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Title: LOW AMPLITUDE IMPACT OF PBX 9501: MODIFIED STEVEN, SPIGOT GUN TESTS

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LOW-AMPLITUDE IMPACT OF PBX 9501: MODIFIED STEVEN, SPIGOT GUN TESTS

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LOW-AMPLITUDE IMPACT OF PBX 9501: MODIFIED STEVEN, SPIGOT GUN TESTS

Low-velocity mechanical impact and subsequent high explosive (HE) reaction are of concern in credible accident scenarios involving the handling, transport, and storage of nuclear weapons. Using modified Steven spigot gun tests, we have investigated the high-explosive violent-reaction (HEVR) potential of PBX 9501 to low-amplitude insult. Reliable modeling predictions require that we identify the relevant parameters and behavioral responses that are key to the reaction mechanism(s) in PBX 9501.

The Steven test was first developed and used by Steven K. Chidester and coworkers at Lawrence Livermore National Laboratory (LLNL) to test the sensitivity of LX-10 to low-velocity impact by a massive projectile. In the Los Alamos National Laboratory (LANL) modified Steven tests, a 2-kilogram mild-steel projectile is launched using a new spigot gun design. The projectile impacts a lightly confined PBX 9501 cylindrical target (see Figure 1).

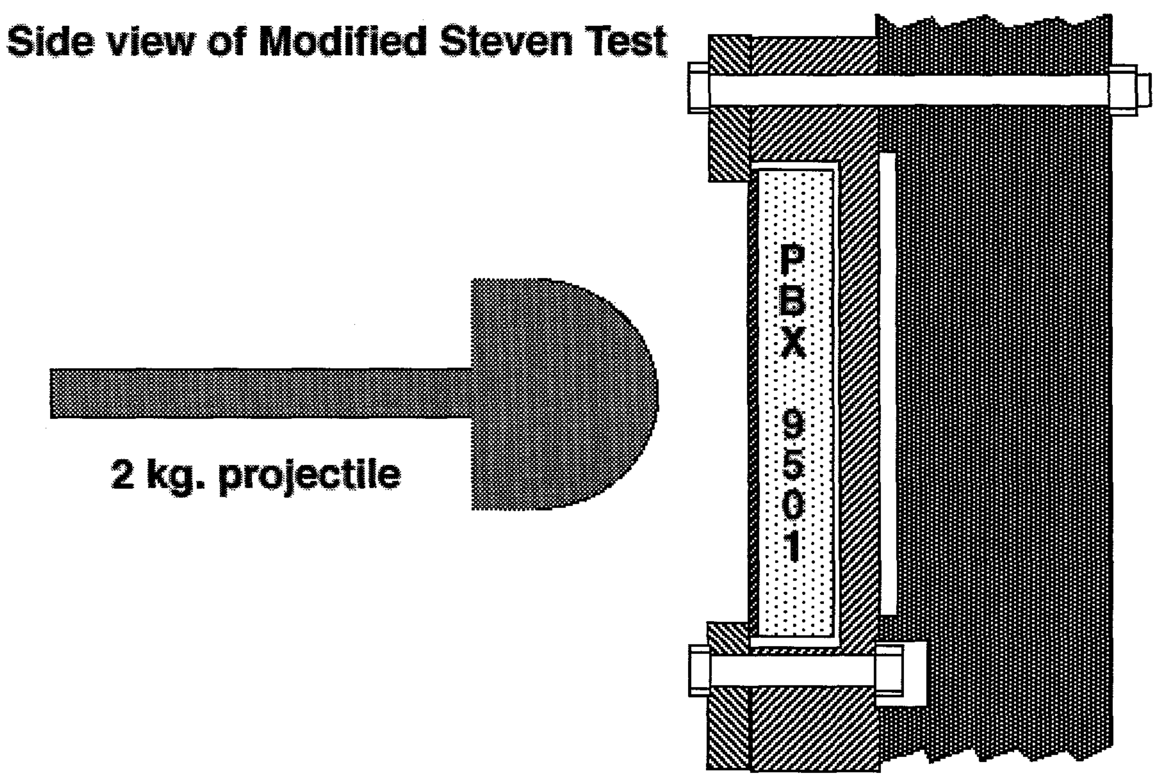

Figure 1: Schematic of modified Steven test design to evaluate low-velocity impact of PBX 9501.

The HEVR project has investigated various aspects of the reaction mechanism by employing different target designs and diagnostics. The first ten PBX 9501 HEVR tests clearly defined a very sharp threshold between targets that did and did not react violently. Five of the tests resulted in violent reactions, but none equivalent to a full-up detonation. As expected, target confinement modifications shifted the threshold to different velocities.

The experimental efforts have been further supported by DYNA2D finite-element and SPRONTO ("esperanto") calculations. The DYNA2D calculations employ an ignition criterion as a function of a characteristic constant, pressure, time, and the maximum shear strain rate to evaluate the threshold level to reaction. The SPRONTO code is a result of embedding the LANL statistical crack-mechanics model SCRAM into the Sandia National Laboratory (SNL) mechanical-deformation code PRONTO. To compute the chemical response of the PBX 9501, the code uses solutions of a one-dimensional heat equation perpendicular to the planes of penny-shaped cracks excited into two-dimensional grinding motion by the impact. Both forms of the calculations use an axisymmetric mesh with an on-center impact.

Additional efforts have been targeted at identifying relevant differences in the response between baseline and stockpile-aged PBX 9501 to low-velocity impacts. The Holston HOL89C730-010 PBX 9501 powder, formulated in 1989, was chosen as the baseline lot for comparison, and it currently meets required specifications for new material. This lot was pressed and machined in 1997 for the modified Steven tests.

The two aged lots of PBX 9501 were chosen from stockpile laboratory test (SLT) units out of the W76 surveillance program. The PBX 9501 main charges were originally pressed in the late 1970s and early to mid-1980s and were machined in 1997 for the modified Steven tests.

Ten baseline tests were compared with eight aged tests. A newly constructed ballistic pendulum and blast gauges calibrated to intentionally detonated PBX 9501 were used to evaluate the relative level of reaction for all eighteen tests. The baseline and aged PBX 9501 demonstrated similar behavior without drastic changes in the threshold projectile velocity within the age range tested. For this new test series the average level of energy release never exceeded 41 percent of a full-up detonation across the entire velocity range.

Five thicker baseline targets were also tested with PBX 9501 pressed and machined from the Holston HOL89C730-010 powder to investigate the potential effect on the threshold velocity. As with the earliest HEVR test series, these new test series displayed a sharp threshold to violent reaction.

We are evaluating possible chemical and particle morphology differences using both surface and analytical testing techniques for post-test characterization of the PBX 9501 retained from both the intact and reacted targets (see Figures 2 and 3). Future research efforts are aimed at identifying the relevant effect of changing the changing the projectile diameter and/or mass, and using different types of diagnostics and target designs to characterize the location, timing, pressure, temperature, and deformation profiles relevant to the reaction mechanism(s).

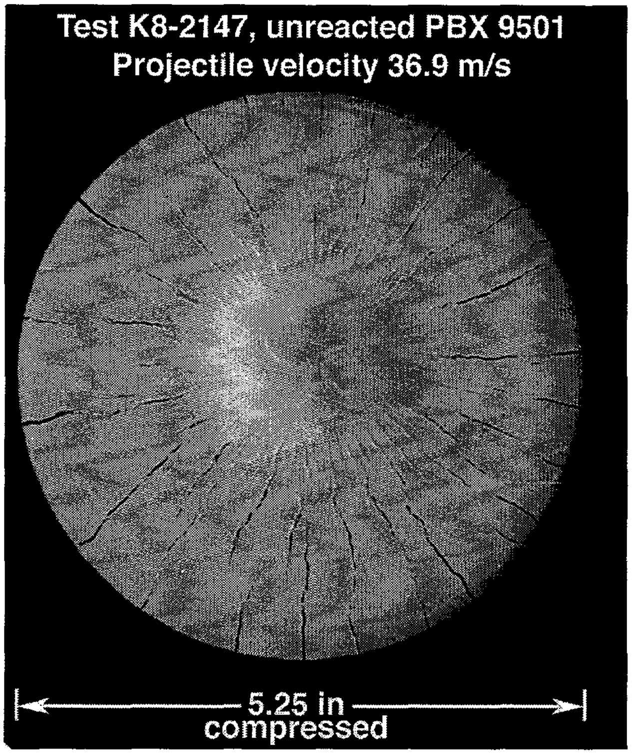

Figure 2: Image of impacted PBX 9501 in intact target.

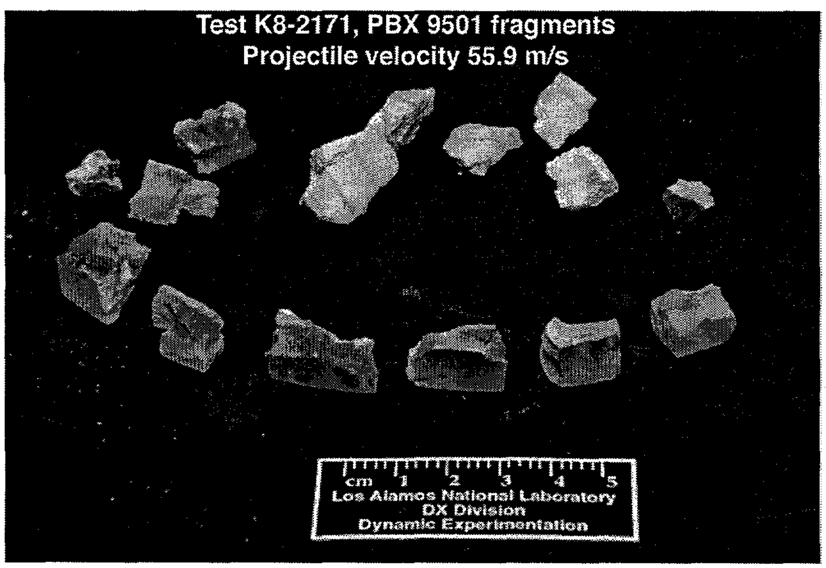

Figure 3: Image of PBX 9501 fragments from reacted target.

[redacted] Low Amplitude Insult of PBX 9501: Modified Steven Spigot Gun Tests

presented by

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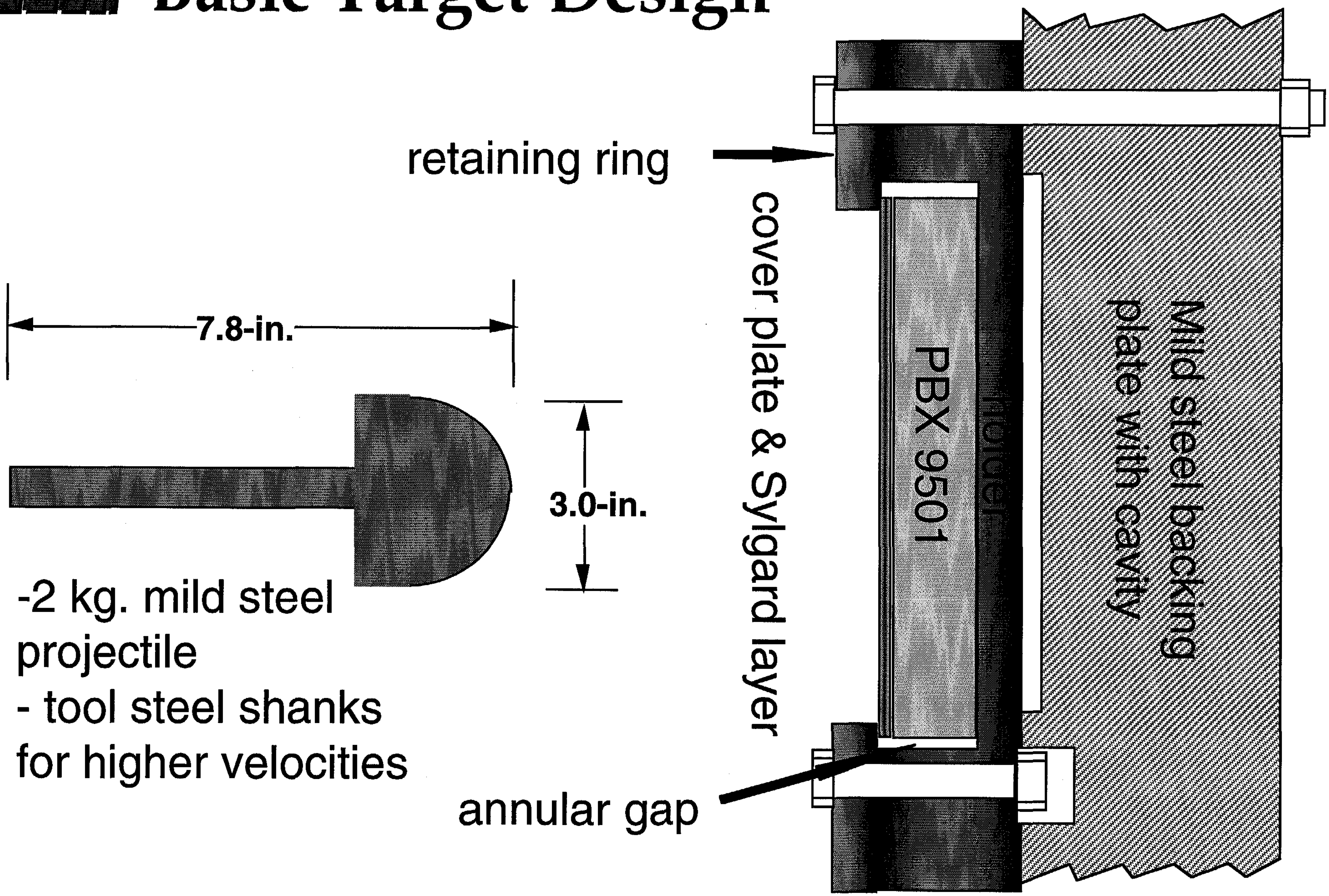
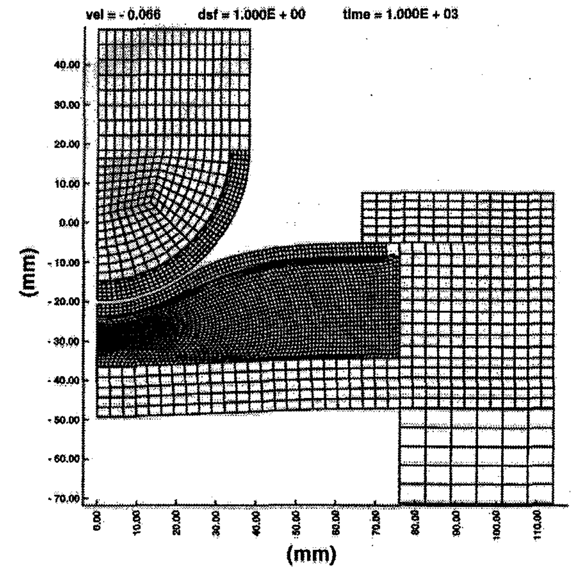
Basic Target Design

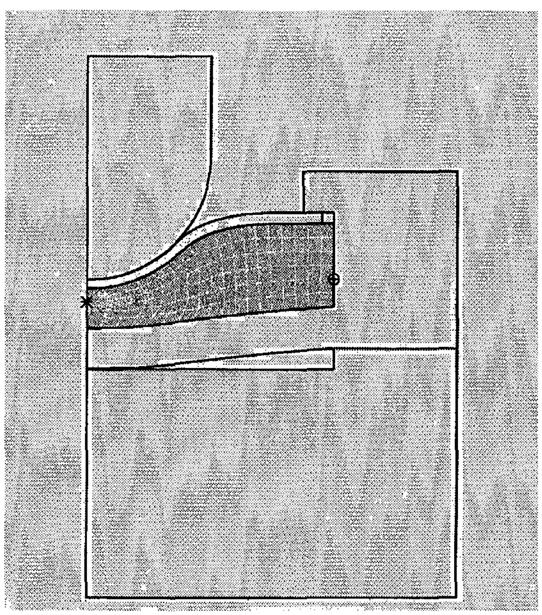


-2 kg. mild steel projectile
- tool steel shanks for higher velocities

2D Modeling: PBX 9501 & LX-10

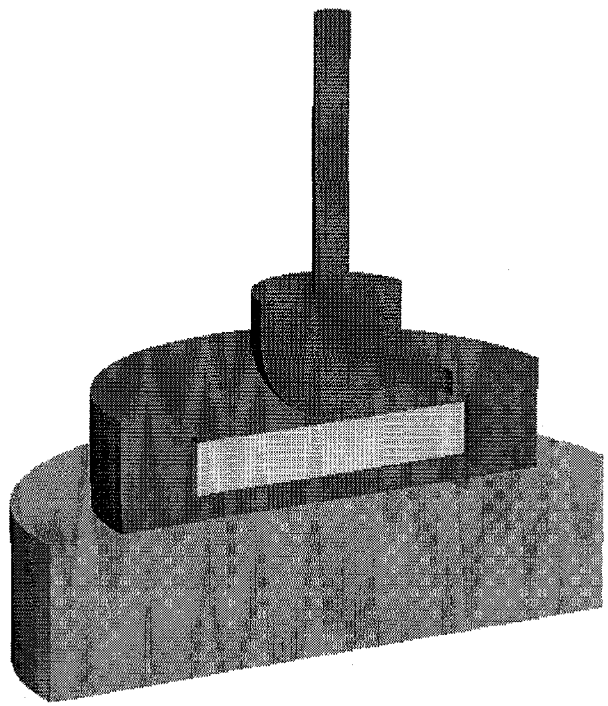
- DYNA2D - Scammon, Browning, Flury
  - no explosive rxn or chemistry models
  - ignition power law criterion:
    $R = K\,P^{2/3}\,(\text{Maximum shear strain rate})^{1.27}\,t^{1/4}$
    - where K= characteristic constant
    - P = pressure,
    - t = time
  - calibration : dent, deformation, & threshold velocity data



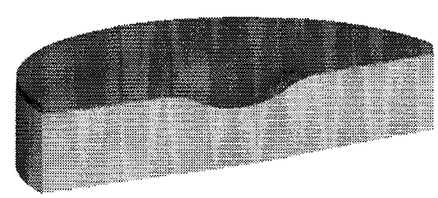


- SPRONTO - Dienes, Middleditch
  - SCRAM statistical crack mechanics embedded in PRONTO mechanical deformation program
  - heating at fracture surfaces due to crack grinding
  - chemical response - 1D soln. of heat eqn. w/melting, liquid viscosity, & Arrhenius terms
  - calibration: threshold velocity data

3D Modeling : Joel Bennett and Keith Haberman, ESA-EA, MOU funding



- DYNA3D 400K cell calc.
- crack model:-Dienes Johnson, Addessio
  - viscoelastic properties calibrated to PBX 9501
  - input crack density & ave. size
- 3D GMC - Todd Williams
  - calibrated against elastic problems
  - debugging damage problems
- NEXT - ignition criterion



[redacted] Target Diagnostics

- Front impact surface
  - HEVR: wire mesh impact grid, graphite rod impact grid & laser impact trigger
  - Surveillance: PVDF foil impact trigger
- HE front surface
  - HEVR: carbon film gauge
- Radial & back surface of HE
  - HEVR: Pinducers, thermocouple, TOA & ionization pins
- Layer or back surface of holder
  - HEVR:Mn gauge array, Mn/carbon film array, carbon film
  - Surveillance: strain gages on the back surface of the target
- Level of reaction - calibrated against detonated PBX 9501
  - Surveillance: blast overpressure gauges, and 2 passive displacement measurements on a ballistic pendulum

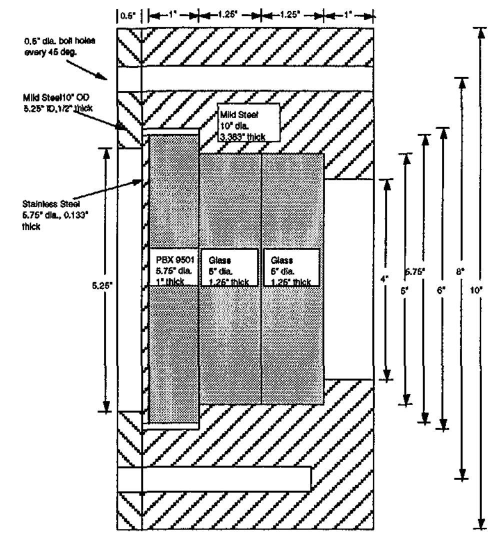
Basic Target Design Differences

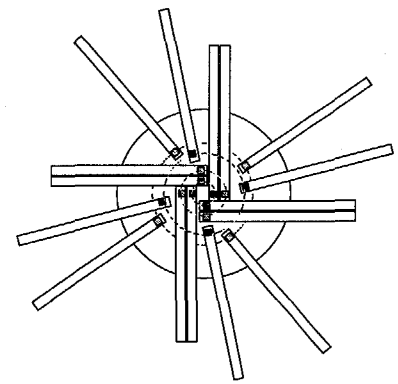
HEVR (larger)	Surveillance (smaller)
304 ss cover - machined 0.125-in. thick	304 ss cover -std. gauge, rolled & cut 0.118-in. thick
PBX 9501 •5.75-in. diam., 1.0-in. thick ($425.5\ cm^3$) • lot 731-003, ave. 1.836 g/cm^3 - 98.7% TMD	PBX 9501 •5.0-in. diam., 0.5-in. thick ($160.9\ cm^3$) •baseline lot 730-010, ave. 1.830 g/cm^3 - 98.4% TMD •182 mo. lot 685-002, ave. 1.840 g/cm^3 - 98.9% TMD •142 mo. lot 730-005, ave. 1.840 g/cm^3 - 98.9% TMD
annular gap - 0.125-in., 8.2% total volume	annular gap - 0.125-in., 17.0% total volume
304 ss holder with 0.5-in. thick back	A-36 steel holder with 0.5-in. thick back
0.25-in. deep cavity	0.75-in. deep cavity

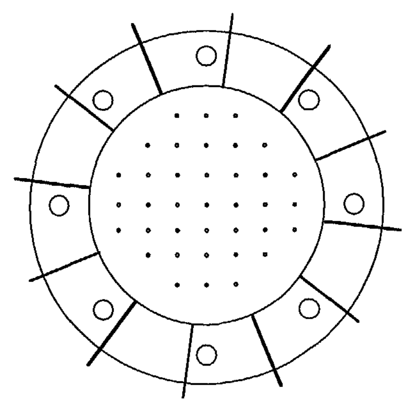
[redacted]

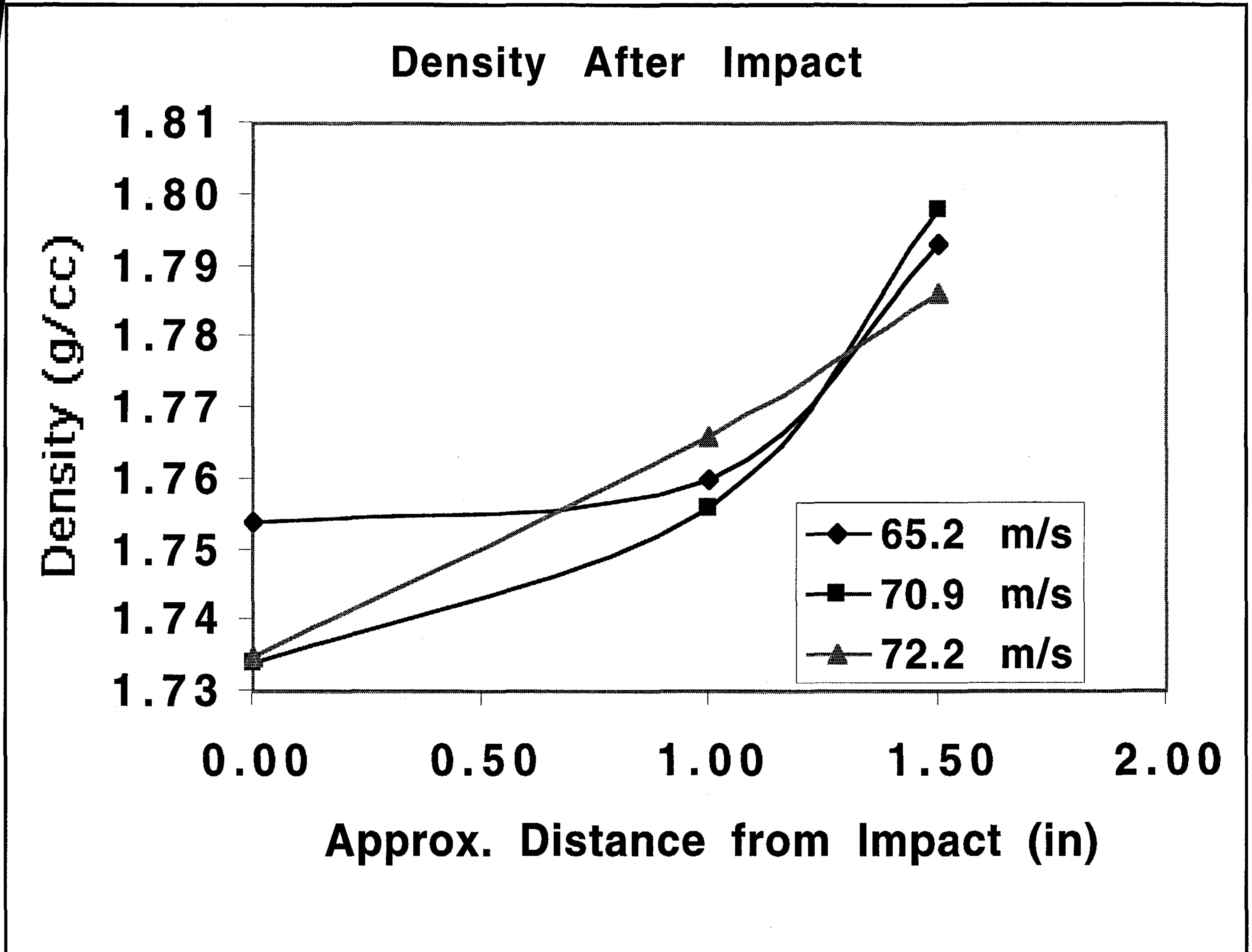
What have we learned?

- Considerable cracking in the quenched targets
- Density gradients -lowest at impact; highest at edge
- Reaction can consume all or part of the PBX 9501 with damage to the target
- Physical evidence of burning/scorching
- Reaction violence ≠ classic CJ detonation
- Front & back surface gauges
  - initially low pressure event 0.1-5 kbars followed by spike
  - suggest multiple sites of ignition
  - Ts in excess of 1400 °C on most violent reaction
  - timing of violent event inversely proportional to impact velocity; 500 μs to 1.0 ms
  - reactive wave velocity 1.0-2.0 mm/μs
- Evidence of partial reaction w/ gas decomposition
- Sharp threshold from 72.2 to 75.1 m/s; no crossovers
- Physical confinement changes - large effect on the threshold

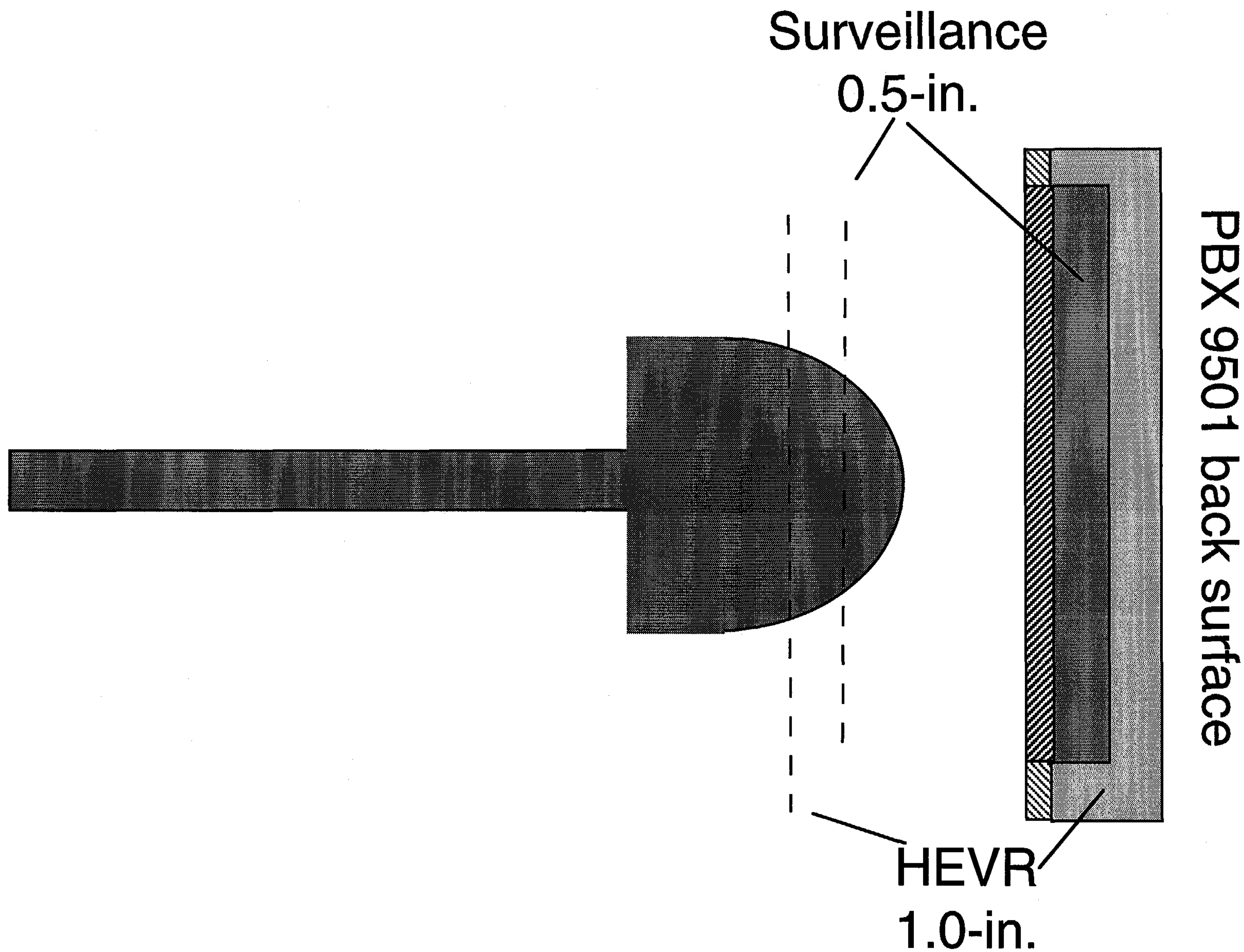




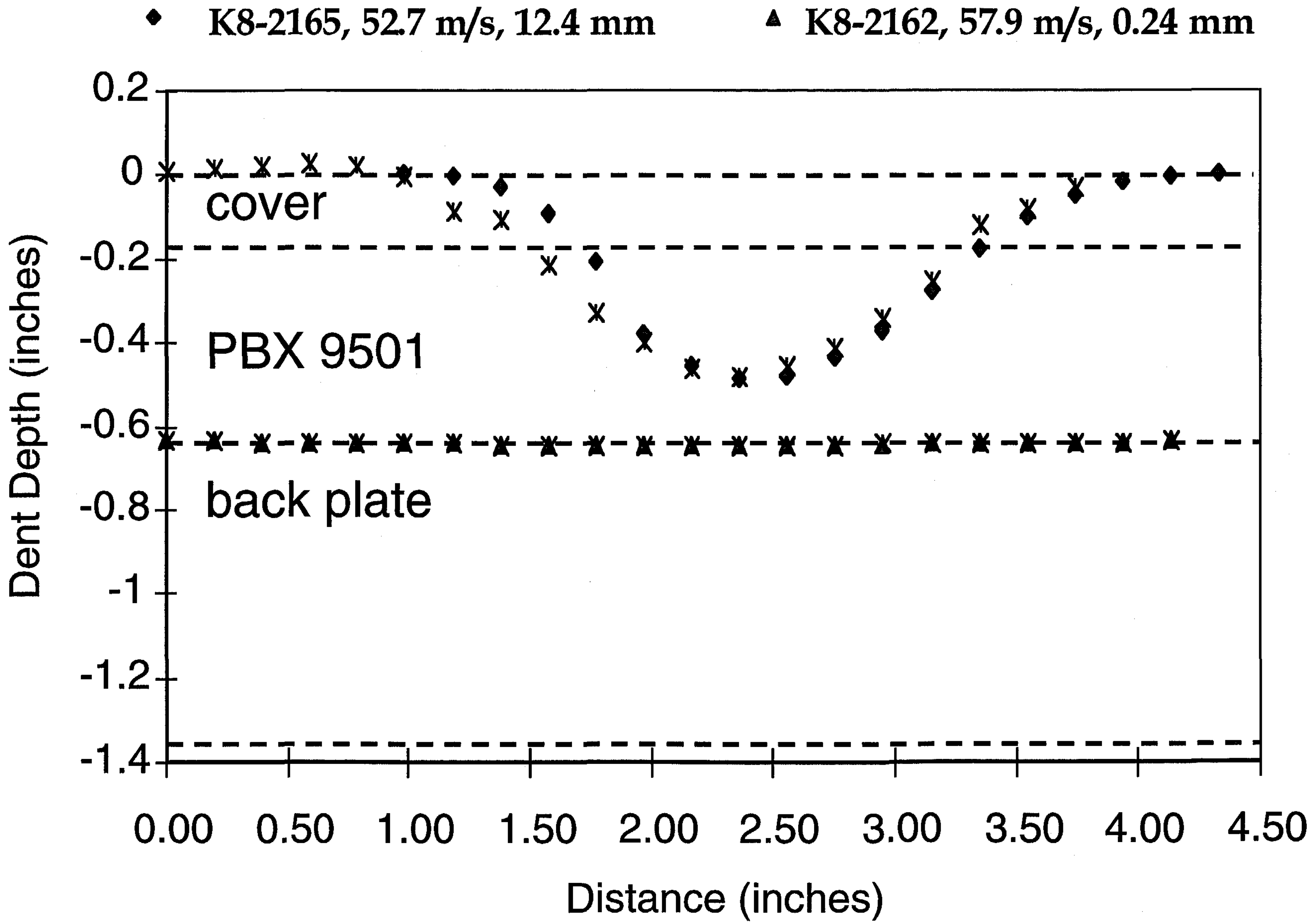



Density After Impact
Density (g/cc)
1.81
1.80
1.79
1.78
1.77
1.76
1.75
1.74
1.73
0.00
0.50
1.00
1.50
2.00
Approx. Distance from Impact (in)
65.2 m/s
70.9 m/s
72.2 m/s

Projectile Penetration Depth

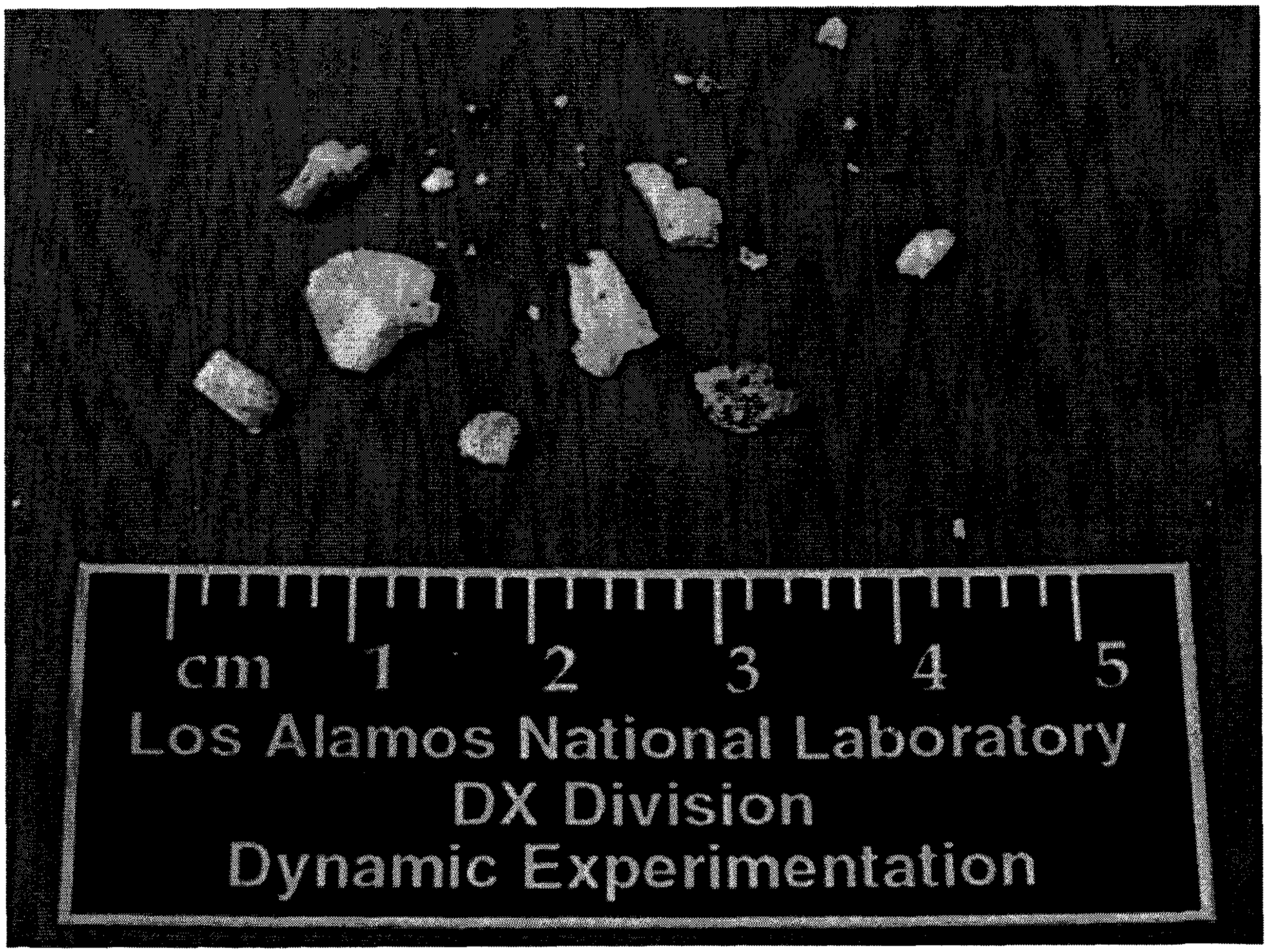


Deformation Data-Materials Calibration



HEVR PBX 9501:

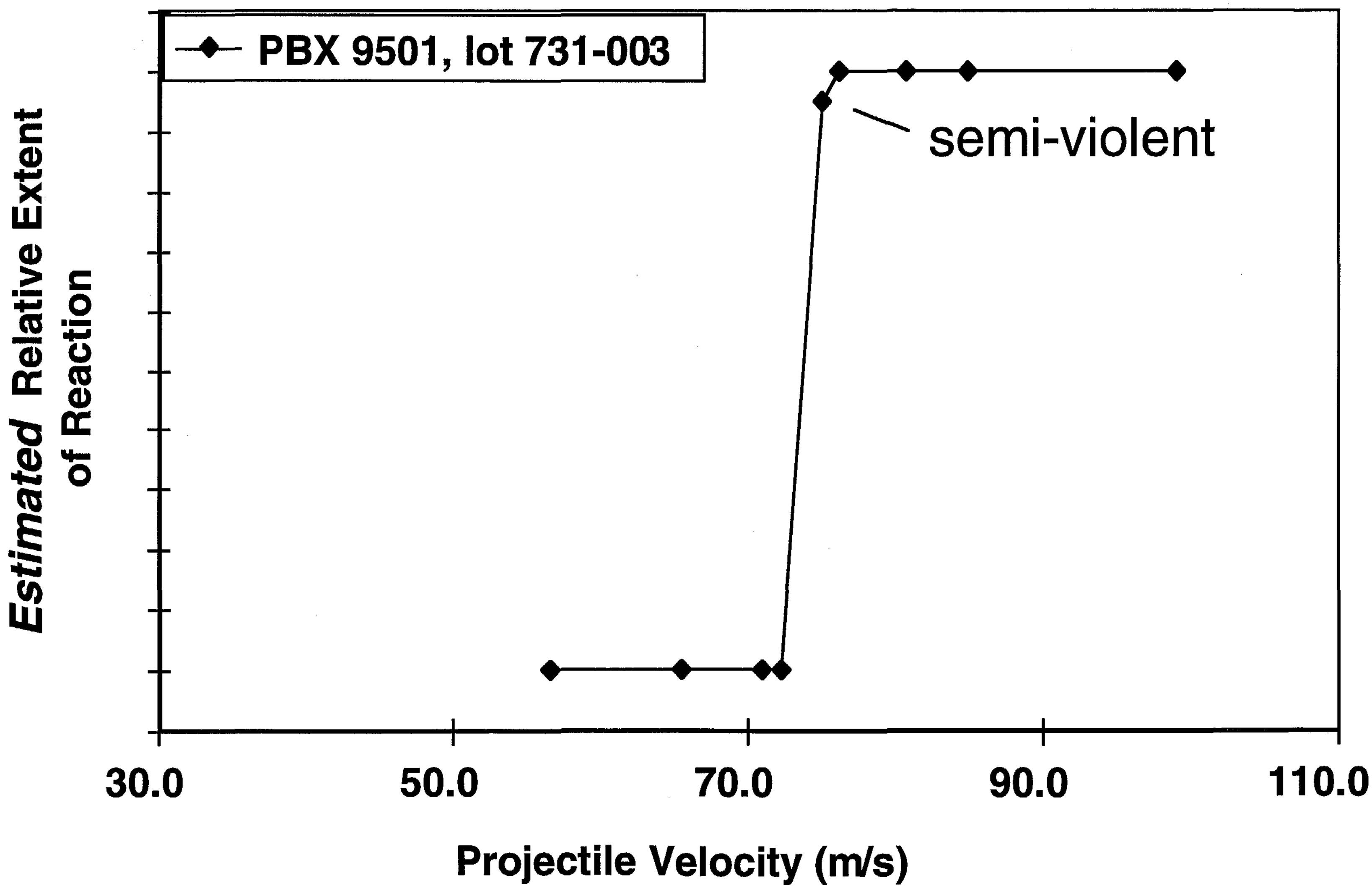
Post-Test Characterization



- PBX 9501 recovered from test K3-1290, semi-violent
- 75.1 m/s (246.3 ft/s)
- ≈ 95 % PBX 9501 consumed

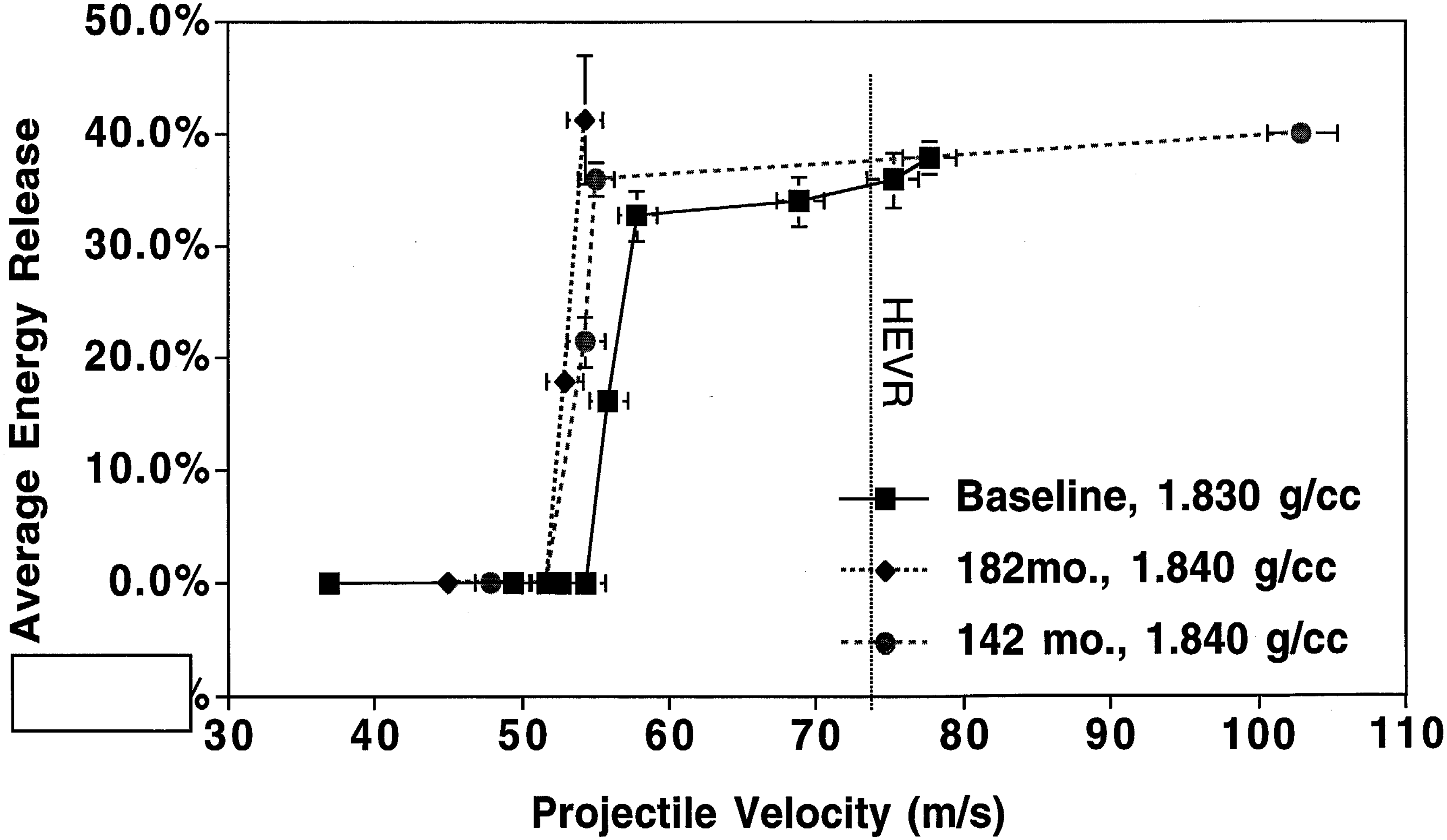
PBX 9501 HEVR Data

72.2 m/s < threshold < 75.1 m/s, 1.836 g/cm^3

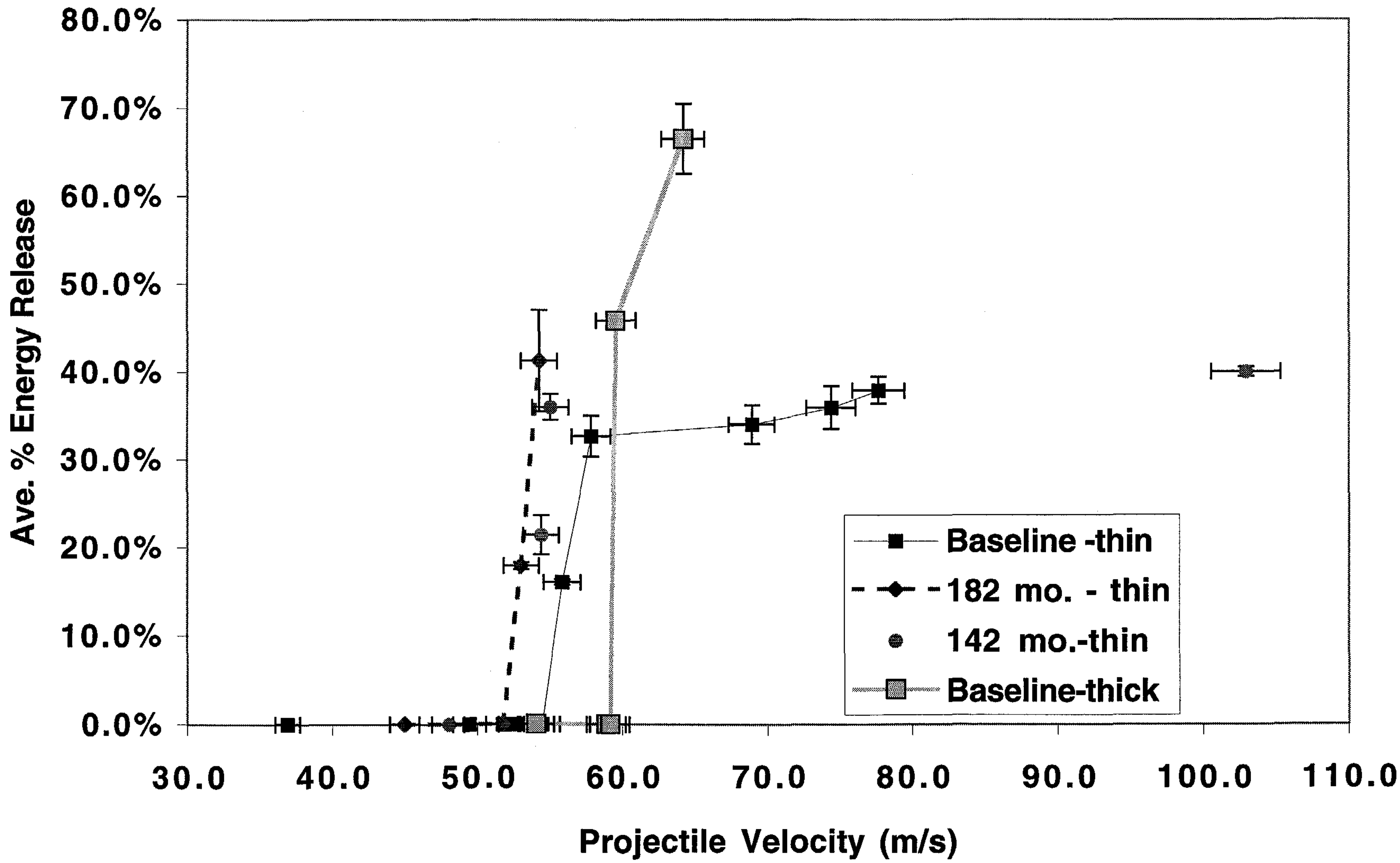


[redacted] PBX 9501 Data

54.4 m/s < 730-010 < 55.9 m/s
51.8 m/s < 685-002 & 730-005 < 53.0 m/s

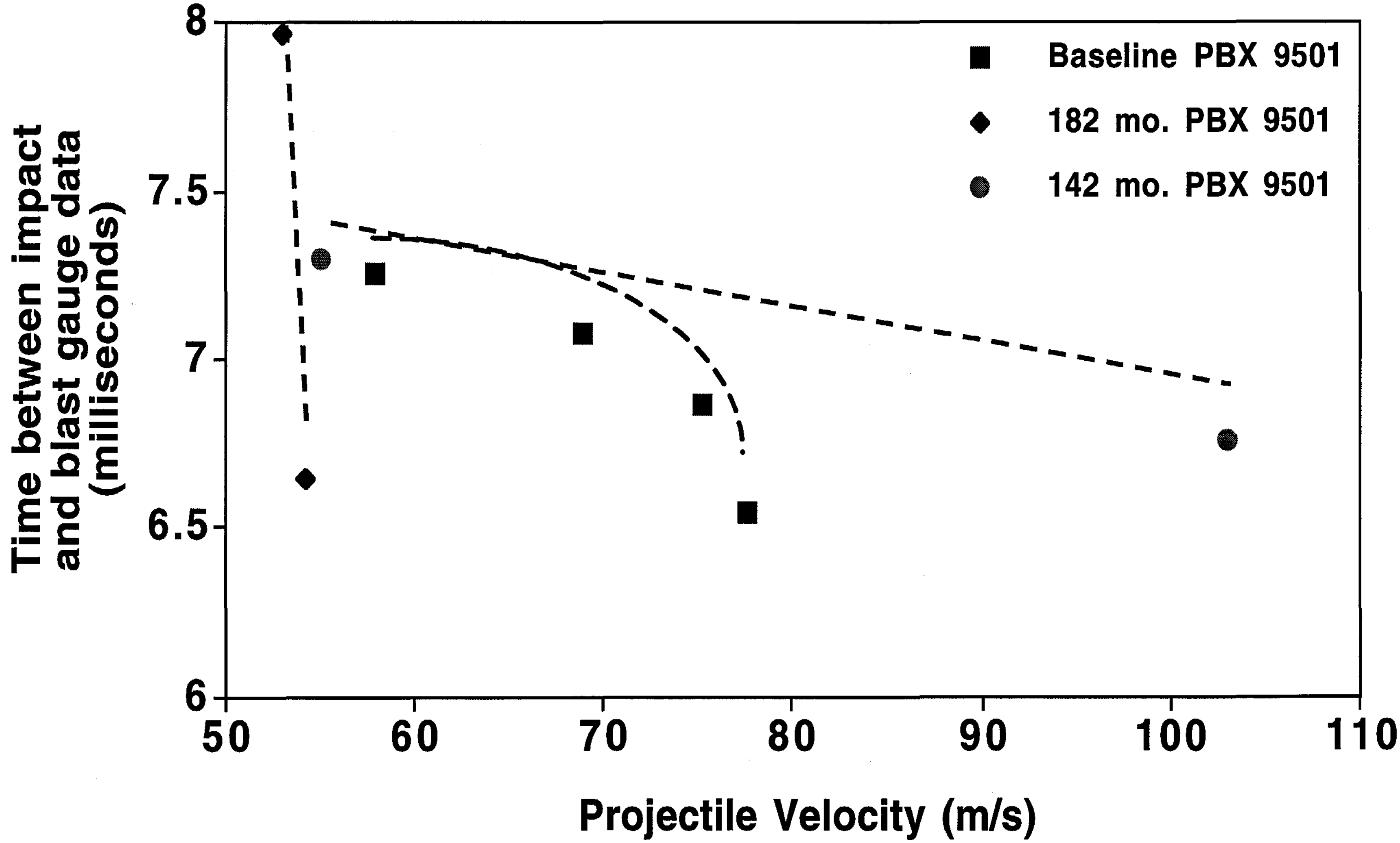


Modified Steven Spigot Gun Tests

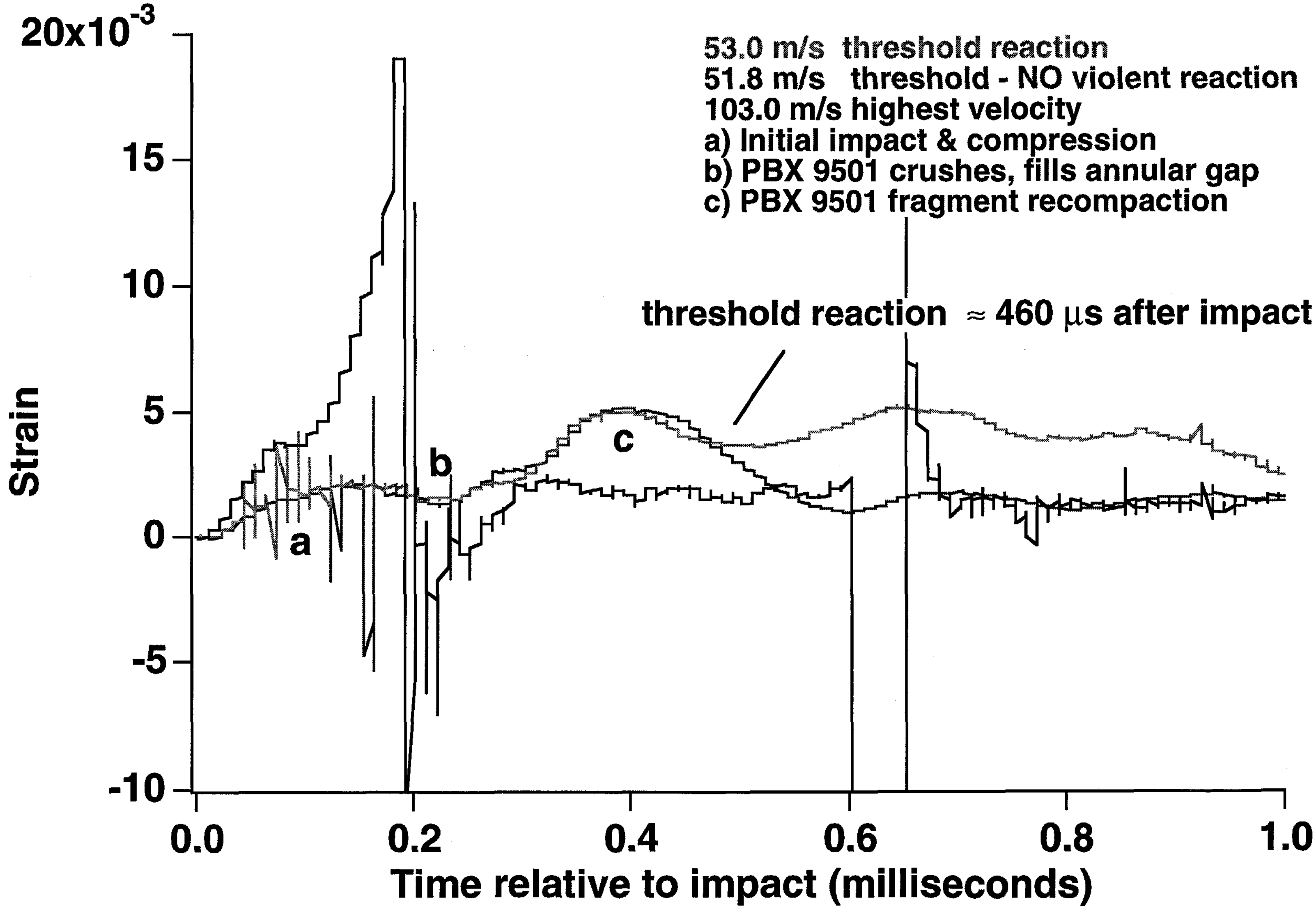


Timing: PVDF to Blast Gauge

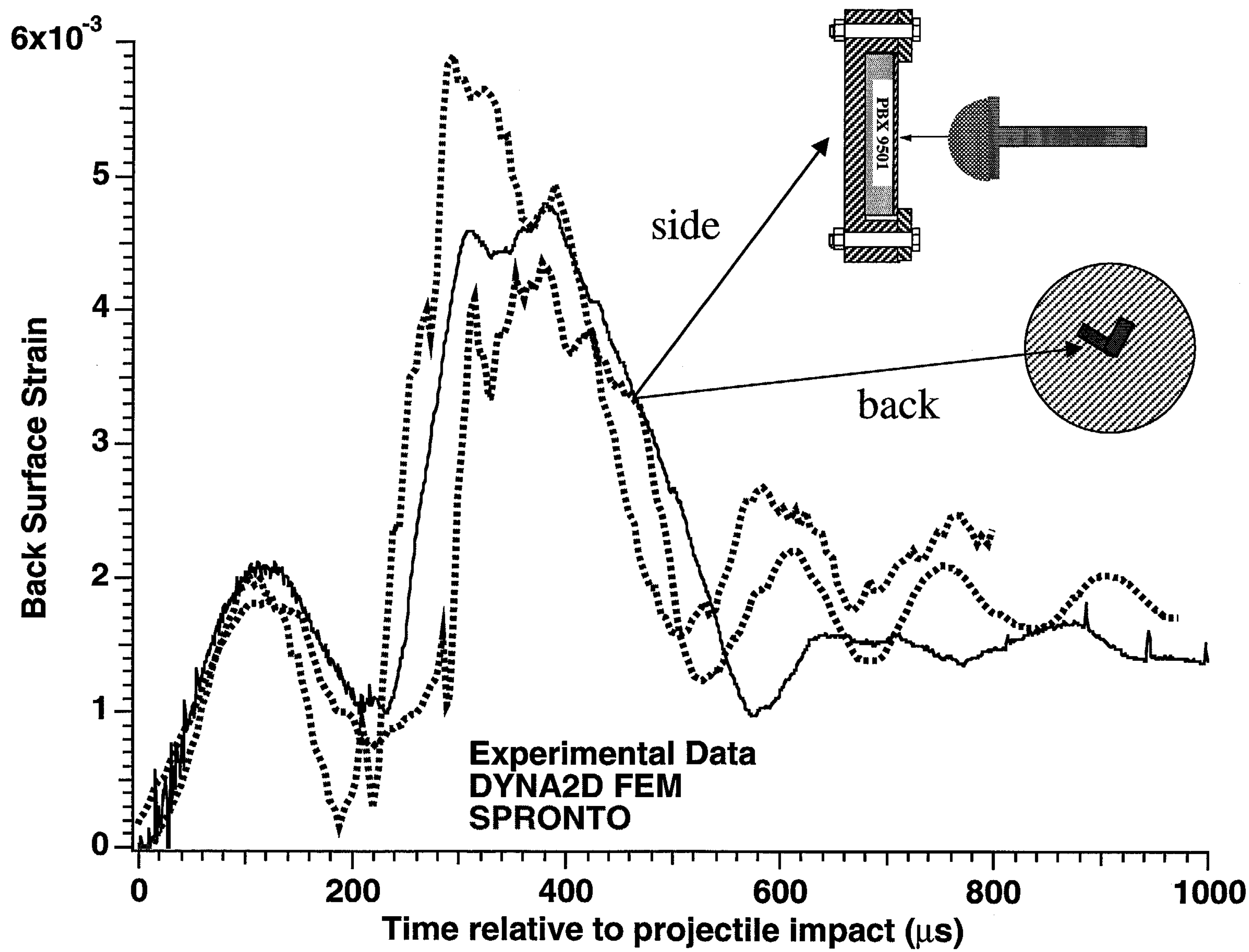
(prompt detonation - 4.7 ms)



PBX 9501 - Strain Data



- Model predictions match experimental dent/deformation and strain features well
- GOAL - full-up weapons simulation



Summary of Target Differences

- HEVR - Large target
  - √ PBX 9501 - 425.5 cm^3 (2.6 x larger)
  - √ sharp reaction threshold
    - » lot 731-003, 1.836 g/cm^3, $72.2 \leq v \leq 75.1$ m/s
  - √ target damage **500 μs to 1 ms** after impact
  - √ evidence of burning & scorching
  - √ **considerable** damage to front cover & target holder
  - √ HE retrieved from only one of the reacted tests
- Surveillance - Small target
  - √ PBX 9501 - 160.9 cm^3
  - √ sharp reaction threshold followed by gradual increase in energy release
    - » baseline 730-010, 1.830 g/cm^3, 54.4 m/s $\leq v \leq$ 57.9 m/s
    - » 685-002 & 730-005, 1.840 g/cm^3, $51.8 \leq v \leq 53.0$ m/s
  - √ target damage **0.6 to 2.8 ms** after impact
  - √ **no** evidence of burning & scorching
  - √ **minimal deformation damage** to front cover, retaining ring &holder
  - √ HE retrieved from every reacted test
  - √ **some yellow discoloration of HE**
  - √ **black film on HE from baseline threshold**

[redacted] Modified Steven Tests LANL - LLNL Differences

- Projectile dimensions, material & mass
- Cover plate material & mass
- HE dimensions
- Holder dimensions & material
- Annular gap
- Teflon ring in smaller target
- Potting material & location

Observations & Questions

- Level of reaction violence $\neq$ PBX 9501 detonation
- Sharp reaction thresholds - aged data shows nominally same type of behavior as baseline data without significant changes in the threshold value
- Ave. energy release (small targets) $\leq$ 41% PBX 9501 detonation
- Steven test is sensitive to changes in the HE
- Evidence of shear dislocation in cracking patterns
- Evidence of melt zone formations and gas evolution
- Indications of possibly different ignition mechanisms?
- More tests are required to identify if changes are specifically due to target, density, or other HE age-related differences
- Preliminary Steven test results indicate only slight changes in the threshold of the aged PBX 9501 ☞ no drastic changes in behavior of the HE within the age range tested

Work in Progress

- Post-test characterization
  - SEM, light microscopy, fracture surfaces, crack mapping, density profiles
- Analytical testing
  - density, particle size distribution, DSC, FTIR, GC, and possibly GPC
- Large -size tests
  - NHB, Pincushion, Glass-backed
- Small-size tests
  - density, velocity, projectile shape, deformation profile, timing

Future Plans

- Evaluate changes in HE density and projectiles on threshold
- Second impact on damaged targets
  - cracked
  - stabilized with RTV12
- Dynamically evaluate HE deformation under impact
- Incorporate new unloading materials parameters into models
- Develop gas phase generation coding
- Couple solid mechanics and chemistry in models
- Begin 3D model work and calibration for weapon predictions