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Precision Low-Yield Weapon Design (PLYWD)

Joint DOD-DOE Phase 1 Study

Final Report (U)

30 December 1994

Lt Col Roger F. Kropf
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Classification Sources

1. CG-W-5, DOD/DOE Nuclear Weapons Classification Guide
2. Lawrence Livermore National Laboratory
3. Los Alamos National Laboratory/Div X-5
4. Sandia National Laboratory/Div 5100
5. US Army Armament, Research, Development, and Engineering Center (ARDEC), Picatinny Arsenal, NJ

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PLYWD Phase 1 Report

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Many people from diverse organizations contributed significantly to this study. We cannot adequately express appreciation for the largely unsung work by so many contributors. The following people were involved in the PLYWD Phase 1 Study. This list is not all inclusive, and we apologize for any omissions.

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(U) EXECUTIVE SUMMARY

(U) Based on a request from Lt Gen Leo Smith, VICE CINCSAC, the Secretary of the Air Force (SAF/AQQ) tasked the Nuclear Weapons Concept Division of the Office of Aerospace Studies (OAS/XRN) to initiate a Phase 1 study of a precision, low-yield weapon design (PLYWD) in December 1991. The Department of Energy headquarters (DOE/HQ) sent a separate tasking letter to DOE Albuquerque Operations (DOE/AL) and the national laboratories directing them to support the study.

(U) The tasking letters defined the PLYWD weapon as an aircraft delivered, precision, low-yield nuclear weapon. The primary criteria was to be reduction of collateral damage while satisfying mission effectiveness requirements. The overall concept of PLYWD was to develop a precision glide bomb with some standoff capability, which would improve upon and replace gravity bombs. Although some form of propulsion was allowed, cruise missile concepts were not considered. Further, the study did not focus on an earth penetrating weapon (EPW), although some penetrating capability was examined because of its potential to reduce collateral damage. The emphasis of the study was on low-yield, precision, air and surface burst weapons.

(U) The study was initially scheduled to be completed in December 1992 but was extended to July 1993 because of the large target base involved and the need for new methodologies to evaluate low-yield weapons. Five working groups and an executive working group were formed which included representatives from the DOE National Laboratories; Defense Nuclear Agency (DNA); Field Command, DNA; United States Geological Survey; Defense Intelligence Agency; Department of the Army, Armament Research, Development and Engineering Center; Air Force Materiel Command, Office of Aerospace Studies; Aeronautical Systems Center; and Headquarters Air Combat Command (ACC). The breadth of scientific, technical, operational, and logistical expertise was invaluable in accomplishing the PLYWD study.

(U) The PLYWD study considered carriage on B-52H, B-1B, B-2, F-15E, F-111F, and F-16 aircraft. Requirements for aircraft such as NATO's Tornado and US Navy aircraft, were not considered in this study but could be considered in a Phase 2 effort.

[redacted] Exemption #1

(U) PLYWD concepts range from near term (i.e., < 5 years) to far term (i.e., > 10 years). Near term concepts include incorporation of nuclear warheads in existing precision guided munitions such as the AGM-130 and AGM-142 weapons. Farther term options include a JSOW-like weapon and standoff bomb designs.

(U) A wide range of warhead conceptual designs are available to incorporate into a PLYWD system. To varying degrees these rely on existing technologies, evolving technologies, reuse of warheads, reuse of warhead components, and new nuclear and nonnuclear component fabrication capabilities. Current technology allows the development of reliable PLYWD weapons systems meeting modern safety requirements. During the study, the need to identify underground test requirements was recognized. Many of the warhead candidates are anticipated not to require underground nuclear testing.

Exemption #1

(U) The PLYWD Executive Working Group recommends that a Phase 2 Feasibility Study for a PLYWD system be initiated in FY 94. This is based on the overall assessment of the PLYWD concepts. PLYWD can be effective against a large fraction of potential targets, can reduce collateral damage on a significant number of targets, is technically feasible, and can provide aircraft standoff (and thus improve survivability). A Phase 2 study should consider the following:

Exemption #(

[redacted]

2. (U) The collateral damage criteria developed in this study should be validated from both military and political perspectives and used in future collateral damage studies.

[redacted]

Exemption #1

4. (U) In light of the continuing global proliferation of hard, buried targets and the utility of a PLYWD EPW system against these targets, an EPW should be considered either as a warhead alternative in a PLYWD Phase 2 study or as a separate EPW Phase 2 study.

5. (U) Because of questions about the certification of non nuclear components, a Phase 2 study should consider in more detail the impact of possible utilization of conventional weapon system components and subsystems within the PLYWD system.

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1 (U) INTRODUCTION

1.1 (U) TASKING

(U) The Assistant Secretary of the Air Force for Acquisition of Strategic Systems (SAF/AQQ) tasked the Nuclear Weapons Concept Division of the Office of Aerospace Studies (OAS/XRN) to initiate a Phase 1 study of precision delivered low-yield nuclear weapons on 11 December 1991. The Department of Energy headquarters (DOE/HQ) sent a separate tasking letter to DOE Albuquerque Operations (DOE/AL) and the national laboratories directing them to support the study. Appendix A contains a copy of the Air Force and DOE tasking letters. The primary purpose of the study, as defined by the tasking documents, was to investigate the possible development of of an aircraft-delivered, precision low-yield nuclear weapon. The use of precision guidance could permit the Air Force to accomplish some missions as effectively, or more effectively, with low-yield weapons. They would potentially have the advantages of reduced collateral damage, lower requirements for special nuclear materials (SNM), and the possibility of carrying more weapons on a single platform.

(U) The key criterion to be used in evaluating options was collateral damage. Additionally, probabilities of damage (Pd) at least equal to current capabilites, survivability, and cost were identified as important criteria. The tasking directed that the study should give consideration to candidates with broad applicability in terms of appropriate missions and delivery aircraft. Estimates of the costs, to include both DOE costs and DOD's system integration cost, were requested. The feasibility and cost advantages of reworking an existing weapon to provide the desired capability was also to be investigated.

(U) The study was scheduled to be completed in December 1992. The completion date was extended to July 1993 because of the large target bases involved and the need for new methodologies to evaluate low-yield weapons. See Appendix A for the letter which extended the completion date for the study. This letter also added the requirement to identify underground testing requirements. The final report was not completed immediately upon completion of the study. Publication was delayed until October 1994.

1.2 (U) BACKGROUND AND SCOPING STUDY

(U) In July 1991, Lt Gen Leo Smith, VICE CINCSAC, approved HQ SAC/XOK sponsorship of a phase 1 study on low-yield/high accuracy nuclear weapons. SAF/AQQS tasked OAS/XRN to conduct a scoping study to better define the target bases, delivery systems, and identify specific questions to be addressed in the phase 1 study. This scoping study was completed in October 1991, and recommended separate Phase 1 studies to address aircraft-delivered and ICBM delivered precision low-yield weapons. The scoping study addressed four specific questions.

[redacted]

(U) Also addressed were the appropriate delivery schemes for such a warhead against these targets. The study concluded that aircraft and ICBM delivery should be studied separately.

(U) The third question addressed by the scoping study was whether the DOE laboratories had technologies capable of providing low yield warheads appropriate for the targets sets, delivery accuracy, and delivery schemes of interest. The conclusion was that the laboratories have the capability to meet the warhead requirements.

(U) The final question addressed in the scoping study was the cost of a low-yield, accurately delivered weapon. The study concluded that only rough order-of-magnitude (ROM) cost estimates would be possible in a phase 1 study.

[redacted]

(U) Concerns raised in the scoping study that needed addressing in a phase 1 study were:

- (U) The ability to quantify collateral damage
- (U) The need for an effectiveness figure-of-merit that can be applied consistently across different warheads, delivery schemes, and targets
- (U) The need to identify any special constraints related to specific delivery or carrier systems

1.3 (U) STUDY STRUCTURE

(U) Five working groups and an executive working group were formed in order to meet the objectives set forth in the tasking letter. They were the mission analysis (MAWG), system engineering (SEWG), warhead design (WDWG), requirements analysis (RAWG), and surety (SUWG) working groups. The original working group charters are included in Appendix B. The following paragraphs give a brief summary of the working group activities.

(U) The Executive Working Group (EWG) provided overall direction for the study and assumed responsibility for study completion.

(U) The MAWG analyzed the operational effectiveness of various warhead and weapon system concepts. They developed the target bases and mission scenarios. The MAWG, in conjunction with the EWG, established measures of collateral damage and analyzed the effects of PLYWD concepts on reducing collateral damage.

(U) The SEWG performed system engineering design and analysis, including preliminary weapon design and layout, warhead/weapon and weapon system/aircraft interfaces, system performance and standoff, guidance and control systems, terminal area sensors, and surety subsystems.

(U) The WDWG was responsible for developing and evaluating warhead design concepts. They provided ROM cost estimates for DOE warhead production.

(U) The RAWG produced the draft military characteristics (MC) and stockpile to to target sequence (STS) documents.

(U) The Surety Working Group (SUWG) ensured that elements of safety and use control were designed into the warhead and weapon system. They reviewed the safety theme and considerations associated with each phase of the STS. The SUWG ensured that use control devices and procedures were an integral part of the weapon design.

(U) The working groups were made up of representatives from the DOE; the DOE National Laboratories; Defense Nuclear Agency (DNA); Field Command, DNA; United States Geological Survey; Defense Intelligence Agency; Department of the Army, Armament Research, Development and Engineering Center; Air Force Materiel Command, Office of Aerospace Studies; Aeronautical Systems Center (Nuclear Systems Engineering Directorate); and Headquarters Air Combat Command (ACC). The breadth of scientific, technical, operational, and logistical expertise was invaluable in accomplishing the PLYWD study. Figure 1 shows the structure of the study.

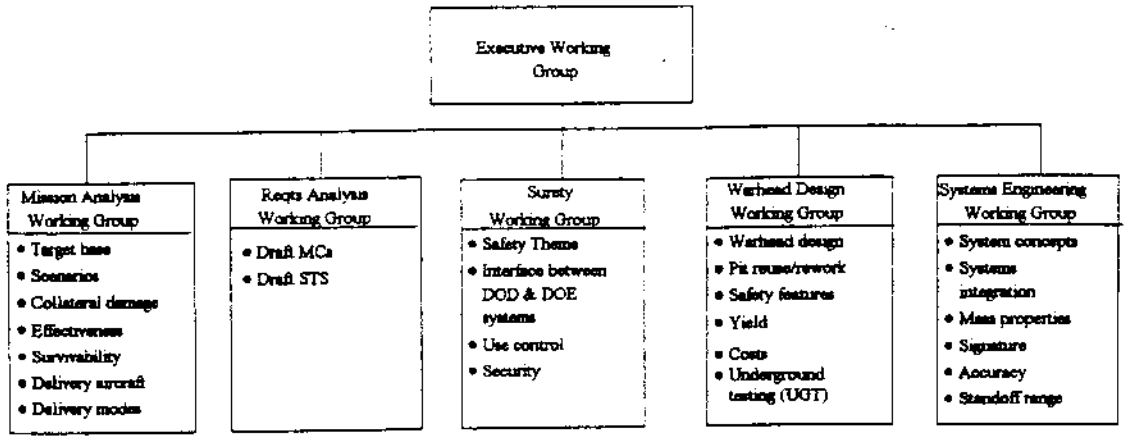

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Figure 1.1 (U) PLYWD Study Structure

1.4 (U) STUDY SCOPE

(U) The tasking letters defined the PLYWD weapon as an aircraft delivered, precision, low-yield nuclear weapon. The primary goal was to be reduction of collateral damage while satisfying mission effectiveness requirements. The overall concept of PLYWD was to develop a precision glide bomb with some standoff capability, which would improve upon and replace gravity bombs. Although some form of propulsion was allowed, cruise missile concepts were not considered. The emphasis of the study was on low-yield, precision, air and surface burst weapons. Earth Penetrating Weapon (EPW) options were also considered because of their potential for lower collateral damage while maintaining lethality against a subset of the targets considered.

(U) The PLYWD study considered carriage on B-52H, B-1B, B-2, F-15E, F-111F, and F-16 aircraft. Requirements for aircraft such as NATO's Tornado and US Navy aircraft, were not considered in this study but could be considered in a Phase 2 effort.

2 (U) NUCLEAR WEAPON SURETY

(U) The Surety Working Group was chartered with ensuring that elements of safety and use control are designed into the warhead and weapon system. They considered all aspects of nuclear surety and assured conformance to appropriate levels of performance, as required by the DOE and DOD. The WDWG had overall responsibility for developing the safety theme. The SUWG reviewed the safety theme and safety considerations associated with each phase of the Stockpile to Target Sequence (STS), identifying those phases which are safety critical. They also evaluated any technology or safety risks associated with advanced safety systems. The SUWG conducted an assessment of improvements in system safety associated with proposed design concepts. Furthermore, the SUWG was responsible for ensuring that appropriate use control devices and procedures are an integral part of the weapon design. Because of the overall systems approach of this study, coordination with other working groups was essential.

2.1 (U) COMMAND DESTRUCT

(U) If a PLYWD device lost guidance and control, the weapon would need some form of destruct to render the warhead unusable. The fuzing mechanism would need to default to a high-order non-nuclear detonation.

(U) There are several concepts that may be valid within the PLYWD conceptual bounds. These include Command Destruct (CD), Enhanced Command Disable (ECD), Auto-Destruct (AD), Command Destruct/Disable (CDD), and Remote Destruct (RD). The applicability of these concepts depends upon the deployment scenarios and specific needs that might arise from those scenarios.

2.2 (U) REQUIREMENTS GUIDELINES

(U) Guidelines for safety, use control and reliability were developed taking into account the software design environment under which PLYWD commands will be given. The following are the guidelines that must be met for each weapon:

2.2.1 (U) Safety Requirements

(U) Prior to weapon loading.

(U) Following weapon load.

(U) Warhead Command States:

- (U) Monitor
- (U) Safe and prior to Command Disable (CD)
- (U) Safe and Permissive Action Link (PAL)
- (U) Arm with Unique Signal Generator (USG) not completed

2.2.2 (U) Use Control Requirements

(U) Prior to weapon loading.

(U) Following weapons loading.

(U) Warhead command states:

- (U) Monitor
- (U) Safe and prior to Command Disable (CD)
- (U) Safe and Permissive Action Link (PAL)

2.2.3 (U) Reliability Requirements

(U) Prior to weapon loading.

(U) Following weapon load.

(U) Warhead command states:

- (U) Monitor
- (U) Safe and prior to Command Disable (CD)
- (U) Safe and Command Disable (CD)
- (U) Safe and Permissive Action Link (PAL)
- (U) Arm with USG not completed
- (U) Prearmed

2.3 (U) SYSTEM 1 AND SYSTEM 2

(U) System 1 provides analog discretes/waveforms PAL, Command Disable, Monitor, and Prearm. It has been implemented on Air Force aircraft and nuclear weapons systems. System 1 aircraft and System 1 weapons combinations have been Nuclear Certified. It requires that a digital to analog conversion be made when a digital aircraft carries a fielded nuclear weapon.

(U) System 2 provides as MIL-STD-1553 digital information PAL, Command Disable, Monitor, Prearm (US11, US12) Targeting, and Platform alignment. System 2 has been partially implemented on the B1-B, but to date there has been no combination of System 2 aircraft/weapons that has been Nuclear Certified. The inability to expand System 1 functionality has driven the PLYWD design concept towards System 2. System 2 interface will be required for a PLYWD delivery system to handle platform alignment and targeting. This is a major consideration for a PLYWD weapon. During SRAM II development, System 2 was proceeding toward resolution of interface issues, and the documentation may be useful for as a leadoff point. Resolution of the implementation of the unique signal issue would have to be accomplished.

2.4 (U) NUCLEAR CERTIFICATION OF CONVENTIONAL WEAPONS COMPONENTS

(U) Many of the PLYWD candidates were based on conventional guided weapons. This brought up the issue of nuclear certification for the components. There are no short cuts to certification. With integrated conventional/nuclear weapon systems, the more stringent requirements of the nuclear system usually add restrictions to the conventional systems.

(U) If hardware or software are to be used with nuclear systems, they must be certified through the same processes used for nuclear systems. Systems must meet the nuclear safety design requirements of AFR 122-9 and 122-10 for software and hardware, respectively. Separation of controls for critical prearming and release functions must be provided. A Technical Nuclear Safety Analysis (TNSA), a Nuclear Weapons System Safety Group (NWSSG) Review, and approved Air Force safety rules must be provided.

(U) Compatibility is another area that must be addressed. For aircraft, hardware and software must meet weapon system Seek Eagle requirements for nuclear compatibility certification under AFR 80-54. For non-aircraft launched missiles, integration of a nuclear system with an existing missile system will be supported by compatibility analysis for that missile system. Compliance with DOE compatibility requirements must be demonstrated in either Major Assembly Release (MAR) report or Aircraft Compatibility Control Drawing (ACCD), as applicable.

(U) Nuclear loading and delivery Technical Order manuals must be provided for aircraft. Conventional munitions technical orders can not be used. Aircraft safe escape is a critical issue with nuclear weapons and the supporting analysis must be done.

2.5 (U) SAFETY (SURETY) BASELINES

(U) The current Baselines for surety issues are:

- (U) Insensitive High Explosives (IHE)
- (U) Enhanced Nuclear Detonation Safety (ENDS)
- (U) Fire Resistant Pit (FRP) --as required
- (U) One Point Safe
- (U) Non-violent Command Disable
- (U) Category F or equivalent PAL
- (U) Minimization of Pu scatter

2.6 (U) RECOMMENDATIONS FOR PHASE 2 STUDY

(U) The following items should be pursued in Phase 2:

- (U) Develop a basis for safety themes that is consistent with both DOE and DOD requirements.
- (U) Recommend desired form of Destruct.
- (U) Expand the Use Control portion of the Surety Baselines.
- (U) Review and comment on the Military Characteristics and Stockpile to Target Sequence as they evolve.

6 (U) REQUIREMENTS

(U) The Requirements Analysis Working Group was chartered to develop draft Military Characteristics and Stockpile-to-Target Sequence documents. These documents are separate reports (PLYWD MCs and STS, April 1993). The MCs give the specific military requirements for this weapon. The STS document provides specific transportation, handling, operational, and storage environments that the weapon will experience. Normal environments are described and should not effect the operation of the weapon to specified limits. Certain abnormal environments are described and may effect the operation of the weapon to specified limits.

(U) Since this is a Phase 1 study effort, many specifics of the system were not available. They would be developed in follow-on studies. As such studies provide specifics, future MCs and STSs will evolve to reflect those changes. Warhead designs, yields, and capabilities will provide changes. Weapon carriers, interfaces, environments, and delivery schemes will also create changes. Identification of special concerns like collateral damage will influence changes.

6.1 (U) MILITARY CHARACTERISTICS

(U) Specific requirements for this weapon are initially described in the tasking for this study but are further developed as more knowledge is gained about the system. These requirements are reflected in the MCs. MCs for a phase 1 do not need to be very developed or expansive; however, the PLYWD Phase 1 MCs attached to this report are much more developed because they were based on the existing B61 nuclear bomb MCs. The B61 bomb MCs were chosen as the base because PLYWD is intended to be carried by fighter and bomber aircraft as is the B61. Recent concerns in the nuclear weapon community for enhanced safety have lead to new and different emphases in weapon design. Early in 1993, the RAWG compared the PLYWD MCs and the W91 MCs for incorporation of appropriate elements. (The W91, warhead for the Short Range Attack Missile (SRAM) Tactical version (SRAM-T), was the latest warhead taken to a high degree of joint DoD-DOE design completeness incorporating enhanced safety designs. The W91 MCs reflected the status of the W91 design.) The PLYWD MCs were updated during this comparison to include appropriate modern safety enhancements.

6.2 (U) STOCKPILE-TO-TARGET SEQUENCE

(U) The B61 STS is the parent document for the PLYWD STS which is much more developed than expected for a phase 1 study. The STS is Draft 2, dated April 1993. No changes were made past that draft because it closely matched the latest requirements.

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7 (U) COSTS

(U) Because of the conceptual nature of phase 1 studies, costs are not normally computed. SAF/AQQ requested that the PLYWD study develop rough order-of-magnitude costs. It should be emphasized that these costs are only rough order-of-magnitude. They are useful for relative comparisons of concepts and provide a general idea of costs. However, more exact costing will be required when more detailed designs are developed in phase 2 and 2A follow on studies. Costs were divided into DOD and DOE costs.

7.1 (U) DOD COSTS

(U) DOD rough order of magnitude (ROM) costs for PLYWD can be broken down into aircraft costs and munitions costs. The aircraft costs include OT&E, software and integration costs, and aircraft retrofit costs. The munitions costs range from no cost to the DOD (for completely supplied DOE weapons) to the costs for munitions test units and production costs for DOD supplied portions (bomb shells and guidance packages based on existing DOD conventional weapons). Tables 7.1 and 7.2 summarize these cost estimates.

7.1.1 (U) Assumptions

(U) The assumptions for this costing are:

- (U) FY1993 dollars
- (U) No contractor effort required for retrofitting warheads
- (U) No change in aerodynamics of weapons/aircraft
- (U) AFOTEC pays OT&E costs, not included in these estimates
- (U) Three captive carry and six flight with drops for flight tests
- (U) Aircraft costs for OT&E for bomber aircraft are not included since they are operational aircraft
- (U) EMD begins in FY95, ends in FY96
- (U) JDAM test units not available until FY99
- (U) JSOW units not available until FY00
- (U) Aircraft retrofit cost are for the number of aircraft as noted below

7.1.2 (U) Aircraft Costs

(U) All weapons designs will require these aircraft related costs. These ROM costs are based on the indicated number of aircraft. It does not include OT&E costs, but does include software, integration, and aircraft retrofit costs.

TABLE 7.1. (U) DOD AIRCRAFT COSTS

Aircraft	Number of Aircraft	Range of ROM Costs (FY93 $M)
F-15E	205	30-45
F-16C	221	8-12
F-111F	75	8-12
B-52H	67	30-45
B-1B	96	50-75
B-2A	10	50-75

7.1.3 (U) Munitions Costs

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(U) PLYWD concepts based on mating a warhead to a conventional weapon incur DOD costs for purchase of these units. The costs include eighteen required test units and purchase of 10, 50, 100, and 300 weapons.

TABLE 7.2. (U) DOD MUNITIONS COSTS

	DOD Costs (FY93 $M) for Number of Weapons Built			
Base Concept	10	50	100	300
DOE Weapons	0	0	0	0
JDAM	3-4.5	6-9	10-15	25-40
GBU-28	3	8	14	38
AGM-142	30	70	120-180	330-500
AGM-130	13	30	55	145
JSOW	8-12	18-27	28-45	75-110

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7.2 (U) DOE ESTIMATED WARHEAD COSTS

(U) All DOE costs are presented in Table 7.3 in constant FY 1993 dollars and include operating costs from Phase Three through the end of production. No laboratory R&D, stockpile maintenance, stockpile evaluation nor nuclear testing costs, are included. Cost estimates were developed in-house by DOE/AL and do not reflect budget quality estimates. Note that future warhead manufacture may have a distinctly different nature than represented by past experience given the development of new technology, the necessity of responding to new political and environmental concerns, and the changes anticipated in DoD-requested production volumes and DOE production capacity. Hence, the costing provided here can only serve as a rough order-of-magnitude guide to potential manufacturing costs. Note that the DOE production costs associated with the near-term candidates (requiring little modification to existing weapons) are relatively modest.

(U) Table 7.3 summarizes the cost estimates for all California and New Mexico candidates. The second and third columns present the estimated total direct unit production costs for builds of 50 and 100 warheads, respectively. The fourth column presents the estimated total direct war reserve production cost for tooling and production/process engineering, and the fifth column presents the direct unit cost per warhead after the first production unit (FPU).

TABLE 7.3 (U) WARHEAD CANDIDATE PRODUCTION COST ESTIMATES
(FY 1993 DOLLARS)

Candidate	Cost range for a 50 warhead build (million $)	Cost range for a 100 warhead build (million $)	Tooling & P/PE costs (million $)	Unit cost after FPU (thousand $)
CA-01	0.045-0.075	0.10-0.15	0	1.0-1.5
CA-02	40-55	45-60	35-50	95-120
CA-03	205-255	225-280	185-230	400-495
CA-04	215-265	235-290	195-240	435-535
CA-05	225-280	245-305	205-255	420-515
CA-06	240-300	265-330	215-270	480-590
CA-07	230-290	255-320	205-260	475-585
CA-08	235-290	260-320	210-260	500-615
CA-09	285-355	310-385	260-325	500-630
CA-10	265-325	285-350	245-300	425-520
CA-11	310-380	335-415	285-345	565-695
CA-12	270-335	290-360	250-310	445-545
CA-13	290-360	320-395	260-325	590-730
CA-14	255-315	285-355	225-275	655-805
CA-15	230-285	260-320	200-250	580-715
CA-16	245-305	270-340	220-270	540-665
CA-17	285-355	325-405	245-305	775-950
CA-18	355-435	390-480	320-390	765-940
CA-19	305-380	330-410	280-350	555-685
CA-20	315-395	345-435	285-355	655-805
NM-01	10-15	10-15	9-14	15-20
NM-02	15-20	15-25	14-24	15-20
NM-03	10-15	15-20	5-10	75-90
NM-04	10-15	15-20	5-10	75-90
NM-05	230-285	250-315	210-255	450-555
NM-06	230-290	255-320	205-260	500-610
NM-07	230-285	255-315	205-255	480-585
NM-08	265-325	295-360	235-290	565-695
NM-09	270-335	295-365	245-305	515-630
NM-10	275-340	300-370	250-310	510-625
NM-11	255-320	275-350	235-290	465-575
NM-12	295-360	320-390	270-330	530-655
NM-13	445-545	465-575	425-515	470-580