High Explosives in Stockpile Surveillance Indicate Constancy

Livermore actively seeks to improve the analysis of high explosives in stockpiled nuclear weapons, keeping in mind the purposes of traditional surveillance: to look for defects in materials and processes, to monitor indicators of both constancy and change, and to confirm that design choices did not cause problems.

ANY weapon in the U.S. nuclear arsenal, if ever deployed, must work exactly as intended. Americans expect that assurance even though international relations since 1989 have brought dramatic and fundamental changes to the U.S. nuclear weapons program. Responsibility for assuring reliability, performance, and safety of the nuclear weapons stockpile belongs to the nuclear design and production community, which conducts the wide range of activities in the Department of Energy's New Material and Stockpile Evaluation Program.

Although stockpile evaluation is not new, methods and tests have undergone marked changes since the program's inception almost four decades ago. Today, each of the participating national laboratories—Lawrence Livermore, Los Alamos, and Sandia—is responsible for the extensive and rigorous tests to evaluate the portions and components of the stockpile weapons that each has designed. This overview of Livermore high-explosives (HE) tests of nuclear stockpile weapons illustrates the degree of assurance toward which the laboratories work.

Stockpile Evaluation

"Stockpile surveillance" is the third, or maintenance, phase of a spectrum of special tests that begins during a weapon's design and ends only with its retirement from the stockpile (see box on p. 13 and Figure 1). Such tests now are the principal means of evaluating the condition of U.S. nuclear weapons. For this phase, stockpile laboratory tests provide "indicators of constancy" through comparison with baseline data gathered during weapon development and production.

Stockpile laboratory tests usually begin during the third or fourth year after the weapon's production begins. Sample weapons removed from the stockpile are dismantled, components are inspected and tested, and then the weapons are reassembled and restored in the stockpile. Increasingly, surveillance activities have focused on one central question: How can a weapon's useful service life be predicted?

In addition to checking for materials and production defects, stockpile surveillance involves monitoring potentially damaging changes to a weapon's components caused by aging or environmental factors. Simply because nothing is wrong, the inference cannot be made that the weapon will last indefinitely. Livermore's Enhanced Surveillance Program is currently examining concepts that improve predictive capabilities.

Should problems appear, the increasing body of data will guide the program to accommodate or eliminate adverse effects. Old or damaged parts are replaced or upgraded before a weapon is reassembled for the stockpile. This aspect of surveillance resembles keeping a stored car in driving condition. Regular inspections can spot signs of damage or deterioration before they become too costly to repair. The vehicle can also be upgraded by installing improved replacement parts.

High Explosives

The ideal high-energy explosive must balance different requirements. HE should be easy to form into parts but resistant to subsequent deformation through temperature, pressure, or mechanical stress. It should be easy to detonate on demand but difficult to explode accidentally. The explosive should also be compatible with all the materials it contacts, and it should retain all its desirable qualities indefinitely.

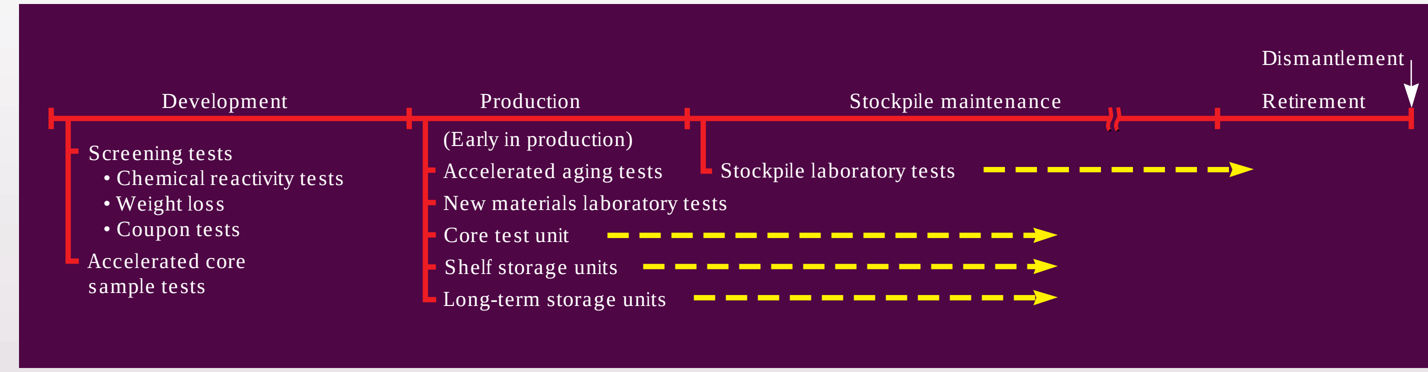


Figure 1. Phases of evaluation in stockpile surveillance.

No such explosive existed in 1944. While using what was available to meet wartime demands, scientists at Los Alamos began to develop a high-energy, relatively safe, dimensionally stable, and compositionally uniform explosive. By 1947, scientists at Los Alamos had created the first plastic-bonded explosive (PBX), an RDX*-polystyrene formulation later designated PBX 9205. Although other PBXs have since been successfully formulated for a wide range of applications, only a handful have displayed the combination of adequate energy content, mechanical properties, sensitivity, and chemical stability required for stockpile nuclear weapons. Since the 1960s, Livermore has been researching and developing safer HE for Livermore-designed weapons.

The plastic coating that binds the explosive granules, typically 5 to 20% of each formulation by weight, is what gives each PBX its distinctive characteristics. Pressing a PBX molding powder converts it into a solid mass, with the polymer binder providing both mechanical rigidity and reduced sensitivity to accidental detonation. The choice of binder affects hardness, safety, and stability.

Too brittle a PBX can sustain damage in normal handling and succumb to extreme temperature swings or thermal shocks, while too soft a PBX may be susceptible to creep and may lack dimensional stability or strength. To achieve safe and stable PBXs, the Laboratory uses two main charge explosives based on HMX and TATB.†

HMX is more energetic than RDX but retains good chemical and thermal stability, important for long-term storage and survival in extreme environments. Sensitivity of any PBX is a complex characteristic strongly affected by HE particle size distribution, viscoelastic properties, binder-to-HE wetting, and storage environment. Only the TATB-based formulations (Figure 2) of Livermore's

HE's Role in a Nuclear Weapon

The nuclear explosive package includes nuclear and non-nuclear components that comprise a primary explosive device and a secondary, both enclosed within a radiation-proof case. A key component of a primary is typically a shell of fissile material—the pit—to be imploded by a surrounding layer of chemical high explosive (HE) termed the main charge.

Stockpile evaluation requires a comprehensive battery of tests that addresses all functional aspects of a weapon throughout its so-called stockpile-to-target sequence, stopping short of actual detonation with nuclear yield. Although the moratorium on underground nuclear testing has precluded detonating a stockpile weapon to assess its reliability, performance, and safety, stockpile evaluation is working to provide an adequate alternative route to the same goal of reliability assessment.

The HE clearly plays a role vital to proper weapon function, but many questions surround the long-term stability of the complex organic molecules of which the HE is composed. To provide assurance that stockpile quality is maintained, Livermore's Stockpile Evaluation team develops diagnostic tests that are performed on the HE in the main charges of stockpile weapons.

* RDX is 1,3,5-trinitro-1,3,5-triazacyclohexane.

† HMX is 1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane; TATB is 1,3,5-triamino-2,4,6-trinitrobenzene. See *S&TR*, November 1996, for more information on TATB.

LX-17 and Los Alamos's PBX 9502 are considered "insensitive" high explosives (IHE); others are termed "conventional."

Evaluating the Package

Livermore is responsible for surveillance of the stockpile weapons that are based on its own designs. The Engineering Directorate and the Defense and Nuclear Technologies Directorate collaborate on Livermore's Stockpile Surveillance Program. General procedures for the annual evaluation begin with a predetermined number of samples of each weapon type chosen at random from the stockpile. All are disassembled to varying degrees for evaluation, but typically only one weapon has its explosive package reduced to its component parts: pit, explosive, detonators, and secondary.

Livermore mechanical engineers and materials scientists develop prototype tests, and then Pantex workers perform the tests on actual stockpile weapons components and materials. The tests focus on what would alter the estimated minimum warhead life or require retrofitting.

The complete evaluation entails four major investigations, each with rigorous safety and technical protocols: (1) examining the HE for changes in appearance and texture, including surface discoloration, cracks (using dye penetrant), or tackiness of any materials; (2) measuring physical and mechanical (tensile, compressive) properties, including density and contour; (3) measuring chemical properties, including HE and binder composition, binder molecular weight, and warhead atmosphere analysis; and (4) conducting performance tests, including pin hydrodynamic tests, "snowball" tests, and detonator test firing or disassembly.

In characterizing materials, Livermore surveillance addresses interrelationships among components. Environmental factors such as radiation, heat, and chemical incompatibility can affect the behavior of components and their interfaces throughout the initiation chain: the detonator, booster, and main charge. Explosives could also suffer aging effects in such properties as creep, growth and density gradients, thermomechanical integrity, initiation capability, detonation performance, sensitivity, and safety.

These concerns are addressed during the warhead's development and early production phases, largely through tests using accelerated aging techniques (primarily elevated temperature) to simulate the long-term effects of internal and external environment. The main goal of accelerated aging tests is determining whether materials, parts, and assemblies are compatible with each other and retain their essential properties.

During surveillance, actual aging and environmental effects are evaluated, using new materials laboratory tests and material qualification test results as baseline data.

Tests of Physical Properties

Density and density uniformity are parameters easily measured with high precision. If HE chemical and density distributions remain substantially constant during storage, no significant change is expected in specific energy or detonation velocity.

Figure 2. TATB material is being prepared for an aging test.

Figure 3. High-explosives chemist Mark Hoffman sets up HE for mechanical tests.

In both stockpile laboratory tests and accelerated aging tests, density distribution is measured using cored samples. These measurements are then compared with recorded densities from each material lot. Laboratory test results show that accelerated aging conditions do not significantly alter the uniformity of HE density; density actually becomes more uniform throughout the main charge.

Tests of Mechanical Properties

As an integral part of the explosive package's structure, HE must retain its own structural integrity. Therefore, tensile and compressive mechanical properties of HE are monitored (see Figure 3). These mechanical properties were found to be correlated with HE composition and density, as well as the crystallinity and nature of the polymeric binder. Mechanical properties may also be affected by changes in the properties of the explosive–binder interface, but these can only be addressed indirectly.

Tensile strength testing. Tensile tests are performed on LX-17, for example, at a low temperature (–20°C) and a slow rate because these conditions simulate the expected worst case (due to thermal expansion mismatches of the materials). This test best shows differences in material quality. Test data for three Livermore weapon systems show no apparent aging trends in LX-17 tensile stress and strain at failure.

Compression testing. For simulating the worst-case conditions for creep (displacement under fixed load) in the warhead, compression tests are performed on LX-17 at an elevated temperature (50°C) and a slow rate (1,440 microstrain per hour).

In surveillance testing, compression values for LX-17 have not failed or fallen outside of material qualification limits. Data on stockpile-aged material from the W87 warhead, however, do show an apparent stiffening of the LX-17 with age (see Figure 4). Although this phenomenon may actually reflect an increase in the crystallinity of the binder, the LX-17 continues to be monitored and will be compared with the behavior in other systems.

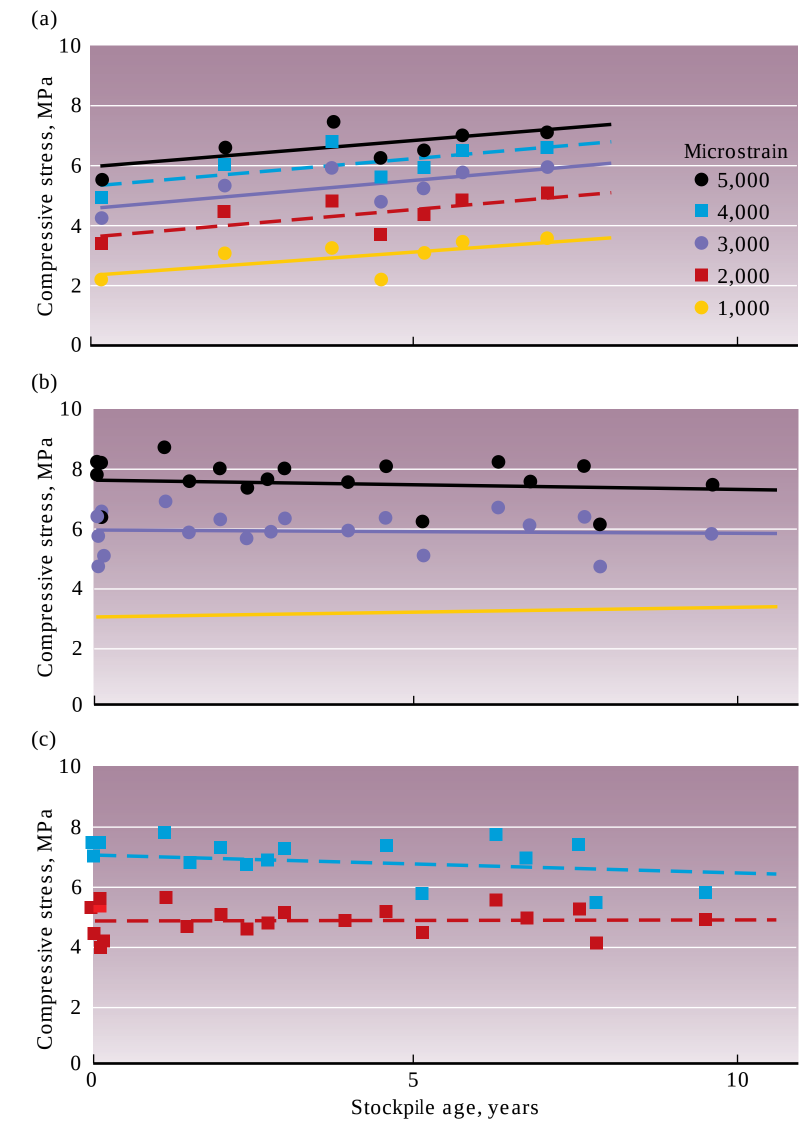


Figure 4. (a) The compressive stress tests for the LX-17 high explosive recovered from the W87 new materials laboratory test (NMLT) units and stockpile laboratory test (SLT) units. The data show a stiffening of the LX-17 at all strain levels, which may be consistent with a gradual increase in the crystallinity of the Kel-F-800 binder. For reasons not clear at this time, this trend is not supported by the observations from the B83 (b) NMLT units and (c) SLT units.

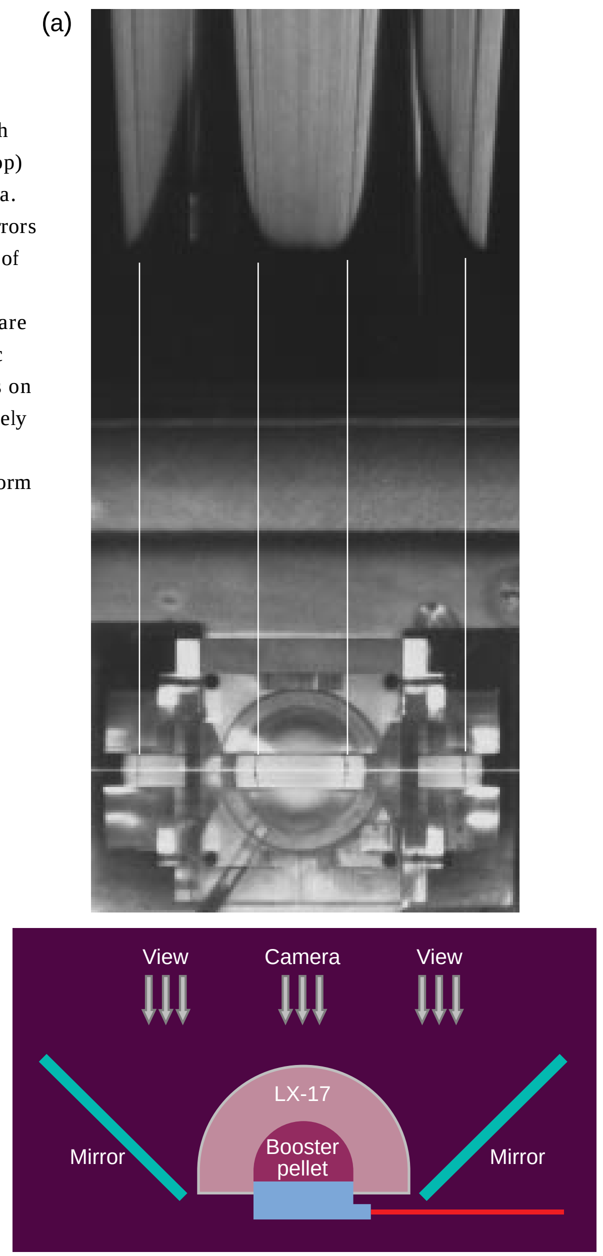
Tests of Chemical Characteristics

As HE ages or degrades, its compatibility with other materials in the primary may suffer. Thus, several types of analysis are employed to evaluate the HE's chemical composition.

Chemical composition analysis. Relative percentages of binder and HE are compared with values obtained from qualification tests of newly produced HE. Percentages of HE different from nominal values could signal significant chemical degradation, which would mean lower energy density for LX-17. To date, however, aging has not affected chemical composition. Changes, if any, remain too subtle for current analytic techniques.

Molecular weight analysis. For this analysis, the polymer binder is extracted from the HE and subjected to gel permeation chromatography (also called size exclusion chromatography). Current techniques have yet to reveal significant aging effects on the molecular weight or molecular weight distribution of LX-17 binder. Small changes in molecular weight that might indicate the onset of degradation, however, are very difficult to detect and characterize. In Livermore's Enhanced Surveillance Program, methods are being developed to improve the ability to detect aging effects.

(a)



(b)

Figure 5. (a) A "snowball" test assembly (bottom) is aligned with samples of snowball test data (top) as recorded by the streak camera. (b) The schematic shows the mirrors that reflect the left and right sets of snowball data.

For illustration, vertical lines are drawn between the photographic breakout record and the markers on the snowball surface. The relatively flat curves at the bottoms of the image data indicate a good, uniform explosion.

Warhead atmosphere gas sampling. Mass spectroscopy and gas chromatography of warhead gas samples can identify material outgassing and ongoing chemical reactions, both of which may indicate degradation or decomposition of the organic compounds in the HE. They also help to verify whether warhead environmental seals have leaked.

Performance Tests

Performance tests tell about the detonation response of the material. Pin hydrodynamic tests check the implosion reliability and performance of the main charge; "snowball" tests help determine the initiation reliability of the booster. Detonators also are test-fired, and certain ones are disassembled for inspection and analysis.

Pin hydrodynamic test. This test monitors changes in the implosion behavior of HE. The test assembly comprises three main subassemblies: a pin-dome assembly, a mock pit, and the HE. The test measures elapsed time from initiation until the explosive drives the mock pit into an array of timing pins, a "pin dome," of known length and location. The HE implodes the mock pit onto the timing pins, which provide data about the temporal and spatial uniformity of implosion. A nonuniform implosion could indicate an HE problem. Excessive density variations, voids, or cracks in the HE, for example, can disrupt the shock-wave propagation from the detonation. To date, surveillance testing has observed none of these problems in stockpile samples.

Snowball test. This test checks reliability of the initiation chain by confirming that the booster initiates the HE. A machined shell of LX-17 is assembled with a booster and detonator to form a "snowball." When this assembly is fired, a streak camera captures spatial and temporal information of the initial, or "breakout," detonation wave on the outer surface of the LX-17 snowball (see Figure 5). The relatively flat curves at the bottom of the image data indicate a good, uniform explosion. Changes in the breakout profile would be used to track the performance of the booster and the condition of the interface with the HE.

Aging tests. So far, surveillance data on HE from the B83, W84, and W87 programs show no evidence of aging effects. Because the W87 system must be requalified for an additional 25 to 30 years, additional data are being gathered and analyzed to improve Livermore's long-term predictive capability. Aged LX-17 is being subjected to far more comprehensive testing than usual for stockpile laboratory test units. In essence, properties of control material from various sources are compared to the chemical, physical, mechanical, and performance properties of aged LX-17 for signs of age-induced changes.

Changes, if any, will be studied further in the Enhanced Surveillance Program. Should no changes be discovered, confidence in the projected longevity of the W87's HE materials will be scientifically supported.

A compatibility program initiated during W84 warhead production is paying dividends by serving as a source of aged materials for advanced study. Some specimens of LX-17, UF-TATB (ultrafine TATB) boosters, and LX-16 pellets from W84 production are already being subjected to accelerated aging in a weapon-like atmosphere for ten years.

The Next Step in Surveillance

Continually sought to improve the analysis of HE in weapons in the stockpile, technologies must still fulfill the purposes of traditional surveillance. First, early in a weapon's stockpile life, materials and processes are scrutinized for defects, and then they are monitored to confirm that design choices do not cause problems.

Other improvements are being evaluated for inclusion in the program: (1) fundamental understanding of aging mechanisms in stockpile materials, (2) better selection of stockpile samples for testing and evaluation, (3) better uses of available materials (stockpile-aged materials, such as those from retired and dismantled weapons), and (4) peer review of surveillance data.

Accordingly, the Livermore Stockpile Surveillance Program has proposed revisions in the surveillance mission to achieve the following capabilities:

- Detecting and identifying changes in stockpile-aged materials that previous surveillance methods may not have discovered.
- Predicting—not simply monitoring—any identified age-induced changes in materials through the use of models.
- Providing information on aged materials to weapons designers, who can assess effects on weapons performance.
- Verifying the safety of aged materials via testing and modeling.

These changes will help improve an already successful Livermore stockpile evaluation program. They will enhance surveillance techniques to assure the nation and its armed forces that Livermore-designed weapons can be safely stored and transported and that they can work exactly as intended throughout their stockpile life.

Key Words: accelerated aging, high explosive (HE), LX-17, nuclear weapon, PBX, pin-dome test, predictive capability, snowball tests, stockpile evaluation, stockpile surveillance, TATB.

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