removing them sooner and the drawback of incurring cost now rather than later.

Increase Material-At-Risk Ceilings by Using Conservative Rather Than Very Conservative Assumptions

DOE imposes a MAR limit specific to each building handling radioactive material so the dose to nearby workers and the public from an accident would not exceed limits specified by DOE. For a given MAR, dose is calculated with a ten-factor "MAR-to-dose" equation that includes the damage the building sustains, the fraction of plutonium released into the atmosphere by the event, and others. Five variables would vary from one scenario to another; NNSA typically assigns them a very conservative worst-case, or "bounding," value to keep dose within guidelines.

According to Kamiar Jamali, Associate Administrator for Safety and Health, Office of Nuclear Safety, NNSA, "Extreme conservatism is often intentionally exercised in safety analyses because it can pay dividends in simplified analysis and review efforts. However, the search for increased conservatism cannot be pursued without consequences. Extreme conservatism can lead to safety conclusions and decisions with significantly higher safety costs, which can make nuclear facilities, even those with very low hazard and risk profiles, prohibitively expensive." He proposed using the mean value for the variables "as the metric that is consistent with the concept of reasonable conservatism in nuclear safety analysis, as its value increases towards higher percentiles of the underlying distribution with increasing levels of uncertainty."[1] (For purposes of safety basis calculations applicable to LANL, mean and median are very close together.)

In the MAR-to-dose equation, using bounding values for a PF-4 accident calculation results in an estimated dose 35,000 times larger than when using median values. Yet an increase in the MAR ceiling in PF-4 by a factor of less than ten, and perhaps less than two, would probably permit enough MAR for production of 80 pits per year in PF-4. Increasing the MAR ceiling could also benefit AC. RLUOB is ideally configured for AC, but DOE regulations limit facilities like it to a level that, in the case of RLUOB, would be 26 g of weapons-grade plutonium, which has the volume of two nickels. Increasing the MAR ceiling by a factor of 40 or less might permit RLUOB to perform most of the AC needed to support production of 80 ppy. The most conservative assumptions provide the greatest margin of safety, but at the highest cost. At issue for Congress: at what point are the marginal costs no longer worth the marginal benefits?

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[1] Kamiar Jamali, "Achieving Reasonable Conservatism in Nuclear Safety Analyses," *National Nuclear Security Administration Technical Bulletin 2014-1,* July 2014, p. 2.

Use Additive Manufacturing to Make Tooling for Pit Work

Additive manufacturing (AM), often called 3-D printing, forms physical objects by depositing multiple layers of material. Many analysts view AM as the future of manufacturing. It can save time, space, and money; reduce waste; reduce the reject rate, increasing throughput; make parts on demand; and switch rapidly from making one part to making another. It can avoid some manufacturing steps, such as drilling holes, saving time and reducing the risk of error. It can make parts that are too complex to be manufactured in any other way. AM is not the best manufacturing method for all materials and components, and may not be suitable for some.

Recognizing the potential of AM, Congress, in P.L. 113-235, the Consolidated and Further Continuing Appropriations Act for FY2015, provided $12.6 million for AM for the nuclear weapons program, and the appropriations committees directed NNSA to provide "a ten-year strategic plan for using additive manufacturing to reduce costs at NNSA production facilities while meeting stringent qualification requirements." The report was due in mid-April 2015. In late April, NNSA indicated that it expects to transmit the report to Congress in several weeks.[2]

NNSA is exploring applications of AM in the nuclear weapons complex. Donald Cook, Deputy Administrator for Defense Programs at NNSA, said in January 2015, "within the last year, more than half of the new fixturing within the new Kansas City National Security Campus was made with AM processes."[3] (Fixtures hold material in place for machining and inspection.)

AM parts, such as tools and fixtures, might support pit production. In some cases, they can be stronger and lighter than conventionally made tools. They can be "lightweighted," e.g., made with honeycomb in areas that do not require much strength and solid in areas that do, providing ergonomic benefit for glovebox work. AM might save time, as it can prototype tools quickly and make them to order, increasing throughput. Currently, tools for pit work are made with conventional methods, which is generally satisfactory. However, "very little work is being done to explore tooling used in conjunction with pit production."[4] At issue for Congress: given the potential of AM, what applications, if any, might it have for pit production?

Use a Different Process to Fabricate Crucibles

The electrorefining process for purifying plutonium, discussed in "Discard Byproducts of Electrorefining," below, is conducted in magnesium oxide crucibles. A crucible consists of an outer cup, about 4.5 inches in diameter, and an inner cup. The process deposits a ring of purified plutonium in the space between the two cups. To fit in a furnace, this ring must be broken into several pieces so it can be melted for casting. This procedure has several problems. First, crucibles have been made as two separate cups, with the inner cup joined with an adhesive to the bottom of the outer cup. Sometimes, given the high heat and the reactive nature of plutonium, the adhesive fails and the cups come apart. Second, a failed electrorefining run produces more waste than a successful run, reducing throughput and increasing cost. Third, the plutonium ring is broken in a glovebox using a hydraulic breaking press; the breaking operation produces chunks, shards, and grains of plutonium metal. Shards may puncture gloves used in gloveboxes, posing a

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[2] Email, April 23, 2015.

[3] Email, January 12, 2015.

[4] Email, Lawrence Livermore National Laboratory, April 3, 2015.

risk to technicians. Fourth, this operation adds a process step and exposes workers to radiation. Fifth, the breaking press glovebox takes space that could be used to add an electrorefining station. So doing would increase the throughput of that process and support a higher pit production rate.

The United Kingdom's Atomic Weapons Establishment (AWE) is conducting final development trials of a crucible that addresses these problems. It is made in one piece with ridges running from the outer wall of the inner cup to the inner wall of the outer cup so that molten purified plutonium is deposited in segments, eliminating the need for a separate glovebox for breaking the plutonium ring and the resulting problems. These crucibles would appear applicable to U.S. electrorefining operations. On the other hand, development of the new crucibles is not complete, and there is no operational experience with them, so there is no guarantee that they will function properly in practice. A decision on whether to use them must therefore await additional data.

Options Involving Process Modifications

Develop and Qualify Accident-Resistant Containers

One way to reduce MAR in PF-4 is to place plutonium in containers designed to withstand a severe accident. If 10% of the plutonium in a container is expected to escape, as compared to all of that plutonium in a glovebox, MAR for that plutonium is reduced by 90%. "Damage ratio" measures the fraction of plutonium expected to escape: for a damage ratio of 1.0, all the plutonium is expected to escape; for a damage ratio of 0.1, one-tenth is expected to escape.

To reduce MAR, the reduction in damage ratio must be credited in PF-4's Documented Safety Analysis, which sets the limit on the amount of MAR allowed in PF-4. To qualify containers as having a certain damage ratio, they are subjected to intense testing. Technicians measure the amount of particulate that comes out of the container after each test. (Damage ratio does not apply to a complete collapse of PF-4, as containers are not expected to survive that event.)

Some years ago, Los Alamos used a container that had a damage ratio of 0.05. Since then, a newer container has been introduced commercially, with a damage ratio of 0.01. These containers are intended for long-term storage, not for ease of use in gloveboxes. Yet a substantial amount of plutonium on PF-4's lab space is in process. Placing more of that plutonium in containers when not in immediate use would reduce MAR on the main floor. At issue: would this use of containers adversely affect plutonium processing?

Process Plutonium Samples More Efficiently

Pit production requires a detailed characterization of plutonium at various stages, from the electrorefined product to hemishells to waste streams, to determine if the sample falls within required specifications. This characterization is done with analytical chemistry (AC). Samples of metal for AC are taken from larger pieces of plutonium and dissolved in acid. The liquid is split into smaller samples for analysis. Many contain milligram or smaller quantities of plutonium.

At present, LANL conducts most plutonium AC in the Chemistry and Metallurgy Research (CMR) building. CMR opened in 1952 and is in poor condition. NNSA plans to halt programmatic activities there by FY2019. As part of that plan, NNSA plans to move most AC to RLUOB. However, it is not known if RLUOB has enough space and a high enough MAR limit to conduct, along with PF-4, the AC needed to support production of 80 ppy. One way to reduce space and MAR required for AC is to analyze fewer samples per pit. That would enable fewer pieces of equipment to support a given rate of production, reducing space requirements and cost and increasing throughput; would make it more likely that RLUOB could perform most AC needed, which would reduce the amount of AC that would have to be done in PF-4; and would reduce waste generated per pit, reducing the load on AC and on waste processing. Similarly, smaller samples, or samples measured with less accuracy for some processes, might suffice.

The chief concern about taking fewer or smaller samples per pit or performing fewer or less accurate analyses is a reduction in precision. This concern can be addressed in several ways. For some process steps, less accurate analytic techniques would suffice; using them may increase throughput. As pit production rate increased, fewer samples per pit taken during metal production would probably suffice to demonstrate that production processes were operating properly. The experience level of technicians would be expected to increase as production rate increased, reducing the need for rework and increase throughput of sample analysis.

Discard Byproducts of Electrorefining

Plutonium must be purified to be used in pits. This process involves several steps; the final step is electrorefining. In electrorefining, an ingot of impure plutonium is placed in the inner cup of a crucible. The rest of both cups are filled with a salt mixture that acts as an electrolyte. Plutonium and salt are melted at high temperature, and an electric current is passed through the mixture. The process produces a ring of purified plutonium and two byproducts, an ingot of impure plutonium (the "heel") in the inner cup, and the salt, which retains some plutonium (here referred to as the Pu-salt mixture). The plutonium in the heel is converted to plutonium oxide; it and the Pu-salt mixture are dissolved (separately) in acid to recover their plutonium.

PF-4 has two "aqueous" process lines, i.e., those that involve a liquid. One uses hydrochloric acid and the other uses nitric acid. They dissolve plutonium compounds in acid. Recovering plutonium from the liquid involves extensive MAR, space, and labor. Might it be possible to reduce this burden? Data from 653 electrorefining runs at LANL, 1964-1977, are available. While the data are old, the process for electrorefining plutonium has not changed much since that time, so the figures provide a rough idea of the products of electrorefining: 9.2% of the plutonium left in the heel; 10.7% left in the salt and stuck to the crucible, almost all of which is in the salt; 78.8% purified in the product ring; and a small amount elsewhere.

Might it be possible to discard the Pu-salt mixture and the heel? That would lose some plutonium, but would avoid the need to use aqueous processes to recover it. The plutonium loss would arguably not be a problem. The U.S. plutonium inventory was 95.4 metric tons as of September 2009, with 43.4 metric tons surplus to defense needs;[5] pits use kilogram quantities of plutonium. The Pu-salt mixture could probably be sent to the Waste Isolation Pilot Plant (WIPP), the nation's underground storage repository for such waste, once it reopens. The heel could be converted to plutonium oxide for shipment. Shipping the material to WIPP would avoid the need to send it through aqueous processes, reducing the space and MAR needed for these processes or permitting existing equipment to process more plutonium in order to support a higher rate of pit production. Congress may wish to consider the costs vs. benefits of discarding this plutonium.

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[5] U.S. Department of Energy, *The United States Plutonium Balance, 1944-2009*, Washington, DC, June 2012, p. 2, http://nnsa.energy.gov/sites/default/files/nnsa/06-12-inlinefiles/PU%20Report%20Revised%2006-26-2012%20%28UNC%29.pdf. One metric ton is 1,000 kilograms, or 2,205 pounds.

Use Calcium Chloride for Electrorefining

Electrorefining uses sodium chloride and potassium chloride. That entails several problems. Plutonium held in salts reduces yield (fraction of total plutonium recovered as pure plutonium), increasing time, space, equipment, MAR, cost, process steps, and worker exposure required to produce a given amount of pure plutonium. Hydrochloric acid processing for recovering plutonium produces a substantial waste stream that requires further treatment. The plutonium content of this waste must be monitored with AC techniques, adding to the workload. Preparing plutonium-contaminated waste for disposition takes up space in PF-4 and elsewhere at LANL. The process from waste generation to processing to disposition is costly.

An alternative would be to use calcium chloride as the electrolyte. Lawrence Livermore National Laboratory (LLNL) has used this method since 1992 and AWE has used it for over a decade. This approach offers several advantages. Calcium chloride retains less plutonium after an electrorefining run, increasing the yield. A process ("salt scrub") can remove most of the rest of the plutonium from the calcium chloride-plutonium mixture. As a result, the salt left after the salt scrub would be expected to contain very little plutonium. Disposing of that salt as waste would release aqueous process capacity. In this way, equipment could produce more plutonium, supporting a higher rate of pit production.

LANL had poor results when it tried this approach in the 1990s. It plans to revisit this option. LANL will use sodium chloride and potassium chloride when electrorefining in PF-4 resumes, but plans to convert to calcium chloride if the process can be successfully demonstrated. LANL expects to draw on LLNL and AWE resources and experience in this effort.

Remove Americium from Plutonium

Weapons-grade plutonium (WGPu) consists of several plutonium isotopes. Each decays radioactively at its own rate. Pu-241 decays much faster than the others, producing americium-241 (Am-241). It is desirable to remove Am-241 because it is an intense emitter of low-energy gamma rays. While these gamma rays are relatively easy to shield, so that gloveboxes protect workers' bodies from them, workers handling aged WGPu in gloveboxes have only gloves to protect their hands. As a result, gamma rays from Am-241 can provide substantial dose to their hands. This dose can be the limiting factor in how many days per year federal regulations and LANL policies permit them to handle plutonium while staying within dose guidelines. Am-241 can be removed through a process, metal chlorination, that captures almost all the americium.

Of the Pu-241 in newly produced WGPu, 89% will have decayed to Am-241 after 50 years. Most U.S. WGPu was produced between 1956 and 1970. It had essentially no impurities resulting from radioactive decay when newly produced; plutonium purified since then has, in effect, had its age reset to zero. There is no official unclassified (and perhaps no classified) figure for the average age of plutonium in the DOE inventory, but preliminary calculations by LANL are that the average age of that plutonium is about 50 years. Due to radioactive decay, little Pu-241 is left to form more Am-241 after 50 years. Since Pu-241 decay is the only source of Am-241, after passing aged plutonium through a final run of metal chlorination to remove Am-241, so little Pu-241 would remain that even if it all decayed to Am-241, the latter would never reach the level in 30-year-old WGPu, and the weapons laboratories have certified weapons with pits that old and older as acceptable for use in the stockpile. This final run would greatly reduce worker exposure. Also, since additional runs of metal chlorination would not be needed for WGPu thus processed, capacity of the metal chlorination line could be reduced, reducing space and operating cost.

Accept More Uranium in Weapons-Grade Plutonium

Pu-241 decays faster than the other plutonium isotopes in WGPu. The others decay over longer times into uranium. After 50 years, uranium accounts for 0.17% of WGPu, and uranium will form at this rate, declining only slightly, for millennia.

At issue is whether newly fabricated pits can use plutonium that has not been purified for several decades, or if the uranium would affect pit performance. The last year in which the United States made pits for the stockpile (with a minor exception) was 1989. NNSA plans a life extension program (LEP) for the B61 bomb, with the first production unit expected in FY2020. Thus the newest pit in B61s would, in 2020, be at least 30 years old. Yet the LEP is to use existing pits, and weapon designers expect to be able to certify the performance of life-extended B61 bombs. Similarly, the W76 warhead was first manufactured in 1978 and is now undergoing an LEP that does not use new pits. A 2007 report by the JASON group evaluated studies on pit lifetime performed by LANL and LLNL, and found "no evidence from the [underground nuclear testing] analyses for plutonium aging mechanisms affecting primary performance on timescales of a century or less in ways that would be detrimental to the enduring stockpile."[6] Thus there may not be a need to conduct electrorefining to purify plutonium for pits for decades. Capacity and space required for pit production could be further reduced if weapon designers were willing to allow a larger uranium content in the WGPu specification. That would depend on detailed studies of properties of WGPu with levels of uranium isotopes that are in existing pits.

Use Near Net Shape Casting to Fabricate Hemishells

Hemishells are cast by gravity feed, i.e., pouring molten plutonium between an inner and outer mold. When it solidifies, the molds are separated and the cast part is removed. The part is heat-treated to impart the required material properties. It is then machined to final dimension. Near net shape casting (NNSC) has a thinner space between the molds, yielding a cast part much closer to final dimension. Otherwise, processing is the same. The thinner space requires less plutonium for casting, reducing the amount of plutonium that must be machined away to produce the hemishell. On the other hand, a thinner cast part could result in a higher reject rate, as there would be less margin for error in machining. To offset this disadvantage, NNSC could use various electronic techniques to align the part more precisely and remove excess material more precisely.

Current equipment can purify enough plutonium to support low production rates, but supply would become a bottleneck at higher pit production rates. Since NNSC uses less plutonium per hemishell, existing equipment could provide plutonium for a higher rate of pit production. Using less plutonium per pit would reduce the waste stream, the burden on material control and accountability, and, on a per-pit basis, worker exposure, MAR, and cost. LANL has conducted some R&D into NNSC using gravity feed and plans to use this method in the future if it proves successful. LANL's planning basis for future pit manufacture includes it. LLNL worked on developing NNSC as early as 1994, and has demonstrated NNSC using plutonium die casting, in which molten plutonium is forced into the space between an inner and outer mold. LLNL stated in April 2015, "Die casting technology is another approach to significantly reduce the amount of plutonium required per casting and therefore, the amount of feed metal."

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[6] R.J. Hemley et al., "Pit Lifetime," JASON, The MITRE Corporation, JSR-06-335, January 11, 2007, p. 1, http://fas.org/irp/agency/dod/jason/pit.pdf. A nuclear weapon's primary stage consists of the pit, high explosives, and other components.

Options Involving Structural Modifications to PF-4

Augment Seismic Resilience of PF-4

PF-4 became operational in 1978; since then, seismic studies have increased the predicted threat to it. For example, an older model assumed that an earthquake would shake the building, while a newer model treated an earthquake as a wave of earth that could push PF-4 over. These studies increased concern that a major earthquake could collapse PF-4. In 2013, to reduce the dose resulting from collapse followed by a fire, LANL reduced PF-4's MAR limit for the main (laboratory) floor from 2,600 kg PE to 1,800 kg PE. To increase MAR, reduce potential dose, and reduce the risk of collapse, LANL is taking steps to strengthen PF-4 seismically.

To strengthen PF-4 against seismic shaking, LANL added a drag strut to the roof. (A drag strut gathers lateral forces from a large flat surface and transmits them to a shear wall, which is designed to resist those forces.) Other steps strengthened PF-4 against pushover. Many columns that run from the basement to the roof support PF-4. Some run through a plutonium vault in the basement. Its ceiling holds them rigidly in place, making them more vulnerable to shear forces that could collapse them. Collapse could result in concrete and steel crashing through the vault ceiling. To strengthen the columns, LANL wrapped them in carbon fiber sealed with epoxy. LANL is now working to strengthen the ties between girders, which are located above the laboratory floor of PF-4, and other structural elements. To reduce the risk of fire, LANL removed about 20 tons of combustible material from PF-4, mostly from the lab floor, and plans to upgrade the system that would deliver water to PF-4 and nearby buildings for firefighting. Such upgrades could greatly reduce the amount of plutonium released in an earthquake and fire. The Consolidated and Further Continuing Appropriations Act, 2015, P.L. 113-235, provided $1 million for seismic safety mitigation for PF-4 and nearby facilities.

Build One Module for Plutonium-238 Work

Plutonium-238 (Pu-238) is highly radioactive. It is used in deep space probes and has some military applications. It is not used in pits. As of February 2013, PF-4 held about 1.6 kg of Pu-238, but because of its high radioactivity it accounted for 24.5% of the building's MAR. For comparison, pit fabrication accounted for 26.4% of the building's MAR. In addition, Pu-238 programs accounted for 9,600 square feet, or 16%, of PF-4 laboratory floor space.

One approach to providing more MAR and space in PF-4 for pit fabrication is to build modules, buried reinforced-concrete structures with about 5,000 square feet of lab space connected to PF-4 by tunnels. As stated in the FY2016 DOE budget request, "NNSA is planning to construct not less than two modular structures that will achieve full operating capability not later than 2027." However, Pu-238 is not uniformly distributed within the space for Pu-238 programs. If some Pu-238 work were moved to a module, that module could accommodate most of the Pu-238-related MAR from PF-4, releasing MAR and space for pit production or other plutonium work. Thus one module for Pu-238 might suffice to enable pit production in PF-4.

Building one module may offer advantages if others are to be built. Modules would have a basic design, and each would be provided the capabilities needed for its specific mission. In contrast, a large multi-mission building would require all features needed for every mission it contained. Building a module would provide lessons that could reduce cost of other modules. NNSA states that modules offer "the potential to scale facility acquisition to appropriations and adapt more quickly to changes in program requirements." On the other hand, some lessons from building a module might increase cost. A design flaw or a need for larger modules or more concrete could make the second module more expensive than the first. Also at issue is whether other measures to increase MAR and space margin might provide enough margin without any modules.

Conclusion: Choosing a Package of Options

This report shows options, many of which NNSA and its labs are pursuing, that can help move toward the ability to manufacture pits at a rate of 80 per year by 2027. One option by itself will not suffice to meet that requirement. As a result, NNSA faces the prospect of assembling a package of options, and Congress faces the prospect of evaluating, perhaps amending, and approving it. Any package would need to optimize among such goals as margin, cost, worker safety, and throughput. Questions and tradeoffs to consider in formulating a package include:

- MAR reduction techniques include strengthening PF-4, using special containers for plutonium not in use, and removing contaminated gloveboxes. Would all such techniques be needed, or would some provide enough MAR margin?
- Using a different wind model and more realistic assumptions could reduce calculated dose by more than half in a major accident at PF-4, permitting more than doubling the MAR allowance for PF-4 quickly and at essentially no cost. Would that suffice?
- Techniques to increase space margin include removing contaminated gloveboxes, setting up a production line able to make 50 ppy with one shift per day and operating it with two shifts per day, and building a module for Pu-238 work. Which combination of techniques would be most cost-effective?
- A module for Pu-238 work would permit moving much MAR out of PF-4 and freeing some space there. Would that module be cost-effective, or would other alternatives render it unnecessary? Would other advantages argue for building a Pu-238 module even if enough margin could be obtained by other means?
- Using conservative rather than very conservative assumptions to calculate dose could reduce the need for costly, time-consuming changes to PF-4. Would that increase risk to workers and the public substantially? What is the risk-benefit balance?

In sum, while arriving at a satisfactory package will require complex analyses, many options offer the potential to boost U.S. pit production capacity toward, if not to, the congressionally mandated requirement of 80 pits per year by 2027.

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