W78 Replacement Program (W87-1): Cost Estimates and Use of Insensitive High Explosives

Report to Congress
December 2018

National Nuclear Security Administration
United States Department of Energy
Washington, DC 20585

Message from the Administrator

Maintaining a safe, secure, and effective nuclear weapons stockpile remains at the forefront of the Department of Energy's National Nuclear Security Administration's (DOE/NNSA) many national security missions. NNSA is working in close partnership with the Department of Defense to provide additional diversity in the attributes and flexibility of the Nation's deterrence options, as directed in the 2018 Nuclear Posture Review (2018 NPR). Among the strategies outlined in the 2018 NPR is the direction to advance W78 warhead replacement activities one year earlier to fiscal year 2019 to support fielding on the Ground-Based Strategic Deterrent by 2030.

This report, "W78 Replacement Program (W87-1): Cost Estimates and Use of Insensitive High Explosives," provides the information requested in the Conference Report (H. Rept. 115-929) accompanying the *Energy and Water, Legislative Branch, and Military Construction and Veterans Affairs Appropriations Act, 2019* (P.L. 115-244).

Pursuant to statutory requirements, this report is being provided to the following Members of Congress:

- **The Honorable Richard Shelby**
  Chairman, Senate Committee on Appropriations
- **The Honorable Patrick Leahy**
  Vice Chairman, Senate Committee on Appropriations
- **The Honorable James Inhofe**
  Chairman, Senate Committee on Armed Services
- **The Honorable Jack Reed**
  Ranking Member, Senate Committee on Armed Services
- **The Honorable Lamar Alexander**
  Chairman, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations
- **The Honorable Dianne Feinstein**
  Ranking Member, Subcommittee on Energy and Water Development
  Senate Committee on Appropriations
- **The Honorable Deb Fischer**
  Chairman, Subcommittee on Strategic Forces
  Senate Committee on Armed Services
- **The Honorable Joe Donnelly**
  Ranking Member, Subcommittee on Strategic Forces
  Senate Committee on Armed Services

- **The Honorable Rodney Frelinghuysen**
  Chairman, House Committee on Appropriations
- **The Honorable Nita M. Lowey**
  Ranking Member, House Committee on Appropriations
- **The Honorable William "Mac" Thornberry**
  Chairman, House Committee on Armed Services
- **The Honorable Adam Smith**
  Ranking Member, House Committee on Armed Services
- **The Honorable Mike Simpson**
  Chairman, Subcommittee on Energy and Water Development, and Related Agencies
  House Committee on Appropriations
- **The Honorable Marcy Kaptur**
  Ranking Member, Subcommittee on Energy and Water Development, and Related Agencies
  House Committee on Appropriations
- **The Honorable Mike Rogers**
  Chairman, Subcommittee on Strategic Forces
  House Committee on Armed Services
- **The Honorable Jim Cooper**
  Ranking Member, Subcommittee on Strategic Forces
  House Committee on Armed Services

If you have any questions or need additional information, please contact me or Nora Khalil, Associate Administrator for External Affairs, at (202) 586-7332.

Sincerely,

Lisa E. Gordon-Hagerty
Under Secretary for Nuclear Security
Administrator, NNSA

Executive Summary

The 2018 Nuclear Posture Review (2018 NPR) affirms that the United States will sustain and deliver on-time the warheads needed to support both strategic and non-strategic nuclear capabilities by completing several key warhead sustainment and modernization activities and studies. Relevant to these efforts is restarting the W78 warhead replacement in fiscal year (FY) 2019, previously planned for FY 2020, to support fielding on the Ground-Based Strategic Deterrent by 2030. In August 2018, the Nuclear Weapons Council (NWC) directed the restart of the W78 warhead replacement program and established the name W87-1 for the warhead. With this direction, the Department of Energy's National Nuclear Security Administration (DOE/NNSA) is no longer planning for an interoperable warhead program as previously conceived. NNSA has no plans to pursue a W78 Life Extension Program (LEP) using the existing aeroshell, similar in scope to the ongoing W76 LEP. A W76 LEP-like refurbishment of the W78 warhead would not meet military requirements and would present several significant challenges and issues, as described in this report.

Previous and current analyses performed by NNSA and the Air Force for a W78 warhead replacement have concluded that a warhead with insensitive high explosives (IHE) meets Air Force and NNSA safety and security requirements and warfighter military characteristics. Replacing the conventional high explosives (CHE) in the current W78 warhead with IHE is the single most significant weapon system change that improves the warhead's safety and security. Using IHE also enables a broader range of solutions to improve use control and facilitates production efficiencies. An important benefit of an IHE-based design is the cost avoidance resulting from improved efficiencies during production and transportation operations.

The NWC approved military characteristics for the W87-1 in August 2018. These military characteristics require NNSA to field IHE in the W87-1 and the Air Force plans to take advantage of IHE benefits in the areas of operational and storage safety and integrated security operations. A W78 LEP would provide little to no improvement to safety and security because the CHE would not be replaced with IHE. The classified annex which accompanies this report provides more specifics on the benefits of IHE for the W87-1 warhead.

The projected cost provided in this report is a representative estimate for the W87-1 program and will be reflected in the next Stockpile Stewardship and Management Plan for FY 2020. The projected cost for the W87-1, in then-year dollars, is a low of $8.6 billion and a high of $14.8 billion. This does not include the cost for pit production. Costs for pit production will be included in the program's Weapon Design and Cost Report, which will be created at the end of Phase 6.2.

NNSA is committed to improving the safety and security of the W78 warhead, meeting military requirements, and meeting 2018 NPR direction by replacing the W78 with an IHE-based W87-1, using a well-tested IHE primary design. Additional information supporting the rationale for using IHE and issues and concerns about a W78 LEP are provided in the classified annex to this report.

W78 Replacement Program (W87-1): Cost Estimates and Use of Insensitive High Explosives

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I. Legislative Language

This report responds to legislative language set forth in the Conference Report accompanying the *Energy and Water, Legislative Branch, and Military Construction and Veterans Affairs Appropriations Act, 2019* (P.L. 115-244) on page 165, wherein it states:

> *"In lieu of language in the House report on the W78 Life Extension Program (LEP), the NNSA is directed to provide to the Committees on Appropriations of both Houses of Congress, not later than 60 days after the of enactment of this Act and prior to commencement of phase 6.2, a report that provides the rationale for an insensitive-high explosive (IHE)-based system, an updated estimate of the cost and schedule for warhead development and production, and a rough order of magnitude cost and schedule comparison of the differences between the requested IW and a W76 LEP-like refurbishment of the W78."*

II. Introduction

The 2018 Nuclear Posture Review (2018 NPR) affirms that the United States will sustain and deliver on-time the warheads needed to support both strategic and non-strategic nuclear capabilities by completing several key warhead sustainment and modernization activities and studies. Relevant to these efforts is restarting the W78 warhead replacement, previously planned for fiscal year (FY) 2020, in FY 2019 to support fielding on the Ground-Based Strategic Deterrent (GBSD) by 2030. With this direction, the Department of Energy's National Nuclear Security Administration (DOE/NNSA) is no longer planning for an interoperable warhead (IW) program as previously conceived.

The W78 warhead is currently deployed on the U.S. Air Force Minuteman III (MMIII) intercontinental ballistic missile. Over time, the program to replace the W78 warhead has changed to reflect adjustments in strategic planning and policy direction. The initial W78 program to address the aging warhead was conceived as a life extension program (LEP), named the W78-1. Soon thereafter, and in conjunction with the adoption of the Nuclear Weapon Council's (NWC) 3+2 strategy in 2012, the program shifted to an IW program and renamed as the W78/88-1 (also referred to as the IW1). In 2014, the NWC made the decision to pause the program and planned the restart of the IW1 program for FY 2020. In response to the goals and priorities outlined in the 2018 NPR, NNSA is no longer planning an IW1 program. In August 2018, the NWC authorized restart of the W78 replacement warhead program and established the name as the W87-1. NNSA has begun to incorporate this name into program documents and reports.

III. Rationale for an Insensitive High Explosive - Based System

High explosives are essential to the operation of all nuclear weapons. High explosives compress the fissile material and initiate the chain of events leading to nuclear yield. NNSA uses two types of high explosives for the weapon's main charge:

- Conventional high explosives (CHE), which are high explosives that detonate when given sufficient stimulus via a high pressure shock. Stimuli from severe accident environments such as those involving impact, fire, or electrical discharge may also initiate the detonation or deflagration of CHE; and
- Insensitive high explosives (IHE), which are high explosives that require a significantly higher shock stimulus than CHE to detonate or react violently. Stimuli from almost all credible accident environments will not initiate IHE.

NNSA's mission incudes improving safety and security of the Nation's nuclear weapons as set forth in Title XXXII of the National Defense Authorization Act for Fiscal Year 2000[1] (NNSA Act). Previous and current analyses performed by NNSA and the Air Force for a W78 replacement warhead have concluded that IHE-based systems meet Air Force and NNSA safety and security requirements and updated military characteristics.

The W78, which is a CHE system, is currently fielded in the Mk12A aeroshell on the MMIII missile. Changing from CHE to IHE in the current Mk12A aeroshell presents significant technical problems: the additional mass and volume of IHE would be difficult to fit into the current Mk12A aeroshell. Fortunately, for the W87-1, conditions allow trade space in terms of mass and volume for an IHE-based primary. The W87-1 will be fielded in the larger Mk21A aeroshell and deployed on the planned GBSD system that will replace MMIII missiles. The GBSD's anticipated capabilities and the larger Mk21A aeroshell together enable NNSA to plan for an IHE system based on a well-tested IHE primary design.

The use of IHE provides four major benefits to the stockpile: it improves safety; improves security; allows robust use control; and facilitates production efficiencies.

Improved Safety

The consequences of a nuclear weapons incident involving high explosive detonation would likely be grave and wide-ranging, including possible loss of life, destruction of infrastructure, dispersal of plutonium and uranium, and extensive cleanup costs. While the CHE formulations in the current stockpile are significantly better than historical materials, IHE is a much more insensitive explosive and was first deployed in nuclear weapons in 1979. Because of IHE's

[1] P.L. 106-65. Section 3211(b)(2) of the NNSA Act states that NNSA's mission is "To maintain and enhance the safety, reliability, and performance of the United States nuclear weapons stockpile, including the ability to design, produce, and test, in order to meet national security requirements."

insensitivity to stimuli, the consensus of the NNSA high explosives community is that IHE is the single greatest improvement that can be made to nuclear weapon safety, particularly in the event of a high energy event such as an airplane crash, missile explosion, or lightning strike.

IHE improves the safety of nuclear weapons throughout manufacture, assembly, maintenance, operation, disassembly, and transport to and from NNSA and Department of Defense (DOD) facilities.

Explosive accidents in the 1950s and 1960s led to development of less sensitive CHE and IHE explosives, both now fielded in the current stockpile. DOE developed a series of tests for high explosives to assess insensitivity, to include:

- Mechanical impact tests (drop-weight, high-speed impact, deformation and puncture, skid tests, and bullet impact);
- Thermal tests (thermal ignition, deflagration, and fire “cook-off”);
- Shock tests (nearby explosion and initiation across gaps); and
- Electrical insults (electrostatic discharge).

Full-system tests have demonstrated the safety advantages of IHE over CHE in a wide range of environments. In the most likely accident scenarios, the use of IHE reduces the probability of an explosion or energetic reaction of a weapon’s primary charge.

Improved Security

Security vulnerability assessments are regularly performed as part of integrated safety and security management to identify hazards and threats and develop controls for them. The use of IHE in a weapon system allows for a greater range of security options, including flexibility in security response and procedures. Relative to IHE weapons, CHE-based weapons are vulnerable to more threats and require more limited security tactics, techniques, and procedures to ensure secure transportation. An IHE-based warhead system would simplify and allow for more effective integrated security operations. Additional information about improved security and IHE are in the classified annex to this report.

Use Control

Use control refers to the positive measures that allow the authorized use or that prevent or delay unauthorized use of U.S. nuclear weapons. Use control is accomplished through a combination of weapon system design features, operational procedures, security, and system safety rules. These features are usually distinguished into two groups, those inside the warhead (intrinsic features) and those outside it (extrinsic features). Using IHE enables a significantly broader range of design and engineering solutions for both intrinsic and extrinsic features to meet the requirement to function only when directed by the President and to never produce unauthorized yield. Additional information on the benefit of IHE in controlling the use of nuclear weapons is provided in the classified annex.

Production Efficiencies

IHE operations are approved as human-safe processes in which humans can be in contact with the explosive work. This level of safety significantly improves efficiency by reducing safety constraints and potentially allowing multiple, parallel operations in current facilities. This contrasts with CHE operations which require additional controls, operational procedures, and plant services. Compared to similar efforts involving CHE, IHE processes can conceivably result in a doubling of throughput.

The most significant production efficiency to be gained is at the Pantex Plant outside of Amarillo, Texas. Pantex is responsible for the assembly, disassembly, and some aspects of system-level surveillance of all weapons in the stockpile, and for dismantling and disposing of weapons that have been retired. Work at Pantex is done in special bays and cells. The design of these facilities embeds capabilities to minimize consequences of a major accident involving the detonation or violent reaction of high explosives.

Cells are designed to collapse on themselves to contain the debris of an inadvertent detonation and minimize off-site effects. All CHE operations (e.g., weapon assembly or disassembly) are conducted in cells that only allow work on one unit at a time. CHE is also prohibited from being stored in the cell during assembly or disassembly operations. CHE material must be brought into the cell for a specific operation (e.g., assembly) and taken out of the cell immediately after an operation. These constraints affect the flow of operations and require additional facility support to transport the CHE to and from authorized storage areas.

Operations on IHE-based weapons are conducted in bays that are designed with the understanding that the probability of high explosive detonation or high explosive violent reaction during weapons operations is essentially zero. Pantex has more bays than cells, and each bay is large enough to allow multiple weapons operations at the same time, if desired. IHE can also be stored within the bays, which eliminates the need for frequent transportation between bays and separate storage locations. The safety advantages of being able to use bays versus cells for IHE operations results in the cost for IHE operations being lower than those for CHE.

IV. Cost Projection for Warhead Development and Production

The cost projection provided in this report is the most representative estimate for the W87-1 program and will be reflected in the next Stockpile Stewardship and Management Plan (SSMP) for FY 2020. The estimate includes both the program's projected budget and other critical activities such as technology maturation. Also, for estimating purposes, the chart depicts scope meeting all objective requirements. Some of that scope may be eliminated during Phase 6.2 evaluations.

The method for developing this cost projection is one used in the SSMP provided to Congress annually. NNSA's method is an analogous and parametric estimating process that uses previous or related program costs as the basis of the estimate. Subject matter experts and programmatic representatives from NNSA, the national security laboratories, and production plants provide complexity scores relative to the reference cost estimate, which factor into the new cost projection. Like SSMP estimates, the cost projection is shown as a range of low to high estimates, and escalated to display then-year dollars. NNSA used an escalation rate of 2.22 percent. The estimated cost projection for the W87-1, in then-year dollars, is a low of $8.6 billion and a high of $14.8 billion (Figure 1).

Figure 1 is an updated cost projection from the FY 2019 SSMP for the W87-1. This projection is the initial program estimate for the W87 scope as it currently exists based on Air Force military characteristics from August 2018. Previous SSMP estimates, which reflect the IW1 program, underestimated the complexity of addressing challenges of newly manufactured warhead components including development of new IHE, enhanced classification anticipated with GBSD, surety features in ballistic missiles, new capability needed for secondary and nuclear explosive package work, increased program management control, and integration with GBSD and Air Force aeroshell acquisition program. These complexities have been adjusted based on experiences and lessons learned from the W80-4, B61-12, and W88 Alt 370 programs. This projection more accurately reflects programmatic funding needs than previous estimates for IW1.

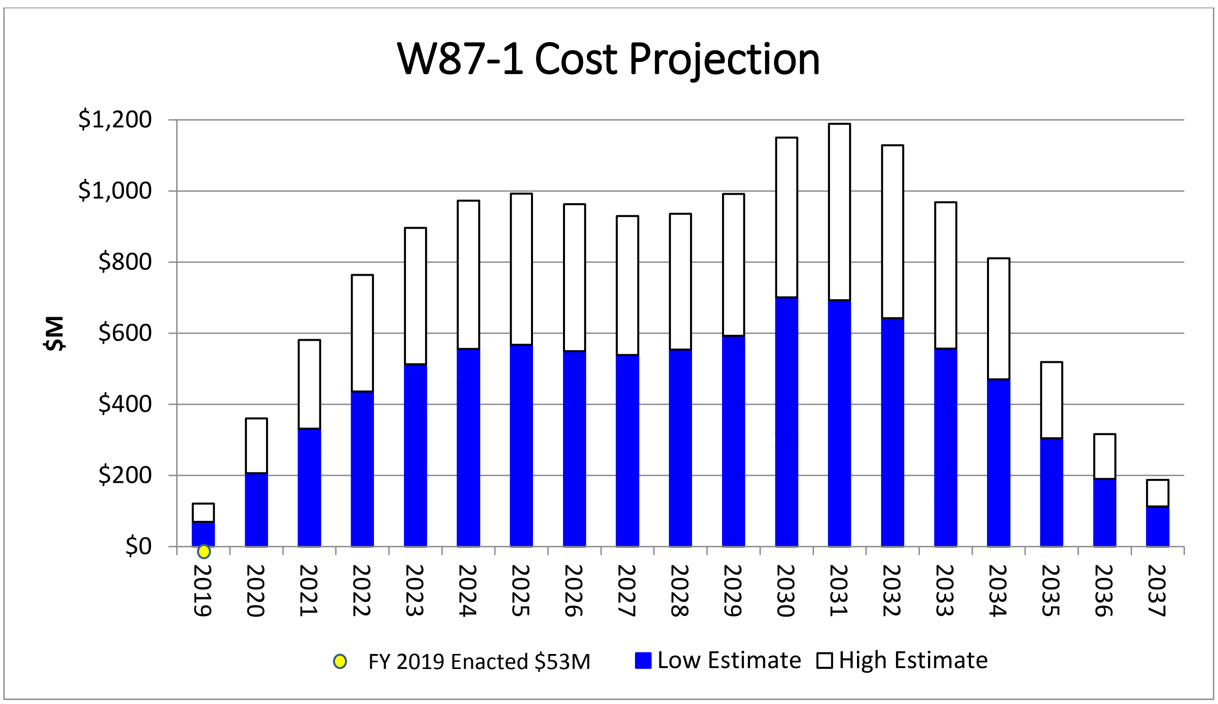

Figure 1 - W87-1 Cost Estimate in Then-Year Dollars

NNSA is currently planning for the W87-1 program to include newly manufactured pits and newly manufactured canned subassemblies (CSAs), but pit costs are not included in the W87-1 cost projection. Because NNSA must manufacture new pits to meet NWC requirements, the requirement and cost for new pit manufacturing capability and capacity development as well as qualification and certification are born by the Plutonium Sustainment program, related facility and infrastructure investments, and capital acquisition projects—not by any specific warhead program. This campaign to establish a national pit manufacturing capability at required capacity must happen even if the W87-1 program must, for some unplanned reason, deploy with a reused pit. If that were to be the case, then the pit manufacturing campaign would provide new pits for the LEP or replacement program that follows the W87-1.

If the W87-1 program does incorporate newly manufactured pits as planned, then the program's production cost will need to include the variable cost of pit production, which is currently not reflected in the W87-1 cost projection above. The Weapon Design and Cost Report (WDCR), which will be created at the end of Phase 6.2, will include pit production costs if the program is authorized to enter Phase 6.3. Until such time as a WDCR is created and for the purpose of this report, NNSA will assume that production cost for the W87-1 with pit manufacturing would increase production year costs by 10 percent (low) and 15 percent (high) consistent with preliminary estimates based on a limited production of W88 pits between FY 2007 and FY 2012. This increase represents an estimate of pit production variable cost that the W87-1 would fund above base pit production capability and capacity.

V. Comparison of W87-1 Cost Projection with W76 LEP-like Refurbishment of the W78

NNSA subject matter experts, programmatic representatives as well as laboratory and production plant representatives created complexity scores for a W76 LEP-like refurbishment of the W78 (W78 LEP) warhead to create a cost estimate. Like SSMP estimates, the updated cost estimate is represented as a range of low estimate to high estimate and escalated to display then-year dollars. NNSA used an escalation rate of 2.22 percent. The estimated cost for a W78 LEP, in then-year dollars, is a low of $8.5 billion and a high of $14.3 billion (Figure 2).

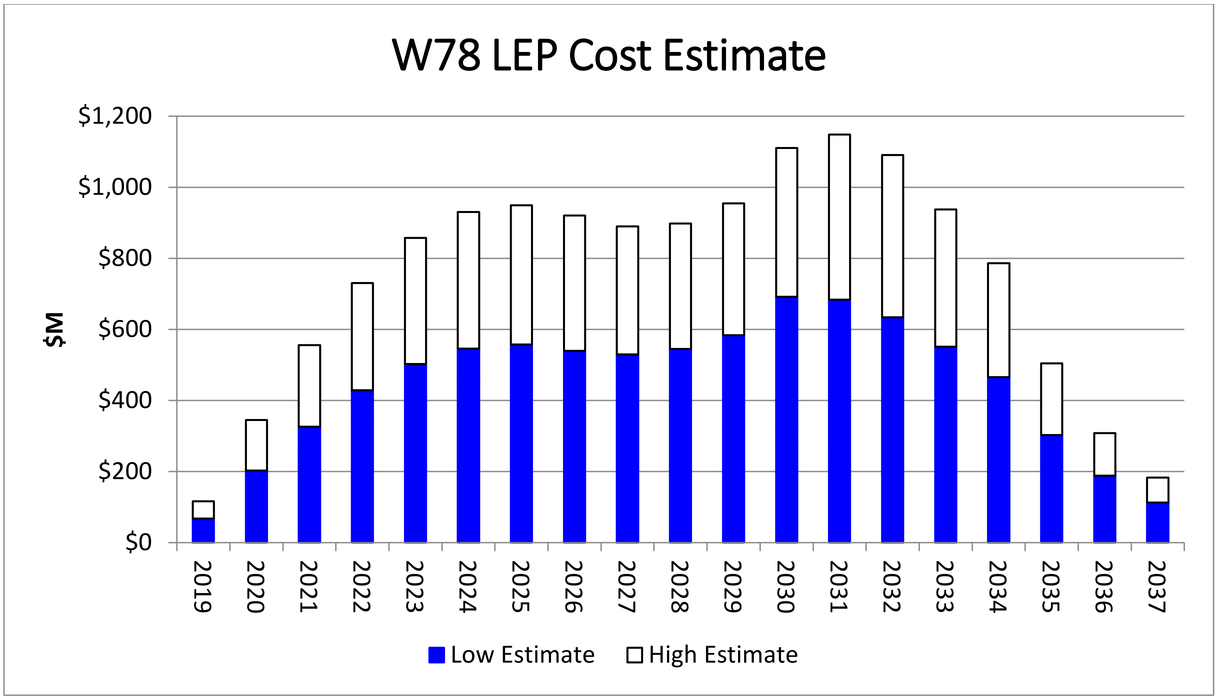

Figure 2 - W76-1 like LEP of the W78 Cost Estimate in Then-Year Dollars

Discussion on Cost Comparison

Table 2 provides a summary of a cost comparison between the planned W87-1 Program and an estimate of a W76 LEP-like refurbishment of the W78 warhead.

Estimate	Low ($M)	High ($M)	Comments
W87-1	$8,585 (+$300)	$14,778 (+$750)	IHE main charge, significant surety improvement, 100 percent newly remanufactured, meets military requirements. Approximate additional costs for pit manufacturing shown in parentheses
W78 LEP	$8,459	$14,218	CHE main charge, scope modeled after W76-1, pit reuse, does not meet military requirements, does not adhere to current NNSA surety improvement requirements

Table 2 - Summary of W87-1 and W78 LEP Cost Estimates

The cost projections of the planned W87-1 and a W78 LEP are very close when the cost of pit production is not included. It is important to note that the W76 LEP was a comprehensive refurbishment program with considerable remanufacturing, including full remanufacturing of the CSA. Consequently, the estimate of a similar comprehensive program for the W78 is comparable to any modernization effort, including replacing the W78 with the W87-1 as the estimates show here. Remanufacturing the W78 CSA is estimated to be much more complex and challenging than remanufacturing the W76 CSA or the present CSA design for the W87-1. The W87-1 estimate includes more complexity and scope related to surety improvements compared to a W78 LEP, and this offsets the difference in complexity in CSA manufacturing. The additional cost to develop and manufacture IHE for the W87-1 compared to the CHE in the W78 LEP is $200 million to $400 million. This is included in the W87-1 cost estimate in Figure 1. The estimated cost of pit production, if borne by the W87-1, would add $300 million to $750 million to the total estimate. This additional cost provides great benefit to the warhead's safety and security capabilities as described in section III. While a W78 LEP program would be marginally less costly, NNSA has concerns and issues with pursuing a W76 LEP-like refurbishment of the W78.

Concerns and Issues with a W76 LEP-Like Refurbishment of the W78

A W76 LEP-like refurbishment of the W78 would present several significant challenges and issues. A W78 LEP would provide little to no improvement to safety and security and would not meet the military characteristics approved by the NWC for a W78 replacement warhead. A W78 LEP would re-use the existing pit, which could necessitate changes to the primary implosion system to increase performance margins to guard against uncertainties due to the aging of plutonium. The existing W78 CSA would be very difficult to manufacture and qualify, and the current military requirement does not support using this CSA. A W78 LEP would not meet current Air Force requirements in the areas of operational and storage safety and integrated security operations. The Air Force's plans for upgrading warhead storage facilities will be designed and qualified to only store IHE warheads, which means a W78 LEP would not meet storage requirements. Additional information on this section is provided in the classified annex.

VI. Conclusion

Warhead modernization incorporating IHE will help achieve the goal of a safe, secure, and effective nuclear weapons stockpile throughout the W87-1 lifecycle. For the Air Force, replacing CHE with IHE is the single most significant change that can improve the safety and security of the Nation's stockpile. Using IHE improves system safety and security and enables a broader range of solutions to improve use control. IHE facilitates production efficiencies as well as eventual cost avoidance that comes from reducing the risk from low-likelihood but high-consequence accidents during operations, production, and transportation. Changing from CHE to IHE can be a challenging technical problem, but the W87-1 warhead will be fielded in the larger Mk21A aeroshell and deployed on the planned GBSD that will provide the space and capability for an IHE design. The primary design being used is based on a well-tested IHE design.

The cost estimates of the planned W87-1 Program and a W78 LEP are very close when the cost of pit production is not included and only 5 – 10 percent greater production cost when pit production is included. While a W78 LEP program would be slightly less costly, it would not meet NNSA and DOD requirements, would not improve warhead safety and security, and would require expensive and complex CSA production and qualification.

Additional information supporting the rationale for using IHE and issues and concerns about a W78 LEP are provided in the classified annex to this report.