# Meltable Nitroguanidine: Development of DGX-Al Formulations

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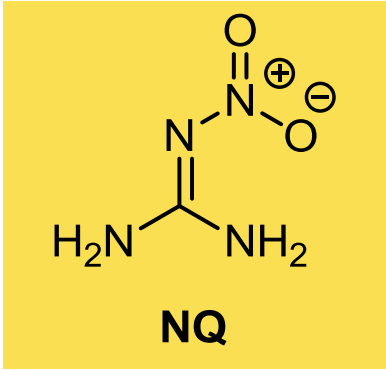
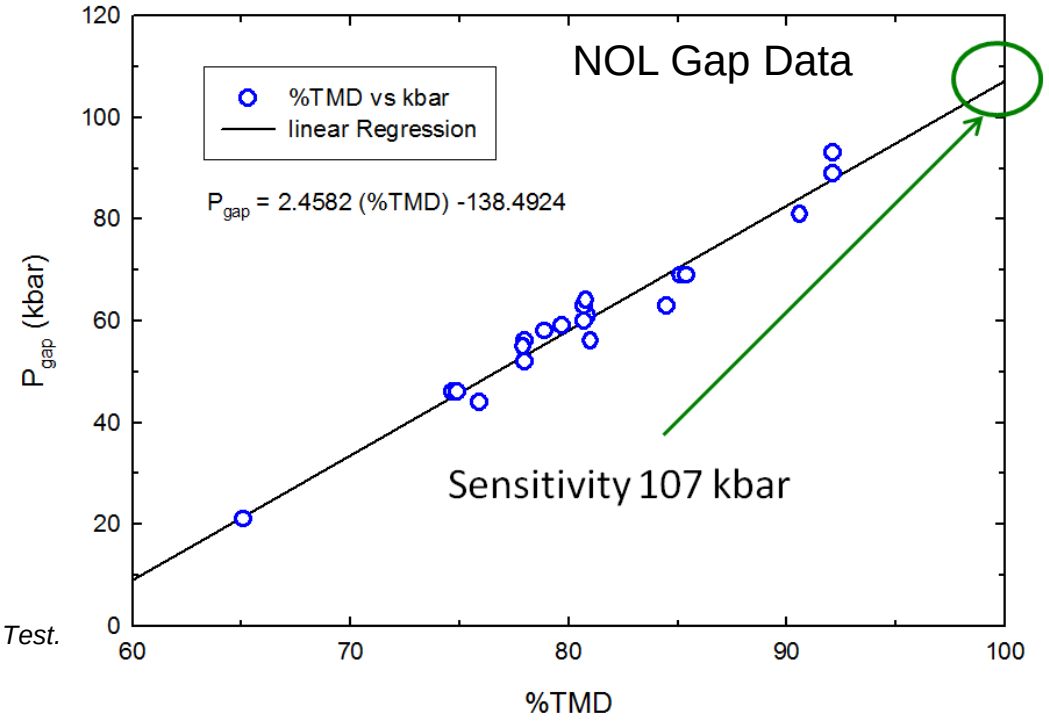
# Ingredient Background

## Nitroguanidine

- **Advantageous properties for use as a powerful insensitive fill**
  - Extremely insensitive to shock (SR)
  - Large critical diameter (SCJ)
  - Mild SCO response (liberates water, cools decomposition)
- **NQ decomposes upon melting ($T_{dec}$ = 250 °C)**
- **Requires PBX formulation**
- **Inert binders dilute explosive power**




**NQ**

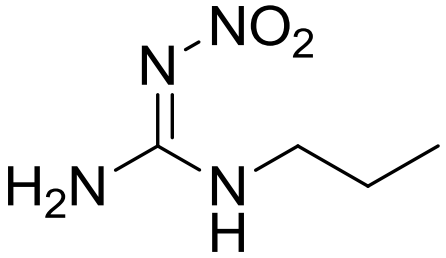


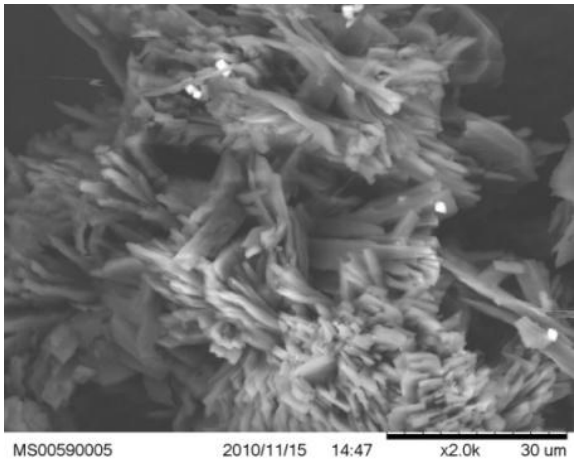


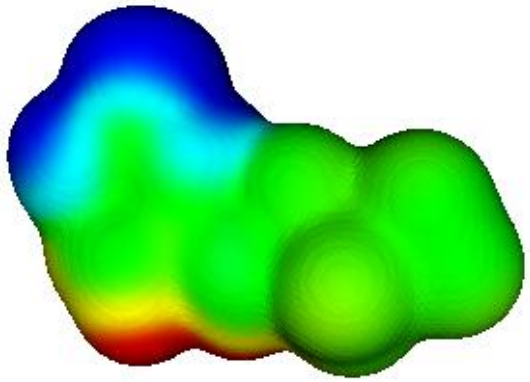
Price, D.; Clairmont, A. R., Jr.; Erkman, J. O. *The NOL Large Scale Gap Test. III. Compilation of Unclassified Data and Supplementary Information for Interpretation of Results*; NOLTR 74-40; United States Naval Ordnance Laboratory: White Oak, MD, March 1974.

## PrNQ

- Simply adds propyl alkyl group to nitroguanidine
- Decreases NQ melting point to 98-100 °C
- Decomposition starts at 220 °C
- Allows for steam-based melt cast processing
- Propyl group expected to further desensitize NQ with a manageable performance diminishment



# DGX-Al Formulation Family

## DGX-Al Formulations

- PrNQ will be combined with aluminum and other particulate solids to comprise DGX-Al family of formulations
- DGX-Al formulations will be highly insensitive, enhanced blast, and environmentally friendly

- **Initial Goal:** Determine detonation velocity and critical diameter of candidate DGX-Al formulations

# Performance Calculations

| Formulation Name | Ingredients | Detonation Velocity (% of PBXN-109) | Detonation Pressure (% of PBXN-109) |
|---|---|---|---|
| DGX-1 | PrNQ·Al | 88.6 | 63.8 |
| DGX-2 | PrNQ·Ingredient A·Al | 89.3 | 65.4 |
| DGX-3 | PrNQ·Ingredient B·Al | 98.6 | 87.8 |
| DGX-4 | PrNQ·Ingredient A·Ingredient B·Al | 99.1 | 89.2 |
| DGX-5 | PrNQ·Ingredient B·Ingredient C·Al | 97.4 | 101.5 |
| DGX-6 | PrNQ· Ingredient B·Ingredient C·Al (more Ingredient C) | 95.8 | 98.3 |

***Ingredients B and C are solid particulates***
***Ingredient C is a sensitizer***

*Cheetah 6.0 User's Manual*, LLNL-SM-416166, 2010.

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Generation 1

*Cheetah 6.0 User's Manual*, LLNL-SM-416166, 2010.

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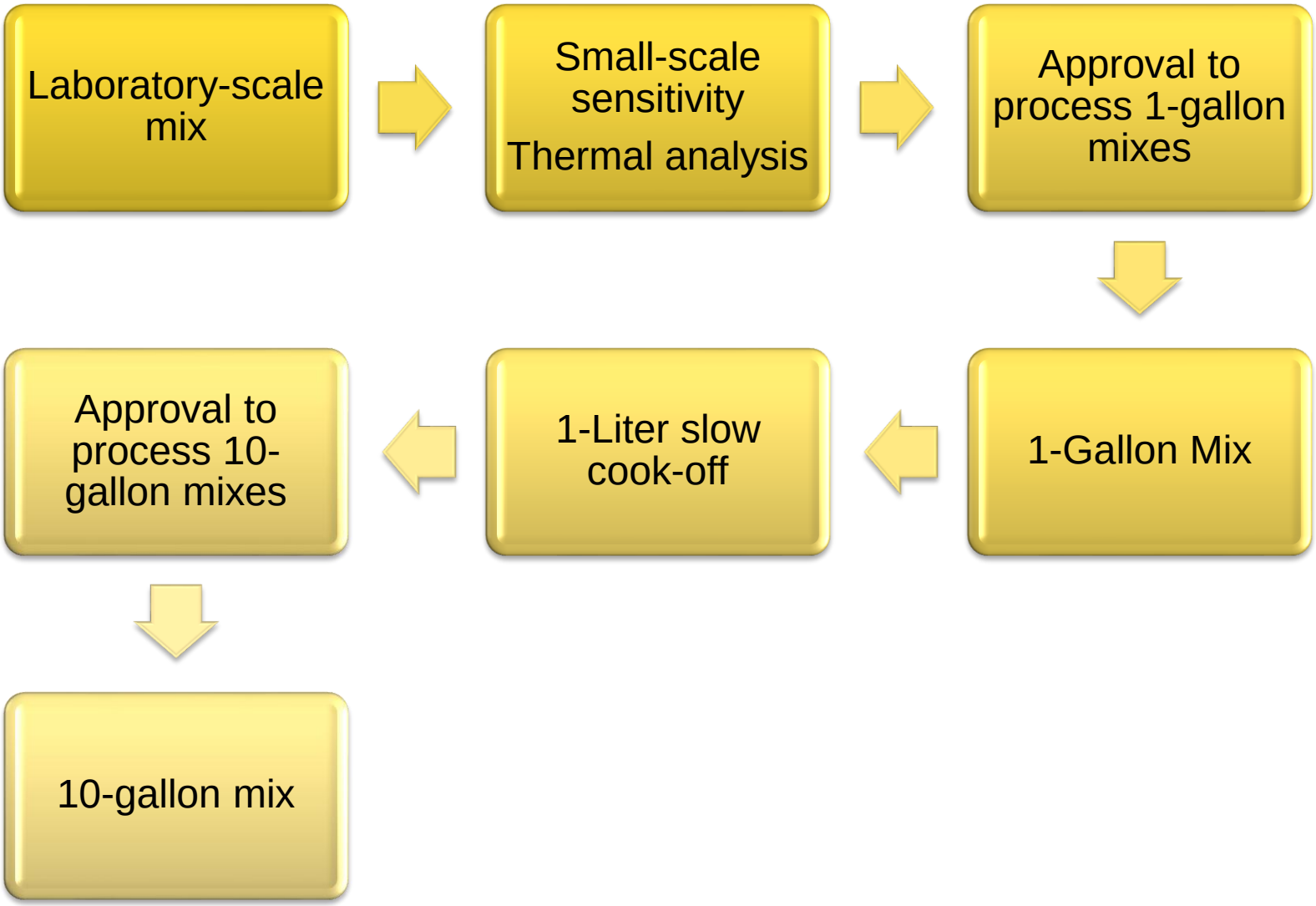
Generation 2

*Cheetah 6.0 User's Manual*, LLNL-SM-416166, 2010.

# Melt-Cast Scaling Process Map



# DGX-Al Generation 1 Processing

| Formulation | Ingredients | Aluminum |
|---|---|---|
| DGX-3a | PrNQ·Ingredient B·Al | Type III Class 7 |
| DGX-3b | PrNQ·Ingredient B·Al | Type IV spherical |
| DGX-4a | PrNQ·Ingredient A·Ingredient B·Al | Type III Class 7 |
| DGX-4b | PrNQ·Ingredient A·Ingredient B·Al | Type IV spherical |

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# DGX-3 Formulation Processing

**DGX-3a**
**(PrNQ, Ingredient B, Type III Class 7 Al)**

**Processed poorly- mix did not pour**

**DGX-3b**
**(PrNQ, Ingredient B, Type IV spherical Al)**

**Processed well- mix poured easily**

# DGX-3 Formulation Processing

**DGX-3a**
**(PrNQ, Ingredient B, Type III Class 7 Al)**

**Processed poorly- mix did not pour**

**DGX-3b**
**(PrNQ, Ingredient B, Type IV spherical Al)**

**Processed well- mix poured easily**

# DGX-4 Formulation Processing

**DGX-4a**
**(PrNQ, Ingredient A, Ingredient B, Type III Class 7 Al)**

**Processed marginally- mix poured with difficulty**

**DGX-4b**
**(PrNQ, Ingredient A, Ingredient B, Type IV spherical Al)**

**Processed well- mix poured easily**

# DGX-4 Formulation Processing

**DGX-4a**
**(PrNQ, Ingredient A, Ingredient B, Type III Class 7 Al)**

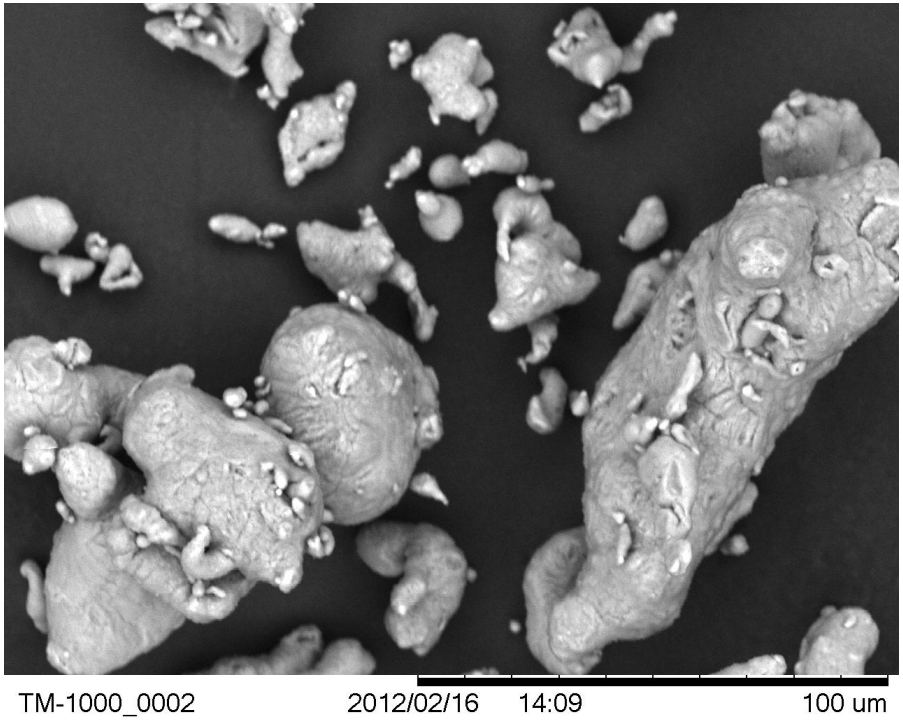
**Processed marginally- mix poured with difficulty**

**DGX-4b**
**(PrNQ, Ingredient A, Ingredient B, Type IV spherical Al)**

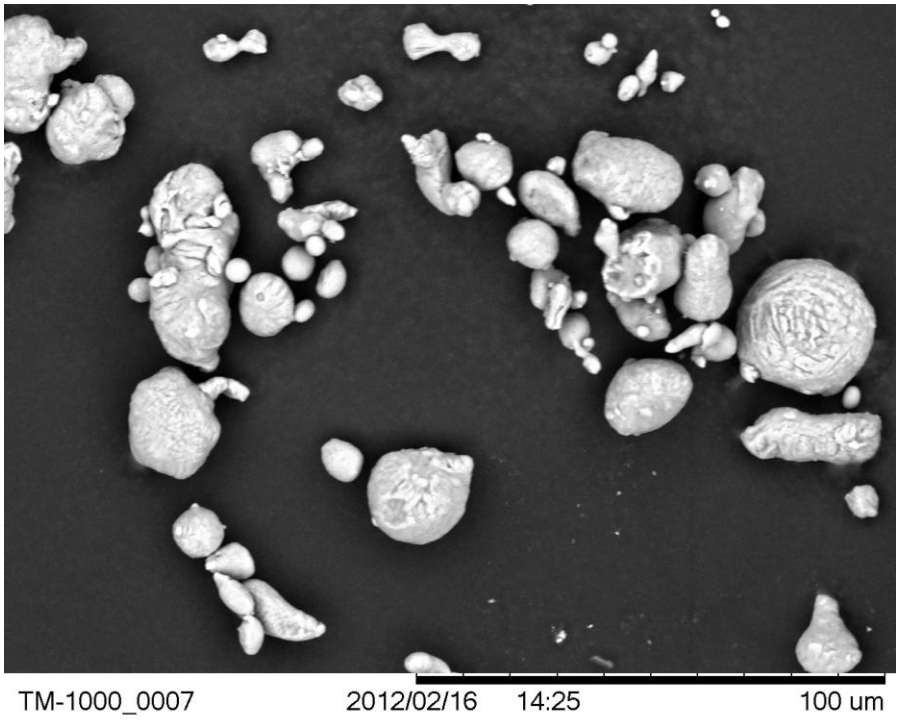
**Processed well- mix poured easily**

# Aluminum SEM Images

## Type III Class 7 Aluminum




## Type IV Spherical Aluminum




- **Type III Class 7 aluminum particles larger and more irregularly shaped**
- **Type IV spherical aluminum smaller, but spherical**
- **Surface area differences likely affected processing success of formulations with solid particulates**

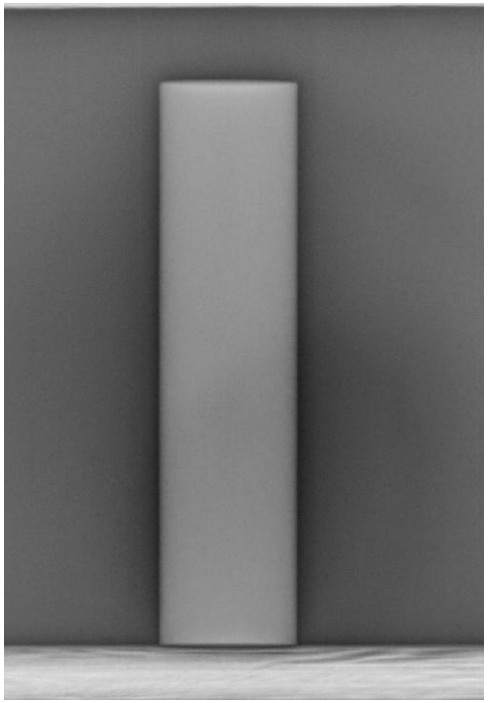
# Small-Scale Sensitivity: DGX-3b and DGX-4b

| Material | Impact ($H_{50}$, in) | BAM Friction (N) | ESD (J) |
|---|---|---|---|
| DGX-3b | > Instrument Max | 247 | 0.625 |
| DGX-4b | > Instrument Max | 318 | 0.250 |
| RDX | 8.6 | 125 | 0.063 |

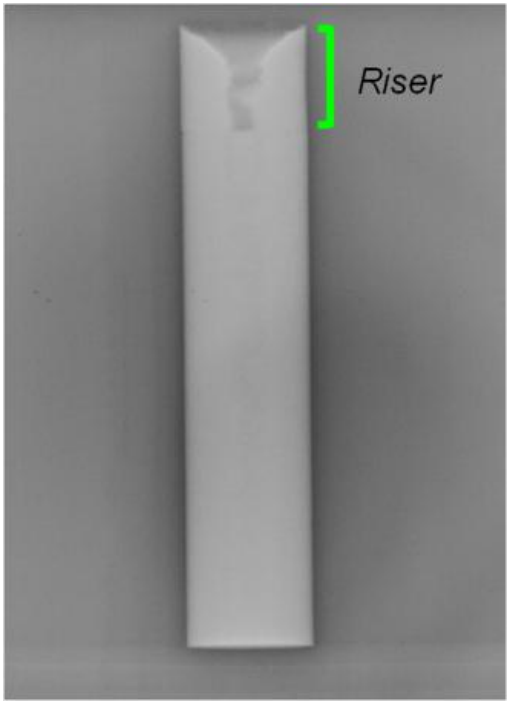
**The insensitivity shown by the small-scale sensitivity testing coupled with favorable thermal safety testing permitted scale-up to 1-gallon mixes**

# Generation 1 Detonation Velocity Testing

**DGX-3b**
**x-ray image**



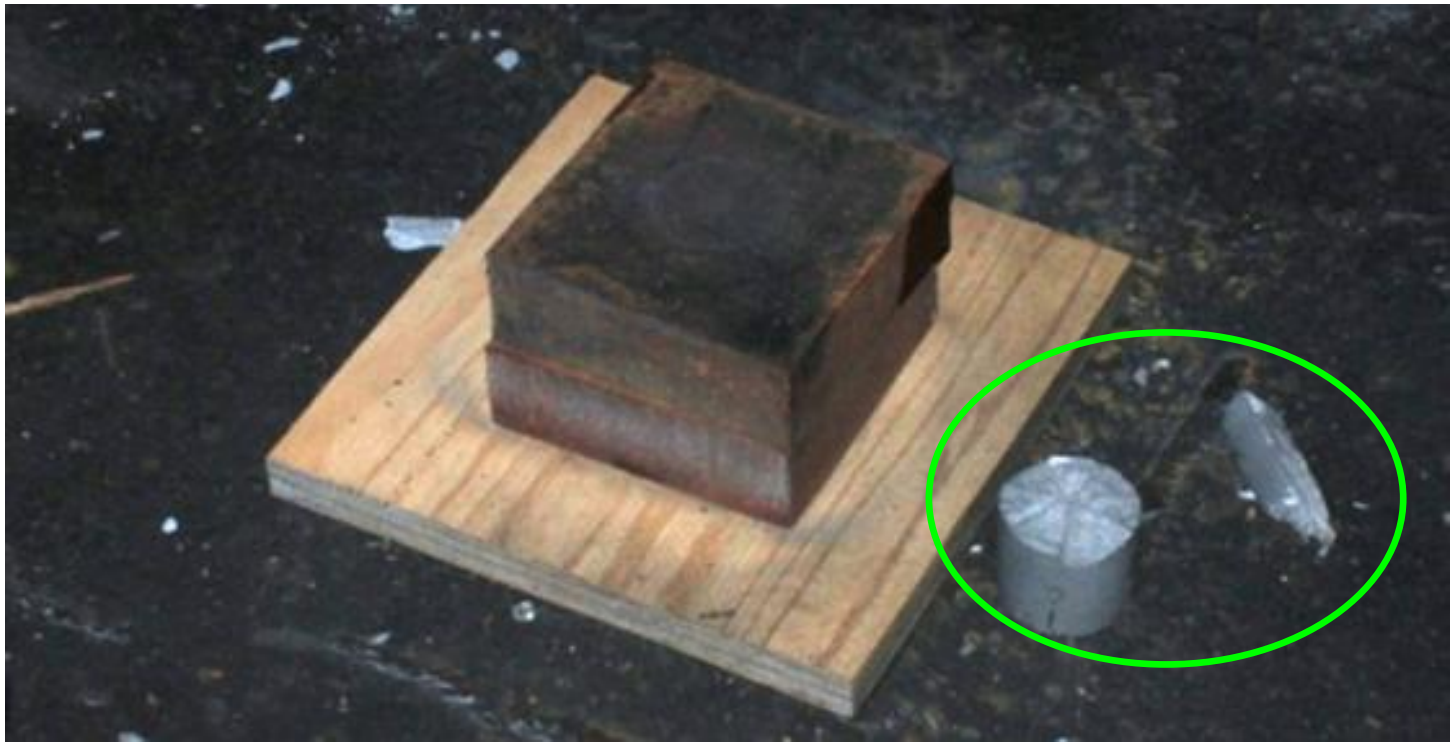
**DGX-4b**
**x-ray image**




**2.5” diameter x 10” long charges cast at high theoretical maximum density**

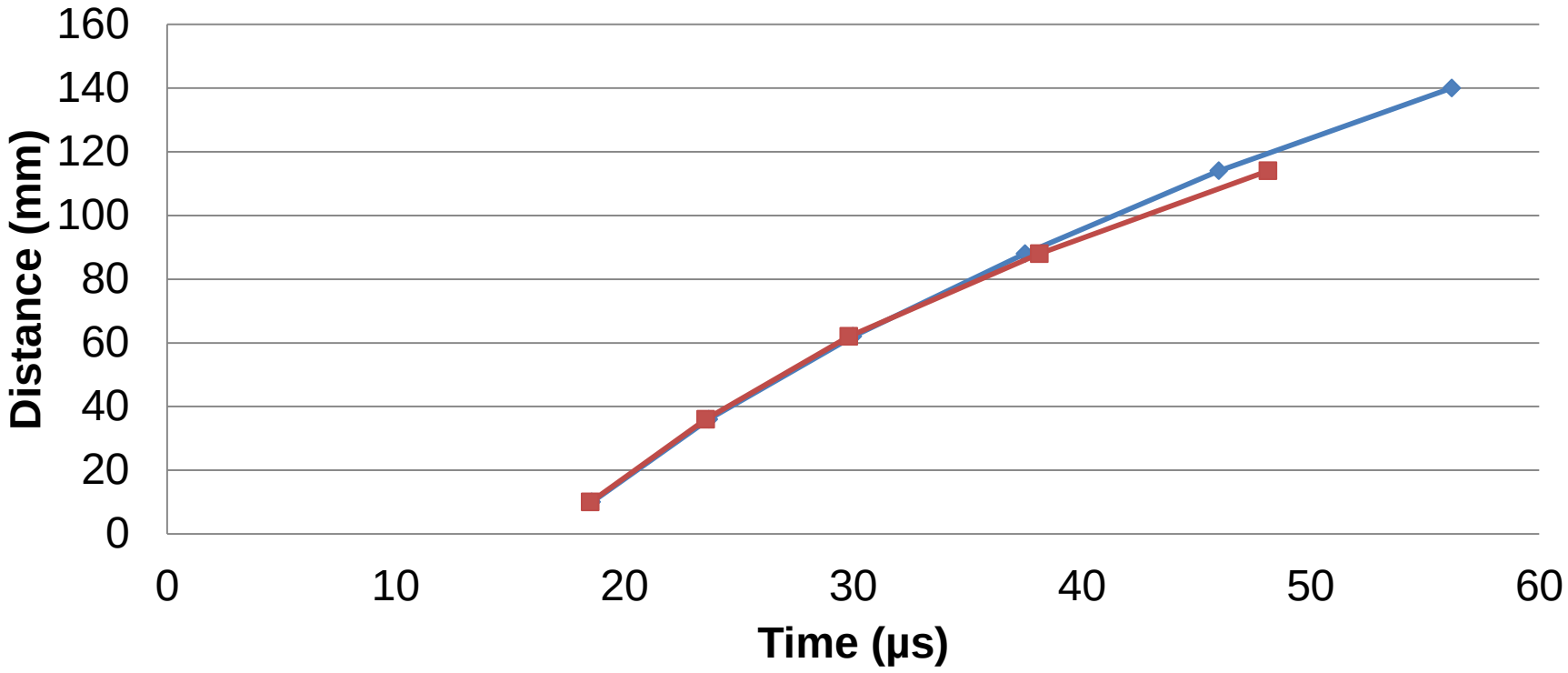
**Test set-up**

# Generation 1 Detonation Velocity Testing Results



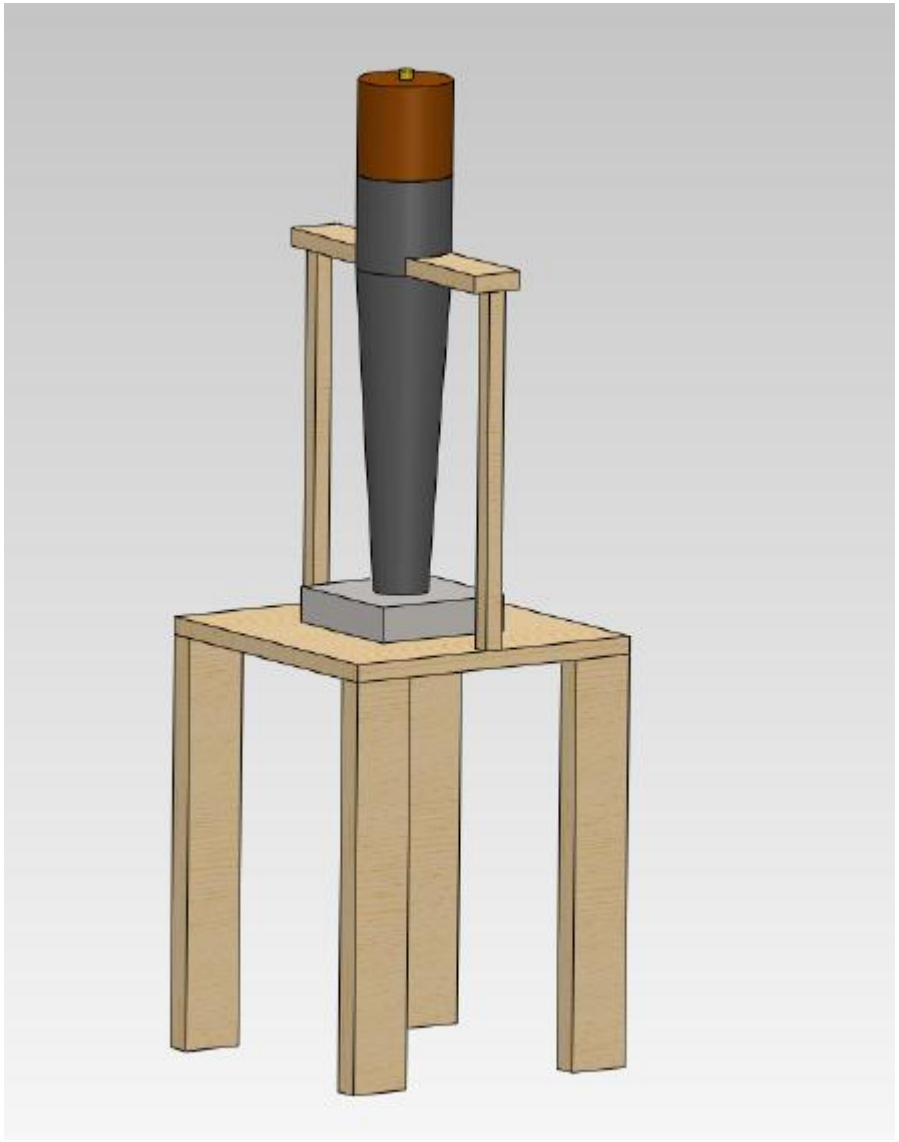
- No detonation observed for either DGX-3b or DGX-4b
- Material recovered after both tests
- Conclusion- critical diameter >2.5” for both

# Generation 1 Decaying Shock Waves




- DGX-3b (blue), DGX-4b (red)
- Maximum shock velocity observed <5 km/s
- Roughly half of pins on each charge did not receive signal for passing shock wave

# Detonation Velocity Cone Tests



- Why a cone test?
  - Eliminates need to test multiple right-cylinder charges to determine critical diameter
  - Minimizes material needs (but still a big charge)
- Drawback- provides only an estimate of critical diameter due to overdriven detonation wave
- Cone description:
  - 5.25” diameter by 5.25” long lead-in section
  - 18” long taper section (3.6$^{o}$) down to 3” diameter
  - 5.25” diameter by 5.25” long composition B booster

# Detonation Velocity Cone Test Formulations

- DGX-3b
  - PrNQ, Ingredient B, and Type IV spherical aluminum
  - Did not detonate at 2.5” diameter
  - Contains fewer ingredients than DGX-4b
  - Approved for processing on the 1-gallon scale

- DGX-6b
  - DGX-3b + a sensitizing ingredient (Ingredient C)
  - Should detonate at a smaller diameter than DGX-3b (good if critical diameter of DGX-3b is excessively large)
  - Approved for processing on the laboratory scale

# Safety Testing for Approval of 10-Gallon Mixes

- **DGX-3b**
  - **Only remaining data piece was 1-liter slow cook-off**
  - **1-liter slow cook-off results were favorable**
  - **Approval was granted to process on the 10-gallon scale**

- **DGX-6b**
  - **Needed small-scale sensitivity and thermal analysis**

| Material | Impact ($H_{50}$, in) | BAM Friction (N) | ESD (J) |
|---|---|---|---|
| DGX-6b | > Instrument Max | 282.24 | 0.250 |
| RDX | 10.12 | 141.12 | 0.125 |

  - **Also needed 1-liter slow cook-off data**
  - **1-liter slow cook-off results were favorable**
  - **Approved for public release**

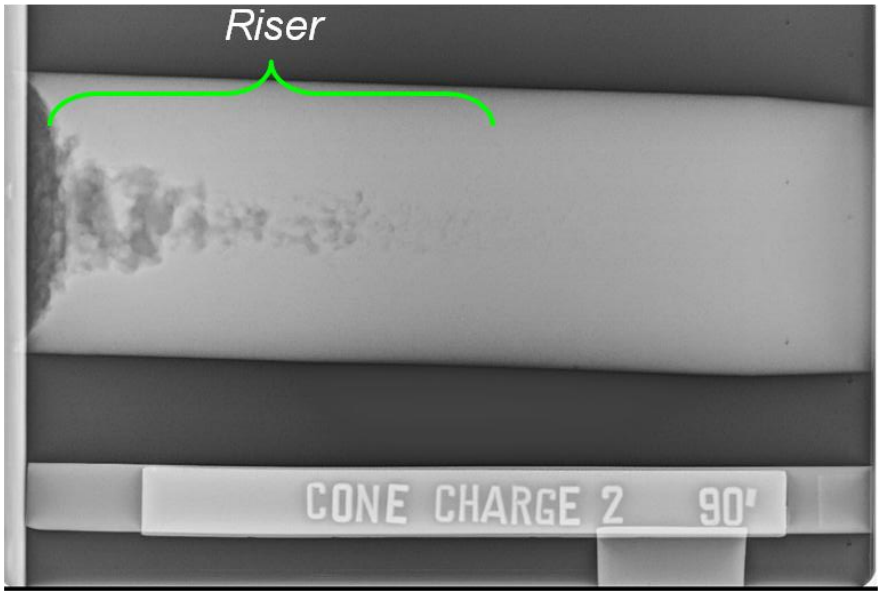
# 10-Gallon Scale Processing

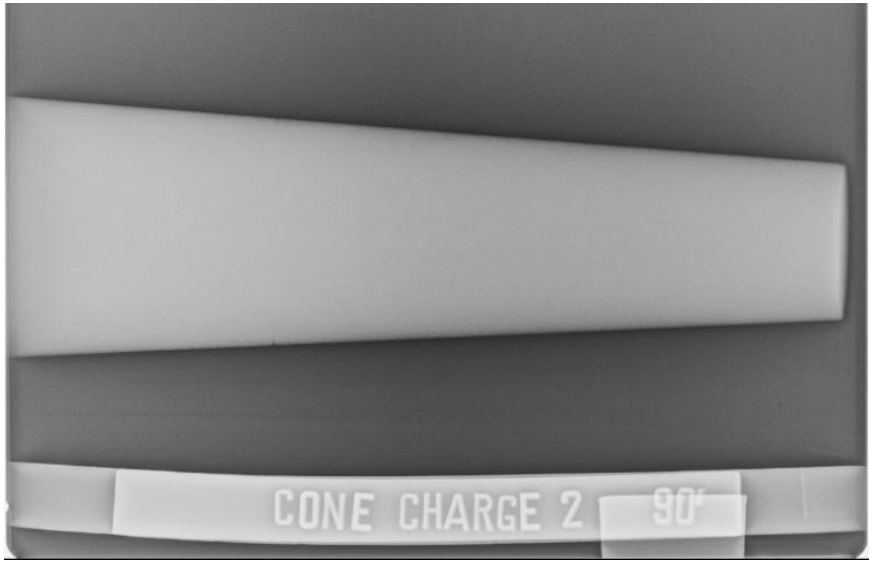
**Insulated 3 piece cone mold**

# 10-Gallon Scale Processing (cont.)

**Charge after removal from mold**

# Cone Charge X-Ray Images

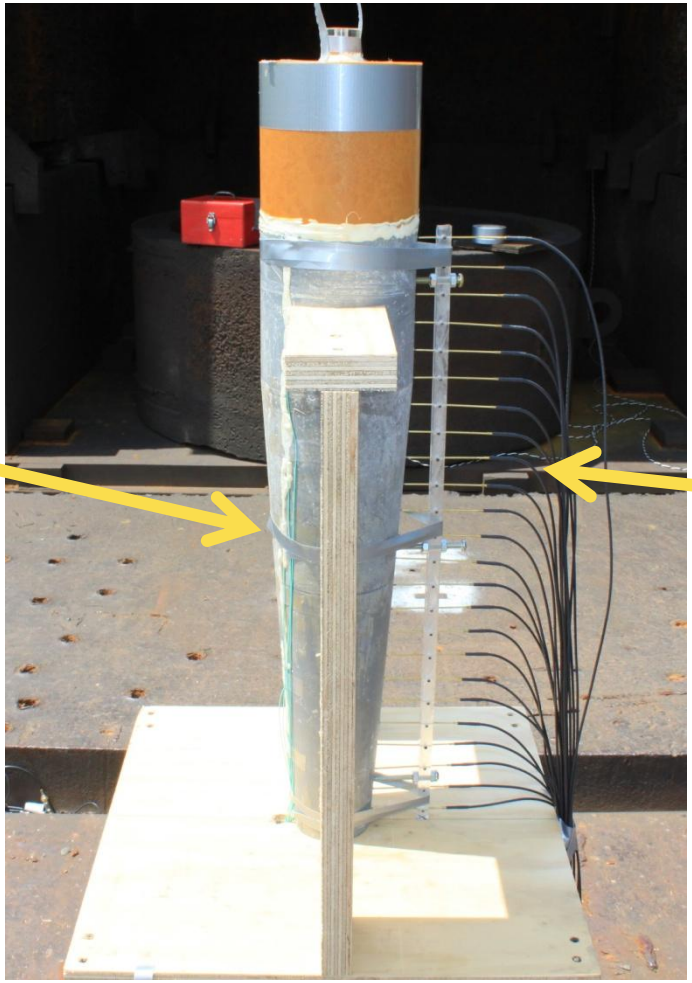



**No voids observed in the experimental section of charge**

# Detonation Velocity Monitoring

- Chirped fiber Bragg grating
- Collaboration with LANL, funded by JMP (POC: George Rodriguez)
- Hi fidelity record of passing detonation wave



- Piezopins
- 1” pin spacing
- Traditional detonation velocity measurement technique

# Detonation Velocity Cone Test Results

- DGX-3b
  - PrNQ, Ingredient B, and Type IV spherical aluminum
  - Did not detonate
  - Material recovered after test
  - Critical diameter >5.25”

Recovered DGX-3b

- DGX-6b
  - Fully detonated at all diameters
  - Large dent in witness plate
  - Detonation velocity near tritonal and PBXN-109
  - Critical diameter <5.25”

DGX-6b witness plate

# Technical Conclusions

- Demonstrated that PrNQ can be used a melt-base for energetic formulations
- Conical detonation velocity tests were conducted on DGX-3b and DGX-6b
- DGX-3b critical diameter > 5.25”
- DGX-6b critical diameter < 3”, detonation velocity near tritonal and PBXN-109
- Future work will be to tailor formulations to achieve desired detonation velocity, critical diameter, detonation pressure, and shock sensitivity

# Participants and Acknowledgements


- OSD JIMTP for funding (Task 12-2-48)
- The JIMTP bomb working group
- ARL's entire Energetics Technology Branch
- George Rodriguez (LANL)
- Steve Gilbertson (LANL)
- Tom Mason (JMP) for funding the chirped fiber Bragg grating work

# Questions?