NUCLEAR WEAPON DEVELOPMENT AND A DESIGN EXAMPLE

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Outline

1. Warhead design process overview
2. My current warhead program
3. Detonator integration

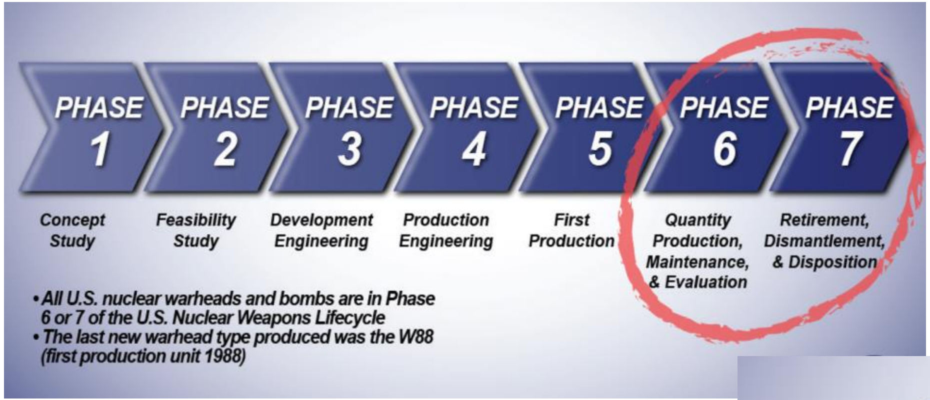
WARHEAD DESIGN PROCESS OVERVIEW

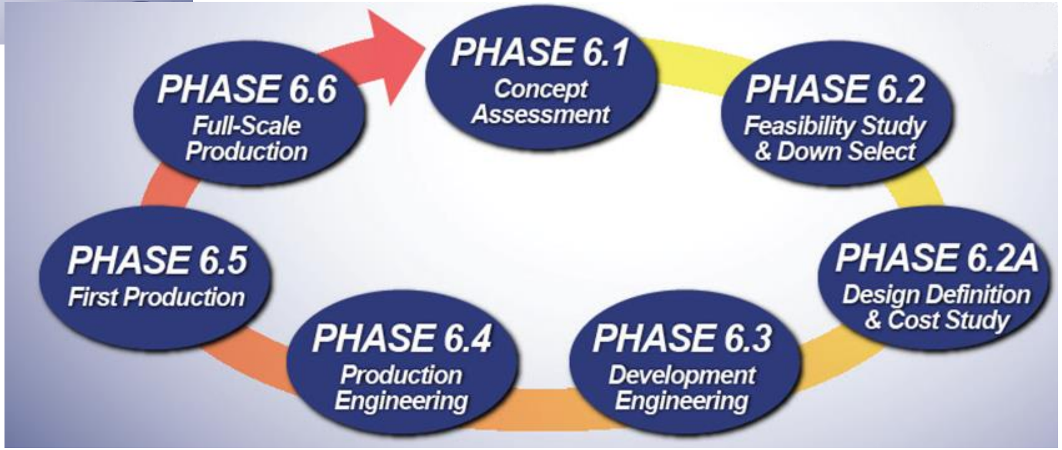
Warhead designers have two major constraints

1. Physics, and connection back to underground test results

2. Lifetimes, and projection of performance out to decades

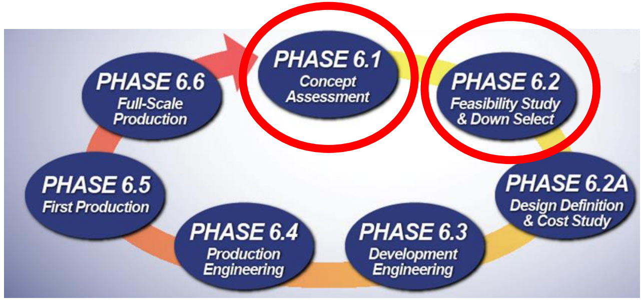
Warhead development follows a well-defined process





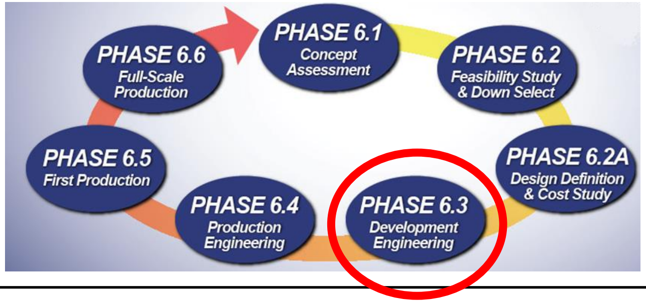
Warhead development begins with concept design and feasibility study

- **Step 1: Define requirements with stakeholders**
  - Military customers set requirements like yield, mass, volume
  - Physicists determine how far the design can deviate from systems that have already been underground tested
  - Department of Energy oversight helps determine what facilities are available for use, which drives which parts must be reused



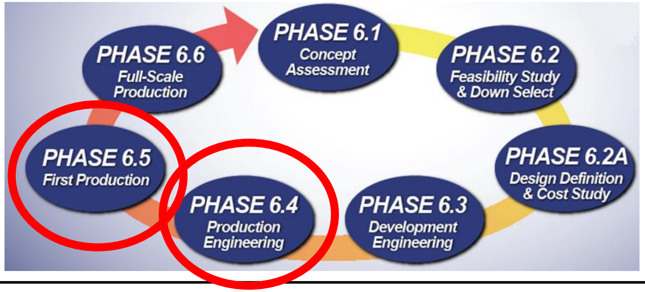
The development phase, 6.3, is when most of the design and validation occurs

- The team develops the detailed design of the system, including engineering drawings
- Iteration with manufacturers begins, ensuring producibility
- Test plans are laid out and executed
  - Component tests to validate parts meet their specific requirements (days to weeks)
  - Subsystem tests to validate parts interface properly (weeks to months)
  - System tests to validate that the entire design functions properly in environments (months to years)
  - Hydrodynamic tests to validate physics functionality
  - Chemical compatibility testing to validate that no poor material interactions exist in the system



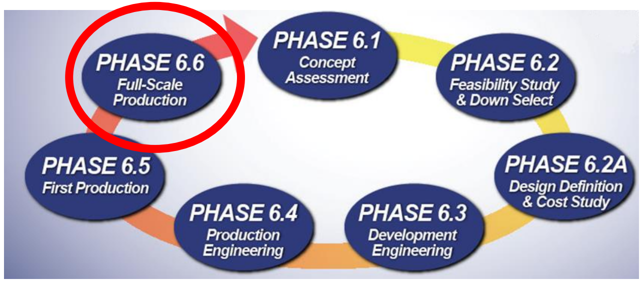
Phase 6.4, production engineering, includes production scale-up activities and continued validation testing

- Nuclear Weapons Council approval is required to move into full-scale production engineering, as costs and impacts to facilities go up significantly during this phase
- Significant production lots are produced, and evaluations are performed to ensure that the parts meet their design intent
- Long-term testing keeps going, including repeats of large tests performed in the previous phase, with the addition of higher-fidelity hardware
- At the end of this phase the First Production Unit is produced
- Design agencies must certify that the warhead will work with its required reliability, for the entire warhead lifetime



Warhead is handed over to a long-term project team at full scale production phase

- Phase 6.6 activities are executed by a production warhead team instead of a life extension program
- Warheads are produced and may go to one of three locations:
  - Storage at the production site
  - Storage at a military facility
  - Fielded at an operational base
- Full-scale production of a given system lasts from three to ten years, depending on the quantities required



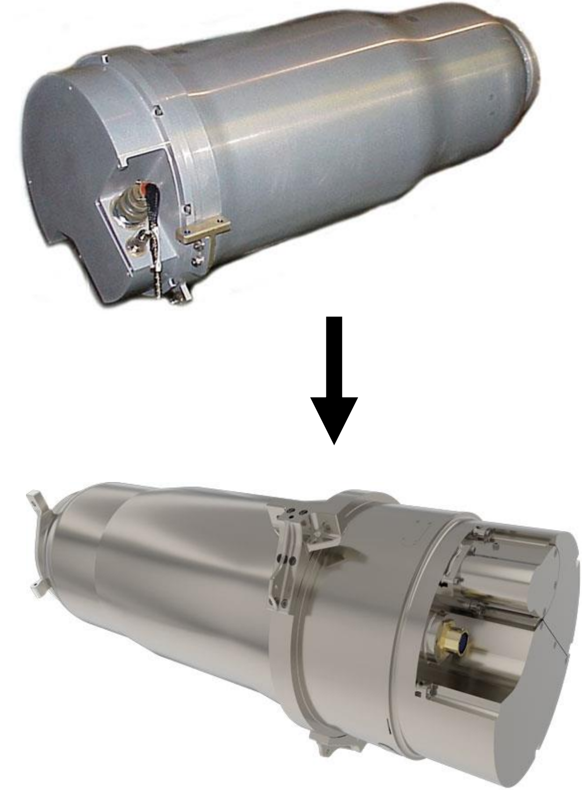
Once production is complete, warheads are surveilled for their entire life cycle

- Assessment of changes to the warhead environment is a task for the life of the warhead
- Annual disassembly cycles and assessment of parts coming out of the warheads allow assessment of the health and longevity of the system
- Any anomalies noted may spark Significant Finding Investigations, in-depth investigations to determine the cause and impacts of the anomaly

THE W80-4 LIFE EXTENSION PROGRAM

My current program is the W80-4 LEP

- The W80-4 Life Extension Program is currently in Phase 6.3
- Refresh and redesign of the W80-1 warhead, which is the nuclear warhead for the Air Launched Cruise Missile
- The W80-1 is a two-stage miniaturized thermonuclear warhead that can provide multiple selectable yields
- The W80-4 will be fielded on the LRSO cruise missile
- I am responsible for the engineering design and integration of the primary stage of the nuclear device

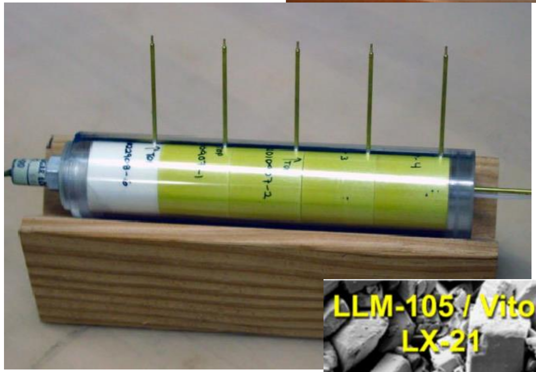


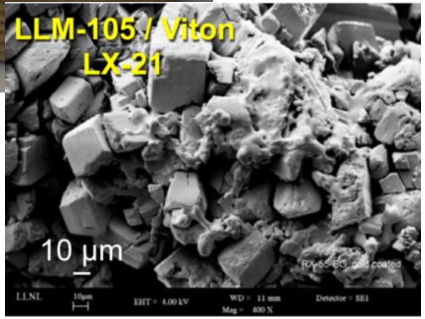
The W80-4 Life Extension Program is an unusually ambitious 6.X program

A typical life extension program refreshes components reaching end of life but makes no other changes

The W80-4 LEP primary includes:

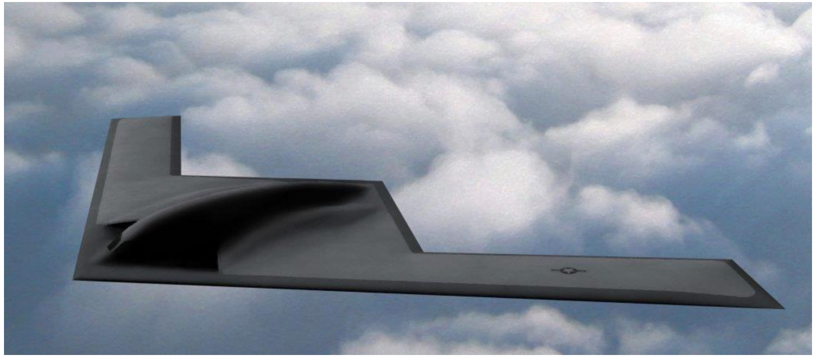
- Remanufactured high explosive main charges
- New insensitive booster materials
- Additively manufactured polymeric components via Direct Ink Write
- **Stronglink detonators**





A major complication of the program is integration with a new platform

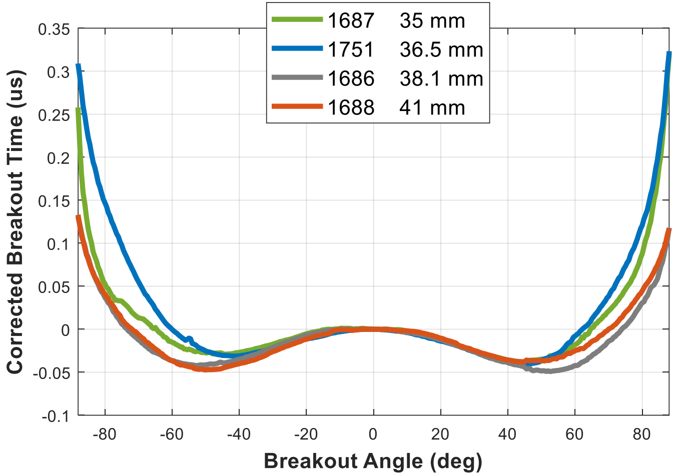
- The W80-4 is being designed in parallel with its delivery platform, the LRSO missile
- The LRSO will be delivered by the B-52 plane and the future B-21 (B-2 replacement bomber)
- No measurements of the handling or flight environments are available to warhead designers
- Best-guess environments are used based on measurements taken on the ALCM

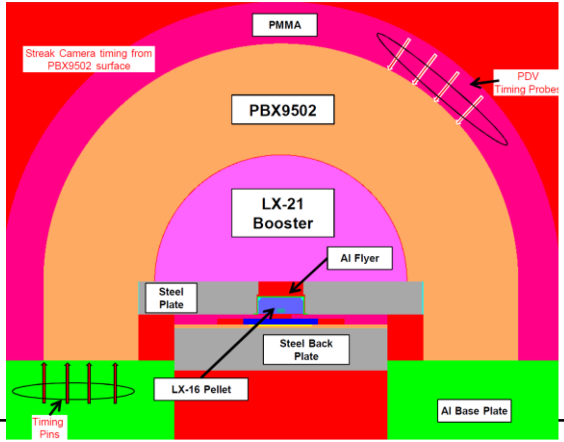


DETONATOR INTEGRATION

Initiation train integration is one of the most critical warhead design aspects

- Detonator performance is a key driver of nuclear system performance
- Explosive breakout is assessed via an experiment called a “snowball” or an “onionskin”
- Shock breakout time must be within a very tight timing specification (hundreds of nanoseconds) to ensure correct implosion geometry

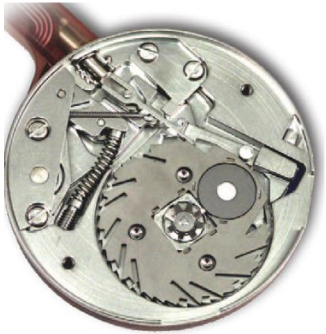


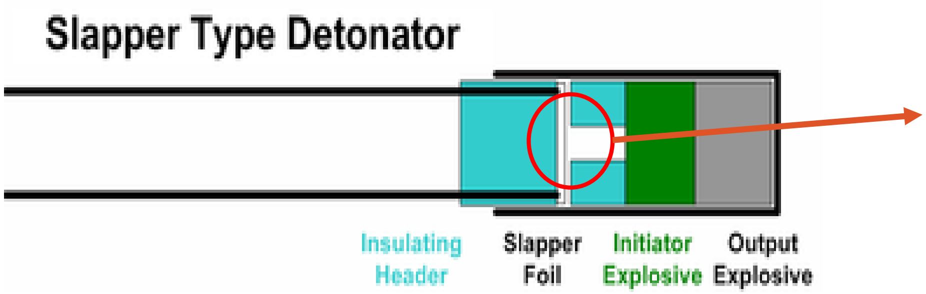


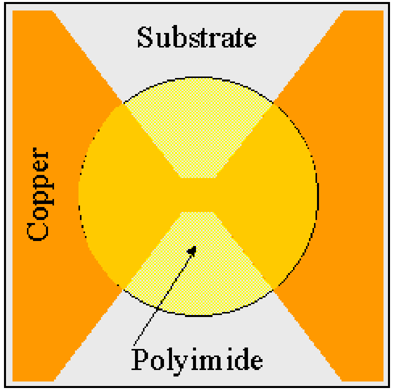
Customer requirements drive implementation of complex detonators

Both DOE orders and military customers desired enhanced safety features

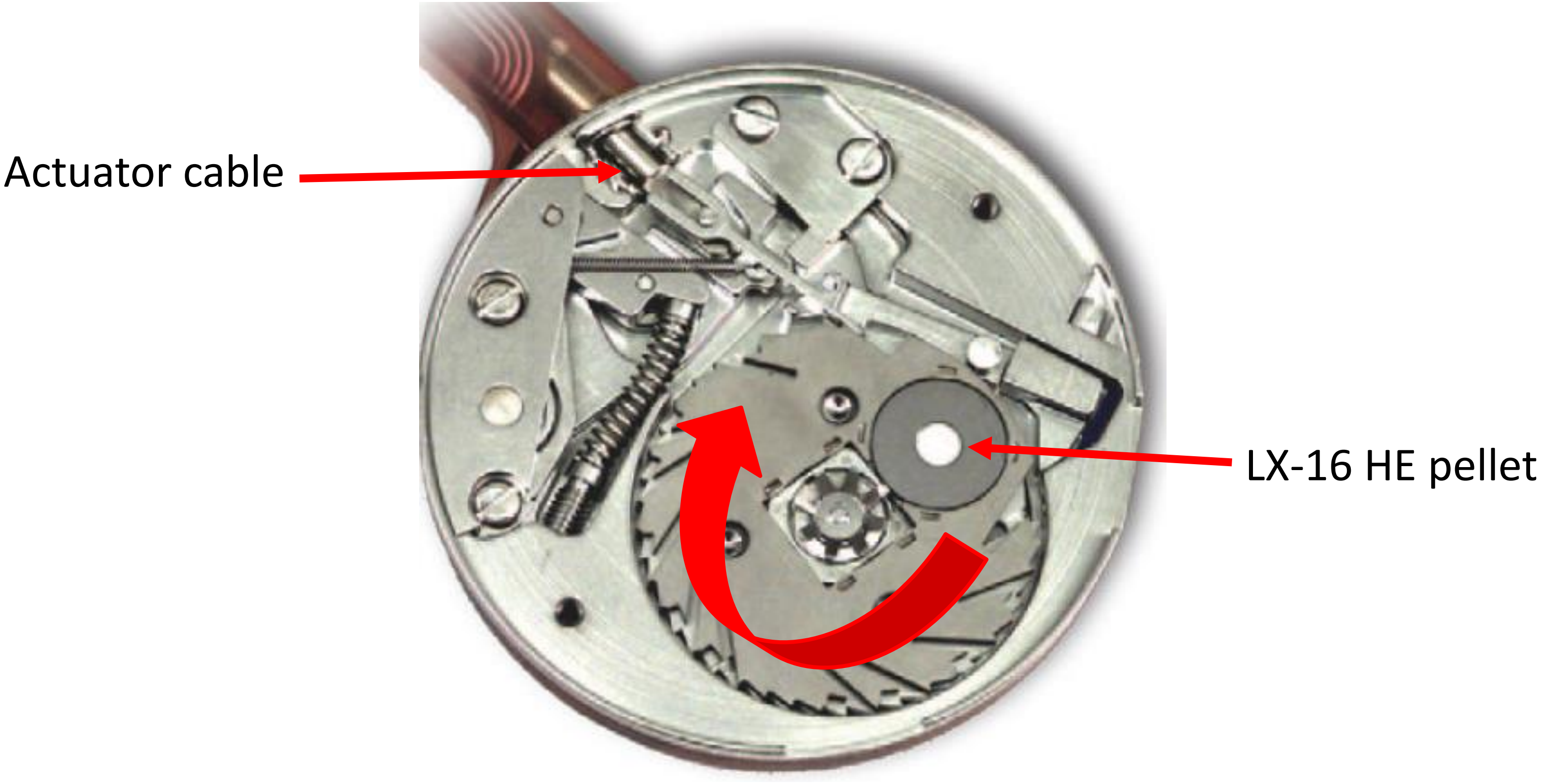
Stronglink Detonators were explicitly required by both Military Characteristic (MC) requirements and DOE orders







Stronglink detonators physically remove the explosive component of the detonator for safety



Stronglink detonators add safety, but also complexity

- Mechanical safing detonators introduce substantial complexity to the initiation system
  - Mechanism design influences positioning of initiation components
  - Safing requires significant flight distances to allow physical motion of components
  - Slapper type detonators are insensitive to human ESD, but require very high firing energy

Major detonator integration issues

1. Detonator sealing

2. In-service configuration

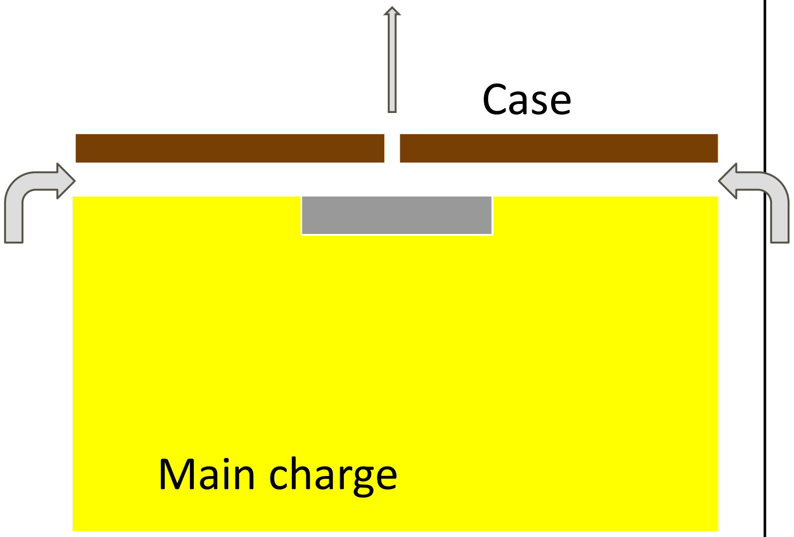
Detonator Sealing

Physics requirements drive encapsulation of the detonators in situ

- Position of components over a stockpile lifetime is highly critical to physics performance, which drives components surrounding the detonators to be encapsulated into their case, and thus, the detonators
- Detonators are very sensitive to the intrusion of foreign material (arming mechanism is sensitive to friction, initiation train components are sensitive to foreign material in flight paths)
- Encapsulation ("potting") process involves the vacuum drawing of an RTV siloxane potting material into a thin gap between the charge/detonator assembly and an outer case
- Seal between the two surfaces only has to perform during assembly. Once the potting material is cured, it won't move
    - The only lifetime requirement for the seal is to do no harm

Detonator sealing design considerations

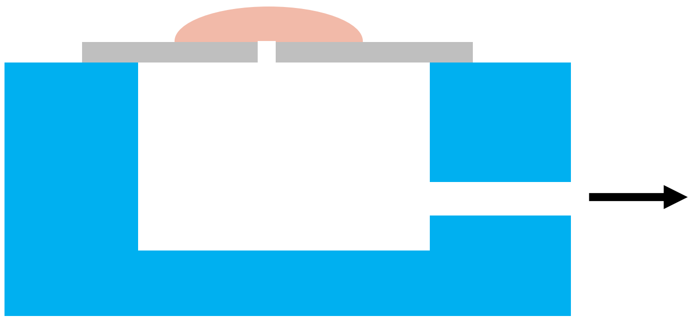
- Seal must hold off potting at a pressure differential of 355 torr (house vacuum)
- Sealing between two parts of dissimilar coefficient of thermal expansion
  - 304L stainless steel puck has a CTE of around 17 µm/m-°C
  - HE has a CTE below ambient of about 50 µm/m-°C, and above ambient of 80 µm/m-°C
- Stress imposed by seal must not cause explosive to fracture (ultimate strength in tension ~1500 psi)



Developing the sealing specification

Determine maximum tolerable leak rate, using plates with pinholes of various sizes

Run	Air Leak Rate	Potting Leak (ΔP = 0 PSI)	Potting Leak (ΔP = 14 PSI)
1	20 psi/min	5 min – N	5 min – Y
2	10 psi/min	5 min – N	5 min – Y
3	5 psi/min	5 min – N	5 min – Y
4	2 psi/min	5 min – N	5 min – N
5	2 psi/min	5 min – N	14 h - trace



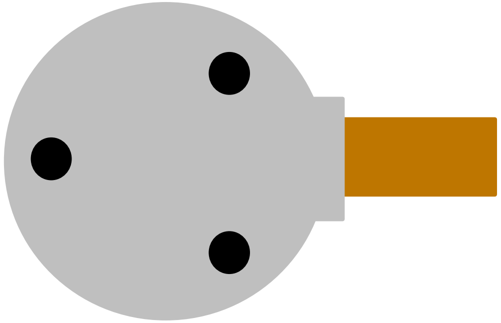
Seal air leak rate requirement set to 1 psi/min

Outer and screw seal selection

- AFLAS O-rings were selected for the detonator-to-HE seal due to their high level of chemical compatibility and availability in 50 durometer rubber

- Initially, the screw seals were O-rings, but the biggest screws that fit are 00-90, and the O-rings were too fiddly
  - Screw heads had a failure torque of 23 in-oz, so the nominal screw closure torque was set to 11.5 in-oz

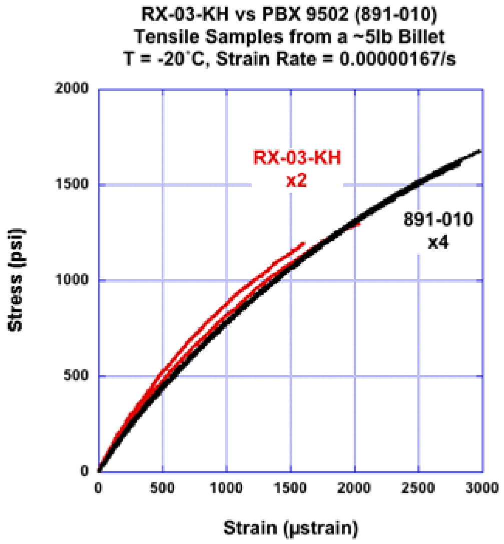
- Determined that crush washers would be better
  - Tested copper, aluminum, polyimide, and Teflon crush washers
  - Polyimide was by far the best material



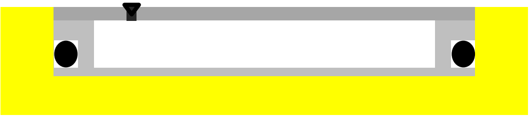
Torque (in-oz)	Pressure (PSI)	Pass/Fail
11.5	15	P
10	15	P
5	15	P
2.5	15	P
2	15	F
2.5	15	F
3	15	P
11.5	21	P
11.5	30	P

Seal must not cause main charge to fracture

- PBX9502 is glassy and brittle, and weak in tension
  - Must not be line-to-line with detonator at any temperature condition to allow room for seal
- Detonator baseline OD max of 34.92 mm
  - Shrinks to 34.87 mm at cold extreme
- HE cavity baseline ID min of 35 mm
  - Shrinks to 34.85 mm at cold extreme
- Requires HE cavity to grow to 35.05 mm diameter
  - Imparts 30 psi into main charge

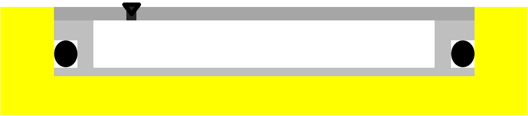


Assembly and seal check process

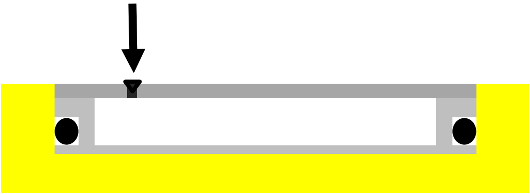


1. Install detonator and remove leak check port screw

2. Pull vacuum and measure pressure decay (1 PSI/min decay spec)



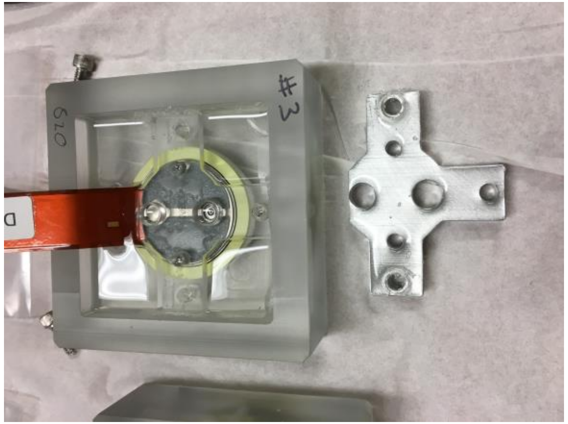
3. Replace leak check port screw with new crush washer



4. Pressurize behind sealed leak check port

Validating the seal design

- Pucks of Lexan were machined to simulate the detonator cavity and placed under load with potting material under vacuum, and checked for encroachment of potting material after the potting had cured
- The testing was the duplicated with pucks of high explosive to verify that it would work with the real materials
- The seal geometry was also used in several higher-level system tests



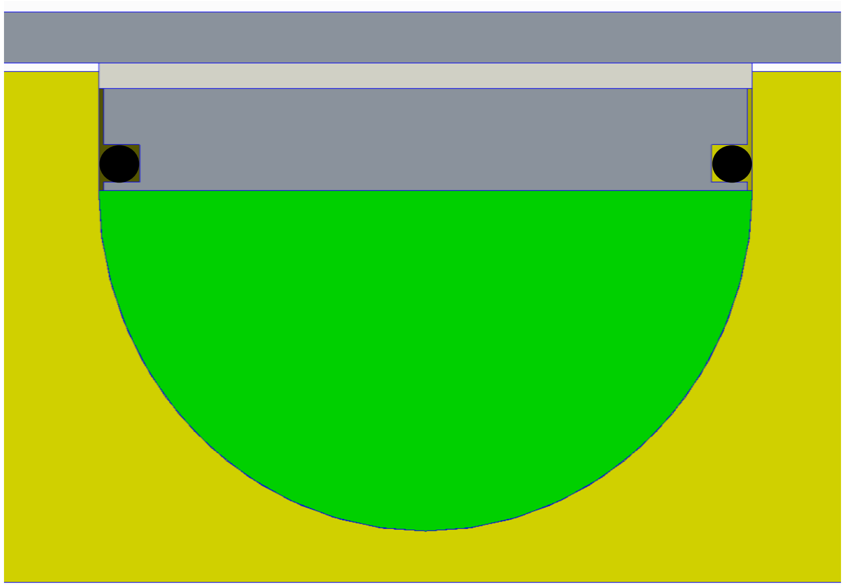
In-system configuration

Detonator requires a hold-down spring

- The detonator weighs about 60 grams, and must remain in place under axial shocks up to 25g, and thus must remain in place over loads up to 14.7 N (3.3 lb)

- O-ring is not required to maintain a seal over the entire lifetime of the warhead, and it cannot be depended upon to hold the det in place, despite providing nominally 3.5 lb of frictional force

- A metal spring is not suitable for this application because it would be gummed up by the potting. A closed-cell hydrogen blown RTV foam was chosen instead. The nominal pad load was set at 20 lb

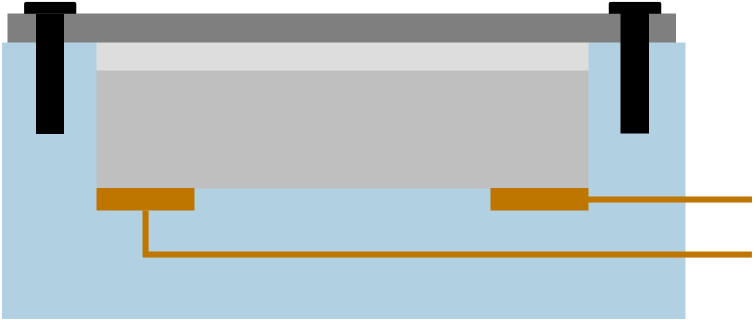


Testing that the spring works

- Shaker testing builds certainty that the spring will work

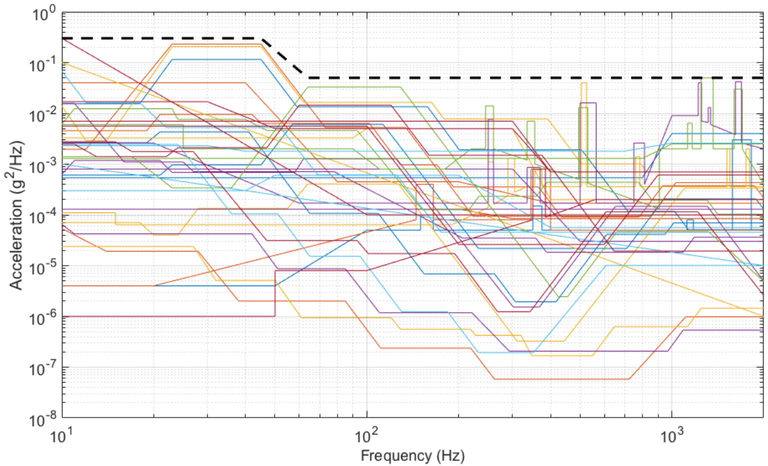
- A test assembly was utilized to simulate the detonator cavity, including
  - mass mock detonator puck
  - real spring
  - real cavity geometry machined into an acrylic cylinder
  - bolted top plate to hold the assembly together

- The main diagnostic is a low-voltage circuit completed by the detonator puck and monitored through the dynamic testing. If the puck lifts off of the copper contacts, the voltage drops to zero



Dynamic test levels were based on random vibration specs and shock specifications

- Vibration specifications are typically envelopes of mechanical spectra assessed on test warheads
- Sine sweeps used instead of random vibrations due to shaker limitations, matching RMS energy in specific frequency ranges
- Expected shocks are up to 25g, 40 ms peak width, but testing was also performed at 3 and 6 dB above (35 g and 50g) to assess margin
- No separation of the detonator from the housing was sensed, indicating that the spring was sufficient



W80-4 Random Vibration Specification

Future testing

Further validation required:

- Compatibility testing to show O-rings do not degrade within the warhead lifetime
  - Chemical compatibility, to prove O-ring and lubricant do not degrade the performance of any surrounding components
  - Long-term survivability of the O-ring, to ensure it does not create debris
- Spring testing at both high and low temperature regimes (-60 to +80 C)
- Diagnostics added to system level tests to gather dynamic and thermal environments at the specific detonator locations, rather than assuming no transfer function between the warhead mounts and the detonator

THANK YOU!

Questions?