2022 INSENSITIVE MUNITIONS AND ENERGETIC MATERIALS (IMEM) TECHNOLOGY SYMPOSIUM

Enhancing The Performance of Insensitive Munitions

October 18 – 20, 2022 | Indianapolis, IN | NDIA.org/IMEM

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NDIA

WHO WE ARE

The National Defense Industrial Association is the trusted leader in defense and national security associations. As a 501(c)(3) corporate and individual membership association, NDIA engages thoughtful and innovative leaders to exchange ideas, information, and capabilities that lead to the development of the best policies, practices, products, and technologies to ensure the safety and security of our nation. NDIA's membership embodies the full spectrum of corporate, government, academic, and individual stakeholders who form a vigorous, responsive, and collaborative community in support of defense and national security. For more than 100 years, NDIA and its predecessor organizations have been at the heart of the mission by dedicating their time, expertise, and energy to ensuring our warfighters have the best training, equipment, and support. For more information, visit **NDIA.org**

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SCHEDULE AT A GLANCE

MONDAY, OCT 17

Registration
Cosmopolitan Foyer
4:00 pm - 6:00 pm

TUESDAY, OCT 18

Registration
Cosmopolitan Foye
8:00 am - 5:30 pm

Keynote: Dr. Brian Fuchs
Cosmopolitan AB
8:10 am - 9:00 am

Reception
Cosmopolitan Foyer
5:10 pm – 6:10 pm

WEDNESDAY, OCT 19

Registration
Cosmopolitan Foyer
7:00 am - 12:00 pm

Keynote: Dr. Robert Wardle
Cosmopolitan AB
8:35 am - 9:15 am

THURSDAY, OCT 20

Registration
Cosmopolitan Foyer
7:00 am - 5:00 pm

Keynote: Dr. Jason Jouet
Cosmopolitan AB
9:00 am – 10:00 am

WELCOME TO 2022 IMEM TECHNOLOGY SYMPOSIUM

On behalf of the Insensitive Munitions and Energetic Materials Committee and our MSIAC partner, I would like to welcome you to the 2022 Insensitive Munitions and Energetic Materials Technology Symposium. This international gathering of the top chemists, system designers and engineers from government laboratories, industry, and academia provides a venue for the exchange and dissemination of the latest research in synthesis, formulation, system design, testing, characterization and safety – all aimed at advancing munitions effectiveness while improving safety for the warfighter. In recent decades, great advances have been made and our munitions are less vulnerable to attack than ever before; however, challenges persist. It is through the continuing work of the authors, presenters, sponsors, and attendees at this conference and across our worldwide defense industry that these challenges will be overcome resulting in safer munitions being produced in our factories and fielded to our warfighters.

Paul Braithwaite
Fellow, Propulsion Systems IR&D Lead
Northrop Grumman Corporation

GET INVOLVED
Learn more about NDIA's Divisions and how to join one at **NDIA.org/Divisions**

MUNITIONS TECHNOLOGY

WHO WE ARE

The Munitions Technology Division maintains an open exchange of technical information among government and industry programs and technical managers, and to identify changes and trends in policy, guidance, and organizational functions that impact the development, production, maintenance, and demilitarization of munitions.

EVENT INFORMATION

LOCATION

Hyatt Regency
One South Capital Avenue
Indianapolis, IN 46204

ATTIRE

Civilian: Business Casual
Military: Uniform of the Day

SURVEY AND PARTICIPANT LIST

You will receive via email a survey and list of participants (name and organization) after the conference. Please complete the survey to make our event even more successful in the future.

EVENT CONTACT

Kimberly Hurley
Director, Meetings
(703) 247-9494
khurley@NDIA.org

PLANNING COMMITTEE

Paul Braithwaite
Symposium Chair

Ken Graham
Committee Member

Christelle Collet
Committee Member

Steve Nicolich
Committee Member

Stephen Struck
Committee Member

SPEAKER GIFTS

In lieu of speaker gifts, a donation is being made to the Fisher House Foundation.

HARASSMENT STATEMENT

NDIA is committed to providing a professional environment free from physical, psychological and verbal harassment. NDIA will not tolerate harassment of any kind, including but not limited to harassment based on ethnicity, religion, disability, physical appearance, gender, or sexual orientation. This policy applies to all participants and attendees at NDIA conferences, meetings and events. Harassment includes offensive gestures and verbal comments, deliberate intimidation, stalking, following, inappropriate photography and recording, sustained disruption of talks or other events, inappropriate physical contact, and unwelcome attention. Participants requested to cease harassing behavior are expected to comply immediately, and failure will serve as grounds for revoking access to the NDIA event.

EVENT CODE OF CONDUCT

NDIA's Event Code of Conduct applies to all National Defense Industrial Association (NDIA), National Training & Simulation Association (NTSA), and Women In Defense (WID) meeting-related events, whether in person at public or private facilities, online, or during virtual events. NDIA, NTSA, and WID are committed to providing a productive and welcoming environment for all participants. All participants are expected to abide by this code as well as NDIA's ethical principles and practices. Visit NDIA.org/CodeOfConduct to review the full policy.

THIOT INGENIERIE

POWDER GUNS ZOLTAN 40 & ZOLTAN 90

up to 2530m/s at 15m

- IMPACTS OF FRAGMENTS
- EVALUATION & DEVELOPMENT OF INSENSITIVE AMMUNITION
- EVALUATION OF ARMORED VEHICLES' LEVEL OF PROTECTION

STANAG AOP 4496

QUALITY OF IMPACT

- **Impact point at 15mm maximum** from the aimed point at 15m
- **Tilt at impact less than 2°** at 15m
- **Total separation of the sabot** before impact

EASE OF USE

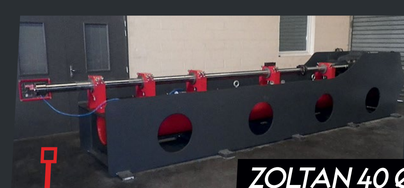
- **Complete supply** including launcher and projectiles
- **Easy installation and removal** of the launcher without special adjustment

SMART MAINTENANCE

- **Easy cleaning** after each shot
- **30 shots** before replacement of wear parts
- **300 shots** before replacement of the interchangeable part of the tube

Customization of the launcher depending on the nature of the powder used by the customer*

TECHNICAL CAPABILITIES



ZOLTAN 40 Ø

14.30mm @ 18.6g FSP
V 15m: 2530 ± 90m/s

20.00mm @ 52.73g FSP
V 15m: 1830 ± 60m/s

ZOLTAN 90 Ø

Up to 300g fragment
V 15m: 2000 ± 90m/s

*performance to be validated according to the nature of the powder

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AGENDA

MONDAY, OCTOBER 17

4:00 – 6:00 pm

REGISTRATION
COSMOPOLITAN FOYER

TUESDAY, OCTOBER 18

7:00 am – 5:30 pm

REGISTRATION
COSMOPOLITAN FOYER

8:00 – 8:10 am

WELCOME REMARKS
COSMOPOLITAN AB

MG James Boozer, USA (Ret)
Executive Vice President, NDIA

8:10 – 9:00 am

KEYNOTE: INSENSITIVE MUNITIONS, IMPORTANT NOW MORE THAN EVER
COSMOPOLITAN AB

Dr. Brian Fuchs
Senior Research Scientist, Insensitive Munitions, U.S. Army Picatinny Arsenal

9:00 – 9:40 am

MSIAC AWARDS PRESENTATION
COSMOPOLITAN AB

Christelle Collet
Technical Specialist Officer, MSIAC

9:40 – 10:10 am

NETWORKING BREAK
COSMOPOLITAN FOYER

10:15 – 10:35 am

ENERGETIC MATERIALS & THE DEFENSE PRODUCTION ACT
COSMOPOLITAN AB

Anthony Di Stasio
Director, Industrial Base Support, USD (A&S)

10:35 – 10:55 am

COMPARISON OF IM THREATS VERSUS THE REAL WORLD
COSMOPOLITAN AB

Christelle Collet
Technical Specialist Officer, MSIAC

10:55 – 11:15 am

NATO INSENSITIVE MUNITIONS PORTFOLIO PROGRESSION LEADING TO INSENSITIVE MUNITIONS – HAZARD CLASSIFICATION (IM-HC) HARMONIZATION

COSMOPOLITAN AB

Daniel Pudlak
CCDC-AC, U.S. Army

11:15 – 11:35 am

INSENSITIVE MUNITIONS – HAZARD CLASSIFICATION HARMONIZATION WORKING GROUP (IM-HC WG) UPDATE & DEVELOPMENT OF AOP-4864

COSMOPOLITAN AB

Daniel Pudlak
CCDC-AC, U.S. Army

11:35 – 11:55 am

MSIAC HIGHLIGHTS & FUTURE PRIORITIES

COSMOPOLITAN AB

Christelle Collet
Technical Specialist Officer, MSIAC

11:55 am – 1:00 pm

NETWORKING LUNCH

COSMOPOLITAN AB

CONCURRENT BREAKOUT SESSIONS

	Insensitive Munitions Policy & Requirements	Energetic Material Formulations & Synthesis
	COSMOPOLITAN AB Session Chair: Joseph LiVolsi	COSMOPOLITAN CD Session Chair: Dr. Jacob Morris
1:00 – 1:20 pm	**24847 – The Status of International & National IM Policies Across Nations** **Christelle Collet** Technical Specialist Officer, MSIAC	**24923 – Estimation of Elastic Constants of Composite Energetic Materials** **Dr. Kevin Jaansalu** TSO Materials Technology, Munitions Safety Information and Analysis Center (MSIAC)
1:25 – 1:45 pm	**24765 – An International Review of Stanag 4488 Gap Testing** **Dr. Ernest Baker** Warheads TSO, NATO MSIAC	**24861 – Improved Continuous Microfluidic Synthesis of Energetic Compounds** **Dr. Christina Christensen** Principal Research Scientist, Northrop Grumman Corporation

1:50 – 2:10 pm	**24766 – Recent Advances of the MSIAC Gap Test Tool & Database** Dr. Ernest Baker Warheads TSO, NATO MSIAC	**24850 – The Story of Ethylenedinitrarmine (EDNA): Synthesis, Crystallization, Formulation & Applications** Dr. Arthur Delage R&D Project Manager, EURENCO
2:15 – 2:35 pm		**24854 – Comparison Of Performance & Insensitivity Properties of Enhanced Blast Plastic Bonded Explosives with Conventional Explosives** Serhat Bilgen Senior Research, TUBITAK SAGE
2:35 – 3:10 pm	**NETWORKING BREAK** COSMOPOLITAN FOYER	

CONCURRENT BREAKOUT SESSIONS

	Insensitive Munitions Test Methods	Energetic Materials Processing
	COSMOPOLITAN AB Session Chair: Nausheen Al-Shehab	COSMOPOLITAN CD Session Chair: Wendy Hummers
3:10 – 3:30 pm	**24857 – The Fundamentals of IM Testing** Jon Toreheim Marketing and Sales Manager, Bofors Test Center	**24781 – Development of ResonantAcoustic® Continuous Microreactor and ResonantAcoustic® Continuous Crystallizer** Dr. Joseph Mayne Senior Chemical Engineer, Resodyn Corporation
3:35 – 3:55 pm	**24865 – Air Drag Measurements for the NATO Insensitive Munitions Fragment** Kevin Miers Mechanical Engineer, U.S. Army DEVCOM Armaments Center	**24834 – Process Improvement of Melt Pour Explosive 3,4-Dinitropyrazole (DNP)** Dr. Tomasz Modzelewski Principal Scientist, BAE Systems, Inc.
4:00 – 4:20 pm	**24852 – Mitigation of Flat 2-Dimensional Shocks to Prevent Sympathetic Reactions** Stefan de Koster Junior Scientist Innovator, TNO	**24843 – Continuous ResonantAcoustic® Production of Energetic Material** Joe Mayne Senior Chemical Engineer, Resodyn Corporation

4:25 – 4:45 pm

CLOSING REMARKS
Nausheen Al-Shehab
Chemical Engineer, U.S. Army DEVCOM AC

24862 – Advances in Resodyn Acoustic Mixer Processing Methods & Characterization

Justin Whaley
Senior Controls Engineer, Resodyn Corporation

4:45 – 4:50 pm

CLOSING REMARKS
Wendy Hummers
Program Director, Elbit Systems Ltd.

5:10 – 6:10 pm

RECEPTION
COSMOPOLITAN FOYER

WEDNESDAY, OCTOBER 19

7:30 am – 12:00 pm

REGISTRATION
COSMOPOLITAN FOYER

8:30 – 8:35 am

OPENING REMARKS
COSMOPOLITAN AB

Paul Braithwaite
Fellow, Propulsion Systems IR&D Lead, Northrop Grumman Corporation
Symposium Chair

8:35 – 9:15 am

KEYNOTE: PATHS FOR EM/IM TO PROVIDE STRATEGIC DIFFERENTIATION
COSMOPOLITAN AB

Dr. Robert Wardle
Principal, Wardle Enterprises: Energetics, Services and Technologies, LLC

9:15 – 10:00 am

ENERGETIC MATERIALS: MOVING FORWARD IN THE 21ST CENTURY
COSMOPOLITAN AB

Paul Braithwaite
Fellow, Propulsion Systems IR&D Lead, Northrop Grumman Corporation
Moderator

Dr. Jacob Morris
Chief, Energetics Material Branch, Munitions Directorate, Air Force Research Laboratory

Laurent Bonhomme
Roxel Group

Dr. David Price
Director of Business Development, NALAS Engineering

Jon Toreheim
Marketing and Sales Manager, Bofors Test Center

10:00 – 10:30 am

NETWORKING BREAK
COSMPOLITAN FOYER

CONCURRENT BREAKOUT SESSIONS

	Insensitive Munitions Modeling	Energetic Material Characteristics
	COSMOPOLITAN AB Session Chair: Dr. Ernest Baker	COSMOPOLITAN CD Session Chair: Melissa Mileham
10:30 – 10:50 am	**24851 – Implementation of Munition Vulnerability Models in the Ship Vulnerability Code Resist** **Gert Scholtes** Senior Research Scientist, TNO DSS	**24839 – Characterization of Impact Induced Reaction of Explosives Using the AFRL High Explosive Survivability Test (HEST)** **Dr. Jesus Mares, Jr.** Engineer, U.S. Air Force Research Laboratory
10:55 – 11:15 am	**24860 – Evaluation of Critical Temperatures via Thermal Runaway Models and Slow Cook Off Testing** **Dr. Jeremy Headrick** R&D Technical Manager, BAE Systems, Inc.	**24872 – Life Cycle Assessment and Aging Characteristics of Novel Signal Pyrotechnics, and Comparison to a Military Reference Composition** **Dr. Richard Bouma** Senior Scientist, TNO
11:20 – 11:40 am	**24993 – Concept for Improving Cook-off Performance of Propellants & Explosives** **Dr. Jon Yagla** Mechanical Engineer, Axient	**24844 – Recent Advancement on Enhanced Blast Explosives Manufacturing at Holston Army Ammunition Plant** **Kyle Bittner** R&D Formulation Chemist, BAE Systems, Inc.
11:45 am – 12:05 pm	**CLOSING REMARKS** **Dr. Ernest Baker** Warheads TSO, NATO MSIAC	**24893 – Comparison of the High-Speed Deformation Behavior of Cast & Additive Manufactured Polymer Bonded Mock Explosives** **Kerry-Ann Stirrup** PhD Candidate, Impact Science Laboratory, Purdue College of Engineering
12:05 – 12:10 pm		**CLOSING REMARKS** **Dr. Melissa Mileham** Staff Research Scientist, Northrop Grumman Corporation
12:10 pm	**ADJOURN**	

THURSDAY, OCTOBER 20

8:00 am – 5:00 pm

REGISTRATION
COSMOPOLITAN FOYER

8:50 – 9:00 am

OPENING REMARKS
COSMOPOLITAN AB

Paul Braithwaite
Fellow, Propulsion Systems IR&D Lead, Northrop Grumman Corporation
Symposium Chair

9:00 – 10:00 am

KEYNOTE: NATIONAL ENERGETIC PLAN
COSMOPOLITAN AB

Jason Jouet
Director of Munitions Technology, Office of the Under Secretary of Defense for Research & Engineering (OUSD(R&E))

10:00 – 10:30 am

NETWORKING BREAK
COSMOPOLITAN FOYER

10:30 – 10:50 am

RECENT VULNERABILITY EVENTS DUE TO NON-IM MUNITIONS
COSMPOLOTIAN AB

Dr. Ernest Baker
Warheads TSO, NATO MSIAC

10:50 – 11:10 am

THE MSIAC SELF-AUDIT TO IMPROVE HOW TESTING FACILITIES CONDUCT IM & HC TESTS
COSMOPOLITAN AB

Christelle Collet
Technical Specialist Officer, MSIAC

11:10 – 11:30 am

COOKOFF ANALYSIS USING AN IMPLICIT AMR APPROACH
COSMOPOLITAN AB

Dr. J. Keith Clutter
Senior Consultant, Integrated Solutions for Systems (IS4S), Inc.

11:30 – 11:50 am

GUN BARREL & PROJECTILE HEATING FOR HOT GUN SAFETY
COSMOPOLITAN AB

Dr. Jon Yagla
Mechanical Engineer, Axient

11:50 am – 1:00 pm

NETWORKING LUNCH
COSMOPOLITAN AB

CONCURRENT BREAKOUT SESSIONS

	Insensitive Munitions Protection Systems	Energetic Materials Modeling
	COSMOPOLITAN AB Session Chair: Ken Graham	COSMOPOLITAN CD Session Chair: Gert Sholtes
1:00 – 1:20 pm	**24749 – Novel Rocket Motor Protection** Daniel Turner Senior Design Authority, Roxel (UK Rocket Motors), Ltd	**24869 – A Numerical Model for Explosive Cook Off** Dr. Brian Fuchs Senior Research Scientist, U.S. Army Picatinny Arsenal
1:25 – 1:45 pm	**24864 – Lightweight IM Impact Protection System for Reducing Reaction of Solid Rocket Motors** Andrew Witzig President & CEO, Shearwater Technology, Inc.	**24959 – A Comprehensive Approach for the Development of the Fundamental Comprehension of How Energetic Defects Form, Propagate & Affect Initiation** Daniel Pudlak CCDC-AC, U.S. Army
1:50 – 2:10 pm	**24867 – SR Barriers for IMX-104 Filled 155mm Artillery Projectiles** Kevin Miers Mechanical Engineer, U.S. Army DEVCOM Armaments Center	**24955 – AI For Energetic Defect Characterization** Antonio Aguirre, Jr. Mathematician, Picatinny Arsenal
2:15 – 2:35 pm	**24866 – Steel FI Barriers Hardness & Obliquity Effects** Kevin Miers Mechanical Engineer, U.S. Army DEVCOM Armaments Center	**24856 – Sample Extraction & Analysis Techniques for Simultaneous Determination of Legacy & IM Constituents** Dr. Austin Scircle Research Chemist, USACE Engineer Research & Development Center
2:35 – 3:05 pm	**NETWORKING BREAK** COSMOPOLITAN FOYER	

NDIA

CONCURRENT BREAKOUT SESSIONS

	Insensitive Munitions Technology Applications	Energetic Materials: Design & Integration
	COSMOPOLITAN AB Session Chair: Steve Struck	COSMOPOLITAN CD Session Chair: Dr. Arthur Delage
3:10 – 3:30 pm	**24840 – Insensitive Hydro-reactive Munitions** **Dr. Nicholas Nechitailo** Senior Subject Matter Expert, Weapons Effects, Fluid-Structure Interactions, Materials Failure, Naval Surface Warfare Center Indian Head EOD Technology Division	**24853 – Investigation of Slow Cook-Off Behavior of Castable PBXs** **Z. Taner Kaya** Senior Researcher, TUBITAK SAGE
3:35 – 3:55 pm	**24863 – Cook-Off Mitigation for Medium Caliber Ammunition** **Nausheen Al-Shehab** Chemical Engineer, U.S. Army DEVCOM AC	**24820 – Development of IM Naval Countermining Charges with Increased Performance** **Chris Reams** RWM Italia
4:00 – 4:20 pm	**24848 – New Test Method for Single Package Test for Transportation** **Erik TuneståI** R&D Project Manager, Eurenco Bofors AB	**CLOSING REMARKS** **Dr. Arthur Delage** R&D Project Manager, EURENCO
4:25 – 4:45 pm	**24876 – Simplified Numerical Methodology to Size Munitions to Withstand Sympathetic Reaction** **Sébastien Bodard** R&D Modelling Team Lead, EURENCO	
4:55 – 5:00 pm	**CLOSING REMARKS** **Steve Struck** Program Manager, U.S. Air Force Research Laboratory (AFRL)	

ABSTRACT DESCRIPTIONS

ENERGETIC MATERIAL CHARACTERISTICS

24839

Characterization of Impact Induced Reaction of Explosives Using the AFRL High Explosive Survivability Test (HEST)

Dr. Mares, J. Jr.

We characterize two Air Force explosives and present lessons learned in the development and utilization of the High Explosive Survivability Test (HEST).

24872

Life Cycle Assessment and Aging Characteristics of Novel Signal Pyrotechnics, and Comparison to a Military Reference Composition

Dr. Bouma, R.

Novel red and green signal NC-based compositions are being developed. A sufficient thermal stability is demonstrated in accelerated ageing experiments. Assessment of the environmental hazards and human health impacts, and a quick scan life cycle analysis, demonstrated the reduced damage costs in comparison to their current military counterparts.

24844

Recent Advancement on Enhanced Blast Explosives Manufacturing at Holston Army Ammunition Plant

Bittner, K.

This paper details the recent advancement in process development, production manufacturing and future process improvement of EB explosives at HSAAP. To date, over 17,000 lbs. of EB explosives had been successfully manufactured at HSAAP; and the quantity will exceed 20,000 lbs. by the end of 2022, and significantly more (> 30,000 lbs.) expected in 2023 and beyond.

24893

Comparison of the High-speed Deformation Behavior of Cast and Additive Manufactured Polymer Bonded Mock Explosives

Stirrup, K.

Samples of mock Polymer Bonded Explosives (PBX) were produced using traditional casting methods and via Vibration Assisted Printing (VAP). To evaluate material behavior while deformed at high speeds, samples were impacted using a single stage gas gun located at the Dynamic Compression Sector of the Advanced Photon Source. In-Situ Phase Contrast Imaging (PCI) showed the printed samples failed due to the collapse of pores inherent to the printing process.

ENERGETIC MATERIAL FORMULATIONS & SYNTHESIS

24923

Estimation of Elastic Constraints of Composite Energetic Materials

Dr. Jaansalu, K.

The best model for prediction of elastic composites is a variation of the logarithmic sum. Any further evaluation or model development would be greatly facilitated by more experimental data.

24861

Improved Continuous Microfluidic Synthesis of Energetic Compounds

Dr. Christensen, C.

Our group has designed and tested a system for the continuous microfluidic synthesis and in-line extraction and purification of energetic materials using commercially available components. This system will reduce hazards associated with batch synthesis of energetics and the need for attended work by employing remote operation of the equipment. The system has been used to demonstrate the continuous processing of glycidyl nitrate from glycerol, an important precursor to poly(glycidyl nitrate) (PGN), an ingredient of significant interest for use in high performance formulations.

24850

The Full Story of Ethylenedinitrarmine (EDNA): Synthesis, Crystallization, Formulation and Applications

Dr. Delage, A.

EthyleneDiNitrAmine (EDNA, C2H6N4O4) has been identified as the best candidate and has been selected as the main filler for new generation powders (thermoplastic) and for explosives applications such as cast PBX formulation based on the less sensitivity of EDNA to shock and friction compared to RDX. This work includes all the steps from synthesis to final applications.

24854

Comparison of Performance and Insensitivity Properties of Enhanced Blast Plastic Bonded Explosives with Conventional Explosives

Bilgen, S.

In this study, plastic-bonded EBXs that contain different type of energetic materials (RDX, HMX) and different amount of metallic powder (30wt% and 45wt%), namely TSP-01-2, TSP-02-1 and TSP-02-2 was developed and compared with conventional explosives such as TNT and Comp-B in terms of performance and insensitivity properties. For performance properties, total pressure impulse, thermal performance (fireball diameter and fireball duration time) properties, detonation velocity and fragmentation test results were compared. For insensitivity properties, shock sensitivity measurements of EBXs were compared with literature values of conventional explosives.

ENERGETIC MATERIALS MODELING

24869

A Numerical Model for Explosive Cook Off

Dr. Fuchs, B.

The generalized equation for conductive heat transfer (without mass transfer) with internal heat generation in a spherical configuration and allowing for degradation was used to study general trends in cook-off behavior. The explosive RDX was selected for the study, as it is a common energetic material used in many compositions. A Python language computer program was written to study two cases, initially uniform material with the surface maintained at a uniform temperature, and a uniform temperature material with the surface heated at a steady rate. It was determined that, slower heating rates tend to have reactions towards the center of the charge, but increase the amount of material degradation, and that there may be no observable heat rise on the surface to indicate impending violent reactions.

24959

A Comprehensive Approach for the Development of the Fundamental Comprehension of How Energetic Defects Form, Propagate, and Affect Initiation

Pudlak, D.

Defects in artillery High Explosive (HE) main-fills have caused catastrophic failures during gun launch, resulting in fatalities and damage to personnel and their weapon systems/platforms. With the new Long Range Performance Fires (LRPF) requirements exceeding gun/barrel designs and flight environments, energetic defect characterization is now more important than ever. Several attempts to investigate particular facets of energetic defects are still on-going, however a new, comprehensive effort has been developed that addresses all facets of energetic defects, in an all-compassing manner. The U.S. Army, DEVCOM-AC is currently executing a comprehensive effort, 'Energetic Defect Characterization – Capability Development Effort (EDC-CDE)', that focuses on the development of the fundamental understanding of energetic defects, including how they form/propagate, how they affect initiation (focusing on interior ballistics specifically, but also taking into account their exterior and terminal ballistics influences), determination of critical defects (including critical parameters, metrics, criteria, etc.), and ultimately the mitigation of critical defects, with visionary goals of implementing improvements to the LAP inspection equipment/processes, such as Smart XCT 3D (X-Ray) embedded with w/ Automated Intelligence / Machine Learning (AI/ML) codes.

24955

AI For Energetic Defect Characterization

Aguirre, A. Jr.

24856

Sample Extraction and Analysis Techniques for Simultaneous Determination of Legacy and IM Constituents

Dr. Scircle, A

Novel methodology development using artificial intelligence to augment human-in-the-loop efforts for identifying the presence of defects in x-ray image datasets of explosively filled ordnance.

ENERGETIC MATERIALS PROCESSING

24781

Development of ResonantAcoustic® Continuous Microreactor and ResonantAcoustic® Continuous Crystallizer

Dr. Mayne, J.

Resodyn has developed novel continuous chemical reactor and continuous crystallizer technologies built on the ResonantAcoustic® Mixing (RAM) platform. This technology is applied to the synthesis and recrystallization of energetic and energetic precursor compounds.

24834

Process Improvement of Melt Pour Explosive 3,4-Dinitropyrazole (DNP)

Dr. Modzelewski, T.

Development of a highly simplified, and environmentally and economically friendly, synthesis method for the manufacture of 3,4-Dinitropyrazole (DNP)

24843

Continuous ResonantAcoustic® Production of Energetic Material

Dr. Joseph Mayne

A Continuous Acoustic Mixing (CAM) Clean-in-Place (CIP) process has been developed at Resodyn Corp. to significantly increase the safety, reduce the cost, and reduce the environmental impact of producing Plastic Bonded Explosive (PBX) and propellant.

24862

Advances in Resodyn Acoustic Mixer Processing Methods and Characterization

Whaley, J.

ResonantAcoustic® Mixers (RAM) have become a technology of choice in the energetics but operation can be non-intuitive to the mixologist accustomed to using conventional mixing processes. Even for advanced users, the behavior of materials can vary drastically in responses to subtle parameter changes. To fully utilize the advantages of RAM manufacturing a set of mixing metrics is used for improving the RAM process and measuring mixedness of the product.

ENERGETIC MATERIALS: DESIGN & INTEGRATION

24853

Investigation of Slow Cook-off Behavior off Castable PBXs

Kaya, T. Z.

Slow heating response of small-scale test items and full-scale munitions due to thermal decomposition of castable polymer bonded explosives (PBXs) (PBXN-109/110/111/113 composition equivalents) was investigated by testing and thermal/CFD modelling efforts.

24820

Development of IM Naval Countermining Charges with Increased Performance

Reams, C

RWM Italia have developed new naval countermining charges to replace legacy, non-IM munitions that were at the end of their service life. The new munitions showed much better IM characteristics and also improved performance vs the legacy munitions.

INSENSITIVE MUNITIONS MODELING

24851

Implementation of a Munition Vulnerability Models in the Ship Vulnerability Code Resist

Scholtes, G.

Stochastic approach to implement munition vulnerability models in platform vulnerability codes to estimate the response of stored munition after a hostile impact.

24860

Evaluation of Critical Temperatures via Thermal Runaway Models and Slow Cook Off Testing

Dr. Headrick, J.

Evaluation of critical temperatures of RDX & HMX explosives formulations via thermal runaway modeling and slow cook off testing.

24993

Concept for Improving Cook-off Performance of Propellants and Explosives

Dr. Yagla, J.

Concept For Improving Cook-off Performance of Propellants and Explosives – Oriented fibers or strands of material of high thermal conductivity are embedded in a mass of energetic material. The strands are arranged to draw heat out of potential hot spots to prevent thermal runaway and explosive reactions. Examples, mathematical principles, and possible means for orienting the strands are provided.

INSENSITIVE MUNITIONS POLICY & REQUIREMENTS

24847

The Status of Internal and National IM Policies Across the Nations

Collet, C.

The recent review that was conducted at MSIAC provides insight to international and national IM policies. After an overview of the IM policy in place for each nation, an analysis of the differences across policies is provided that highlights possible ways of improvement at a NATO level. This overview may also provide useful information to those nations that have not yet implemented their own IM policy.

24765

An International Review of STANAG 4488 Gap Testing

Dr. Baker, E.

MSIAC has recently completed an international review of STANAG 4488 Gap Testing.

24766

Recent Advances of the MSIAC Gap Testing Tool and Database

Dr. Baker, E.

MSIAC recently completed a project that extended the NEWGATES database for gap test results and increased its predictive capabilities. As a result, an updated version of NEWGATES (v1.12) has been released.

INSENSITIVE MUNITIONS PROTECTION SYSTEMS

24749

Novel Rocket Motor Protection

Turner, D.

Roxel UK have been investigating the potential of a new, novel, armour system to provide protection to rocket motors against impact IM threats to mitigate against the use of higher performance, more sensitive, propellants."

24864

Lightweight IM Impact Protection System for Reducing Reaction of Solid Rocket Motors

Witzig, A.

This paper details the development and evaluation of a lightweight insensitive munition ballistic protection system for reducing the reactive response of solid rocket motors.

24867

SR Barriers for IMX-104 Filled 155mm Artillery Projectiles

Miers, K.

SR barriers were computationally designed, fabricated and tested on IMX-104 filled 155mm artillery projectiles. At least one of the designs provided a successful passing reaction, and this work documents the design process and experimental results.

24866

Steel FI Barriers Hardness and Obliquity Effects

Miers, K.

Steel armor has traditionally been able to mitigate the NATO FI threat in a cost effective and reasonably weight-efficient manner. However it has been suggested that further improvements in FI mitigation may be achieved by increasing steel hardness and toughness, as well as by taking advantage of potential obliquity effects. Steel plates of 4340 RC38 and D2 tool steel hardened to RC60 were fabricated and subjected to FI testing at both 0 and 45 degrees obliquity. The behind armor debris was captured with celotex panels, and the residual velocity was measured with high speed video. It was determined that spall failure dominates the fragment breakup behavior, and that the improvement in velocity reduction afforded by increased hardness and obliquity is limited by brittle failure.

INSENSITIVE MUNITIONS TECHNOLOGY APPLICATIONS

24840

Insensitive Hydro-Reactive Munitions

Dr. Nechitailo, N.

This paper describes the explosive reaction of aluminum projectiles with wet sand. Understanding the underlying phenomena may lead to the development of a new class of low-cost no-fuze, no-explosives insensitive munitions.

24863

Cook-Off Mitigation for Medium Caliber Ammunition

Al-Shehab, N.

This paper discusses development of Particle Impact Mitigation Sleeve (PIMS) to improve munition response to Fragment Impact Threats.

24848

New Test Method for Single Package Test for Transportation

Tunestål, E.

Eurenco has developed and evaluated a new test method for 16.4.1 Test 6(a) Single package test. The new method has a quick setup method, can be pre-fabricated and from the tests a methodology to classify propellants without testing has also been proposed.

24876

Simplified Numerical Methodology to Size Munitions to Withstand Sympathetic Reaction

Bodard, S.

In this presentation, we address a step by step numerical methodology to study sympathetic reaction modeling, from 1D computation to select viable candidates, to 2D computations with validated hypothesis for finer analysis. This methodology aims to be fast and general enough to treat cases where the donor has fragmented or not before interacting with the acceptor.

INSENSITIVE MUNITIONS TEST METHODS

24857

The Fundamentals of IM Testing

Toreheim, J.

In this presentation a detailed method of how to design test setups and how to conduct each of the six standardized IM tests in a cost efficient way is given.

24865

Air Drag Measurements for the NATO Insensitive Munitions Fragment

Miers, K. T.

In this work, we have performed a series of drag coefficient measurements for the NATO IM fragment at the test velocities of interest (2530 m/s). The theory of drag measurement is discussed, with accurate measurements requiring many timing stations and long total range lengths in excess of 1000 calibers for hypersonic projectiles. Several experiments were performed indicating a drag coefficient of approximately 1.2-1.5, on the high end of what was expected. Accounting for air drag and correctly computing velocity should help provide increased confidence that the required impact velocities are being achieved for a given test configuration.

24852

Mitigation of Flat 2-Dimensional Shocks to Prevent Sympathetic Reactions

De Koster, S.

Investigation in the mitigation of a flat 2-Dimensional shock wave to prevent sympathetic reactions of plastic explosives in a wooden box.

KEYNOTE BIOGRAPHIES

DR. BRIAN FUCHS

Senior Research Scientist
U.S. Army Picatinny Arsenal

Dr. Brian Fuchs is the Senior Research Scientist for Insensitive Munitions at the Combat Capabilities Development Command Armaments Center at Picatinny Arsenal. Fuchs conducts research pertaining to energetic materials, energetic materials printing, warheads technology and explosive safety. He serves as a technical consultant in the areas of Insensitive Munitions, testing, safety and detonation physics to other organizations.

Employment highlight include having been awarded the department of the Army Research and Development Achievement Awards in 1989, 1999, 2002, 2003, and 2009, and the Army Research and Development Achievement Award for excellence in Leadership in 2009. He received the 2016 National Defense Industrial Award Firepower technology Award. He is a member of the Army Insensitive Munitions Board, past chairman of the Joint Services Insensitive Munitions Technical Panel, serves on the Combat Capabilities Development Command Armaments Center, Energetic Material Qualification Board for Explosives and is Chairman of NATO's Munitions Safety Information Analysis Center steering Committee (MSIAC).

Fuchs has received 13 patents in the areas in the areas of explosive formulations, loading techniques, warheads, fuze technologies, printed detonators, and printed detonators, and printed electronics. He is a faculty member for Picatinny Arsenal's Armament Graduate school and an adjunct professor for the Stevens Institute of Technology.

DR. ROBERT WARDLE

Principal
Wardle Enterprises: Energetics, Services and Technologies, LLC

Dr. Robert Wardle is the principal at Wardle Enterprises: Energetics, Services & Technologies. Before holding his current position, he was senior director of advanced programs at Northrop Grumman (NGC) and he spent 35 years at the research and development department at Northrop and predecessor organizations back to Thiokol Corporation. He received his Ph.D. in chemistry from Caltech. At NGC since 1986, he was involved in synthesis, characterization, formulation, fielding and aging/surveillance of energetic materials. At NGC, he moved through a series of increasingly responsible positions from lab chemist to director of R&D Laboratories.

In his role as Senior Director of Advanced Programs, he led the Propulsion Systems IR&D effort, built and commissioned a full scale AP plant, led hypersonic glide body development and production, synthesis of energetic materials including CL-20, production of military flares and decoys, and a broad spectrum of propellant, explosives and pyrotechnics related R&D programs.

DR. JASON JOUET

Director of Munitions Technologies
Office of the Under Secretary of Defense for Research and Engineering

Dr. Jason Jouet is responsible for the strategy, oversight, and supervision of the Department's munitions-relevant science and technology (S&T) investments. Munitions S&T comprises activities to improve or enhance kinetic weapon lethality, propulsion, target detection, fuzing, guidance, navigation and control, manufacturing, and advanced material development. Jouet also directs the OSD Joint DoD/DOE Munitions Program and the Joint Enhanced Munitions Technology Program with a total cumulative budget of $64m, maturing cross-cutting, enabling technologies that are beyond service risk tolerance, to increase lethality, performance, and readiness for warfighters' weapons systems to bolster U.S. technical superiority for decisive and asymmetric advantage.

Prior to this appointment, Jouet was Deputy Director for Manufacturing Technology within the Manufacturing & Industrial Base Policy office of OUSD (AT&L). In this role, he directed the OSD Manufacturing Science & Technology Program, focusing on the advancement of cross-cutting manufacturing technology to enable production of technology at cost, quality, and quantity suitable for acquisition.

Prior to coming to OSD, from 2001 to 2016, Jouet served as the Head, High Energy Materials Branch, Senior Research Scientist, and Program Manager at the Naval Surface Warfare Center Indian Head Division and was a recipient of the Dr. Dolores M. Etter Award for Top Navy Scientists and Engineers of the Year in 2010.

Jouet earned a Bachelor of Science in Chemistry from the University of Texas-Austin in 1995 and a Ph.D. in Chemistry from Duke University in 2000.

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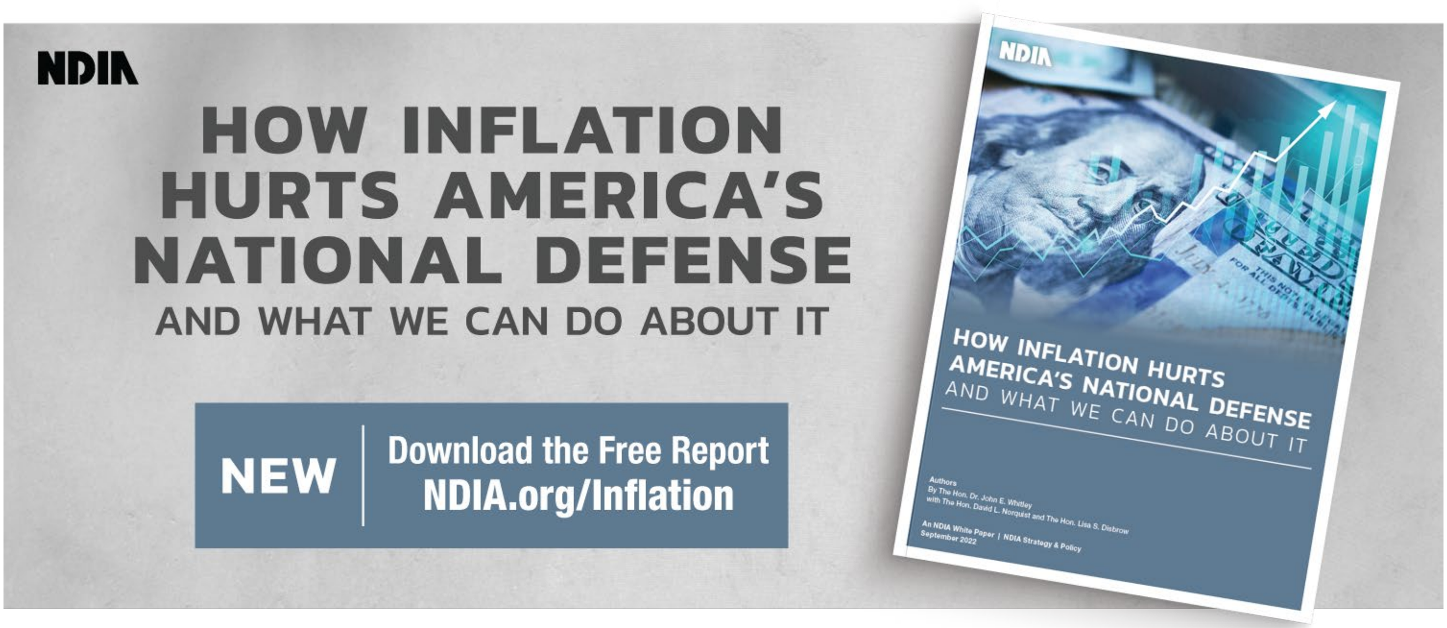
BAE Systems Ordnance Systems Inc. (OSI) produces a full range of high quality explosive and propellant products for the U.S. Department of Defense, Department of Energy and commercial customers. We are the operating contractor for the Holston Army Ammunition Plant located in Kingsport, Tennessee, and for the Radford Army Ammunition Plant in Radford, Virginia.

As the recognized leader in managing government-owned, contractor-operated facilities, OSI supports the U.S. Government to safely, efficiently and cost effectively develop and produce reliable propellant and explosive ordnance products. Our award-winning innovations also include munition-related services such as modernization program management, energetics research and development, engineering design, and inventory management.

energetics technology center

REGISTRATION

ETC provides engineering and data analytics services, policy development, and technology development to the government, academia, and private industry. We are a 501 (c)(3) non-profit organization incorporated in 2006 to support national military policy development projects. Our team looks for opportunities to conduct impactful work for the Defense Department, State, Regional, and Local governments, and the private sector. At ETC, we proudly support our Warfighters and our National Security Enterprise. Visit us at etcmd.com.



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PLAN AHEAD FOR SUCCESS | 2022 – 23 FEATURED MEETINGS, CONFERENCES, AND EVENTS

2022 JOINT AIA/NDIA INDUSTRIAL SECURITY COMMITTEE CONFERENCE

OCTOBER 24 – 26, 2022 | Tucson, AZ

Security Clearance Reforms | Insider Threat Guidance | Cybersecurity Policy

2023 EXPEDITIONARY WARFARE CONFERENCE

February 22 – 24, 2023 | Arlington, VA

Maritime Electronic Warfare | Naval Fires And Aviation | Seabasing

AIRCRAFT SURVIVABILITY SYMPOSIUM

November 1 – 3*, 2022 | Monterey, CA

Combat Survivability | Concealment and Deception | Countermeasures | Urban Warfare | Vulnerability Reduction

2023 TACTICAL WHEELED VEHICLES CONFERENCE

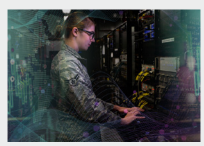
February 27 – March 1, 2023 | Columbus, OH

Autonomous Vehicles | Electric Drive | Modernization & Sustainment | Acquisition

25TH ANNUAL SYSTEMS & MISSION ENGINEERING CONFERENCE

November 1 – 3, 2022 | Orlando, FL

Program Management | Security Models | Test & Evaluation | Manufacturing



2023 HUMAN SYSTEMS CONFERENCE

March 1 – 2, 2023 | Arlington, VA

Human Systems Integration | Human Factors Engineering | Artificial Intelligence

33RD ANNUAL NDIA SO/LIC SYMPOSIUM

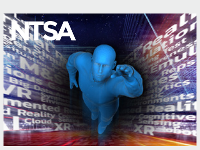
November 17 – 18, 2022 | Washington, DC

Special Operations Forces | Strategic Competition

2023 PACIFIC OPERATIONAL SCIENCE & TECHNOLOGY (POST) CONFERENCE

March 6 – 9, 2023 | Honolulu, HI**

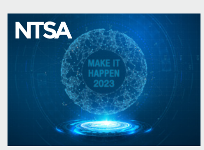
Regional Security | Science & Engineering Technology | Technology Engagement



I/ITSEC 2022

November 28 – December 2, 2022 | Orlando, FL

Simulation | Training | Virtual Reality



MODSIM WORLD 2023

May 22 – 23, 2023 | Norfolk, VA

Medical Simulation | Machine Learning | Extended Reality | Gamification

*All Classified | **Partially Classified

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U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMAMENTS CENTER

Insensitive Munitions, Important Now More than Ever

Brian Fuchs, Phd
Senior Research Scientist (Insensitive Munitions)
U.S. Army

13 Sept 2022

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Jessica Vaughn	U.S. Army CCDC-AvMC
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Terri Crawford	Booz I Allen I Hamilton
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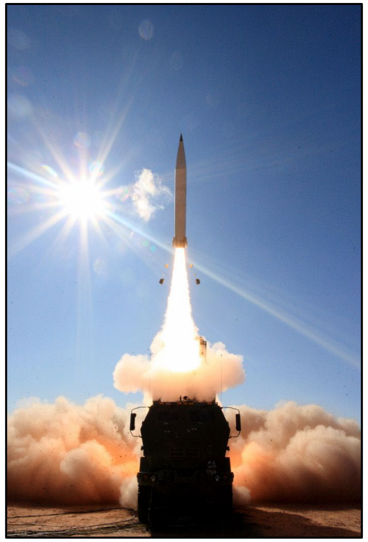
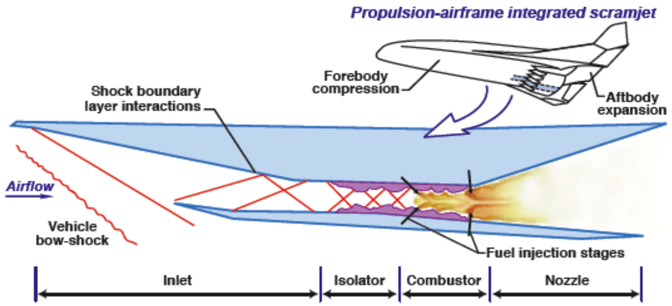
Introduction

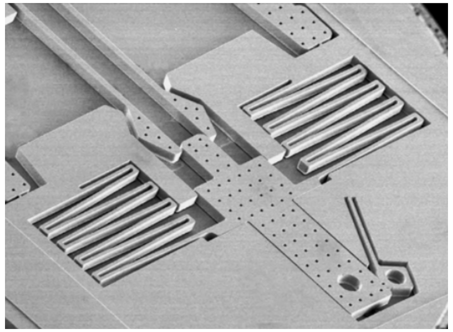
In order to meet the ever changing requirements of the warfighter and national defense munitions, development must continue to evolve. This is true for all areas of armament technology, including Insensitive Munitions. This talk will highlight some of the changes and technical challenges as well as the community's responses. Additionally, the need for further IM development will be discussed in relation to world events.



Technology is Changing Rapidly

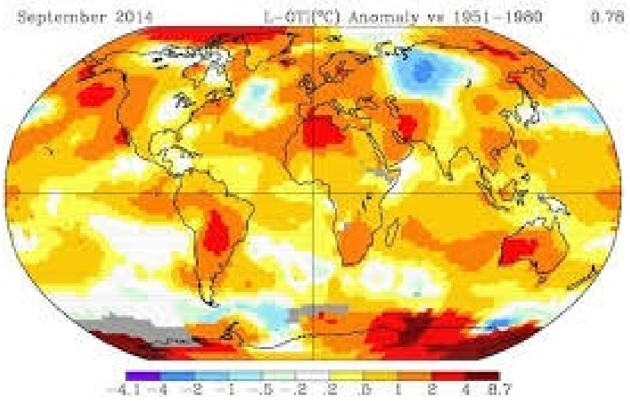
- Artificial Intelligence
- Data Mining
- Additive Manufacturing
- Non-Carbon Based Fuels
- Autonomous Robots
- Unmanned Aircraft Systems and Swarms
- Electronic Warfare
- High Power Lasers
- Hypersonics
- Ramjets and Scramjets
- Smart Munitions
- MEMS





The World is Changing Rapidly

- Changing Economic Powers
- Chinese Belt and Road Initiative
- Rapid Development of Some Countries
- Changes in Eastern Europe
- A Larger NATO
- Increased Importance of Artic Regions
- New International Alliances
- Changes in International Trade
- Climate Changes



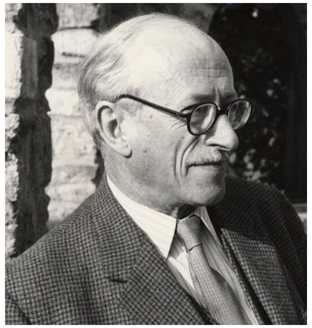
The Philosophy of Warfare Continues to Evolve

Sun Tzu

Victorious warriors win first and then go to war, while defeated warriors go to war first and then seek to win.

Carl von Clausewitz

War is nothing but a continuation of politics with the admixture of other means.



B. H. Liddell Hart

The only thing harder than getting a new idea into the military mind is to get an old one out.

- Mosaic Warfare
  - So many weapon and sensor platforms directed at the enemy, that its forces are overwhelmed
- Kill Chain
  - Structure of an attack
- Russian Hybrid Warfare
  - a blend of conventional, irregular and cyber warfare
- Chinese “Informatized Local Wars” and fully modernized military
- Unconventional warfare and asymmetric capabilities

The Internationalization of Munitions Development

DEVCOM ARMAMENTS CENTER


Boeing and Nammo's Ramjet 155. Photo: Boeing.

Boeing [BA] and the **Norwegian** defense firm **Nammo** have announced a successful test of its Ramjet 155 projectile weapon, which the companies developed for the **U.S. Army** to find new long-range artillery solutions.

The F-35 is developed, produced, and supported by a team of **eight international program partners** — the U.S., United Kingdom, Italy, Netherlands, Australia, Norway, Denmark and Canada.


https://www.lockheedmartin.com/en-us/products/f-35/f-35-global-partnership.html

January 18, 2022, the **Israel** Missile Defense Organization (IMDO) of the Directorate of the Defense Research and Development (DDR&D) at Israel's Ministry of Defense, together with the **U.S. Missile Defense Agency (MDA**) and Israeli Defense Forces, conducted a successful flight test of the Arrow Weapon System (AWS) and the Arrow 3 interceptor at a test site in central Israel.

As development costs increase for newer, sophisticated munitions, cost sharing through international collaboration is growing. All nations are becoming more interdependent upon foreign buys of munitions.

IM Threats

IM tests and evaluations are threat based. Each munition project / program shall develop a Threat Hazard Assessment (THA), which analyzes threats and probabilities. A series of standardized tests has been developed. The THA is used to modify these tests or introduce new tests as needed.

	FUEL FIRE	NEARBY HEAT	BULLETS	FRAGMENTS	SYMPATHETIC REACTION	SHAPED CHARGE JET
Threats	Truck or aircraft fire on a flight deck	Fire in adjacent magazine, stores or vehicle	Small arms from terrorists or combat	Bombs, artillery, or IEDs	Detonation of adjacent stores	RPG, Bomblets, ATGMs
						

A World without Insensitive Munitions
The War in the Ukraine

Ammunition depot explosions at Nova Kakhovka

Russian Tank

Russian Ship Moskva *source India Today*

Dr. Baker states that because none of the munitions "incorporated IM technology features and are filled with relatively sensitive explosives, it is no surprise that these incidents occurred and were to the severity observed."

THURSDAY, OCTOBER 20

10:30 - 10:50 am

RECENT VULNERABILITY EVENTS DUE TO NON-IM MUNITIONS
COSMPOLOTIAN AB

Dr. Ernest Baker
Warheads TSO, NATO MSIAC

“You must learn from the mistakes of others as you will never live long enough to make them all yourself.” –Multiple Sources

Missed Benefits of IM: Russia

- Improved Survivability for the Warfighter ✗
- Improved Survivability of Assets ✗
- Improved Logistics: ✗
  - Munitions can be stored closer to where they are needed
  - Minimize loss of munitions due to enemy action
- Improved Hazard Classification ✗
- Reduce likelihood of accidents in explosives factories ✗


Newsweek

WORLD

Multiple Dead After Mysterious Explosion at Russian Ammunition Plant

BY THOMAS KIKA ON 5/2/22 AT 12:05 PM EDT


BBC Sign in Home News Sport Reel Worklife Travel Future

NEWS

Home | Queen Elizabeth II | War in Ukraine | Coronavirus | Climate | Video | World | US & Canada | UK | Business | Tech

World | Africa | Asia | Australia | Europe | Latin America | Middle East

Dzerzhinsk explosion: Blast at Russian explosives factory injures 79

1 June 2019

It is not clear which individual incidents are related to a weak Insensitive Munitions program, but the shear number indicates that many are. It should be noted that rigorous safety and storage protocols were also nonexistent.

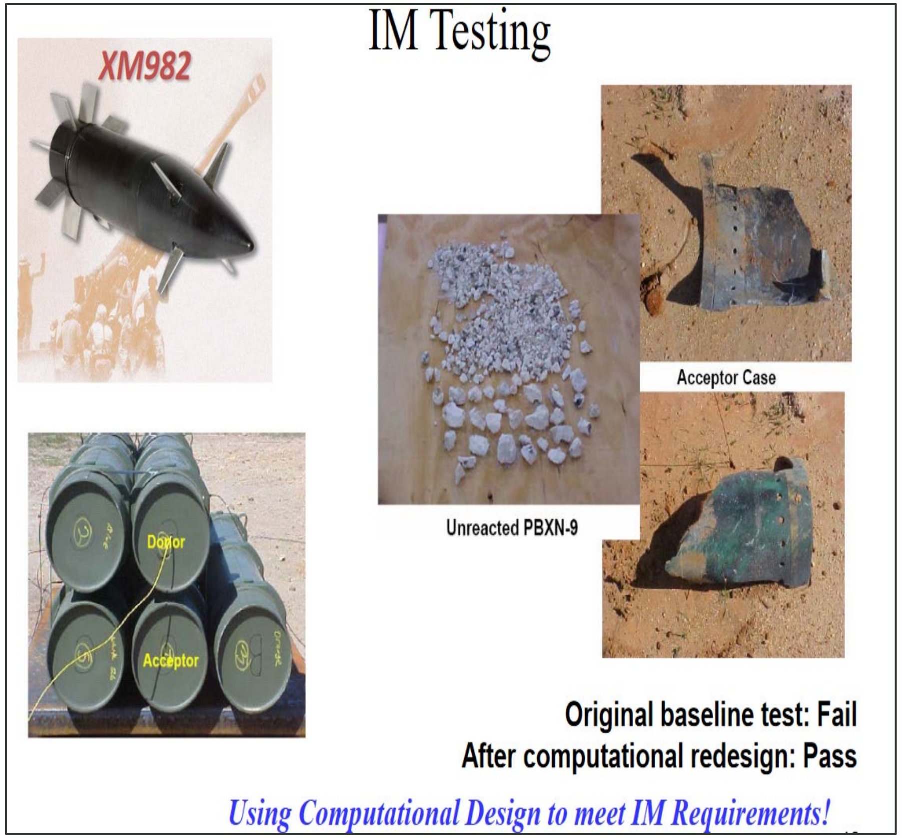
“Amateurs talk strategy, professionals discuss logistics.”- General Omar Bradley

There is a Better Way: NATO/ MSIAC

- The U.S. Army's Explosive IMX-101, developed by BAE Systems, has been named one of "The 50 Best Inventions of 2010" by TIME Magazine. The Army team at Picatinny Arsenal earlier this year approved IMX-101 as an effective replacement to TNT in artillery. This decision revolutionized the way military ordnance is stored and transported; therefore, saving lives on and off the battlefield.

IMX-104 Fast Cook-off Test Results

https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2017/armament/BakerTutorialA.pdf



- Most accurate US artillery shell was added to Ukraine's arsenal. The Pentagon is spending $92 million to replenish its stock- *Bloomberg, US Edition, 2022*

Magnitude of IM Events

The Bad News:

Catastrophic losses from incidents involving the inadvertent initiation and detonation of our munitions resulting in severe property damage, serious injury and loss of life.

USS Forrestal (1967)
134 killed, 161 injured,
$1.63B (2022 Dollars)

Doha, Kuwait (1991)
3 killed, 49 injured,
102 vehicles destroyed

The Good News:

- **Operational efficiencies gained from reduced hazard classification**
- **Economic efficiencies reduced storage and transportation requirements**

MRAP vehicle destroyed by an IED that ruptured the hull and fuel tank, engulfing the vehicle in flames, including (16) M768 60mm IM mortar rounds.

All 7 crew members survived

Modular Artillery Charge plant after a fire. There was significant fire damage but no blast or fragmentation damage.

No Injuries

Changes in US IM Development

- Joint Insensitive Munitions Technology Program (JIMTP) was established in 2007 to develop IM technologies:
  - Served as a bridging mechanism to fund efforts to "jump start" the development of IM technologies for PEO/PM implementation
  - Program results are being used by the PMs to obtain IM solutions for multiple systems

- JIMTP's emphasis was changed to meet the DoD's need for speed, range and lethality; and has been rebranded as the Joint Enhanced Munitions Technology Program (JEMTP)

- Per a memorandum dated 5 March 2019, signed by Jih Fen Lei, Deputy Director, Research, Technology, and Laboratories:

"IM compliance requirements remain an important aspect of munitions reliably and readiness and thus will remain a critical characteristic of the program."

IM Remains a Legal Requirement

USC, Title 10, Chapter 141, Section 2389 December 2001:

- "§ 2389. Ensuring safety regarding insensitive munitions. The Secretary of Defense shall ensure, to the extent practicable, that insensitive munitions under development or procurement are safe throughout development and fielding when subject to unplanned stimuli."

DoDD 5000.01, September 9, 2020:

- The acquisition and procurement of DoD weapons and information systems **must be consistent with all applicable domestic law**, and the resulting systems must comply with applicable treaties and international agreements (for arms control agreements, see DoD Directive (DoDD) 2060.01), customary international law, and the law of armed conflict (also known as the laws and customs of war).

Changes in the Insensitive Munitions Community and Processes

TUESDAY, OCTOBER 18	
10:35 - 10:55 am	COMPARISON OF IM THREATS VERSUS THE REAL WORLD COSMOPOLITAN AB Christelle Collet Technical Specialist Officer, MSIAC

TUESDAY, OCTOBER 18	
10:55 - 11:15 am	NATO INSENSITIVE MUNITIONS PORTFOLIO PROGRESSION LEADING TO INSENSITIVE MUNITIONS - HAZARD CLASSIFICATION (IM-HC) HARMONIZATION COSMOPOLITAN AB Daniel Pudlak CCDC-AC, U.S. Army

TUESDAY, OCTOBER 18	
1:00 - 1:20 pm	**24847 – The Status of International and National IM Policies Across the Nations** LOCATION Christelle Collet Technical Specialist Officer, MSIAC

Evolution of Insensitive Munitions

2018	Shaped Charge Jet Impact changed to match the predominant threat of an RPG-7
2018	Fast Cook-off propane procedures clarified to allow and promote its greater use
2019	Slow Cook-off heating rate increased from 3.3˚C/hr to 15 ˚C/hr to better reflect real world events
2020	IM AOPs reorganized for uniformity and clarity
Current	Harmonization of Hazard Class and IM to streamline testing and development
Current	Moving towards a “whole body of evidence approach” (technical evaluations based on a rigorous review of science)

NATO IM Portfolio Progression to IM-HC Harmonization

2010
- **NATO IM Portfolio Structural Revision**
  - Created new AOPs (Requirements Document)
  - Revised STANAGs (Policy Document)
  - Created SRD (Guidance Document)

- **Creation of AOPs from STANAGs**
  - 8 new documents (6 Test AOPs, Overarching AOP-39 & associated SRD):
    - AOP-39, AOP-39.1, AOP-4240, AOP-4241, AOP-4382, AOP-4396, AOP-4496, AOP-4526
  - Created Annex M (Document Modification History)

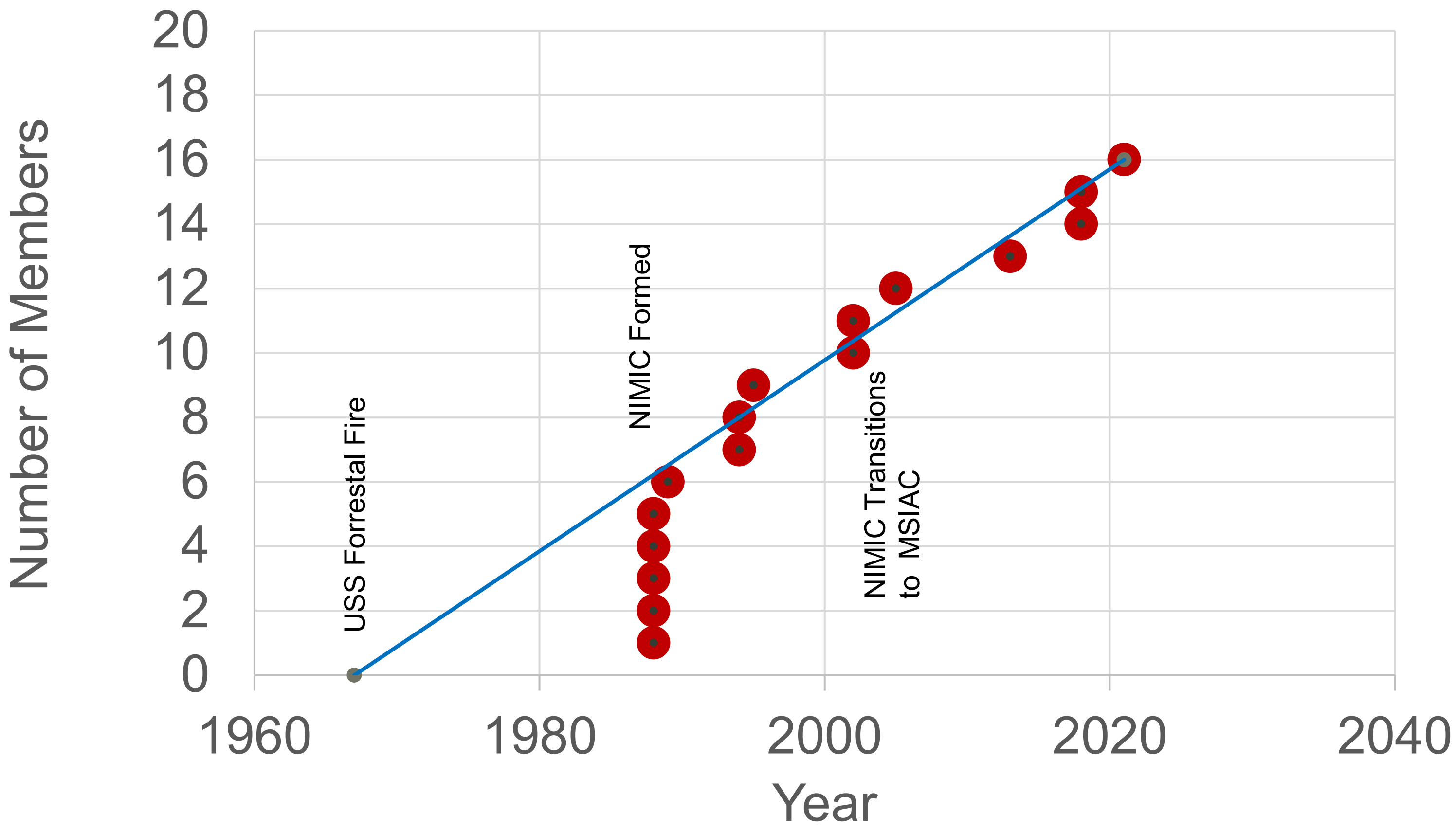
2019
- **Revision of NATO IM Portfolio**
  - 8 new AOPs promulgated in 2021-2022
    - Improved: consistency, accuracy, relevancy, readability and clarity compared to first iterations of AOPs and old STANAGs

2021
    - Created new tool/matrix that simplified revision of portfolio with multiple documents

2022
- **Harmonization of IM-HC-S3**
  - Currently revising AOP-39
    - Incorporate latest changes to portfolio, ensure relevancy and reduce redundancy
  - New overarching AOP-4864 under development
    - Harmonize IM, HC, S3, etc.
    - Reduces cost, schedule, test assets required

2025
    - Incorporate risk assessment

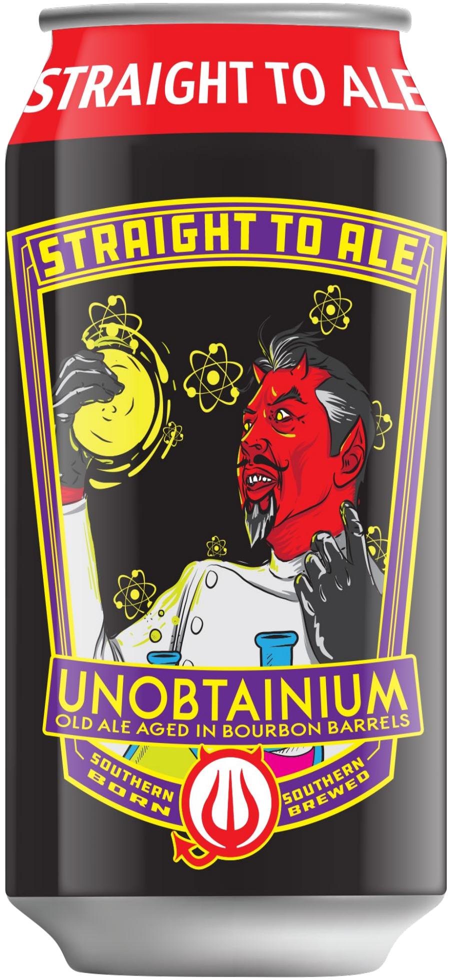
International Participation in MSIAC



A Word of Caution, the Hunt for Unobtainium

DEVCOM ARMAMENTS CENTER

Just changing the propellant or explosive does not guarantee a less violent reaction. Almost any material can fail IM tests (e.g. improper designs; confinement, packaging, shielding, etc.). No magic material exists that will solve all sensitivity and performance problems.




Burning C-4


Steam Explosion
Dana Corporation plant in Paris, Tennessee

http://www.dli.mn.gov/workers/boiler-engineer/fire-tube-steam-boiler-explosions

"For every complex problem there is an answer that is clear, simple and **wrong**" -H.L. Mencken

Expanding Threats

The 2018 National Defense Strategy identified the problem:

It is now undeniable that the homeland is no longer a sanctuary. America is a target, whether from terrorists seeking to attack our citizens; malicious cyber activity against personal, commercial, or government infrastructure, or political and information subversion. New threats to commercial and military uses of space are emerging, while increasing digital connectivity of all aspects of life, business, government, and military creates significant vulnerabilities. During conflict, attacks against our critical defense, government, and economic infrastructure must be anticipated.

NATO/MSIAC members have little tolerance for avoidable accidents.
We must expand our consideration of potential threats.

Near Peer IM Programs are Accelerating

Study on a novel high energetic and insensitive munitions formulation: TKX-50 based melt cast high explosive

Yuehai Yu,[a] Shusen Chen,[a] Tujuan Li,[a] Shaohua Jin,[a] Guangyuan Zhang,[b] Minglei Chen[b] and Lijie Li*[a]

Study of the sympathetic detonation reaction behavior of a fuze explosive train under the impact of blast fragments

Youcai Xiao, Xiangdong Xiao, Chenyang Fan, Yanyi Xiong, Zhijun Wang & Yi Sun

Journal of Mechanical Science and Technology **35**, 2575–2584 (2021)

Numerical simulation of fragment impacting solid rocket motors

Cite as: AIP Advances 12, 055204 (2022); doi: 10.1063/5.0088412
Submitted: 16 February 2022 • Accepted: 11 April 2022 •
Published Online: 3 May 2022

Zhejun Wang,[a)] Hongfu Qiang, Biao Geng, and Tingjing Geng

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materials MDPI

Materials (Basel). 2022 Apr; 15(7): 2438. PMCID: PMC8999548
Published online 2022 Mar 25. doi: 10.3390/ma15072438 PMID: 35407769

Slow Cook-Off Experiment and Numerical Simulation of Spherical NQ-Based Melt-Cast Explosive

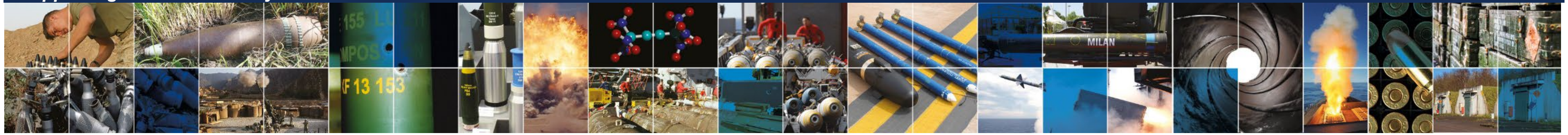
Yongshen Li,[1] Xue Zhao,[1,*] Jiuhou Rui,[1] Sen Xu,[2] Shengquan Chang,[3] Lizhe Zhai,[1] Siqi Qiu,[1] and Yuanyuan Li[1]

Next Steps

- Improve IM mitigation technologies
- Ensure the developed technologies are used in new systems to the greatest extent possible
- Continually review evolving threats
    - Improve standard tests to reflect current threats as our understanding improves
    - Develop new tests as required
        - The spall impact test was dropped when no longer applicable
        - Will we need a laser impact test in the future?
- Educate program managers and developers on the advantages of Insensitive Munitions programs
- Apply our knowledge of munitions systems to fulfill the needs of the warfighter
- Streamline processes to promote rapid fielding of needed munitions
- Promote the continuous adoption of international standards and collaboration

MSIAC
Munitions Safety Information Analysis Center

Supporting Munitions Safety



Munition Safety Awards Ceremony

Insensitive Munitions & Energetic Materials Technology Symposium

18th – 20th October 2022 - Indianapolis, IN, USA

Christelle Collet
on behalf of Chuck Denham
(MSIAC Project Manager)

Nominations Received

MSIAC has received 1 nomination for **Career Achievement**:

- Ken Tomasello

And 2 nominations for **Technical Achievement**:

- The US Defense Ammunition Center (DAC)
- Development of an IM aircraft bomb model Mk82 General Purpose (Emploi Général) Reduced Vulnerability (Vulnérabilité Réduite) - EGVR

MUNITION SAFETY AWARDS

Nominee for Career Achievement

Nominee for Career Achievement

Ken Tomasello (nominated by Joe LiVolsi and Cynthia Manns)

Major contributions to the IM community:

- Beginning in 1978, Mr. Tomasello was involved in development of **new energetic materials**.
- He received a Special Act award in 1983 for his work on **low vulnerability (LOVA) propellants**.
- From 2001, Mr. Tomasello was a Senior Scientist at the NOSSA and Program Manager for the **IMAD Program**.
- Mr. Tomasello has represented the United States to her NATO allies as chairman of the Conference of National Armaments Directors (CNAD) **Ammunition Safety Group (CASG) Munition Systems Design and Assessment (AC326 Subgroup B)**.
- Mr. Tomasello developed and launched the **Insensitive Munitions Technology Tool (IMT2)**, a web based relational database on the Defense Science and Technology Knowledge Online web site.
- Mr. Tomasello specifically has assisted the Navy and US DOD munitions community through forming, writing the instruction for, and launching the Navy's **Munition Reaction Evaluation Board (MREB)**.
- He also authored and distributed the Navy's **policy on active and passive reaction mitigation devices** used in munitions.
- Mr. Ken Tomasello, retired in December 2021 from the US NOSSA after **43 years** of exemplary and dedicated service in **explosives safety** and its relationship to **Insensitive Munitions**.
- Since his retirement, Mr. Tomasello has continued to support the IMAD Program and his successors in the NOSSA IM Office with mentorship and the benefits of his long experience.

Nominees for Technical Achievement

Nominees for Technical Achievement

Defense Ammunition Center (DAC) – Team Lead: Mr. Keith Brailsford
(nominated by Ms. Theresa A. Smith)

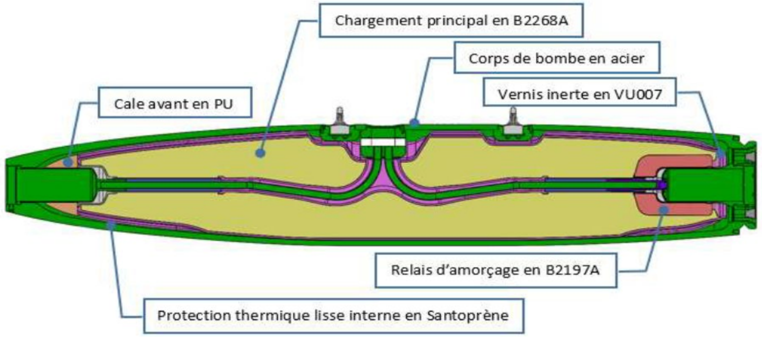
- The Defense Ammunition Center is the premier explosives safety knowledge center for the United States Army and provides direct support to the Office of the Deputy Assistant Secretary of the Army Installations, Energy and Environment.
- Significant contributions:
  - Risk Management Division: After a division reorganization and a subsequent improvement in the workflow process, **a reduction by 25% for FY21** was identified in processing time for site plans and construction reviews from initial receipt to obtaining Army Approval.
  - Explosives Safety Test Program: Thanks to a multi-year design review, modeling and simulation effort in the ECMs of the Miesau Army Depot, the **NEW was increased of 75% from 25-30K NEW to 100-125K NEW**. This effort will likely save millions of dollars in unnecessary new construction/renovation cost and allow Miesau Army Depot to continue to fulfill its critical ammunition support mission in the European Theater.
  - Engineering Division supported a **shipment of a high visibility Iron Dome Defense System-Army** (IDDS-A) Magazine loaded with Tamir missiles. The IDDS-A supports the need for an Interim Cruise Missile Defense Capability as identified in the John McCain Act (NDAA2019).
  - The DAC provided critical certification training on Ammunition Logistics, Surveillance, and Explosives Safety to **208,267 students**, which encompassed all Services, contractors, and international partners to enhance readiness of forces.

Nominees for Technical Achievement

Development of an IM aircraft bomb model Mk82 General Purpose (Emploi Général) Reduced Vulnerability (Vulnérabilité Réduite)

(nominated by Mrs. Valerie Vincent)

- IM design efforts present on this bomb:
  - Use of explosive B2268A, made up of more than 50% NTO (less sensitive);
  - Presence of venting devices located in the central and rear parts of the bomb;
  - Presence of a dedicated stiffener plug in the fuze well to defeat HFI
- DGA granted a MURAT ** Label for this munition



IM Assessment of the bare munition

STANAG 4439 Requirements		FH	SH	BI	SR	FI-L	FI-H	SCJI
IM Signature	NR							
	V	●		●		●	●	○
	IV		●		●			
	III							
	II							
	I							

Full compliance with STANAG 4439
● : Assessment by Full-scale test
○ : Assessment by analysis and/or read-across with other configurations

IM Assessment in logistic configuration

STANAG 4439 Requirements		FH	SH	BI	SR	FI-L	FI-H	SCJI
IM Signature	NR							
	V	●	●	○		○	○	●
	IV				●			
	III							
	II							
	I							

Nominees for Technical Achievement

Development of an IM aircraft bomb model Mk82 General Purpose (Emploi Général) Reduced Vulnerability (Vulnérabilité Réduite)
(nominated by Ms. Valerie Vincent)

Team members:

- **Fabio Sgarzi**
  RWMI
- **Gianpietro Roccatagliata**
  RWMI
- **Bruno Nouguez**
  EURENCO
- **Philippe Chabin**
  EURENCO
- **Laurent Lafargue**
  DGA
- **Kévin Roussel**
  DGA
- **Joffrey Duchon**
  DGA - IM Committee
- **Jérôme L'Hostis**
  DGA - IM Committee
- **Frank Dupuis**
  DGA - IM Committee
- **Fabien Chassagne**
  DGA - IM Committee
- **Valérie Vincent**
  DGA - IM Committee

Awardees

Career Achievement:

- Ken Tomasello

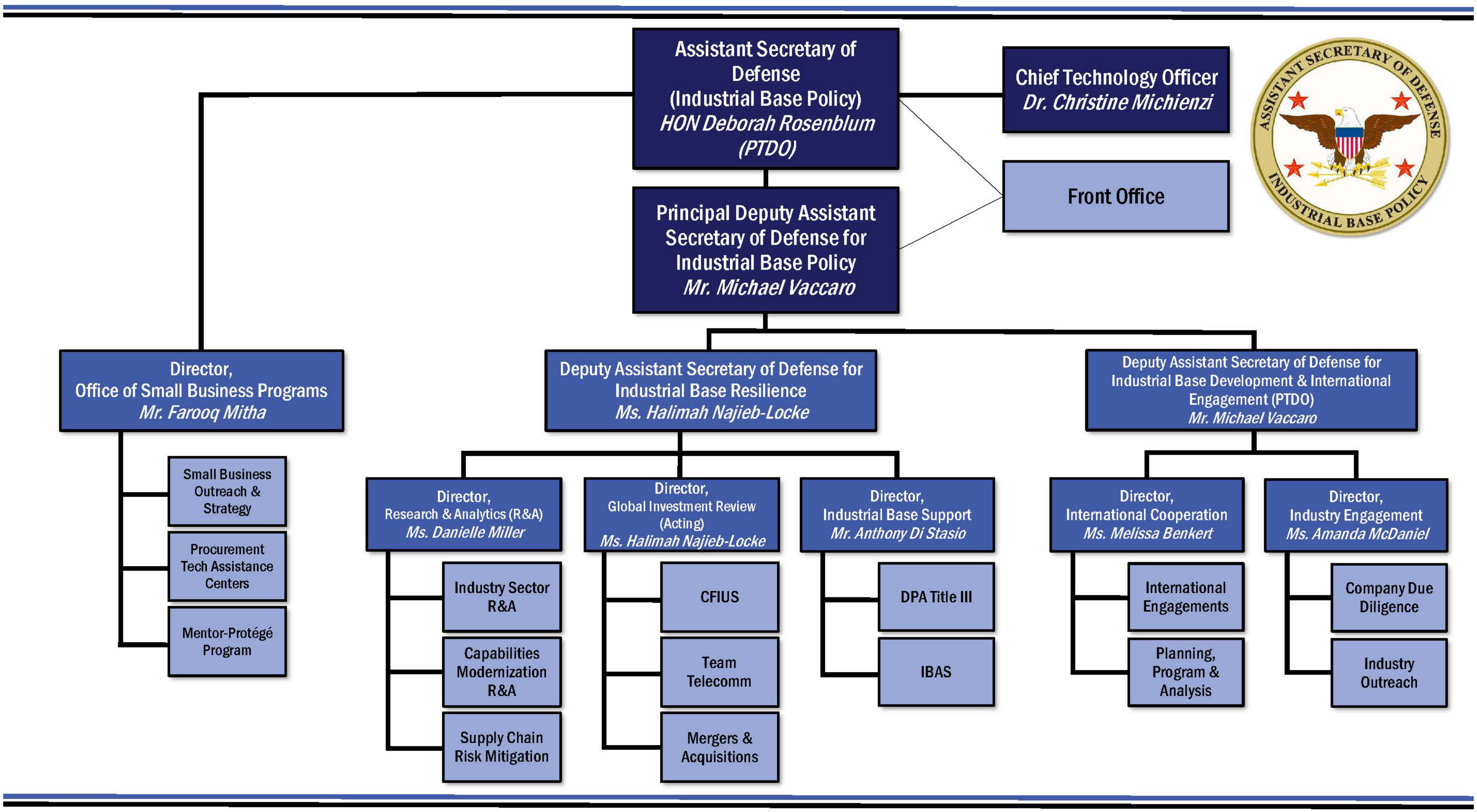
Technical Achievement:

- The team “Development of an IM aircraft bomb model Mk82 General Purpose (Emploi Général) Reduced Vulnerability (Vulnérabilité Réduite)”

Defense Production Act (DPA) Title III
NDIA IMEMTS
18 October 2022

Anthony Di Stasio
Director (Acting), Industrial Base Investments

IBP Organizational Chart



Defense Production Act
(40 U.S.C. 4501 et seq.)

- The Defense Production Act (DPA) authorizes the **President** to **ensure the availability of U.S. and Canadian industry for U.S. defense, essential civilian, and homeland security requirements**.
- The **House Committee on Financial Services** and the **Senate Committee on Banking, Housing, and Urban Affairs** have jurisdiction over DPA.

DPA Authorities		
Title I	Title III	Title VII
Priorities and Allocations	Expansion of Productive Capacity and Supply	General Provisions
• Prioritize Federal contracts over all other orders • Control distribution of scarce materials within the civilian economy • Allocate scarce materials against Federal or private contracts • Prevent hoarding of scarce materials	• Incentives to develop, maintain, modernize, and expand production capacity or critical technologies: – Loans/ loan guarantees – Purchases/ purchase commitments – Grants and subsidies	• Mandatory survey authority of any U.S.-registered business entity • Anti-trust immunity for industry, to develop and implement national emergency preparedness plans • Committee on Foreign Investment in the U.S. (CFIUS) • Civilian Executive Reserve, called into Federal service during a national emergency

Title III Authorities and Priority Areas

Authorities

Loan Guarantees §301 (50 U.S.C. 4531)	Loans §302 (50 U.S.C. 4532)	Purchase Commitments §303 (50 U.S.C. 4533)	Purchases §303 (50 U.S.C. 4533)
• May be extended when credit is not available to the loan applicant under reasonable terms and conditions sufficient to finance the activity • Prospective earning power of the loan applicant and the character and value of the security pledged provide a reasonable assurance of repayment of the loan to be guaranteed	• May be extended when private financing is beyond the risk of the commercial market • Projected earnings following the loan are sufficient to cover repayment costs	• Create a guaranteed demand to reduce risks for industry to make their own investments	• Provide direct subsidies to companies to assist in establishing production capabilities including: – Purchase and installation of production equipment in privately owned or Government owned facilities – Engineering support to improve quality and yield of production facilities – Sample quantities for process validation and customer qualification testing

Priority Areas

Sustain Critical Production	Commercialize Research and Development Efforts	Scale Emerging Technologies
"To create, maintain, protect, expand, or restore domestic industrial capabilities essential for National Defense"	"From Government sponsored research and development to commercial applications" and "from commercial research and development to National Defense"	"For the increased use of emerging technologies in security program applications and the rapid transition of emerging technologies"

DPA Title III Statutory Criteria

- **The execution of Section 303 (50 U.S.C. § 4533) authorities requires the President, on a non-delegable basis, to identify a domestic industrial base shortfall as meeting three specific criteria:**
  - — The industrial resource, material, or critical technology item is essential to national defense;
  - — Without Presidential action under [50 U.S.C. § 4533], United States industry cannot reasonably be expected to provide the capability for the needed industrial resource, material, or critical technology item in a timely manner; and
  - — Purchases, purchase commitments, or other action pursuant to [50 U.S.C. § 4533] are the most cost effective, expedient, and practical alternative method for meeting the need
- **Presidential Determinations (PDs) are:**
  - — Non-expiring and able to be leveraged for different projects addressing the same shortfalls
  - — Varying in breadth and scope depending upon the shortfall/challenge addressed
- **PDs are not:**
  - — An appropriation or funding mechanism
  - — A mandate to address a specific shortfall or pursue a specific course of action

DPA Title III Statutory Criteria Cont.

- **Under peacetime conditions, the DPA statute imposes constraints on the exercise of Section 303 authorities:**
  - — All investments require a PD
  - — All actions >$50M require Congressional notification and a 30-day waiting period before action can be taken
  - — All actions >$50M require Congressional authorization
- The law currently allows for the **waiver of statutory criteria** in two specific instances:
  - — During a period of **national emergency** declared by the Congress or the President
  - — Upon a determination by the President, on a nondelegable basis, that action is **necessary to avert an industrial resource or critical technology item shortfall** that would severely impair national defense capability. (50 U.S.C. § 4533).

History and Status of Presidential Determinations and Waivers

- 105 total active PDs and 2 Waivers dating to 1987
- 20 PDs and 2 Waivers signed since FY 2019

Presidential Determination/Waiver	Signature Date	Authorization Value
Alane Fuel Production	5 October 2018	$50M
Circular Lithium-Sea Water Batteries Production	5 October 2018	$50M
Energetic Materials Production for DoD Munitions	16 January 2019	$50M
Precursors Production for DoD Munitions	16 January 2019	$50M
Inert Materials Production for DoD Munitions	16 January 2019	$50M
Advanced Manufacturing Techniques for DoD Munitions	16 January 2019	$50M
Sonobuoys Production	12 March 2019	$50M
Small Unmanned Aerial Systems	12 June 2019	$50M
Rare Earth Permanent Magnets Production (2x PDs)	22 July 2019	$100M
Rare Earth Separation and Processing Capability (2x PDs)	22 July 2019	$100M
Rare Earth Metal and Alloy Processing Capability	22 July 2019	$50M
Domestic Capacity Expansion for F135 Integrally Bladed Rotors	22 July 2019	$50M
COVID-19 Response (Waiver)	27 March 2020	No Limit
High/Ultra High Temperature Composite for Hypersonics	24 June 2020	$50M
Submarine Industrial Base Production Capacity Essential to the VCS Program (3x PDs)	21 December 2021	No Limit
Radiation-Hardened and Strategic Radiation-Hardened Microelectronics	21 December 2021	No Limit
Critical Materials in Large-Capacity Batteries	31 March 2022	No Limit
Material Critical to Support the Defense Against Adversarial Aggression (Waiver)	3 October 2022	No Limit

Why is everyone talking about DPA?

- While the DPA was enacted in 1950, the past few years have seen an **increased interest** in the authorities from the Executive and Legislative Branches, Government agencies, and the public.
- Congress **appropriated $1B** to the DPA Purchases account via the **CARES Act** “to prevent, prepare for, and respond to coronavirus”.
  - **DoD’s DPA-Title III program developed <u>three lines of effort</u>**:
    - Health Resources ($213M)
    - Defense Industrial Base (DIB) ($687M)
    - DFC Loans ($100M)
  - Greatly **reduced acquisition timelines** resulting in the obligation of $800M in ~10 months
- The COVID response has encouraged the Executive and Legislative branches to view the DPA authorities as **valuable tools** to be leveraged outside of its historical DoD applications.

5-Year Investment Plans
Critical Chemicals

- DPA Title III Program has developed a 5 year strategy and investment plans focused increased leveraging of authorities to address most critical shortfalls.

Awarded Efforts: Obligation (Fully or Partially) Occurred

Planned Efforts: Not Awarded to Date

Targeted Investment Areas	FY20	FY21	FY22	FY23	FY24	FY25	FY26
Precursors				$103.0M			
Inerts				$6.0M			
Explosive	$0.5M			$96.9M			
Advanced Manufacturing Techniques (AMT)				$20.0M			

New PD Required

5-Year Investment Plans
Hypersonics

- DPA Title III Program has developed a 5 year strategy and investment plans focused increased leveraging of authorities to address most critical shortfalls.

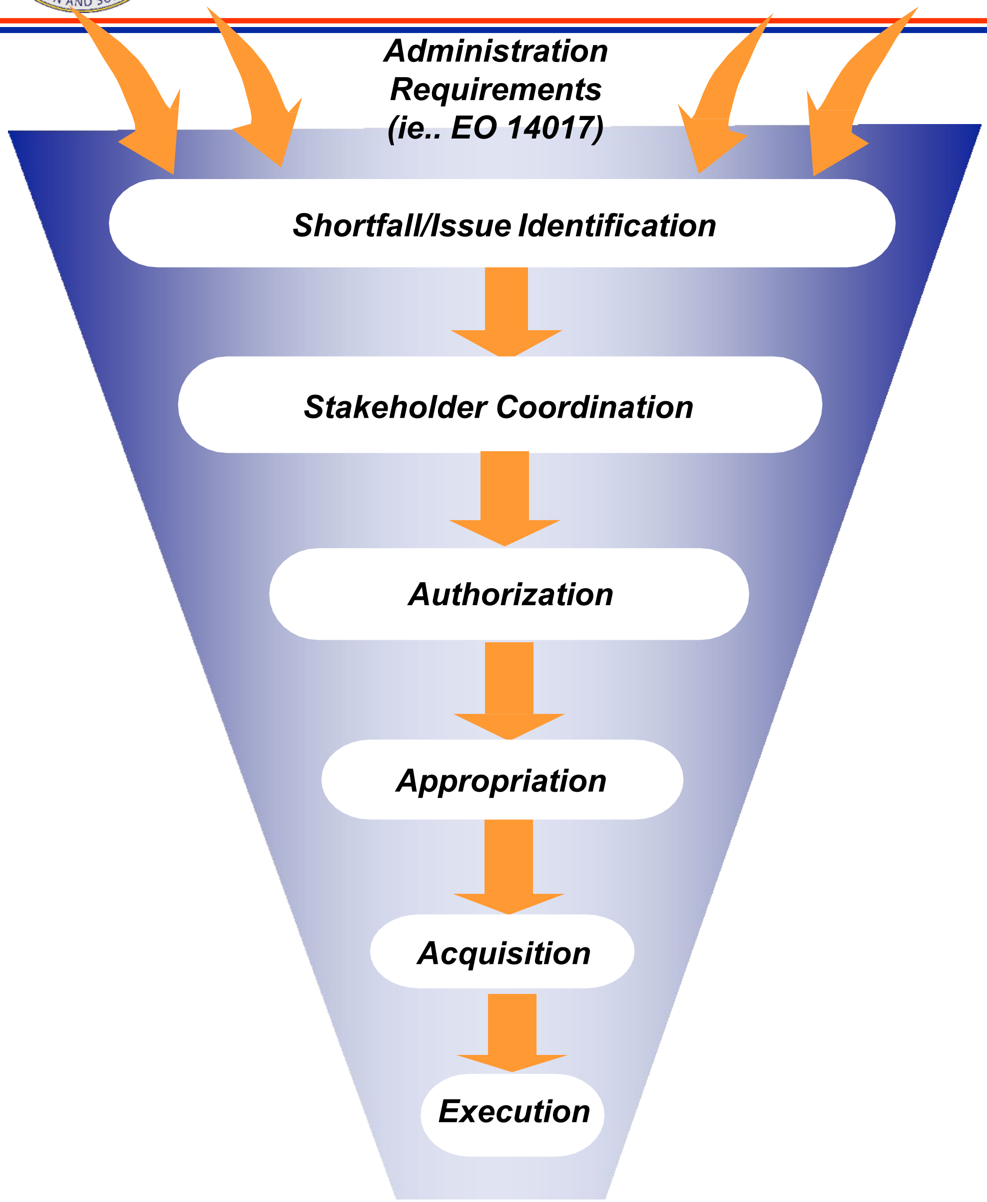
Awarded Efforts: Obligation (Fully or Partially) Occurred

Planned Efforts: Not Awarded to Date

Targeted Investment Areas	FY20	FY21	FY22	FY23	FY24	FY25	FY26
Guidance and Control				$ 19.0M-- Avionics	$31.5M– GNC Upgrades (GPS Denied)		
Propulsion				$19.0M – Conventional Boost & Air Breathing (LFRJ / SFRJ)	$45.0M– Advanced Air Breathing (LFRDE, SFRDE, VFDR)		
Lethality			See Critical Chemicals Roadmap				
Vehicle			$25.0M – High Temp Materials		$25.0M - Fibers		

New PD Required

Requirements Evaluation



- **Issue Identification**
  - Industry- Open Funding Opportunity Announcement
    - https://sam.gov/opp/f373370cfe504a0c9ac0ad41dccee52e/view
  - Industry Mailbox
    - osd.pentagon.ousd-a-s.mbx.dpa-title-iii-industry-inquiries@mail.mil
  - DoD or Other Government Agency – “Intake” Form
- **Authorization and Appropriation**
  - Development of new/increase spending limit on Presidential Determinations
- **Acquisition**
  - Develop DoD requirements
  - Select T3 investment requirements
  - Develop statement of objectives

DPA Title III Funds & Execution

- DPA Title III appropriations are **non-expiring procurement funds** and are valid until expended.
- **Congress must be notified** of planned expenditures.
- **Congress must write into law authorization** to spend more than $50 million in aggregate action on a single shortfall.
- Title III requests Government stakeholders provide funding towards projects.
- All transfers to the DPA Fund must be done through Above Threshold Reprogramming (ATR) or through the POM Process.

Title III Program Determines to Proceed with Effort → Stakeholders Send Funds to DPA Funds through ATRs or POM Process After Signing MOA → DPA Funds consist of Stakeholder contributions and Congressional Appropriations → DPA Title III MIPRs Funds to AFRL Title III Executive Agent Program Office (EAPO) → AFRL EAPO Obligates Funds and Executes Contract

ATRs

- ATRS move funding from one appropriation to another appropriations and must be approved by Congress (HAC-D, SAC-D, HASC, SASC)
- Additional guidance on ATRs may be found in the Financial Management Regulation (FMR) Volume 3, Chapter 6

POM

- Stakeholder organization includes the reprogramming to DPA Fund in its POM submission
- Funding realignment occurs during the President's Budget Build in Decision Document System (DDS)
- Realigned funds are reflected in DPA Title III's Budget Submission to Congress

Executive Order (E.O.) 14017, America's Supply Chains

- **Executive Order 14017** required a **whole-of-government effort** to assess risk, identify impacts, and propose recommendations in support of a healthy manufacturing and defense industrial base – a critical aspect of economic and national security.
- Leverage assets:
  - — Bipartisan support
  - — Interagency knowledge
  - — Established program
- Mitigate Pricing Threats

Title III Support to E.O. 14017

- **A whole-of-government effort** to assess risk, identify impacts, and propose recommendations in support of a healthy manufacturing and defense industrial base – a critical aspect of economic and national security
- **Select Kinetic Capabilities**
  - **Chemicals**
    - On-shore or secure US source for DoD critical chemicals for propulsion and lethality
  - **Hypersonic Industrial Base**
    - Improve and expand the industrial base to support the building, testing, and deployment of strategic and quick strike weapons
- **Energy Storage and Batteries/Strategic and Critical Materials**
  - **Rare Earth Elements**
    - Re-establishing domestic mine-to-magnet production for EV's and weapon systems
- **Microelectronics (ME)**
  - **Electronics**
    - Maintain and increase the U.S. share of global semiconductor production to strengthen and secure DIB
  - **Space**
    - Develop and sustain domestic capabilities for radiation-hardened manufacturing and testing
  - **Small Unmanned Arial Systems**
    - Re-establishing U.S. capability for secure, interoperable systems for DoD and commercial use
- **Castings and Forgings**
  - **Thin Wall Castings**
    - Expansion of sole source supplier for aerospace grade magnesium and aluminum products for rotorcraft

Defense Production Act Title III

- **<u>IS</u>:**
  - **Efficient and effective** way to improve the industrial base
    - Modernize, expand, transform
  - **<u>One method</u>** for creating and sustaining market demand
  - Final stop (sometimes) on the way to production
  - **Cross-cutting investment vehicle** to solve root causes, not symptoms
  - Able to **engage** tactically with industry and strategically with policy and legislation
  - **<u>Planned over a five year period to address challenges and shortfalls in priority order</u>**
- **<u>IS NOT:</u>**
  - Title I
  - **A magic bullet**
  - The **solution to all industrial base problems**
  - Appropriate for **service specific** challenges
    - Single platform/service
    - A solution for service specific challenges

Burning Questions

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Supporting Munitions Safety

Comparison of IM Threats versus the Real World

Insensitive Munitions and Energetics Materials Symposium
18th – 20th October 2022, Indianapolis, IN, USA

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Background

- This presentation demonstrates the applicability of the three of the six standardized IM threats (**FH**, SH, **BI**, FI, **SCJI** and SR) to other credible aggressions that may occur during the life cycle of munitions.

- By comparing the standardized energy loading provided to the munition in IM tests with the energy loading from other credible threats that may occur in the "real world", it shows to what extent IM threats can be considered conservative.

- This analysis is based on the most recent IM-related NATO standards:
  - the overarching AOP-39 Edn D Ver02;
  - the new standard related document: AOP-39.1 Edn A Ver01 on guidance on the organisation, conduct and reporting of full scale tests; and
  - the suite of IM test AOPs (Edn A Ver02).

Fast Heating

- AOP-4240 Edn A Ver02 Fast heating test procedures for munitions

"The Fast Heating Test is designed only to simulate the most intense heating conditions likely to be created in a hydrocarbon fuel pool fire. This test does not, however, simulate a particular in-service or accident scenario."

- Three methods:
  - Liquid Pool Fire
  - Fuel Burner Fire
  - Mini Pool Fire

These two methods were included in the AOP for environmental reasons

US NSWCDD 3.7 m square propane burner

Fast Heating

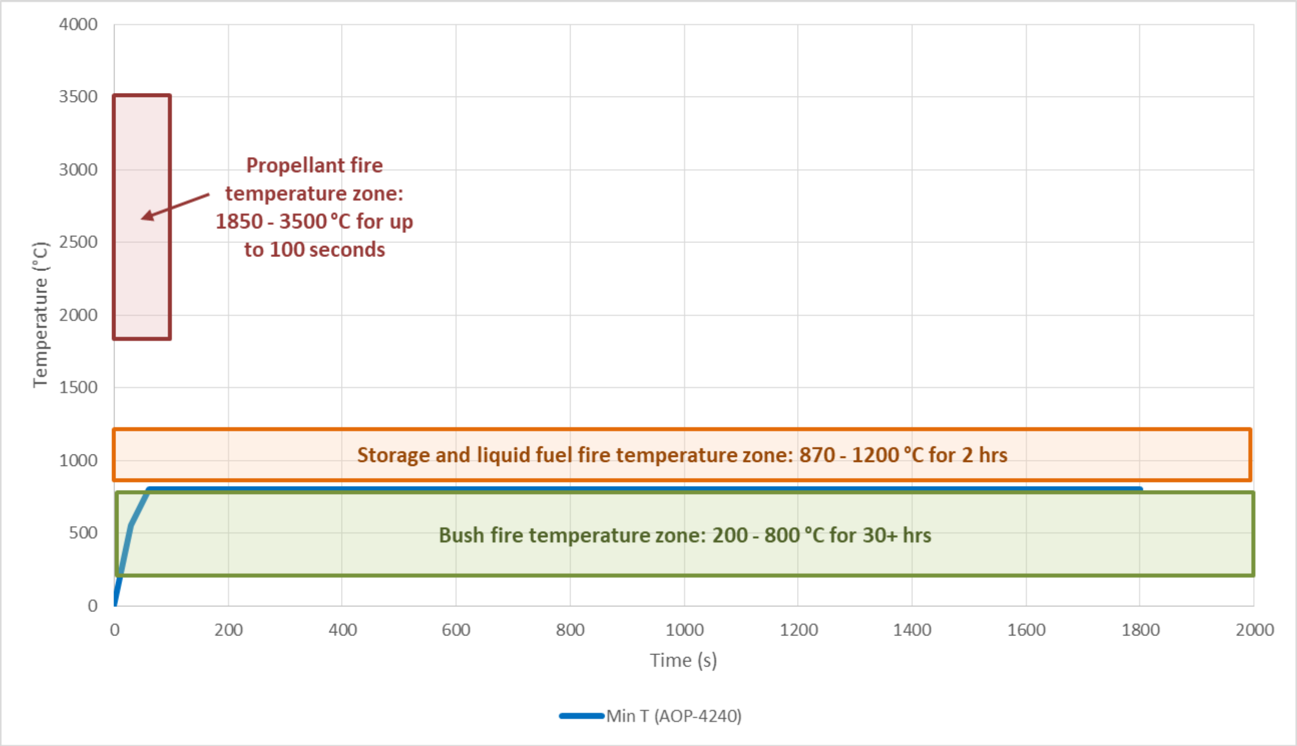
- Temperature requirements
  - An average flame temperature of at least 800 °C during the test.
  - The flame temperature shall reach 550 °C under 30 seconds after ignition.

- Discussion about what is worse case
  - Packaged versus unpackaged
  - Which heating rate?
  - Which heat flux?

- Background and test origin:
  - Annex B of AOP-4240
  - MSIAC report L-97

Fast Heating

- Comparison of AOP temperature requirement with typical fire temperature zones

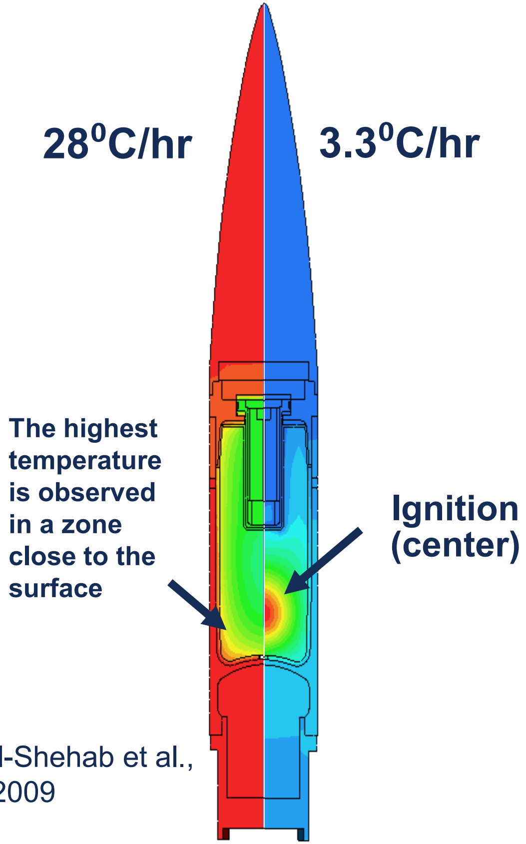


Fast Heating

- Consideration about the heating rate: does a higher heating rate represent the worst case scenario?
  - The available results show that no reaction types more violent than Type III have ever been reported at FH on rocket motors (this is not the case at SH)

Heating Source	• Torching • EM Burning • Exhausts • Pyrotechnics	• Fuel Fire • Wood fire • Propane burner • Building Fire	• Hot Breach • Gun Battlecarry • Launcher • Nuclear plant • Aircraft debris • Remote fire • Aerodynamic Heating • Adjacent compartment fire	• Solar Heating • Steam leak
Regime	Fast Cookoff (FCO)		Intermediate Cookoff (ICO)	Slow Cookoff (SCO)
Temperatures (Order of magnitude)	1000 to 2000 °C	~1000 °C	100 to 300 °C	~ 100 °C
Heating rates (Order of magnitude)	50 to 100 °C/sec	1 to 20 °C/sec	25°C/hr to 50 °C/min	< 20 °C/hr

Source: Peugeot, MSIAC report L-97, 2003



Source: Al-Shehab et al., IMEMTS 2009

Bullet Impact

- AOP-4241 Edn A Ver02 Bullet impact test procedures for munitions

  “The Bullet Impact Test is only designed to simulate the most violent response that a viable bullet impact threat would produce.”
  “This test only represents a particular set of conditions as it is not possible to cater to the wide range of weapons, sizes of bullets, strike velocities or angles of attack in the real world.”

- Three methods
  - Three 12.7 mm x 99 mm AP impacts, 850 +/- 20 m/s
  - Single 12.7 mm x 99 mm AP impact, 850 +/- 20 m/s
  - Tailorable alternative based on Threat Hazard Assessment (THA)

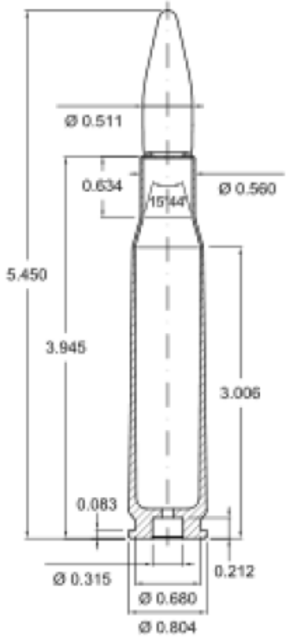
- Background and test history
  - Annex B of AOP-4241
  - Dr. E.L. Baker “Bullet Impact and Munitions Crushing, MSIAC Technical Questions”, MESF 2022

Bullet Impact

- Example munitions that fulfill the 12.7 mm x 99 mm AP requirements:
  - DM51
  - M2 AP
  - AP-M8

- Discussion about what is worst case
  - One versus three shots
  - Lower versus higher velocity
  - 12.7 mm versus 7.62 mm

- Competing mechanisms
  - Damage
  - Venting
  - Stuck (hot) projectile
  - *Worst case is not always the highest energy threat*



Calibre	0.5 in. (12.7 mm)
Cartridge mass	115 g
Projectile mass	42 g
Velocity at the barrel muzzle	930 m/s
Energy	18,162.9 J

Bullet Impact

- Sources of real world bullet impact
  - Jane's ammunition handbook 2021-2022
  - Wikipedia: Table of handgun and rifle cartridges
  - Current threats from Russia
    - Assault rifles: AK-12 and AK-15 to replace AK-74M, AK-74M replaced AK-47 based rifles
      - 5.45 mm x 39 mm and 7.62 mm x 39 mm
    - Sniper rifles from US and new Lobaev
      - .50 BMG (12.7 mm x 99 mm)
    - Infrantry machine guns, NSV and Kord meant to replace DShK
      - 12.7 x 108 mm

https://en.wikipedia.org/wiki/Table_of_handgun_and_rifle_cartridges
https://www.popularmechanics.com/military/weapons/a20138224/russian-military-new-assault-rifles-ak-12-ak-15/
https://www.rbth.com/russian-kitchen/334486-russia-unveils-its-most-powerful-sniper-rifle
https://en.wikipedia.org/wiki/DShK

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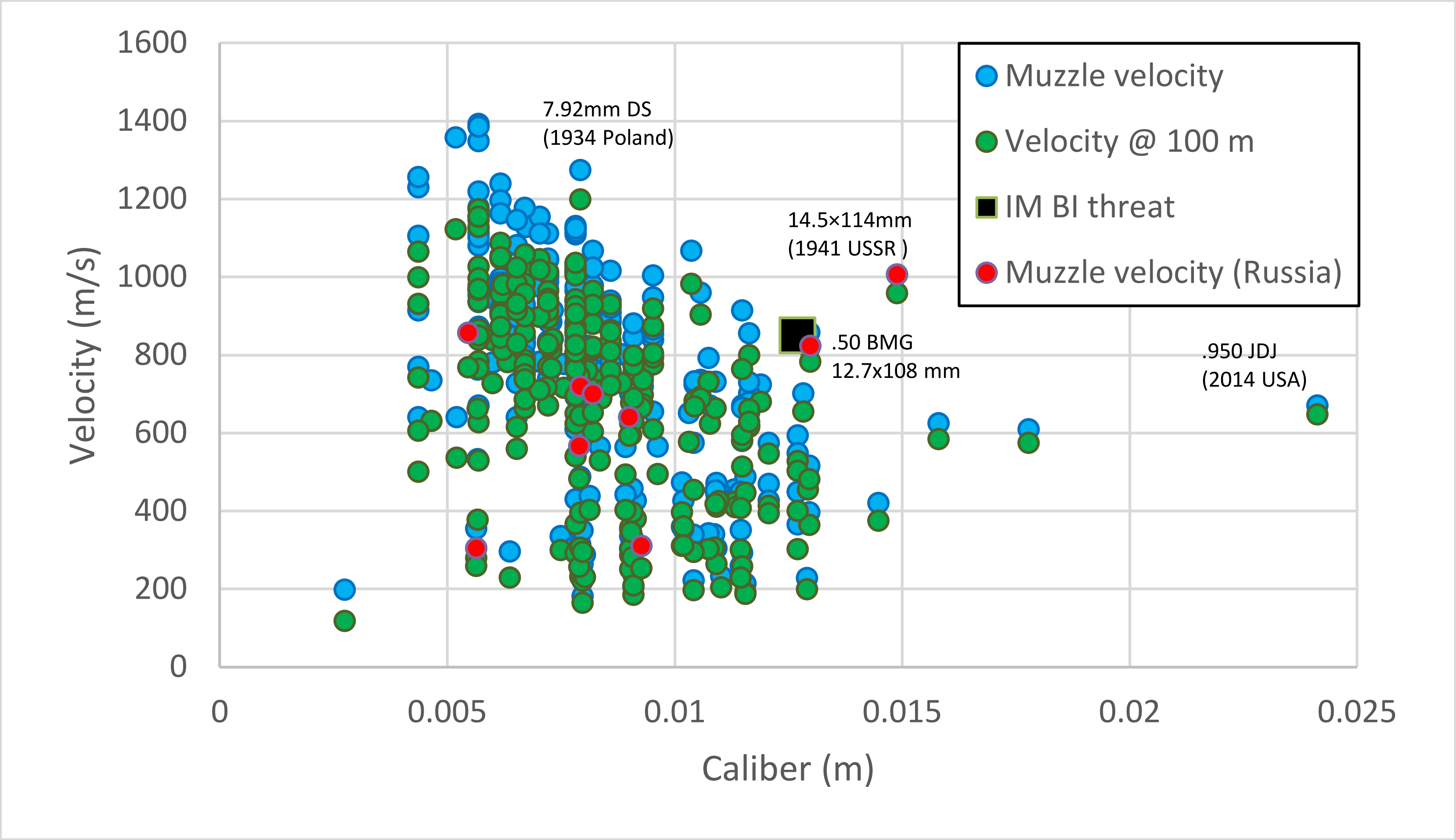
Bullet Impact



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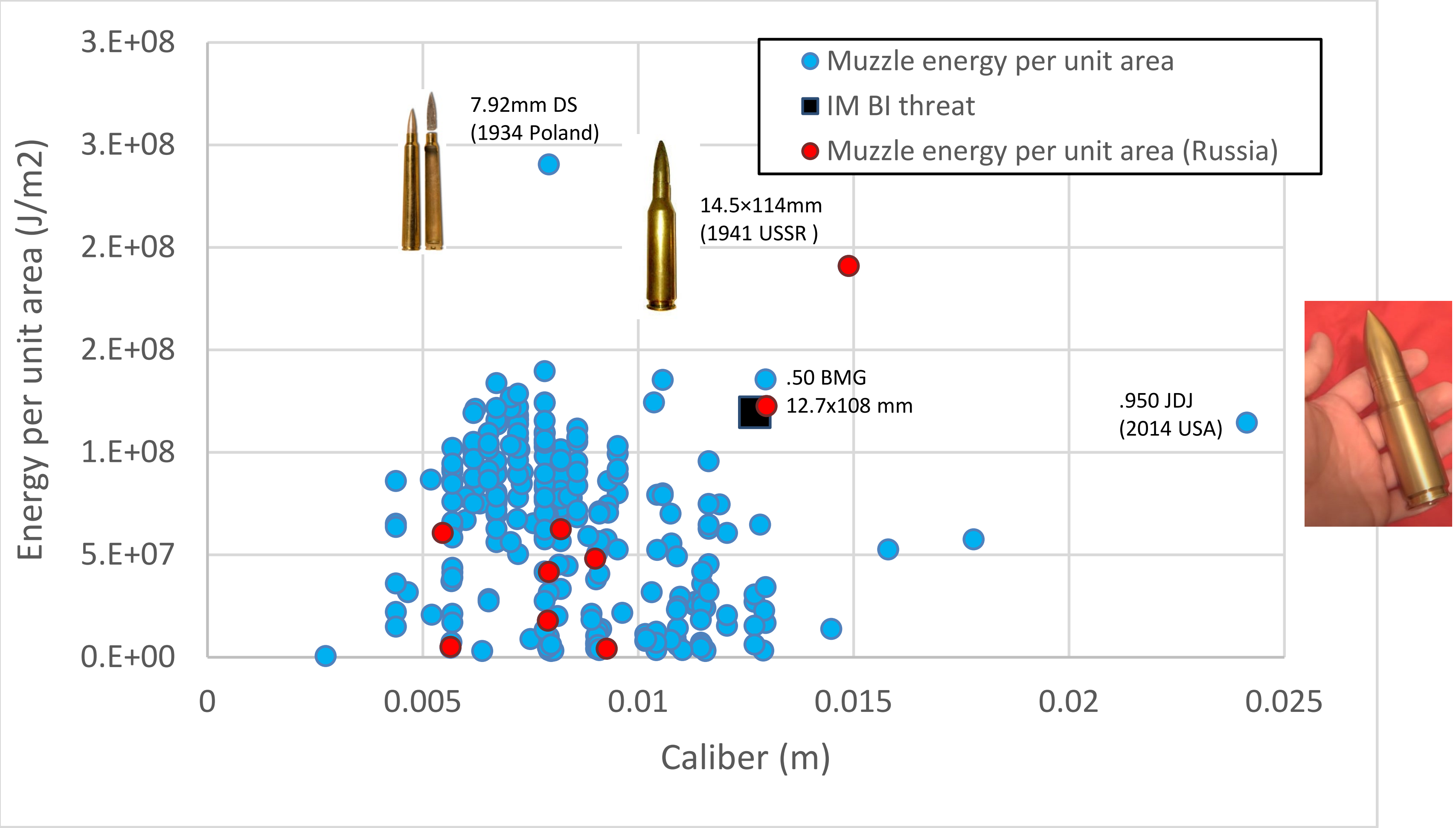
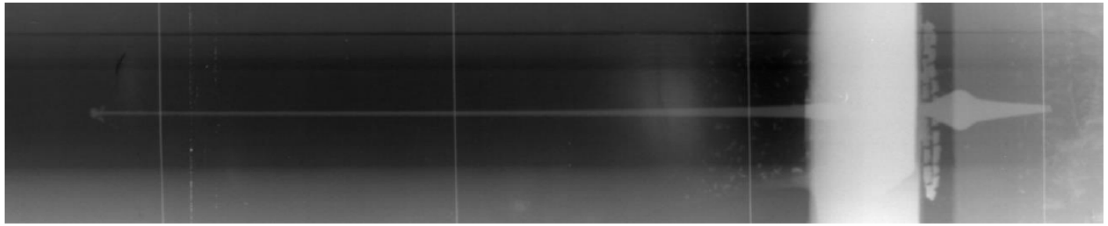
Bullet Impact



Shaped Charge Jet Impact

- AOP-4526 Edn A Ver02 Shaped Charge Jet Impact test procedures for munitions
  - *The Shaped Charge Jet Impact Test is only designed to simulate the most violent response that a viable shaped charge jet impact threat would produce.*
  - *This test only represents a particular set of conditions as it is not possible to cater to the wide range of shaped charge weapons, impact velocities or angles of attack in the real world.*
- Two methods:
  - SCJI as described in AOP
  - SCJI following from a THA
- Background and test origin:
  - Annex B of AOP-4526



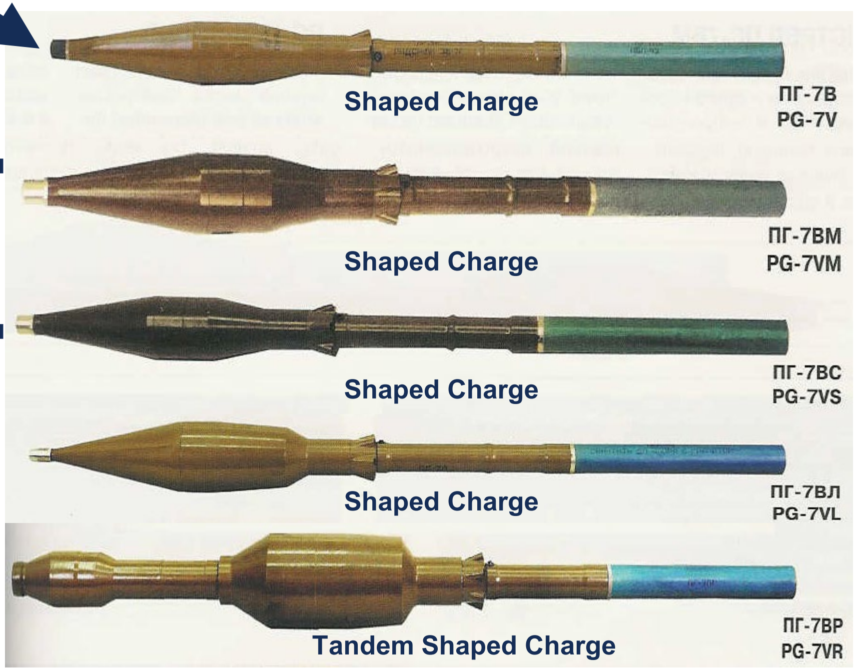
CCEB-62 Jet Characterization

AOP-4526 Edn A Ver02 based PG-7 Grenades

- The RPG-7 (Rocket Propelled Grenade type 7) launcher is widely available and used throughout the world.
- Production RPG-7 grenades observed to have erratic performance
- PG-7V is the most common, but lowest level threat
- PG-7VM and PG-7VS are smaller, but higher performance

Penetration Capacity, mm

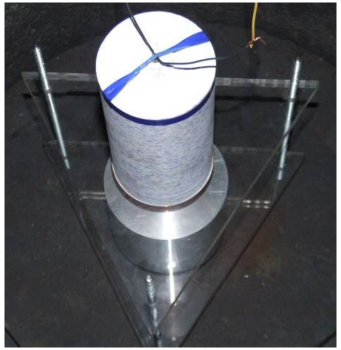
	Caliber, mm	Weight, kg	Armor steel	Concrete wall	Brick wall
PG-7V	85	2.2	Over 260	Over 600	Over 1000
PG-7VM	70.5	2.0	Over 300	Over 700	Over 1000
PG-7VS	72	2.0	Over 400	Over 1000	Over 1500
PG-7VL	93	2.6	Over 500	Over 1200	Over 1700
PG-7VR	105	4.5	Over 600	Over 1500	Over 2000

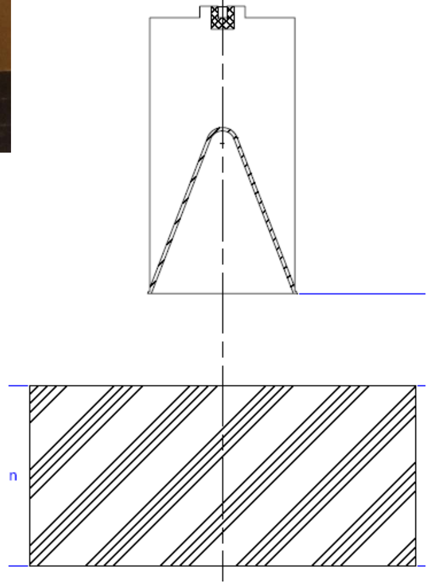


PG-7 Surrogates

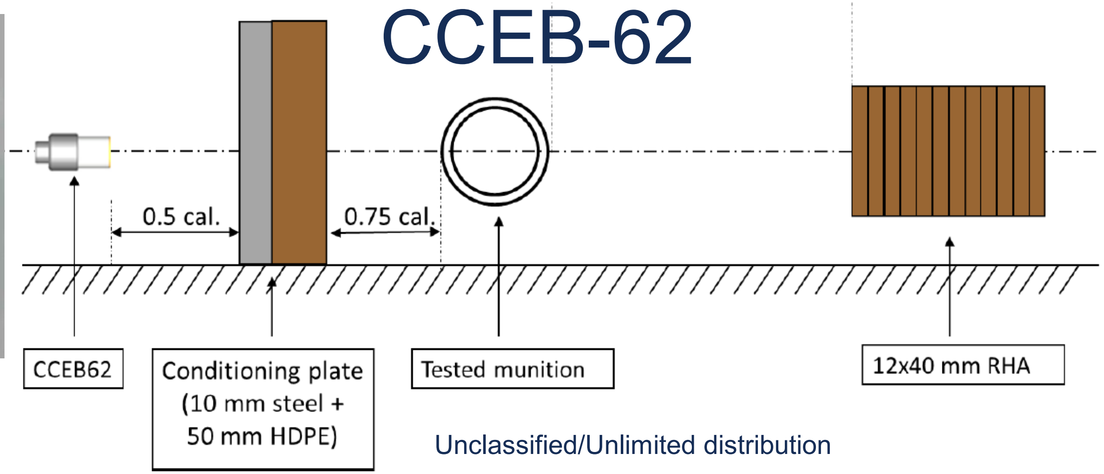
- The USA and France have developed high precision shaped charge surrogate test configurations that are reproducible representations of RPG-7 attacks (AOP-4526, Appendix A)
- USA: 81mm, LX-14 standardized shaped charge test configuration has been shown to closely replicate the attack of a PG-7V
- France: CCEB-62 is slightly smaller and higher performance similar to the PG-7VM and PG-7VS

81mm





CCEB-62



PG-7 Surrogates

- MSIAC did a comparison of the USA 81 mm and France CCEB-62 shaped charge jet tests. (MSIAC TQ 2021-FRA-3083)

- Held's criteria (v^2d) is a commonly used initiation criteria used for shaped charge jet attacks. v=jet velocity, d=jet diameter
  - USA 81mm: $v^2d = 120\ mm^3/\mu s^2$ for the jet tip
  - France CCEB-62: $v^2d = 133\ mm^3/\mu s^2$ for the jet tip

- Work by W. Arnold (IMEMTS 2015) concludes that the critical v^2d increases for increasing shaped charge size for covered confined explosives.

- The France CCEB-62 is a slightly higher threat than the USA 81mm.
  - Pass the French SCJI test …you'll pass the US SCJI test
  - Fail the French SCJI test …you'll PROBABLY fail the US SCJI test
  - Pass the US SCJI test …you'll PROBABLY pass the French SCJI test
  - Fail the US SCJI test …you'll fail the French SCJI test

- AOP-4526 Edn A Ver02 is representative of PG-7 shaped charge threats.

- Other shaped charge threats do exist (ATGMs, medium caliber). The RPG-7 is the most prevalent shoulder fired rocket threat.

Conclusions

- Comparison to real world threats shows IM threats are representative of real aggressions and are generally on the conservative side:
  - FH test temperature requirements present a maximum for bush fires and a minimum for storage / liquid fuel fires. They are difficult to compare with short duration propellant fires.
  - BI test requirements present a maximum for energy per unit area of small caliber threats except for some anti-tank munitions.
  - SCJI test requirements are representative of PG-7 shaped charge threats.

Conclusions

- A similar analysis was conducted for the three other IM threats: SH, FI and SR (not included in this presentation).

- MSIAC will report the findings of this study in a limited report to be published end of 2022.

Questions?

The Slow Mo Guys – YouTube video available at
https://www.youtube.com/watch?v=dHfQYGGUS4U

MSIAC
Munitions Safety Information Analysis Center

Supporting Munitions Safety

MSIAC Highlights and Future Priorities

Insensitive Munitions & Energetic Materials Technology Symposium
18th – 20th October 2022 - Indianapolis, IN, USA

Christelle Collet
on behalf of Chuck Denham
(MSIAC Project Manager)

History

History of MSIAC is linked to history of Insensitive Munitions (IM)

- Need for IM arose from horrific accidents of 1960 and 1970s

History

HORRIFIC MUNITION ACCIDENTS
NATIONS RECOGNIZE NEED TO REDUCE DANGER TO OUR OWN FORCES

1951 — RFA Bedenham accidental detonation of depth charges
13 killed

1960

1967 — USS Forrestal accidental ignition of a Zuni rocket
134 killed, 161 injured

1969 — USS Enterprise accidental cook-off of a Zuni rocket
28 killed, 344 injured

1970

1973 — Roseville, CA Railyard accidental cook-off of MK-81 bombs
48 injured

1980 — USS Nimitz accide
cook-off of Sparrow mis
14 killed, 48 inju

Our Organization

Technical Information Analysis Center Focusing on Munitions Safety

– NATO Project Office
– Independently Funded by its Member Nations (16 currently)

Areas of Expertise:

- Warhead Technology
- Propulsion Technology
- Materials Technology
- Energetic Materials
- Munitions Transport and Storage Safety
- Munitions Systems

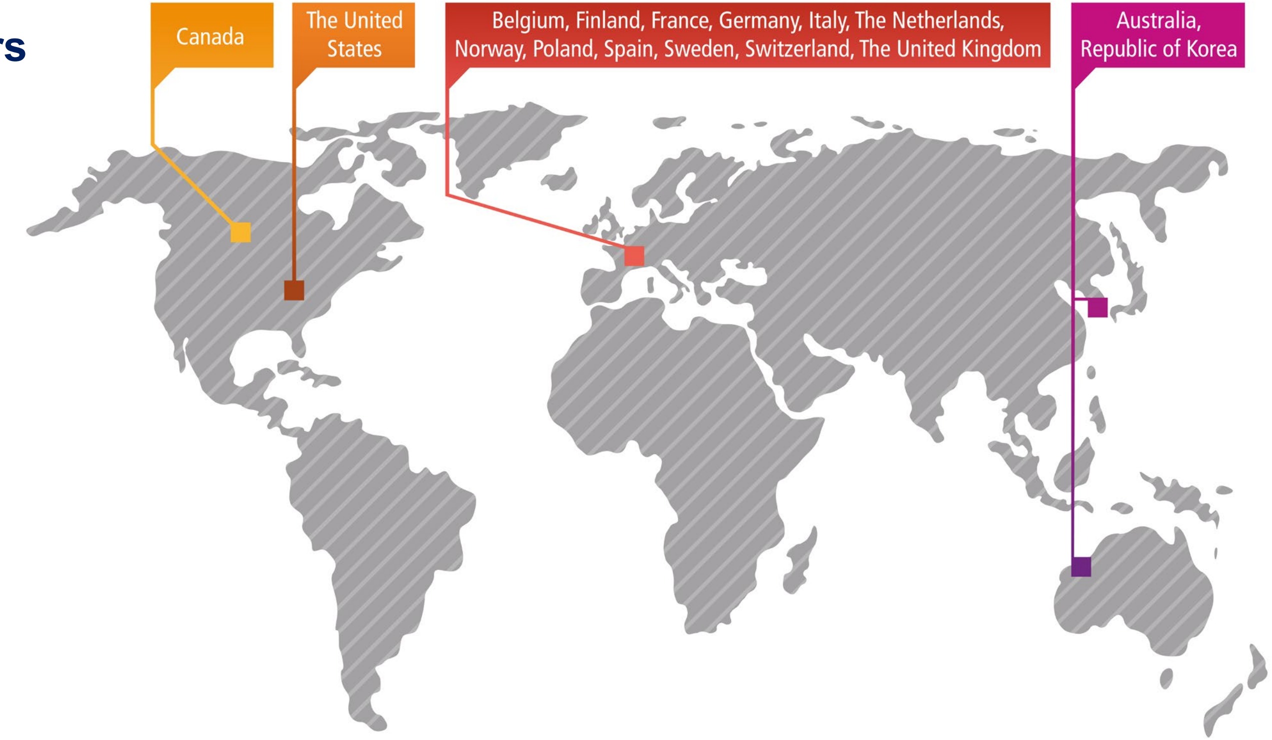
Products & Services:

- Technical Questions
- Promotion/participation International Conferences
- Support to NATO WG activities
- Training and Workshops
- Technical Reports
- Repository of Technical Information

Eliminating Safety Risks from Unintended Reactions of Munitions and Energetic Materials throughout their Lifecycle

MSIAC Member Nations

- **MSIAC Strategies, Policies, & Work Efforts Defined by a Steering Committee (SC)**
  - 1 SC Representative per Member Nation, 1 Vote per Member Nation
  - 1 Elected Chairman (non-voting) from a Member Nation
- **16 Members**



Steering Committee & NFPO

Chairperson

Dr Brian Fuchs

Members	National Focal Point Officers	Service Representatives
CDR Luke Miller	LCDR Emma Griffith	
LTCOL Gunnar Plovie	CAPT Christophe Van de Velde	
Ms Kim Brooks	Ms Mira Pellerin	
Mrs Seija Miettinen-Bellevergue	Ms Maija Hihkio	
Mr Serge Bordachar		
Dr Thomas Malyusz	Mr Joerg Heymer	Mr Philipp Hamhuis
LCDR Alberto Tessitori		
Mr Albert Bouma		
Mr Gunnar Ove Nevstad		
Dr Agata Kamienska Duda		
Mr Jin Soo Choi	Mr Kieun Lee	
LTCOL Emilio Larriba de la Rubia		
Mr Johan Niemi	Mr Christer Daun	
Dr Philippe Mouchet	Dr Patrick Folly	
Mr Ian Carr	Mr Kevin Liddell	
Mr Andy Rash	Mr Andrew Nelson	Mr Stephen Struck *Air Force* Dr Brian Roos *Army* Dr Josephine Covino *DoD* Mr Jeffrey Roquemore *Navy*

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Diane Vanoverstraeten

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- STORAGE & TRANSPORT – *Martijn van der Voort*
- ENERGETIC MATERIALS – *Chris Hollands*
- WARHEAD TECHNOLOGY – *Dr Ernie Baker*
- PROPULSION TECHNOLOGY – *Christelle Collet*
- MATERIALS TECHNOLOGY – *Dr Kevin Jaansalu*

IT SUPPORT

- SYSTEM SUPPORT – *Dimitris Tsoukalos*
- DATA SPECIALIST – *Vacant*

Trainees
Victor der Weduwen (NLD)
Juliette Lo (FRA)

Stokes Fellow
(MSIAC Funded Training Fellowship)
Dr Georgios Zografakis (UK, GRC)

Knowledge & Access to Community of Technical Experts Across our Member Nations

Strategic Planning

Strategic Context

Budgetary Constraints
Readiness
Interoperability
Smart Defense

Strategic Drivers

Competing Operational and Safety Requirements
Increased Demand for Accurate and Flexible Munition Risk Assessment
Downward Trend in Energetic Materials Munitions Technical Expertise
Increased Cost and Complexity of Munitions
Increased Exposure of Munitions to Challenging Environmental Conditions

Strategic Planning

Work Elements

Products and Services for the Technical Community

MSIAC Munitions Safety Information Analysis Center
Supporting Member Nations in the Enhancement of their Munitions Life Cycle Safety

January 2021

MSIAC
2021 WORK PLAN

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Highlights

- After the Covid period (2020 – 2021), MSIAC has been busy catching up with the munitions safety community:
  - We organised 7 in-person country visits: UK, Canada, USA, France, Poland, Norway and Australia
  - We attended and/or contributed to 10 international conferences and meetings: UK MESF, Fulmination, IMEMG IM Day, APTS, Workshop on Pyrotechnic Combustion Mechanisms, ICT, International Armament Conference, IMEMTS, PARARI
  - We organised 4 in-person sessions of our now well-known AASTP-1/5 courses, in Wroclaw, Versailles, UK and Belgium
  - We supervised 2 student interns and 1 Stokes Fellow
  - We organised 4 technical meetings on issues with HD 1.3, HERO, and EM Qualification (x 2)

Highlights (cont'd)

- We continued to support the NATO CASG AC/326 main group and subgroup meetings
- We received 50 technical questions (as of Sep 2022) … but only answered to 33, apologies…
- And in the mean time, we managed to publish 5 new MSIAC limited reports on the following topics:
  - L-285 - MSIAC Technical Questions Annual Summary Report 2021
  - L-284 - Critical Diameter and Shaped Charge Jet Impact
  - L-283 - Recent Vulnerability Events due to Non-IM Munitions
  - L-281 - Lifing Approaches and Ageing Algorithms
  - L-280 - Mixing Rules for Energetic Materials – Transport Properties

- But we still have a lot to do in the next future to promote insensitive munitions and safer energetic materials, now more than ever!

Future Priorities at MSIAC for 2023 and beyond

MSIAC Munitions Safety Information Analysis Center
Supporting Munitions Safety

- In addition to our routine activities…
  - Country visits, conferences, answer to technical questions, maintaining and populating our tools and databases, support to NATO AC/326 committees,…
- …we will focus on the new following topics:
  - Organization of a workshop on “Mutual Assurance / Recognition and Novel S3 Approaches”
  - Investigation on the use of flow synthesis
  - Review of surrogate materials and their applications
  - Comparison of cost benefit tools
  - Effect of ageing on energetic materials and munitions

Conclusion

- MSIAC continues to provide support on Insensitive Munitions and Munitions Safety
- Policy remains an active area for MSIAC with support provided to AC/326 to facilitate review of munition safety standards
- Workshops and answer to technical questions continue to be of key importance to help advance munitions safety efforts
- MSIAC has an exciting programme of work for 2023 and beyond, and we are looking forward to tackle it!
- For more information, visit our website: www.msiac.nato.int or follow us on LinkedIn: https://www.linkedin.com/company/81572314/

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Supporting Munitions Safety

Review of IM policies across the nations

Insensitive Munitions & Energetic Materials Technology Symposium
18th – 20th October 2022 - Indianapolis, IN, USA

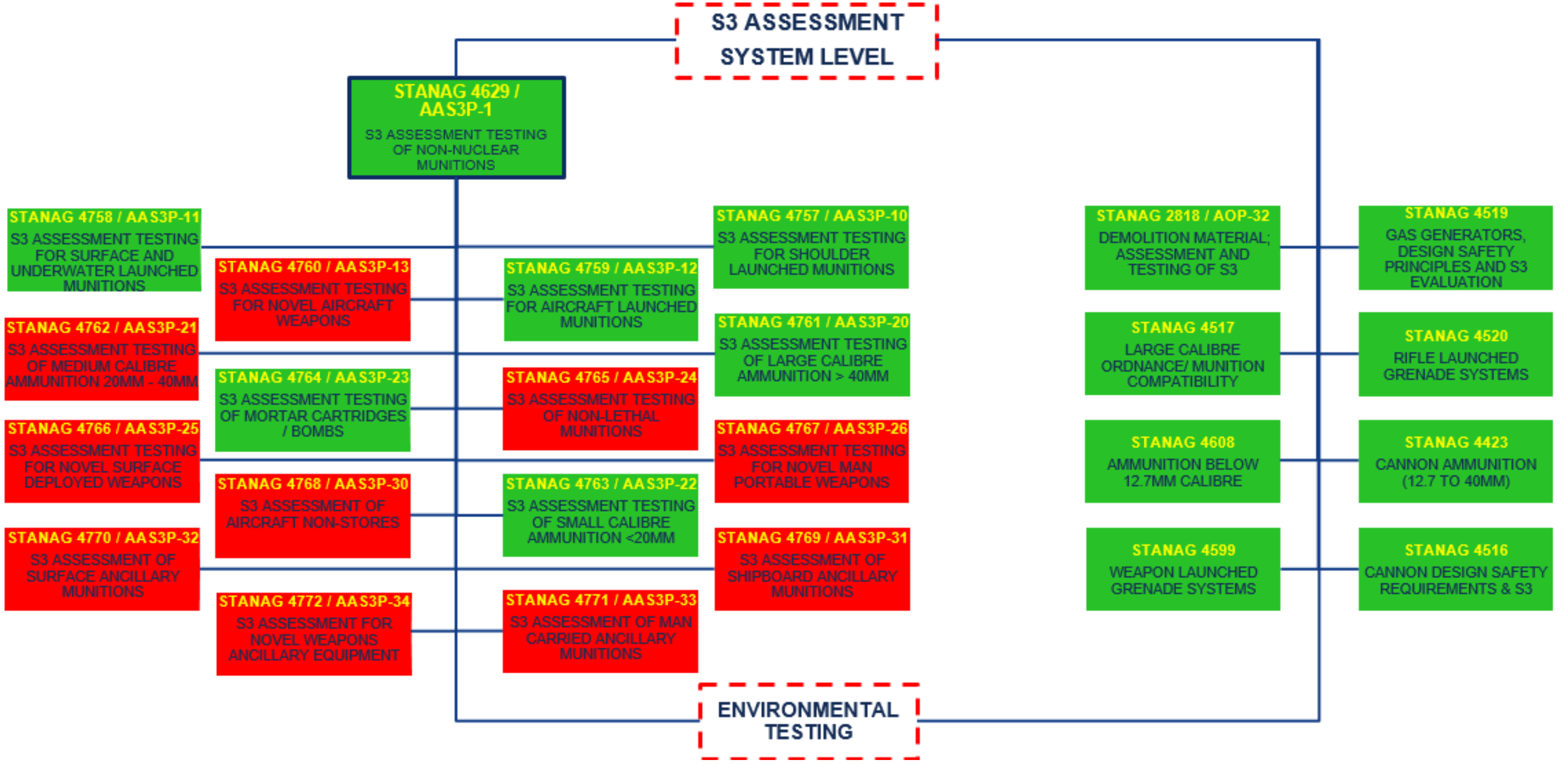
Christelle Collet
TSO Propulsion Technology
c.collet@msiac.nato.int

Introduction

- The last time MSIAC had analysed the international and national IM policies was in the early 2000s.
- Since then, no such review has been conducted → it is thus appropriate to review the IM policies of the nations.
- To do so, MSIAC searched its database of documents and surveyed its member nations in order to analyse the most recent versions of international and national IM policies.
- A limited report gathers the full output of this activity: L-290 (limited to MSIAC member nations – under internal review).

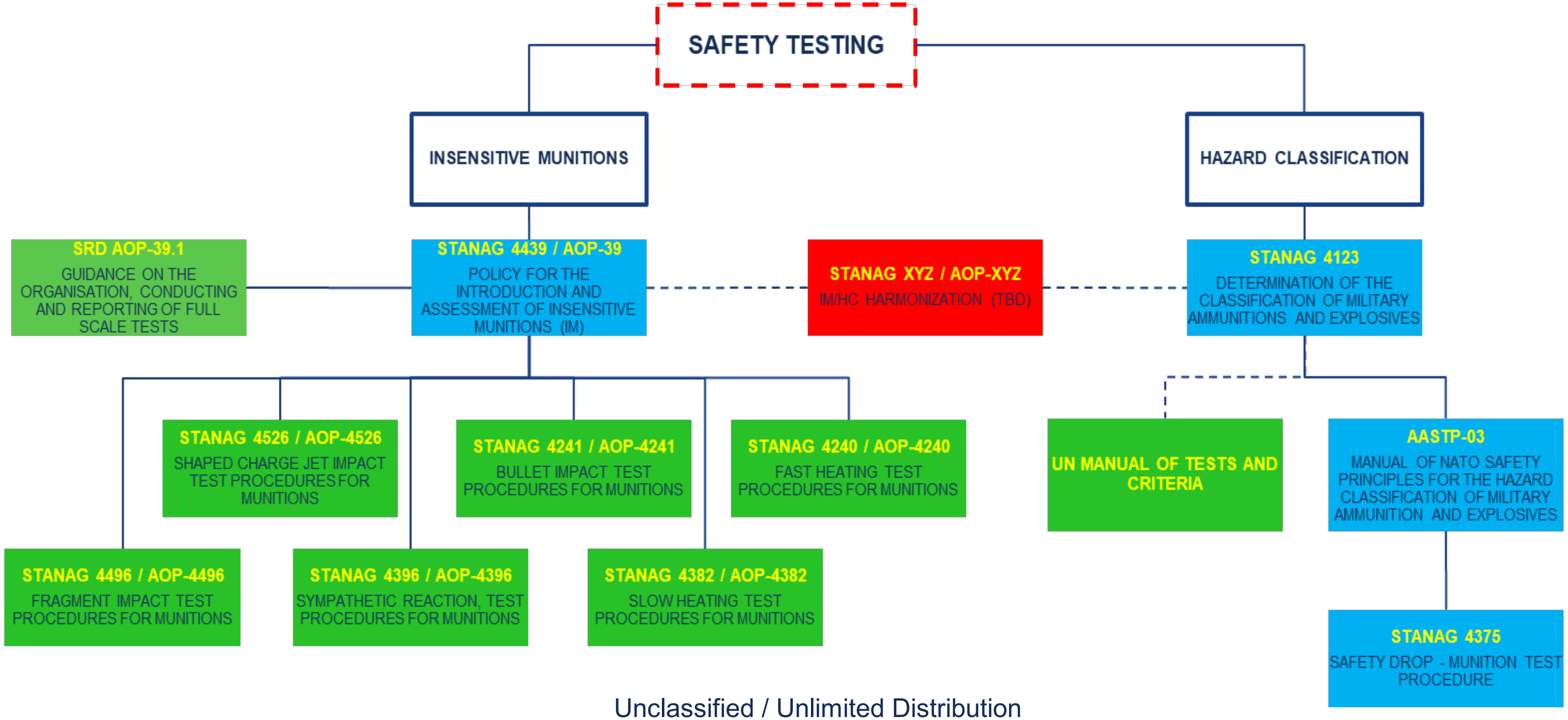
Overview of NATO Standards on S3

- These standards help ensure that sufficient and appropriate evidence is collected to allow prediction of the amount of environmental stress a munition should be able to withstand without degrading to an unsafe condition.



Overview of NATO Standards on Safety Testing

- Safety testing considers extreme but credible threats to munitions from accidents or enemy action, and seeks to quantify their response to these threats.
- Unlike S3 assessment testing, a reaction of the munition to these tests is, in most cases, expected.



IM Policy in the Nations - AUS

- Documents Examined
  - DEFLOGMAN Part 2 Volume 9 Chapter 4 “Insensitive Munitions”, version 2012
  - DEOP 102 - Part 2 Chapter 6 “Hazard and Threat Identification”, version 2021

- Specifics
  - Australia is currently in the process of cancelling their existing IM Policy in preference for the recently published content of DEOP 102 as the existing policy is not consistent with AUS legislation
  - IM assessment is a mandatory requirement and is part of S3 assessment
  - Use of the So Far As is Reasonably Practicable (SFARP) principle

IM Policy in the Nations - CAN

- Documents Examined

  - DAOD 3002-2, “Insensitive Munitions”, versions 2008 and 2017
  - DAOD 3002-1, “Certification of Ammunition and Explosives”, version 2017

- Specifics
  - The 2017 version of DAOD 3002-2 includes explicit mention of risk management in case of non IM-compliance
  - It also refers to DAOD 3002-1 which is the top-level document governing S3

- Exemptions from IM assessment

  - Ammunition or explosives in use prior to 2004 and scheduled for replacement prior to 2020
  - Ammunition and explosives in HD 1.4

IM Policy in the Nations - FIN

- Documents Examined
    - PEHOS PAK, 10:01 – Insensitive Munition Policy (2005)

- Specificities
    - "*The Finnish Defence Forces is committed to introduce into service munitions which are as insensitive as reasonably practicable and fulfill the requirements for performance. The course of action is in line with the principles in STANAG 4439*"
    - IM assessment is interlinked with S3 qualification programs
- Exemptions from IM assessment
    - Legacy munitions already procured
    - Ammunition and explosives substances assigned to HD 1.4

IM Policy in the Nations - FRA

- Documents Examined
  - MoD IPE Instructions #211893 (2011), #1184, #1187 and #1190

- Specifics
  - The overarching French IM policy is detailed in the IPE instruction #211893
  - France uses the term “MURAT” (“MUnition à Risques ATténués”) for IM
  - The detailed procedure for assigning a MURAT label is available in the IPE Instruction #1184
  - France uses 3 levels of MURAT: MURAT 1*, 2*, 3*.
  - France is now considering to take into account the benefits of MURAT in HD for storage
- Exemptions from IM assessment

  - Munitions containing small quantities of active materials and not representing serious hazards in the logistic phase (typically munitions that are assigned HD 1.4)

IM Policy in the Nations - DEU

- Documents Examined

  - A-2070/3 “Munitionstechnische Sicherheit der Bundeswehr und Schießsicherheit der Bundeswehr”
  - A-425/1 “Standardisierung”

- Specifics
  - The German IM policy is globally aligned on STANAG 4439 / AOP-39
  - Deviations only possible when experience suggests or the needs of a project dictate it

- Exemptions from IM Assessment
  - SAAs with a caliber of less than 12.7 mm are usually not tested

IM Policy in the Nations - ITA

- Documents Examined

  - Guidelines for the development, assessment and checking of Insensitive Munitions (IM); Linee Guida Nazionali per lo Sviluppo, la valutazione e la verifica delle munizioni a rischiio attenuato MURAT, 2000

- Specifics
  - Heavy Fragment Impact (HFI) is part of the required tests for IM assessment
  - Like France, Italy defined three levels of “IMness” (NB: with different passing criteria as France): IM$^{\Phi}$, IM$^{\Phi\Phi}$, and IM$^{\Phi\Phi\Phi}$
  - The IM levels are associated with expected benefits in storage
  - IM and S3 programs are interconnected with the use of IM test results to provide direct inputs to S3 programs

IM Policy in the Nations - NLD

- Documents Examined
  - Netherlands IM Overview by van Gool and Bouma, 1999
- Specifics
  - So far, there is no national IM policy in place in the Netherlands
  - The conduct of specific IM tests for each munition type are part of the S3 evaluation which is prescribed in nine national Generic S3 Programs
  - The aim of the future Dutch IM policy is to prescribe relevant IM treats that will be standard for certain article groups but may be adjusted by a threat hazard approach

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IM Policy in the Nations - NOR

- Documents Examined

  - “Insensitive Munition Policy – Norway” by Lt Col Morten Kjellvang, 2017

- Specifics
  - “*All procurement of ammunition must include a statement of compliance with the IM-requirements goals specified in STANAG 4439 and AOP-39*”
  - IM assessment is considered to be part of the qualification process

- Exemptions from IM assessment
  - Articles in HD 1.1 when operational requirements make use of IM inappropriate, or no IM solutions exists.
  - Articles in HD 1.2, 1.3 and 1.4 where initiation of more than one ammunition article represents a very low probability, and where each single ammunition article does not represent hazard consequences to personnel or materiel

IM Policy in the Nations - UK

- Documents Examined
  - DSA-03.OME (formerly JSP 520) Part 1 Chapter 11 on “Insensitive Munitions”, 2021

- Specifics
  - The key principle in the UK IM policy is that the sensitivity of the munition must be “As Low As Reasonable Practicable” or ALARP
  - The UK IM policy applies on all new munition acquisitions. For already in-service munitions, they are “*kept under review to identify insertion opportunities (…) to achieve full or improved levels of IM compliance*.”
  - The munitions are subjected to IM tests in accordance with a THA

- Exemptions from IM assessment
  - Where the stimuli significantly overmatches the credible worst case response of the system under test (e.g. shaped charge jet would be assessed as overmatching a pyrotechnic smoke store)

IM Policy in the Nations - USA

- Documents Examined

  - US Code, Title 10, Chapter 141, Section 2389 December 2001
  - DoD Directive 5000.01, The Defense Acquisition System, 2020
  - MIL-STD-2105E, 2022

- Specifics
  - A THA is systematically conducted to establish which standard IM stimuli are appropriate or applicable. This results in an IM test plan which can be standard or tailored
  - Wherever possible, a combined IM/HC test plan should be developed and conducted
  - Acceptance of alternative ways to replace full-scale assessment tests (e.g. M&S, relevant small scale tests conducted in the frame of EMQ)

- Exemptions from IM assessment

  - SAAs that are currently in the inventory, and all future similar technology SAAs, with no incendiary or high explosive projectiles as per OUSD Memo dated 3 Jul 2001
  - CAD/PAD as per OUSD Memo dated 10 Oct 2003

IM Policy in the Nations - Summary

- The well-known “IMEMG card” provides a table of the IM passing criteria in use in NATO and in a selection of nations

REPRESENTATION OF THE IM REQUIREMENTS 2021

THREAT	TEST PROCEDURES: Stimuli	TEST PROCEDURES: STANAG	NATO (STANAG 4439): IM requirements	NATO: AASTP-1 SsD 1.2.3	UK: JSP 520	GERMANY: Fü S IV 3	ITALY (DG-AT IM Guidelines 2000): Φ	ITALY: ΦΦ	ITALY: ΦΦΦ	FRANCE (INSTRUCTION N° 211893 July 21st, 2011): ★	FRANCE: ★★	FRANCE: ★★★[4]	USA: MIL-STD-2105D
Magazine / store fire or aircraft / vehicle fuel fire	FH	4240	V	V	V	V	V	V	V	IV[2]	V[3]	V[3]	V
Fire in adjacent magazine, store or vehicle	SH	4382	V	V	V	V	V	V	V	III	V	V	V
Small arms attack	BI	4241	V	V	V	V	V	V	V	III	V	V	V
Most severe reaction of same munition in magazine, store, aircraft or vehicle	SR	4396	III	III	III	III	III	III	III	III	III	III	III
Fragmenting munitions attack	FI	4496	V		V	V		I[1]	V		V	V	V
	FI Heavy Fragment	4496						I[1]	V		III	III	
Shaped charge weapon attack	SCJI	4526	III		III	III		I[1]	III		III	III	III

1 Type I or more, as per THA 2 Without propulsion 3 Only after five minutes 4 All EM compliant with UN Orange Book Test Series 7

STANAG 4439 "Policy for introduction and assessment of Insensitive Munitions" • AOP 39 "Guidance on the Assessment and Development of Insensitive Munitions"

Any variation in the threats shall be justified through an approved munition Threat Hazard Analysis (THA) cf. STANAG 4439 para.10. The IM Signature is assessed for any particular configuration of a munition during its life cycle.

IM Policy in the Nations - Summary

- Three main approaches exist:
  - Target full IM compliance as per STANAG 4439 / AOP-39 criteria, and authorize waivers in case of non IM-compliance. Such IM waivers may have a limited time validity.
  - Use of a progressive approach, with the identification of different IM levels and without systematically conducting a THA process. Only France and Italy follow this approach.
  - Use of a tailored approach where the requirement for IM testing / assessment and the level that must be achieved is bespoke to each individual munition and proportionate to the risk, as per the THA.
    - The USA follows this approach where the IM test plan is exclusively based on the approved THA, with a limited use of IM waivers.
    - Australia and the UK also follow this approach by applying the “SFARP” or “ALARP” risk principle, upon appropriate justification but with no use of IM waivers.

Conclusions

- Most MSIAC nations have implemented a national IM policy. They are based on STANAG 4439 / AOP-39
- Three main approaches have been identified: a full-compliancy approach possibly associated to the use of IM waivers, a progressive approach with the use of IM levels, and the SFARP/ALARP approach
- Differences exist in the relationship between IM and S3 assessment
- Exemptions from IM assessment are generally applied to SAA and, to a lesser extent, to pyrotechnic systems and other articles containing small quantities of primary explosives/pyrotechnics

Any Questions?

Improved Continuous Microfluidic Synthesis of Energetic Compounds

Christina Christensen, PhD (Presenter)
Melissa Mileham, PhD (Co-Author)

Insensitive Munitions & Energetic Materials Technology Symposium
October 18, 2022

NORTHROP GRUMMAN

Chemical Synthesis Methods

Batch Operation	Continuous Operation	Microfluidic Operation
High flexibility; preferred for multi-product/purpose operation, useful for a large range of reaction scale	Low flexibility; designed for a single process, not practical for development-scale production	Mid flexibility; lab and pilot scale reactor modifications are simple, reactors cannot handle all types of reaction media, useful for development to pilot plant scale
Low capital cost	High capital cost	Low capital cost
High consequence hazard; Large volumes of energetic materials being processed	High consequence hazard; large volumes of energetic materials being processed	**Low consequence hazard; µL to mL volumes of energetic materials being processed**
Reasonable scale-up from lab scale	Reasonable scale-up from lab scale – involves engineering/modeling	**Simple scale-up from lab scale**
Not suitable for unattended operation → labor intensive → high operating cost	Simple conversion to unattended operations → low operating cost	**Simple conversion to unattended operations → low operating cost**

NORTHROP GRUMMAN

What Types of Reactions are Good Candidates for Flow Synthesis?

Reaction Characteristics	Possible Benefit of Flow Synthesis
Pressures exceed reactor capability? Temperatures exceed reactor capability? Chemistry not compatible with reactor? Equilibrium reactions?	Likely no benefit and/or not possible
Solid precipitates? Very slow kinetics? Solid reactants or catalysts? Gaseous reactants? Homogeneous catalysts?	Possible benefits, significant technical challenges
Gas evolution in reaction? Reaction benefits from high pressure? Unstable intermediates? Fast kinetics? Highly toxic reactants or byproducts? Reactions requires or benefits from low temperature (< -10 °C)? Rapid mixing required? Highly exothermic? Over-reaction possible? Requires precise stoichiometric control?	Likely to benefit

Calabrese, G. S.; Pissavini, S. *AIChE Journal,* **2011**, *57(4)*, 828-834.

NORTHROP GRUMMAN

Advantages Of Microfluidic Reactors

- Efficient heat and mass transfer
  - Highly exothermic reactions are common in energetic synthesis (nitration, oxidation, acid neutralizations, etc.). If exotherms are not properly managed, run-away reactions can occur.
  - Allow for previously “forbidden” reactions because of high level of control (high temp/pressure, concentrated products, etc.)
  - Provides non-physical mixing of reactants
- Low reactive volume (microliters to milliliters of solution)
  - Low consequence hazard
- Easy scale-up, high versatility
  - Very high throughput at lab scale (20 conditions/day)
  - Scale is increased by lengthening reactor path or including parallel reactors
  - Modular equipment for easy customization
- Low labor costs and capital depreciation
- Continuous process feedback, consistency in production
- Multiple suppliers of off-the-shelf continuous flow reactors available*
  - *Chemtrix full work stations shown as examples

Chemtrix Lab-scale Work Station

Chemtrix Kilo-scale Work Station

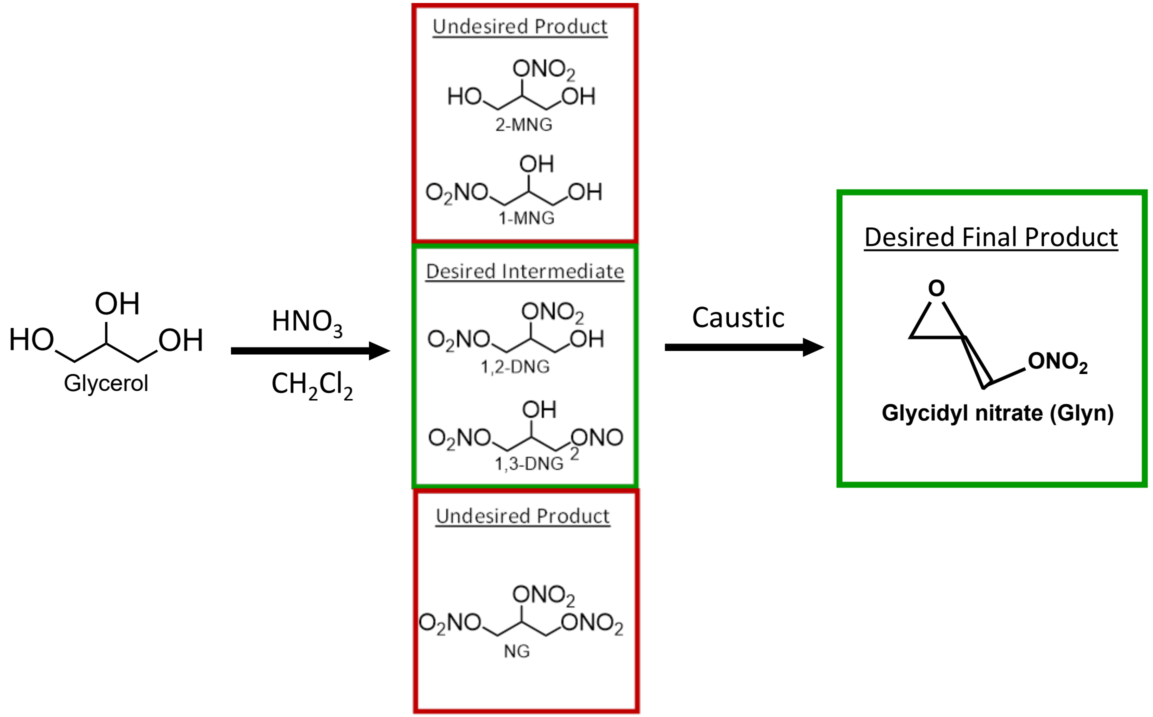
https://www.chemtrix.com

Test Case – Synthesis of Glycidyl Nitrate (GLYN)

- GLYN is the precursor for poly(glycidyl nitrate) PGN, an energetic binder of significant interest for insensitive munitions

- Highsmith method: conversion of glycerol to glycidyl nitrate (theoretically least expensive synthesis route)

- Challenges:
  - Two step process, first low pH nitration then high pH caustic ring closure (technical and compatibility challenges)
  - Highly exothermic process (including glycerol nitration and acid neutralization)
  - Targeting intermediate nitrated product (requires precise controls to achieve reasonable yield)
    - Hazardous biproduct (nitroglycerin) requires additional care to balance to both maximize target yield while minimizing hazards



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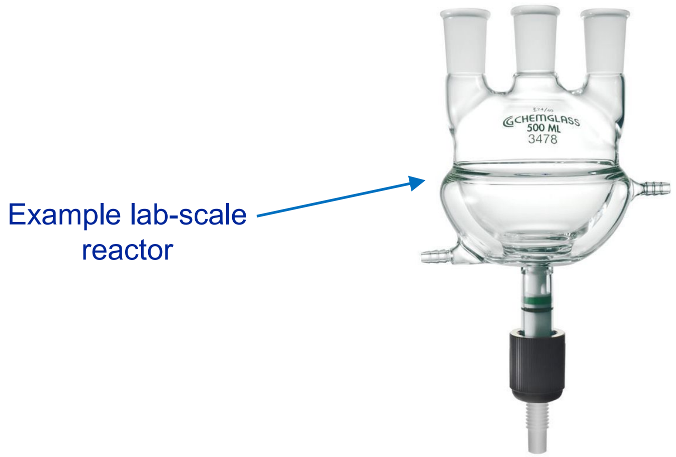
GLYN Synthesis Methods

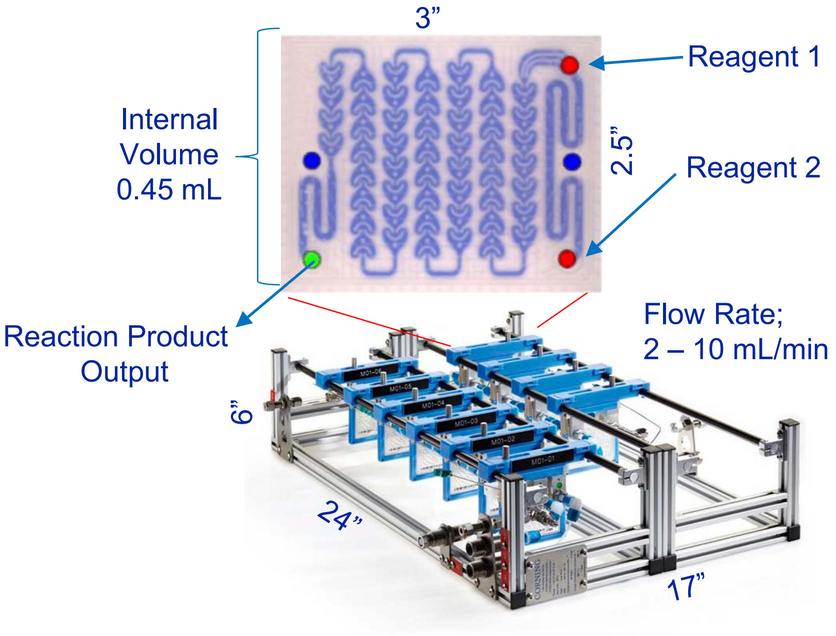
Legacy GLYN Synthesis Process

Attended batch reactions conducted by R&D scientists using large scale laboratory glassware (5 & 22L Reactor).



New GLYN Synthesis Process

Remote microfluidic continuous flow reactor. Example of Dow Corning AFR shown below.



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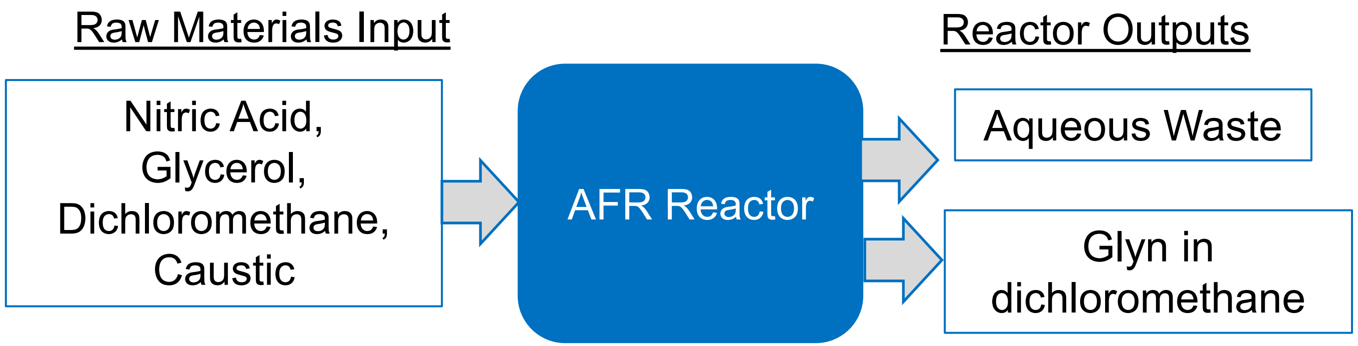
Continuous Synthesis of GLYN

High Level Process Overview - Target



Safety Advantages

- Small reactive volume (<20mL)
- Unattended process
- Greatly improved heat transfer compared to batch reactions
- No mechanical stirring
- Direct isolation of reaction product into appropriate storage vessel/locker

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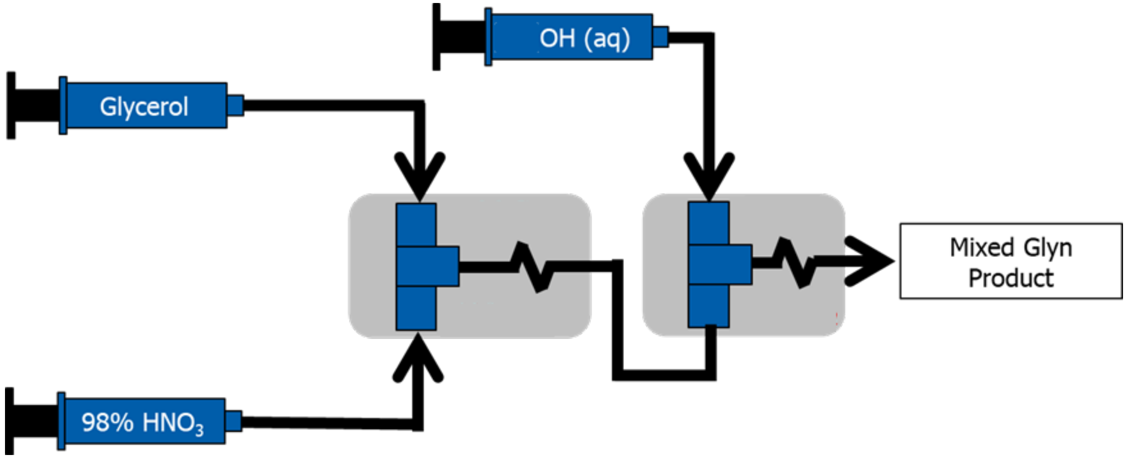
Simple Prototype Reactor Design

- Two-step microfluidic synthesis of Glyn demonstrated at small scale using reactor built in-house
  - Reactor operated at low-flow
  - Microfluidic-sized flow channels
  - Patented Process
- Best conditions:
  - Conversion rate similar to those seen in batch reactions

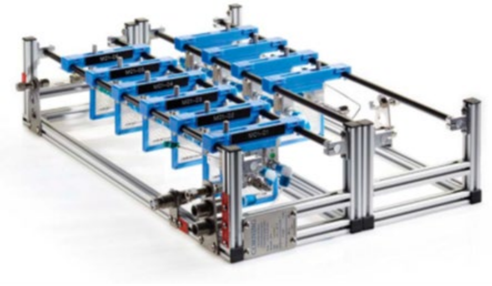


- Takeaways:
  - Reactor composed of all PTFE/PFA wetted parts could withstand both nitration and caustic conditions
  - Long nitration retention times and high acid concentrations are required to optimize DNG production
  - Neutralization of acid during caustic ring closure prone to precipitating salts – possible safety hazard
  - Batch extraction of Glyn using dichloromethane (DCM) required in work-up after sample collection

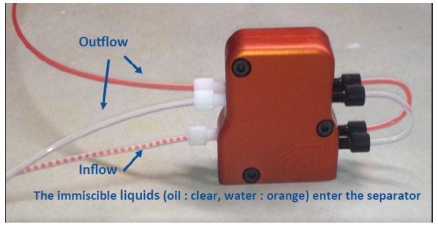
NORTHROP GRUMMAN

Next Steps – Improving Process Design

- Simple T-joint/tubing reactor → DOW-Corning AFR reactor
  - Advective mixers in plates decrease required residence time
  - Fully jacketed with high coolant flow for more efficient heat transfer
  - Modular design allows for quick and easy changes to reactor configuration
  - Microfluidic flow channels
  - Scaled-up versions available



- Addition of liquid-liquid in-line separators
  - In-line extraction of products into dichloromethane removes batch work-up step after product collection
  - Small internal volume
  - Scaled-up versions available

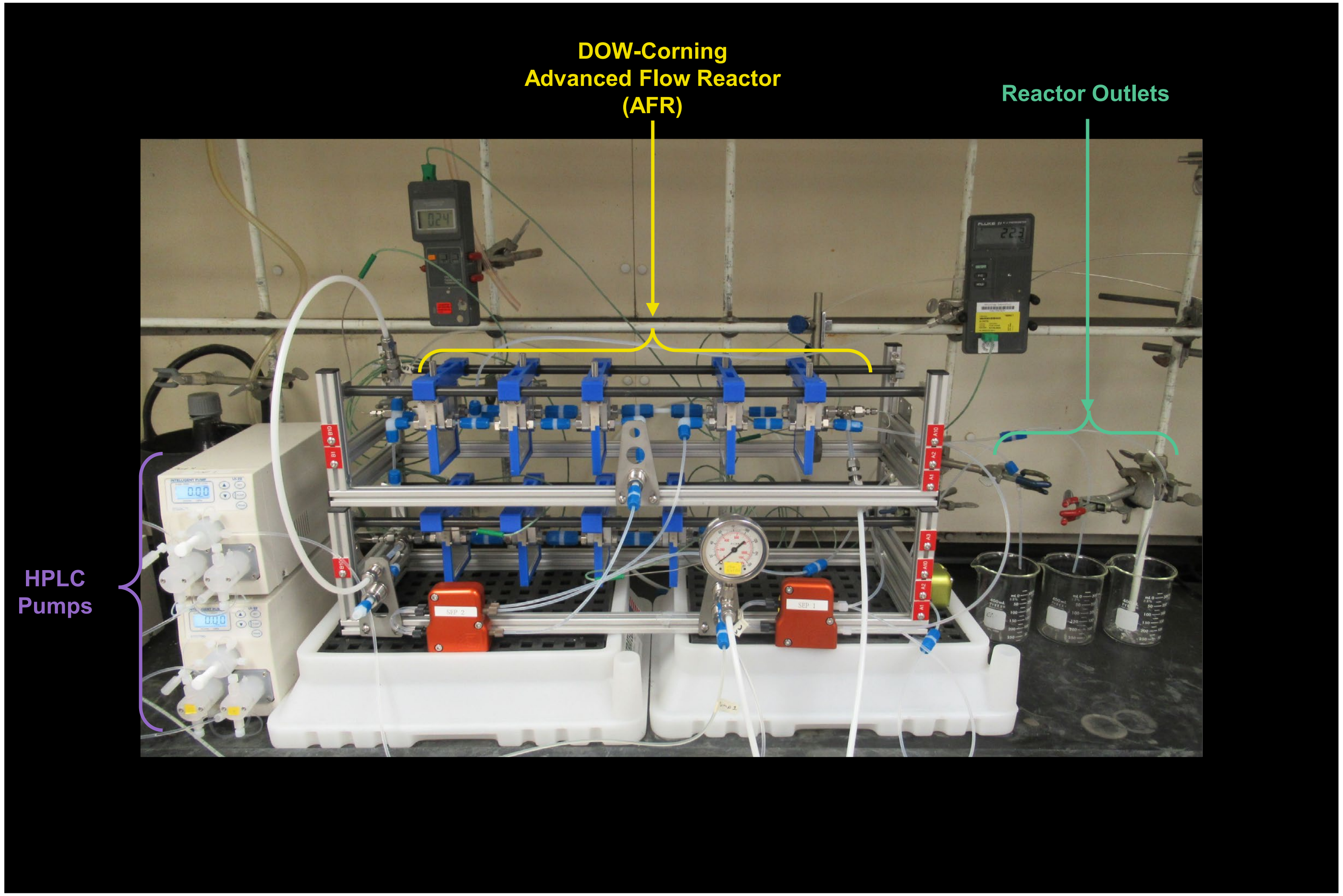


- Syringe pumps → continuous operation peristaltic pumps
  - Can be remotely operated and monitored, auto shut-off at set pressure

- Simple temperature bath → High-flow, fully enclosed heat exchange module with precise temperature control

- Addition of in-line flow sensors
  - Chemically resistant wetted parts, uses non-invasive microthermal sensing

Example Reactor Setup



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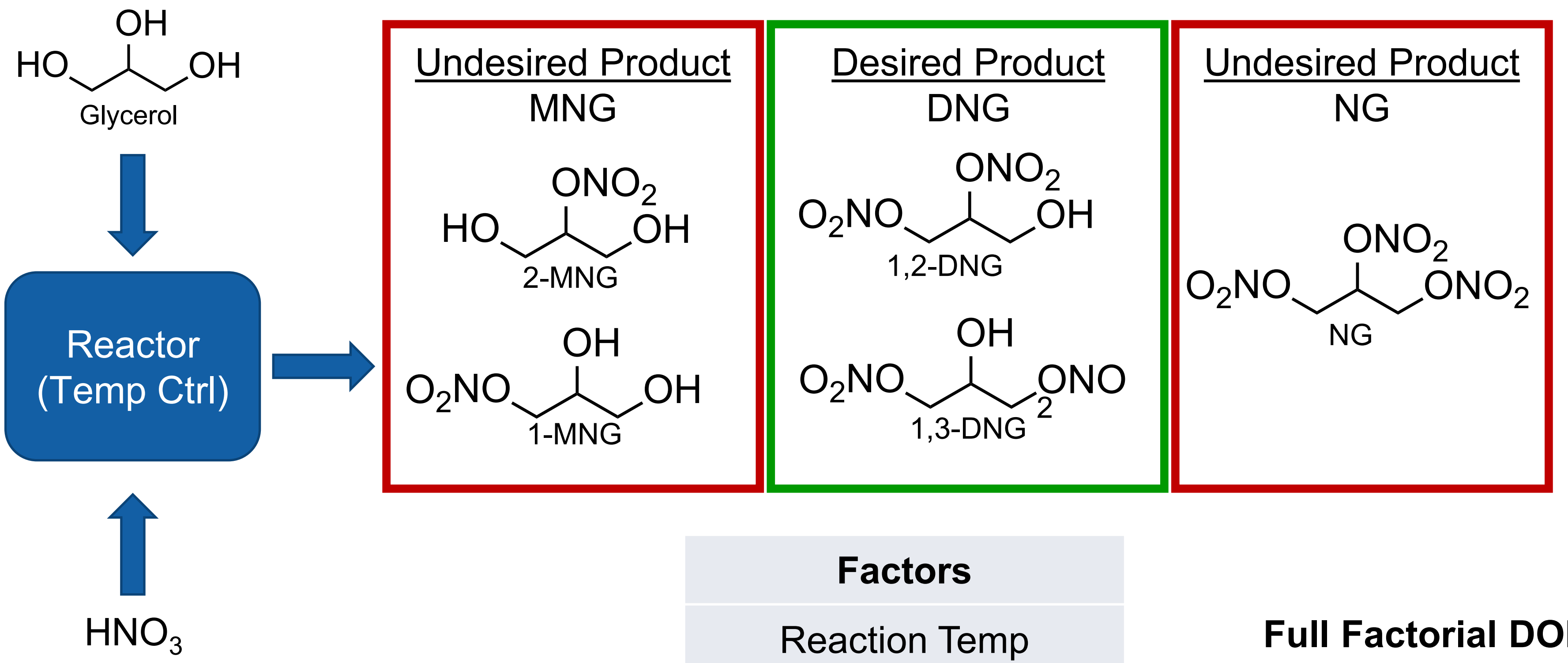
Nitration Characterization – Variables



Factors
Reaction Temp
HNO_3 to Glycerol Ratio
Residence Time

Full Factorial DOE Tested
Low, Mid and High of Variables

How do the selected factors effect the concentrations of MNG, DNG, and NG?
The goal is to minimize MNG and NG while maximizing DNG.

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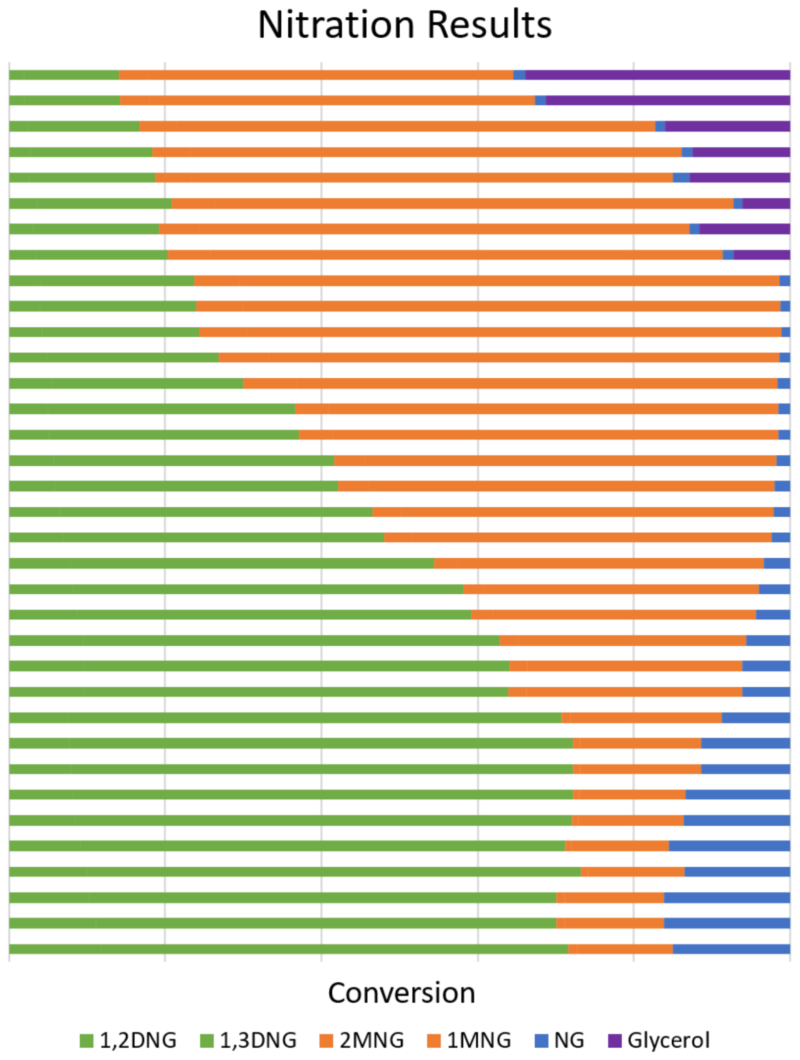
Nitration Characterization (1st Step) – Results

- **Demonstrated rapid optimization: 32 Conditions in only 2 days of testing**
- Maintained high conversion to DNG while minimizing NG side product
- Able to operate at high temperatures without fluctuations
- Short residence times (reduced more than 10X compared to in-house reactor)
- ANOVA (Analysis of Variance):
  - Acid ratio had by far the largest effect on glycerol nitration products, followed by temperature, with little to no effect of residence time in the region studied*
    - *Note that preliminary studies showed that a minimum residence time was required to see these effects

Sample	Temp	HNO_3/ Glycerol	Residence Time
1	Low	Low	Low
1B	Low	Low	Low
5	Low	Low	Mid
8	Low	Low	High
33	Low	Low	Low
14	Mid	Low	Mid
15	Mid	Low	Low
18	Mid	Low	Mid
21	Mid	Low	High
22	High	Low	Low
25	High	Low	Low
26	High	Low	Mid
30	High	Low	High
2	Low	Mid	Low
2B	Low	Mid	Low
3	Low	Mid	Mid
7	Low	Mid	Mid
11	Low	Mid	High
12	Mid	Mid	Low
17	Mid	Mid	Mid
19	Mid	Mid	High
24	High	Mid	Low
27	High	Mid	Mid
29	High	Mid	High
31	High	Mid	High
4	Low	High	Low
6	Low	High	Mid
9	Low	High	Mid
10	Low	High	High
13	Low	High	Low
16	Mid	High	Mid
20	Mid	High	High
23	High	High	Low
28	High	High	Mid
32	High	High	High



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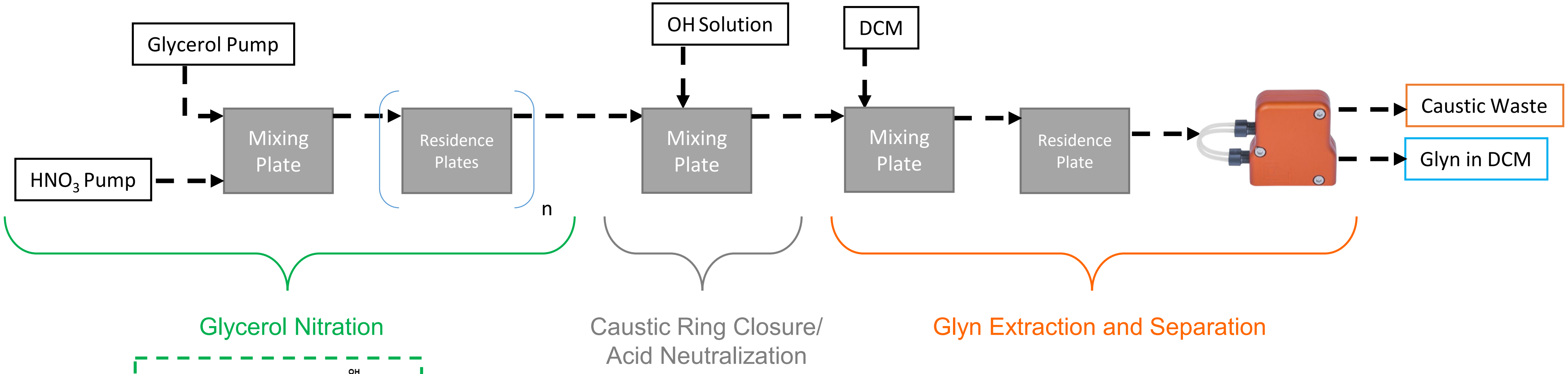
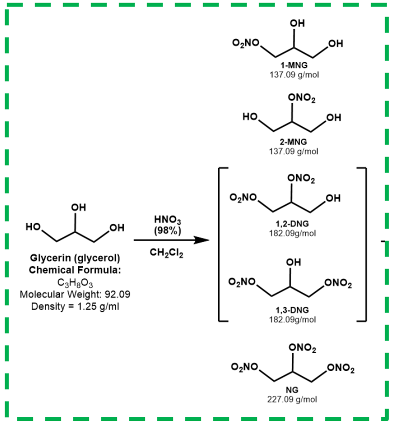
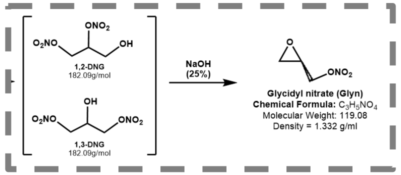
Reactor Configuration – Nitration + Ring Closure in Series

- Adding caustic treatment (ring closure) and DCM extraction/separation to AFR nitration configuration







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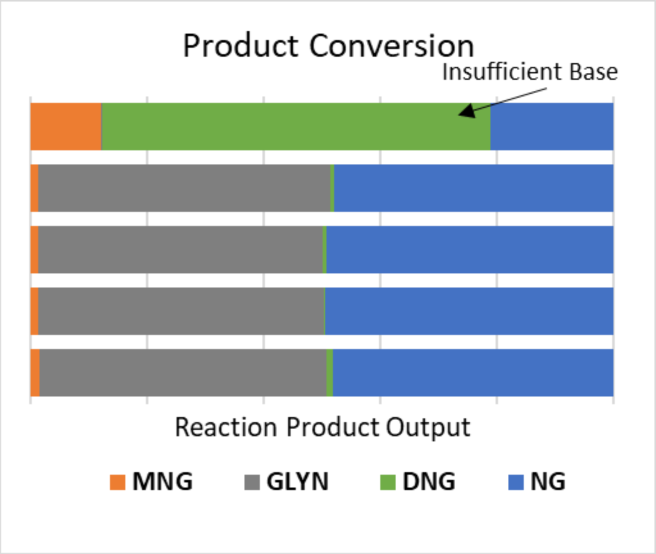
2-Step Characterization

- Low nitration flow, reactor flow near maximum
- Glyn isolated in DCM via in-line extraction
  - Low MNG/DNG contamination
- Synthesis and conversion rate lower than desired, NG content high



- Successfully synthesized and extracted Glyn in flow with low MNG/DNG contamination
- Low overall output, higher NG than desired

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Demonstration of GLYN Synthesis in Updated Configuration

- Improved reactor configuration tested (proprietary, patent in work)
- Best conditions yielded 3X higher than standard configuration
  - Only small variations in overall conversion and output in range studied
  - Greatly improved overall output, but did not significantly decrease NG (solution in work)
  - Side product contamination (can affect polymerization to PGN):
    - **No MNG detected, very small amounts of DNG in final product flow**

- Further optimization in progress
  - Expect to see higher overall yield and full conversion of DNG to GLYN
  - New reactor configuration expected to greatly decrease NG levels

- Demonstration of remote operation and larger-scale collection in progress

- Improved reactor configuration tripled production of GLYN

- Demonstrated clean output of GLYN with low levels of undernitrated product contamination

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Summary

- **Successfully designed and tested a microfluidic reactor with in-line purification and extraction system using commercially available flow modules**, including the DOW Corning Advanced Flow Reactor (AFR), continuous operation peristaltic pumps, in-line liquid-liquid phase separators and in-line flow meters
  - Configured so that pumps can flow sensors can be remotely operated and monitored
  - Currently waiting on delivery of additional hardware to remotely control flow pathways – will allow for full automation of reactor
  - No temperature fluctuations observed, clogging hazards managed, small overall volumes of nitrated products
- **Test case: GLYN Synthesis**
  - Nitration of glycerol to dinitroglycerine (DNG) was demonstrated at conversion rates comparable to batch synthesis at rates approaching kilo scale
  - Two-step/one-reactor nitration and ring closure in series, including separation of organic product stream from aqueous waste, was successful
    - **Demonstrated nearly 4X the production rate seen in original in-house reactor without extraction**
    - Further optimization in work with additional needed hardware, expect to double production rate

Demonstrated ability of modular microfluidic equipment to quickly change testing parameters and reactor configurations

Allows for rapid optimization of processes; precise control of temperature, residence time and reactant ratios allows for much greater tuning of reactions compared with traditional batch synthesis

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Contributors: Dr. Joe Scavuzzo, Dr. Lou Cannizzo

Funding: Northrop Grumman Internal Research and Development

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THE FUNDAMENTALS OF IM TESTING

IMEMTS 2022

JON TOREHEIM

BOFORS TEST CENTER

BOFORS TEST CENTER

Industry/Academia: Unclassified
Unclassified. Distribution Unlimited.

TIME = $$$

WHY?

POLICY: AOP-39

FAST HEATING: AOP-4240

SLOW HEATING: AOP-4382

SYMPATHETIC REACTION: AOP-4396

FRAGMENT IMPACT: AOP-4496

BULLET IMPACT: AOP-4241

SHAPED CHARGE JET: AOP-4526

SRD AOP-39.1

OK, BUT HOW TO CONDUCT THEM?

IT IS NOT

THE

METHOD

IT IS

A

METHOD

SUITABLE GENERIC TEST EQUIPMENT

A LARGE, FLAT AND UNOBSTRUCTED AREA

VIDEO CAMERAS

HIGH SPEED VIDEO CAMERAS

AIR BLAST PRESSURE GAUGES

DOPPLER RADAR

THERMOCOUPLES

WITNESS PLATES

WEATHER STATION

GPS SYSTEM

DATA ACQUISITION SYSTEMS

THE LOST SKETCHES

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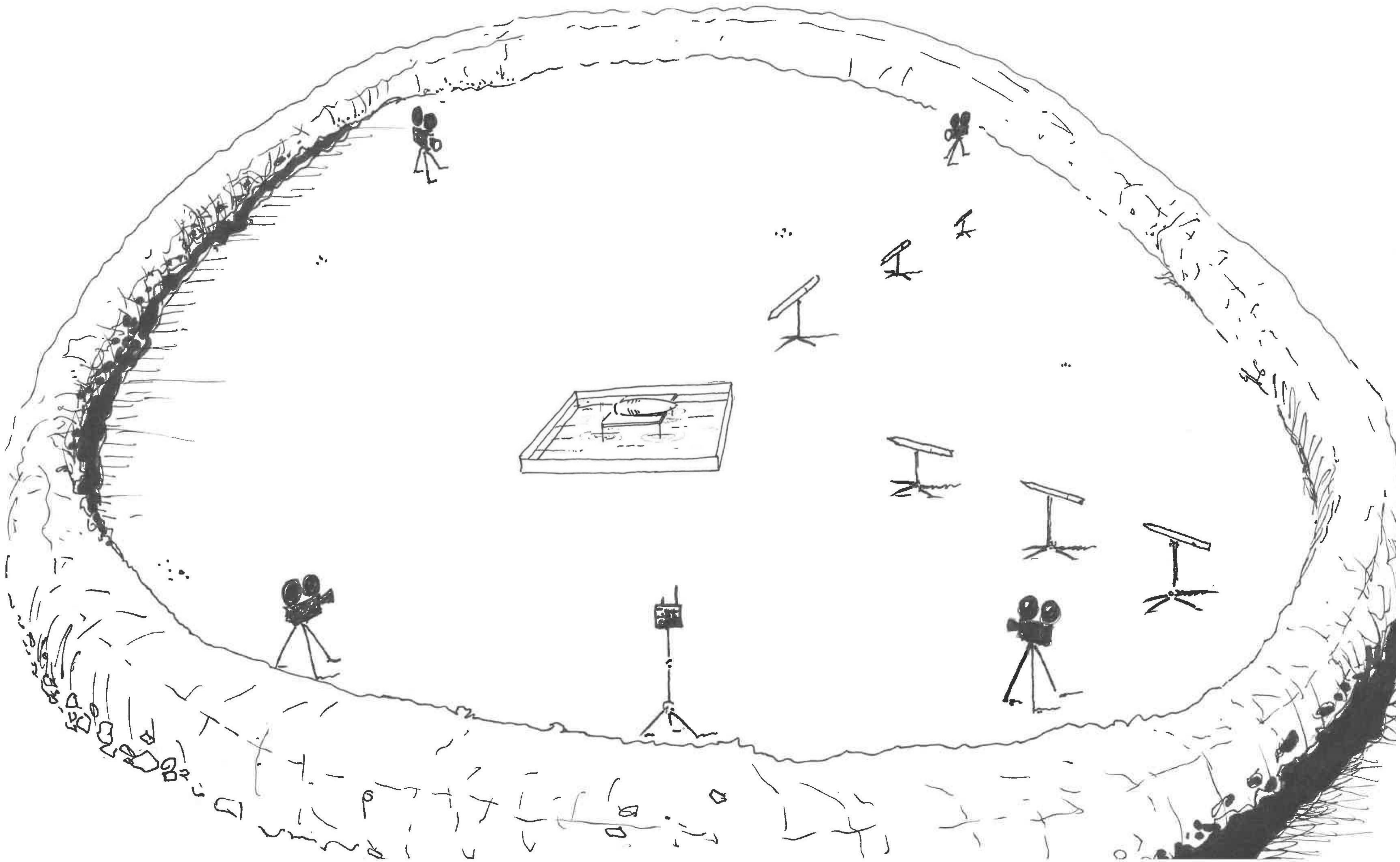
Industry/Academia: Unclassified
Unclassified. Distribution Unlimited.

TEST SETUP; FAST COOK-OFF



HEARTH

JET FUEL (AND WATER) OR PROPANE

STEEL TABLE

IGNITERS

THERMOCOUPLES

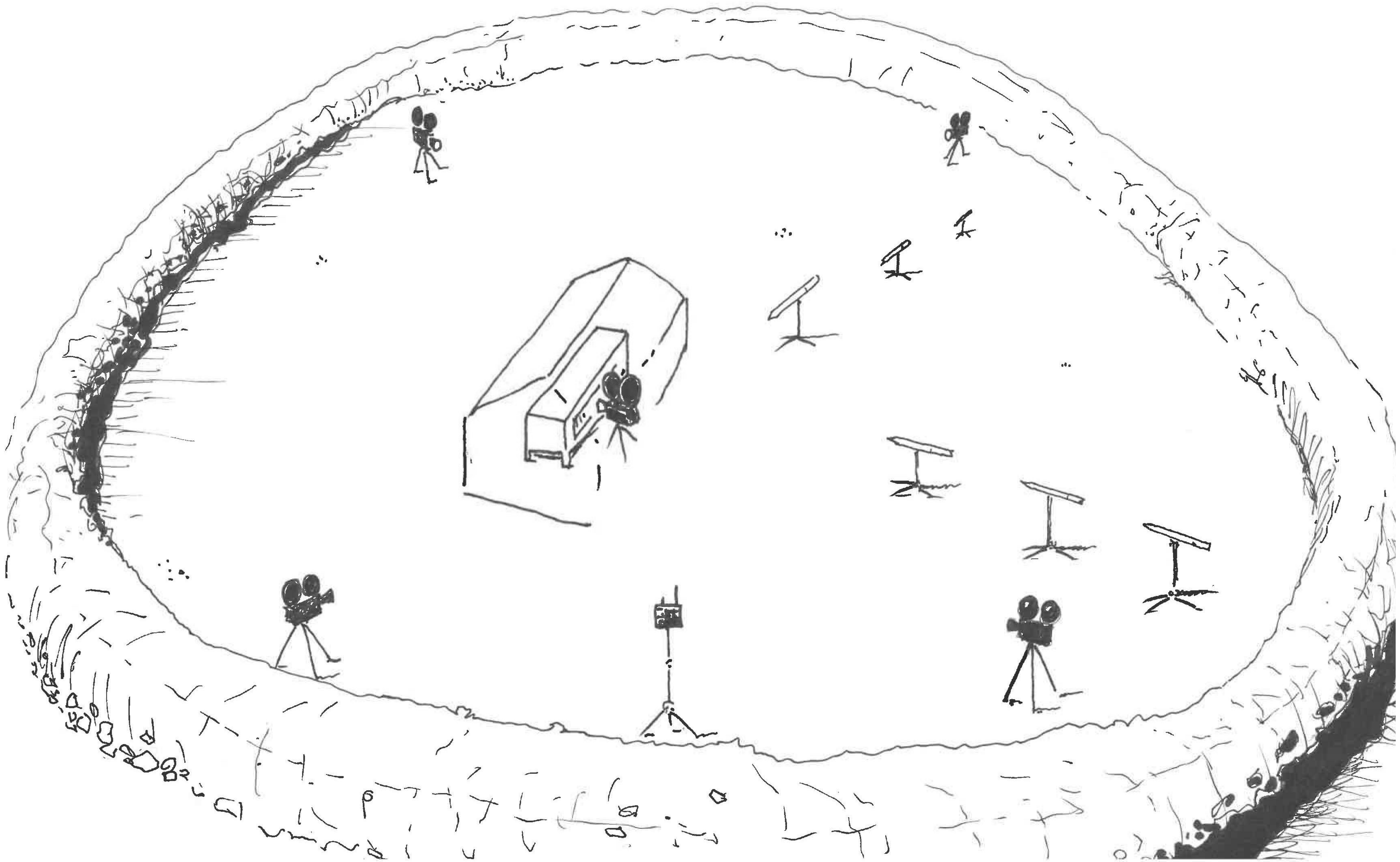
WEATHER STATION

VIDEO CAMERAS

AIR BLAST PRESSURE GAUGES

BOFORS TEST CENTER

TEST SETUP; SLOW COOK-OFF



OVEN

TENT

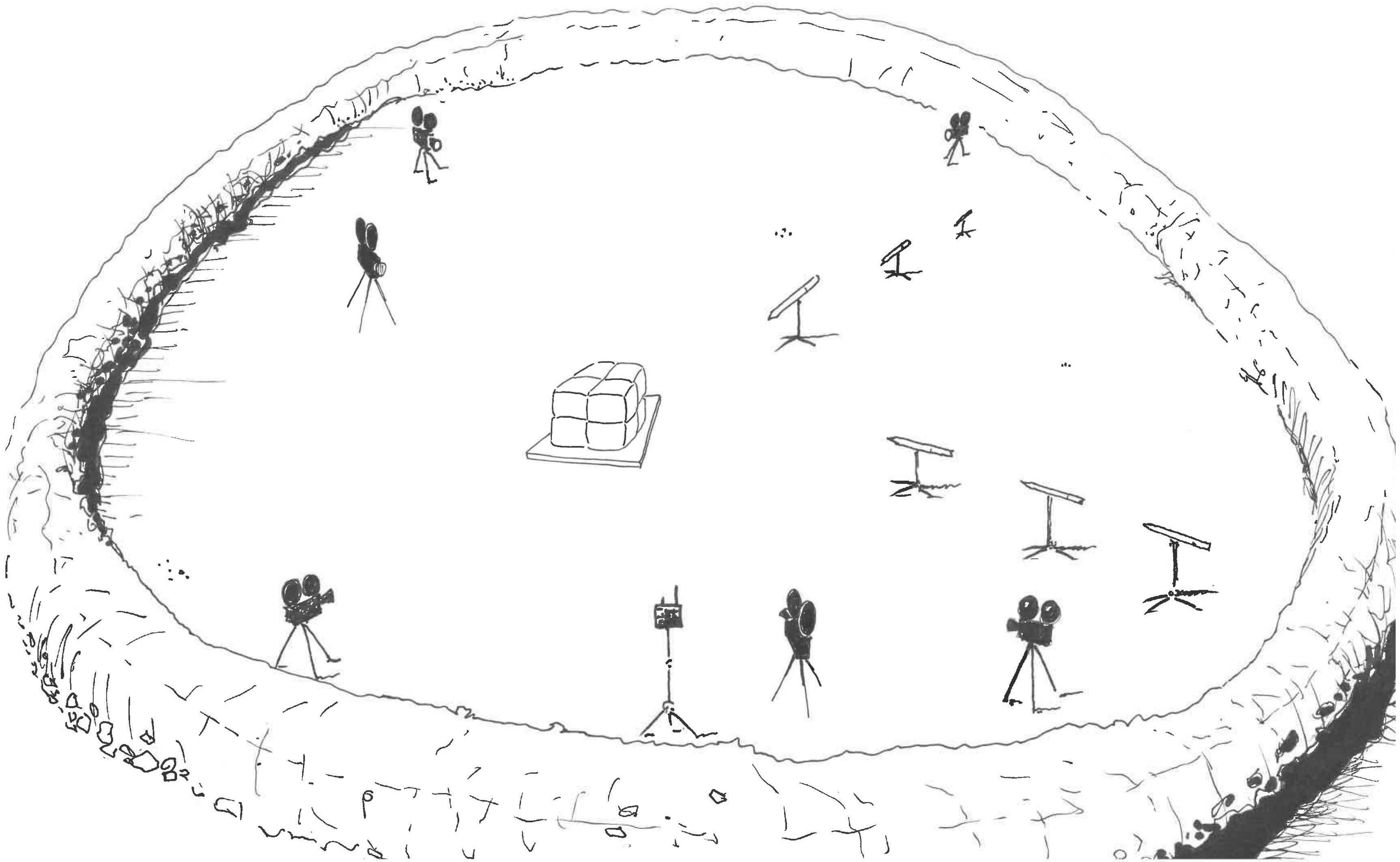
THERMOCOUPLES

VIDEO CAMERAS

(WEATHER STATION)

(AIR BLAST PRESSURE GAUGES)

TEST SETUP; SYMPATHETIC REACTION



WITNESS PLATE

HIGH SPEED VIDEO CAMERAS

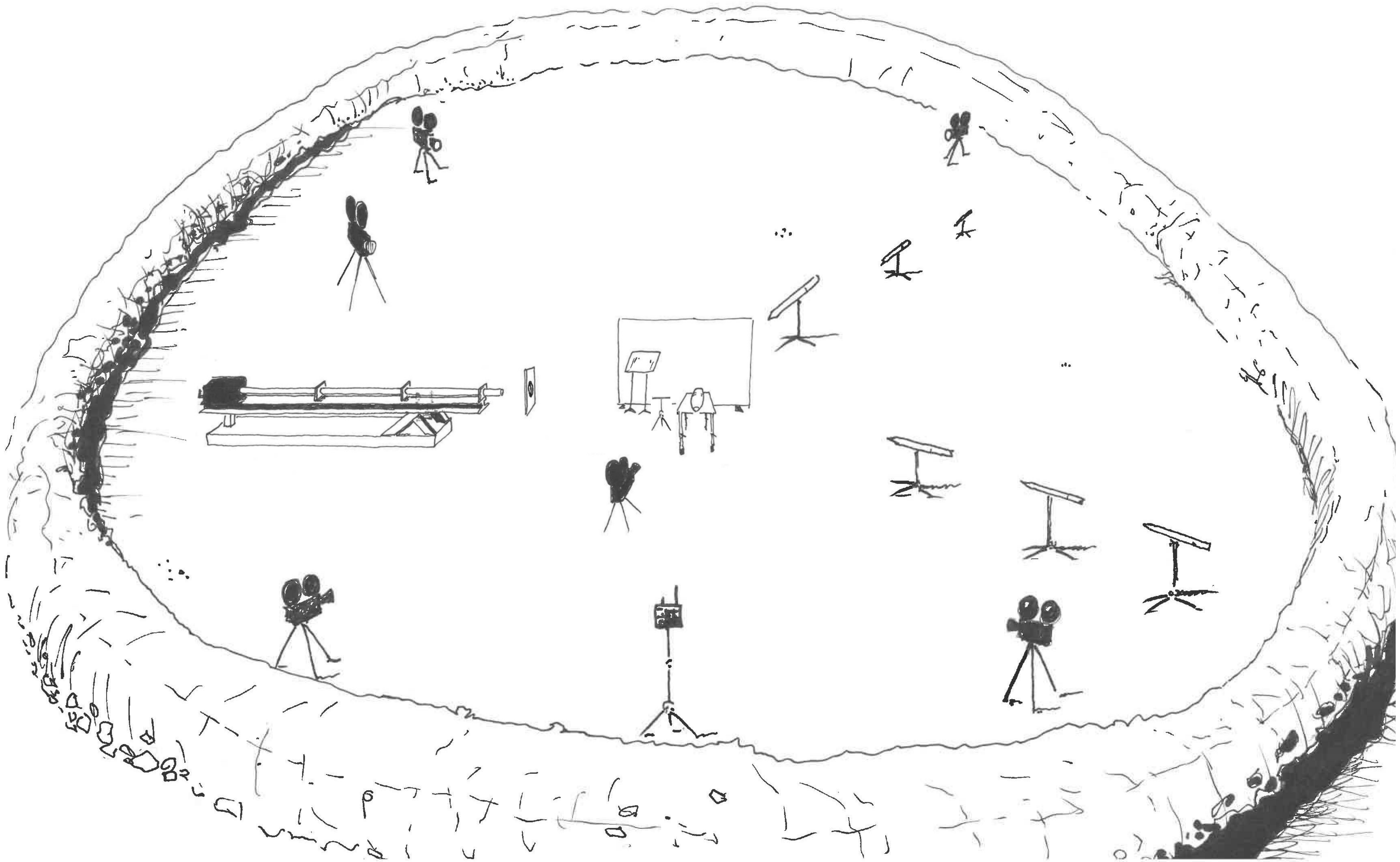
VIDEO CAMERAS

AIR BLAST PRESSURE GAUGES

WEATHER STATION

(EXTERNAL CONFINEMENT)

TEST SETUP; FRAGMENT IMPACT



GUN

SABOT CATCHER PLATE

STEEL TABLE

WITNESS PLATE

MIRRORS

PHOTO BACKGROUND SCREEN

DISTANCE REFERENCE

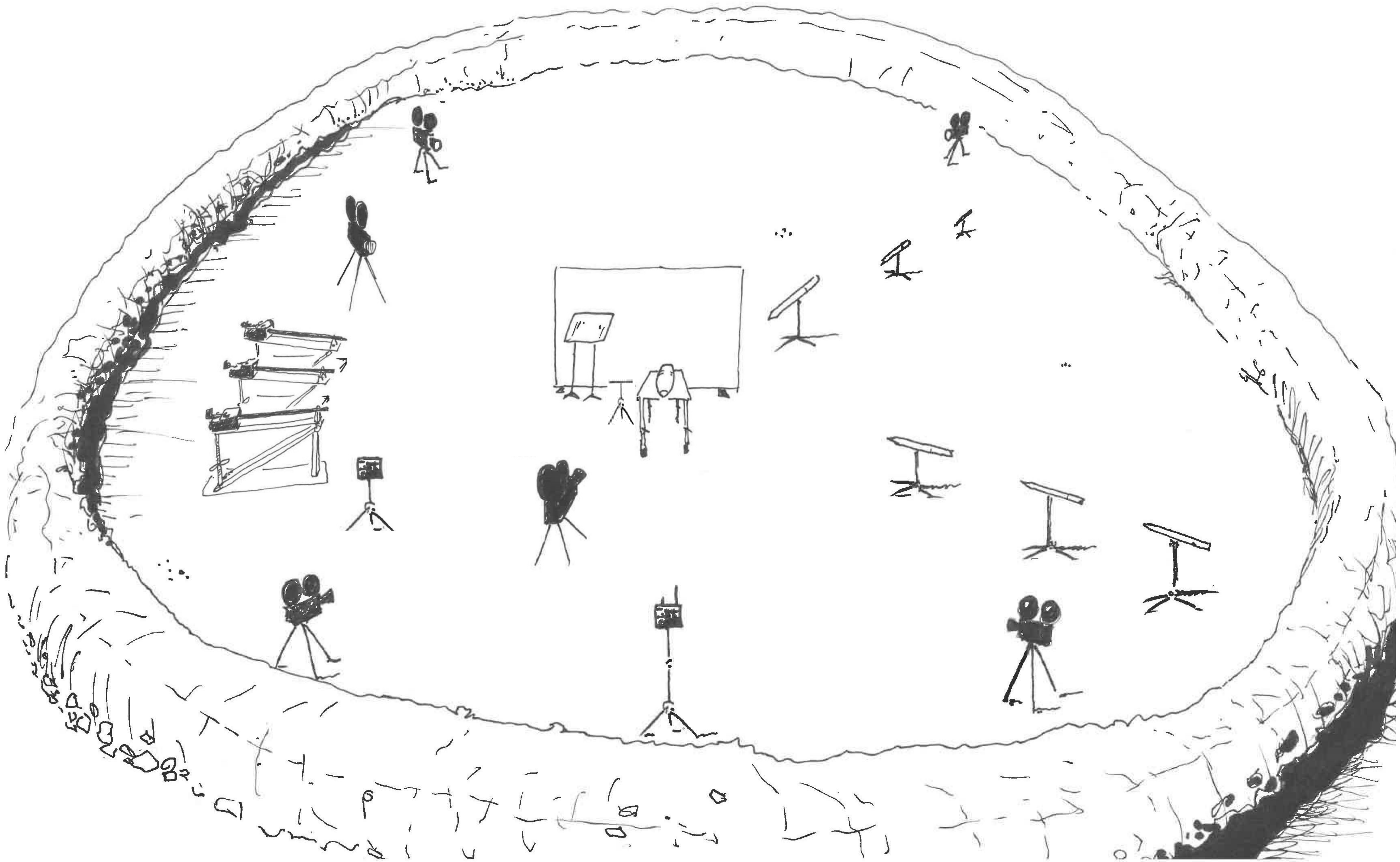
HIGH SPEED VIDEO CAMERAS

VIDEO CAMERAS

AIR BLAST PRESSURE GAUGES

WEATHER STATION

TEST SETUP; BULLET IMPACT



GUN(S)

DOPPLER RADAR

STEEL TABLE

WITNESS PLATE

MIRRORS

PHOTO BACKGROUND SCREEN

DISTANCE REFERENCE

HIGH SPEED VIDEO CAMERAS

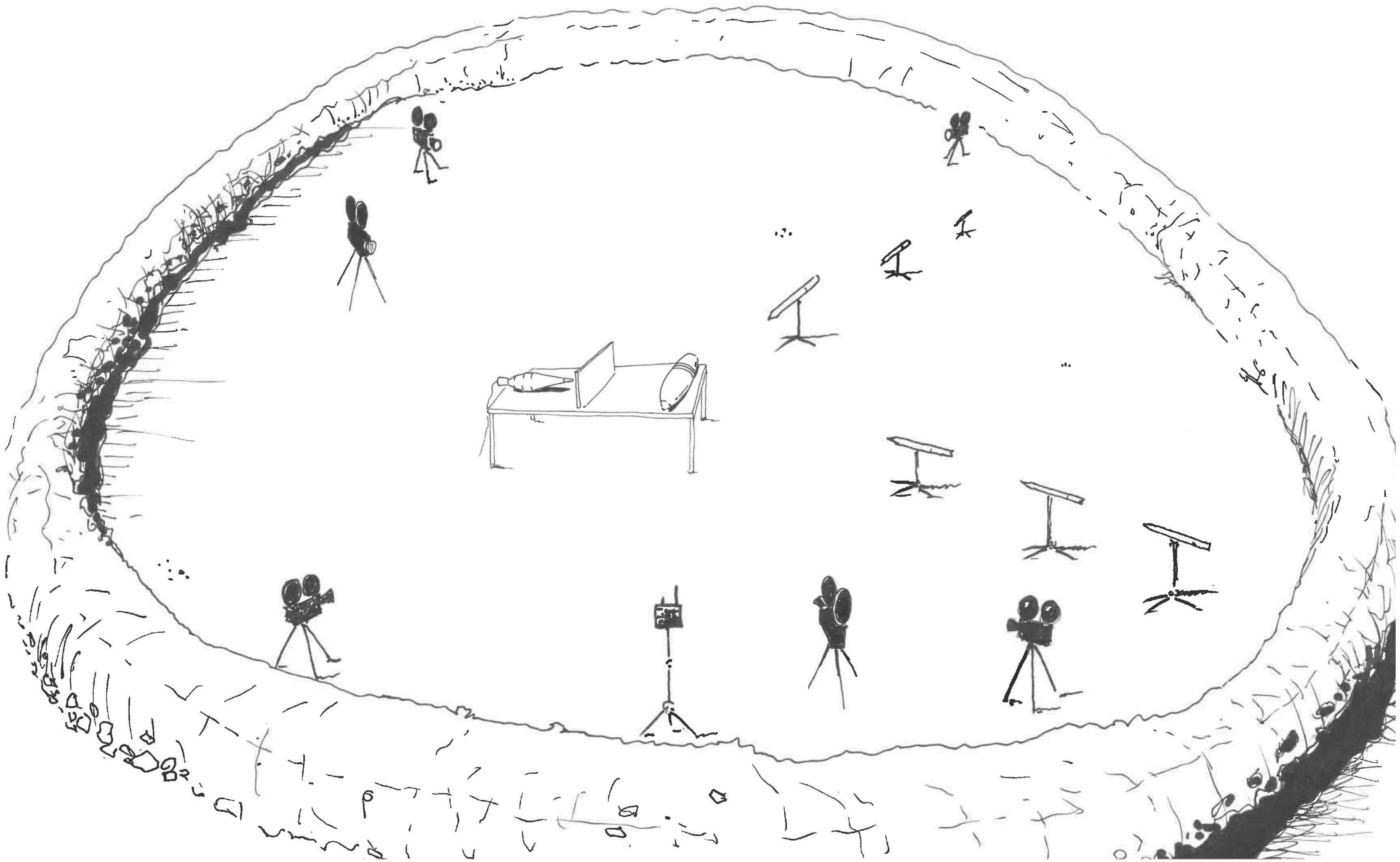
VIDEO CAMERAS

AIR BLAST PRESSURE GAUGES

WEATHER STATION

BOFORS TEST CENTER

TEST SETUP; SHAPED CHARGE JET



SHAPED CHARGE JET (RPG)

CONDITIONING PLATE

STEEL TABLE

WITNESS PLATE

HIGH SPEED VIDEO CAMERAS

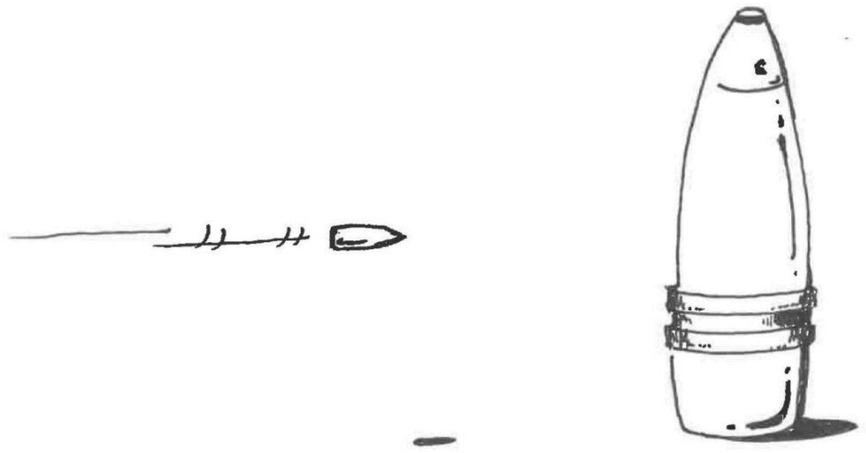
VIDEO CAMERAS

AIR BLAST PRESSURE GAUGES

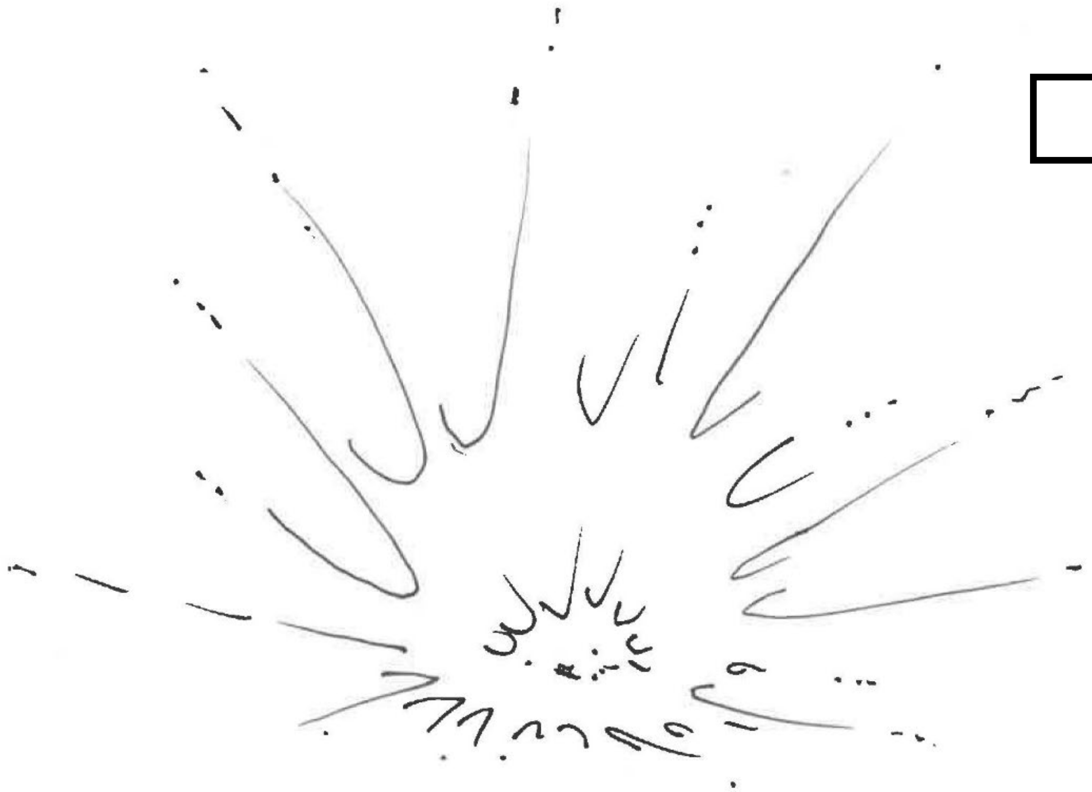
WEATHER STATION

CONDUCT BASELINE TESTS!

SRD AOP-39.1



SHOOT AT AN INERT TEST ITEM



INITIATE A LIVE TEST ITEM TO FULL REACTION

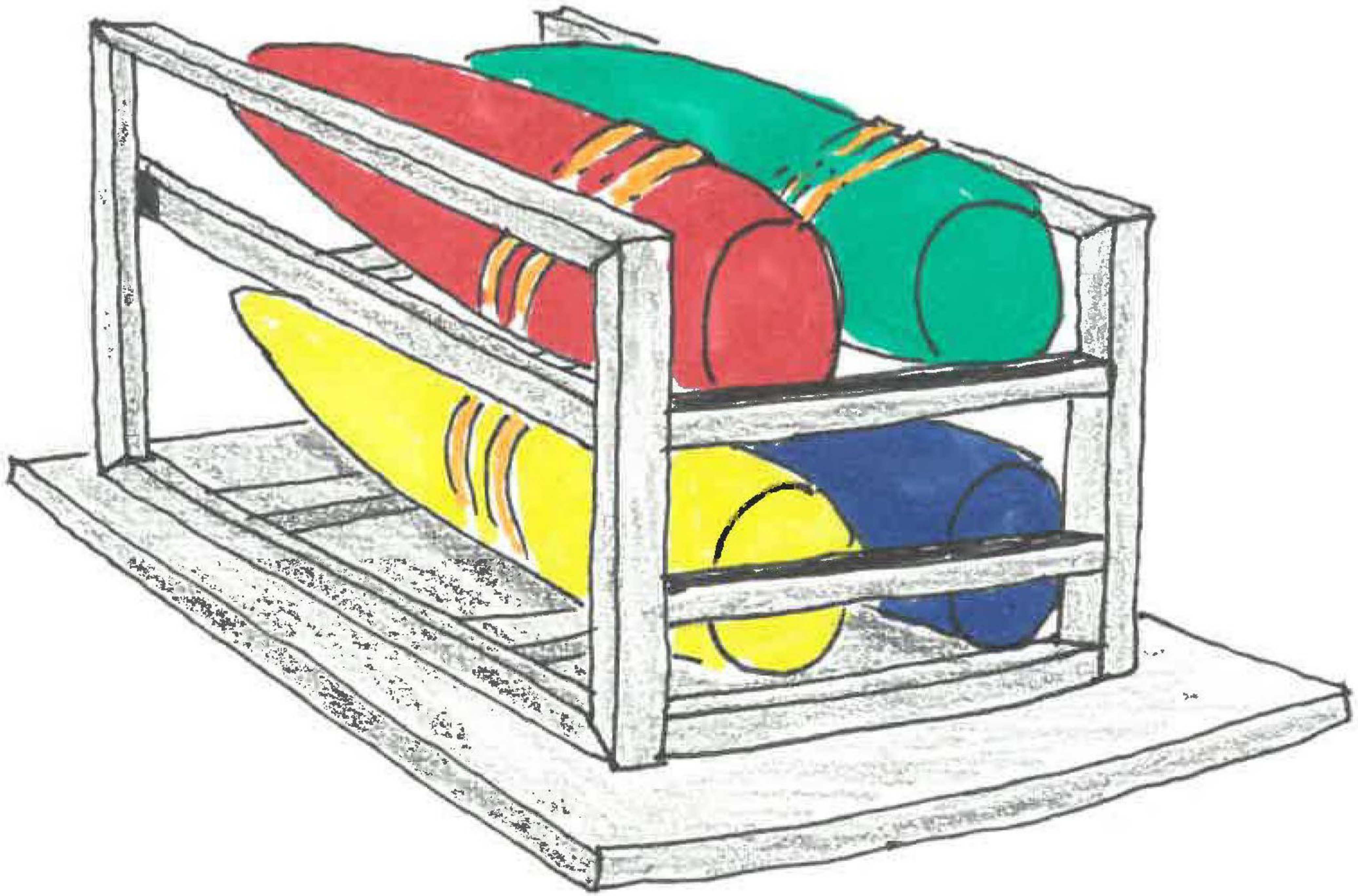
COMPARE:

- THE SIZE AND SHAPE OF THE FRAGMENTS
- THE SCATTERING OF DEBRIS
- THE AIR BLAST PRESSURES

WITH THE RESULTS OF YOUR LIVE TESTS

PAINT YOUR TEST ITEMS!

SRD AOP-39.1



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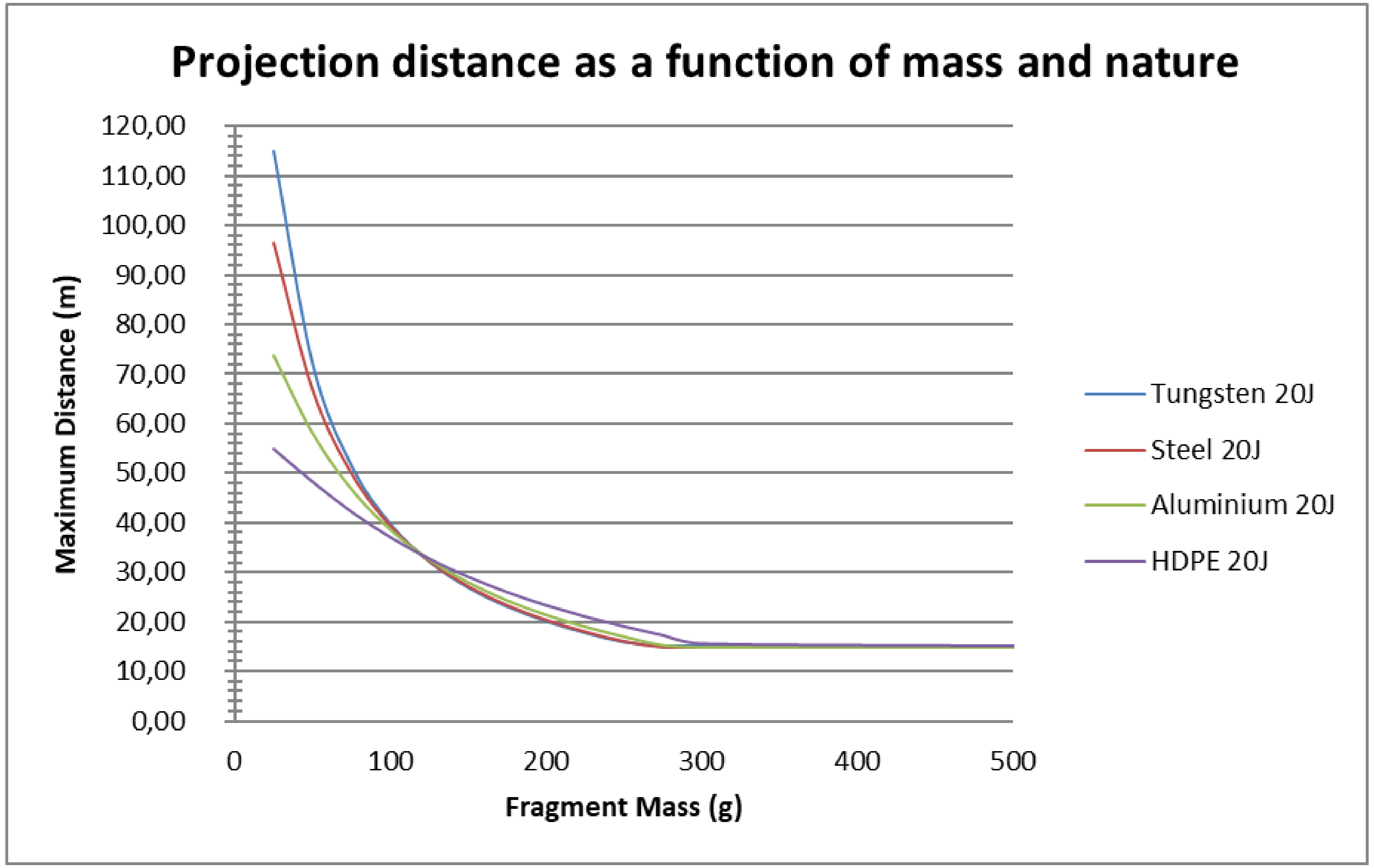
THE ASSESSMENT

WHAT IS IMPORTANT?

EVIDENCE

1. FRAGMENTS; SHAPE, SIZE AND DISTRIBUTION
2. WITNESS PLATES; PERFORATION, PLASTIC DEFORMATION
3. ENERGETIC MATERIAL; BURNED OR UNBURNED, DISTRIBUTION
4. PROJECTION DISTANCE
5. AIR BLAST PRESSURES



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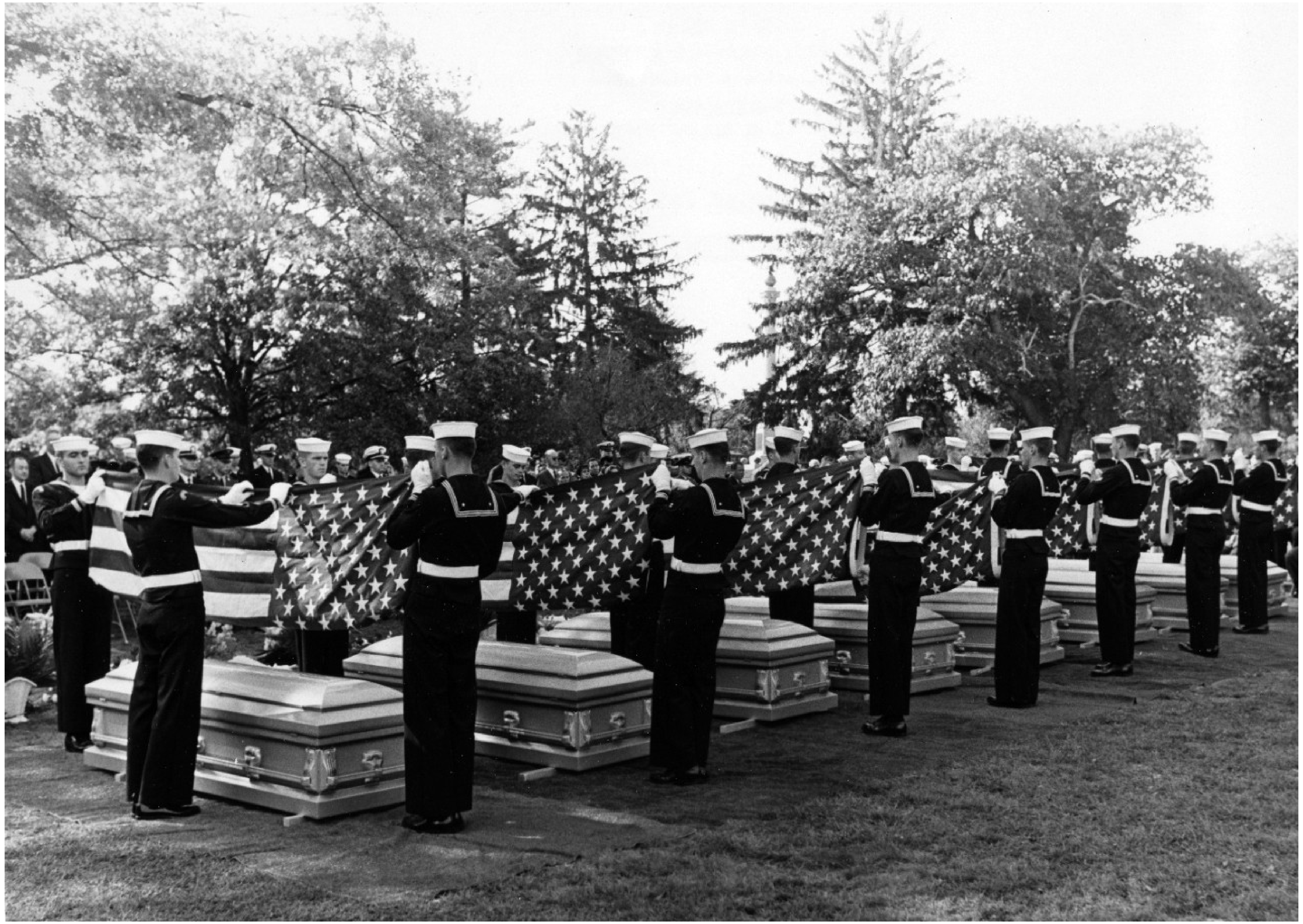
ARE INSENSITIVE MUNITIONS WORTH THE EXTRA COSTS AND EFFORTS?

BOFORS TEST CENTER

YOU BET THEY ARE!

BOFORS TEST CENTER

OR IS THIS AN ACCEPTABLE ALTERNATIVE?



ANY QUESTIONS?

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WELCOME TO HELL

U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMAMENTS CENTER

Air Drag Measurements for the NATO Insensitive Munitions Fragment

Kevin T. Miers, Nausheen M. Al-Shehab

2022 Insensitive Munitions and Energetic Materials Technology Symposium

Indianapolis, IN, USA

Presented by Kevin T. Miers, Mechanical Engineer
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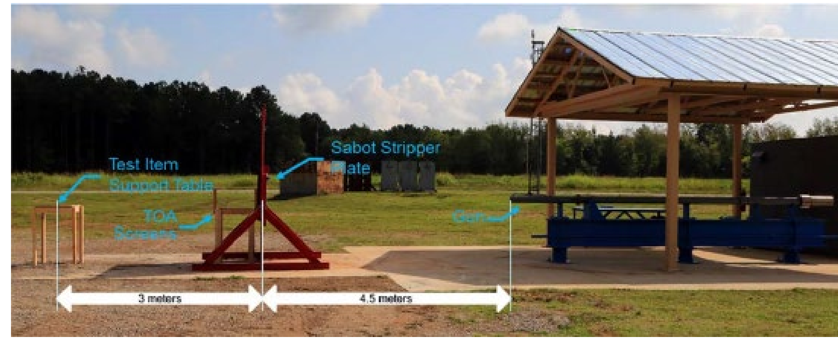
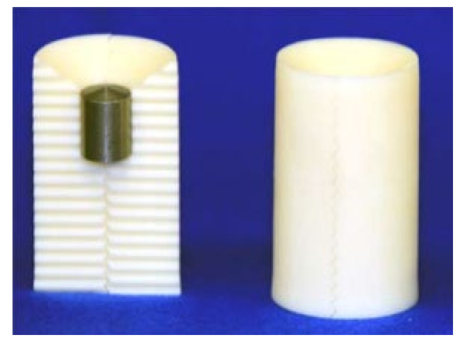
OUTLINE

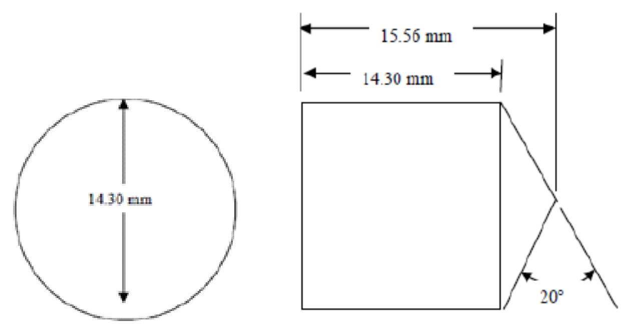
- Background
- Theory
- Experimental Methodology
- Results and Discussion
- Summary and Conclusions; Future Work

BACKGROUND

- Test article placed as close to FI gun as is practical
- Larger test items may need to be moved further down the shot line
- 2530 m/s challenging for powder guns, barrel wear
- Accounting for air drag should provide increased confidence in impact velocity
- In this work we have performed a series of drag coefficient measurements at test velocities of interest







THEORY

$$m\frac{dV}{dt} = -\frac{1}{2}\rho V^2 S C_D \qquad s = \frac{1}{l} = \int_{t_0}^{t} V dt$$

F=ma

$$\frac{d(\ln V)}{ds} = \frac{1}{V}\frac{dV}{ds} = -\left(\frac{\rho S l}{2m}\right) C_D \equiv -C_D^*$$

F=ma (dimensionless length)

$$t = t_0 + \frac{l\left(e^{C_D^* s} - 1\right)}{V_0 C_D^*}$$

Solution for time of arrival (dimensionless length)

$$\approx t_0 + \left(\frac{l}{V_0}\right) s + \left(\frac{l C_D^*}{2V_0}\right) s^2 + \cdots$$

$$\approx t_0 + \left(\frac{1}{V_0}\right) x + \left(\frac{\rho S C_D}{4 m V_0}\right) x^2 + \cdots$$

Solution for time of arrival (Taylor series expansion)

THEORY (CONT'D)

$$t = t_0 + a_1 x + a_2 x^2 + a_3 x^3 \quad \text{where}$$

$$a_1 = \frac{1}{V_0} \qquad a_2 = \frac{\rho S C_D}{4mV_0} \quad \rightarrow \quad C_D = \left(\frac{4m}{\rho S}\right)\left(\frac{a_2}{a_1}\right)$$

Solution for time of arrival (actual length)

- Perform cubic least squares fit to TOA data with x=0, V=V0, t=t0 at **range midpoint**
- Linear term determines velocity at range midpoint (x=0)
- Quadratic, second order term contains drag coefficient
- Cubic, third order term absorbs Mach number variation

How long a range length needed to accurately measure C_D?

THEORY (CONT'D)

$$d_t = \frac{l(e^{C_D^* s} - 1)}{V_0 C_D^*} - \frac{ls}{V_0} \approx \frac{l C_D^* s^2}{2V_0} = \frac{\rho S l^2}{16 m V_0} C_D L^2$$

Maximum time decrement – difference in TOA at range endpoints, assuming drag vs. no drag

$$e_t / d_t$$

TOA measurement error e_t should be small compared to d_t for accurate drag measurements!

d_t increases with square of total range length!

THEORY (CONT'D)

$$d_t = \frac{l\left(e^{C_D^* s} - 1\right)}{V_0 C_D^*} - \frac{ls}{V_0} \approx \frac{l C_D^* s^2}{2V_0} = \frac{\rho S l^2}{16 m V_0} C_D L^2$$

rho	1.225	Air Density, kg/m^3
len	0.0143	Fragment Diameter, m
S	0.000160606	Fragment Presented Area, m^2
m	0.0186	Fragment Mass, kg
V0	2530	Fragment Velocity, m/s
CD	1.4	Assumed Drag Coefficient, dimensionless
Lft	75	Assumed Total Range Length, ft
Lm	22.86	Assumed Total Range Length, m
Lcal	1598.601399	Assumed Total Range Length, calibers
dt	191.1723526	Maximum Time Decrement, us
terr	1	Timing Error, us
xerr in	1	Spacing error, in
xerr m	0.0254	Spacing error, m
xeq	10.03952569	Spacing Equivalent Timing Error, us
teq	10.08920592	Total Equivalent Timing Error, us
toterr	**5.28**	Anticipated Measured Drag Error, %

Long flight path needed so that detected deceleration not overwhelmed by measurement error!

THEORY (CONT'D)

How many timing stations do you need assuming uniform known measurement error?

$$e_i^2 = \left(\frac{\partial a_i}{\partial t_1} e_{t1}\right)^2 + \left(\frac{\partial a_i}{\partial t_2} e_{t2}\right)^2 + \cdots + \left(\frac{\partial a_i}{\partial t_n} e_{tn}\right)^2$$

Can explicitly calculate error in each least squares fit coefficient as function of number and spacing of timing stations!

$$\left(\frac{e_i}{e_t}\right)^2 = \sum_{j=1}^{n} \left(\frac{\partial a_i}{\partial t_j}\right)^2$$

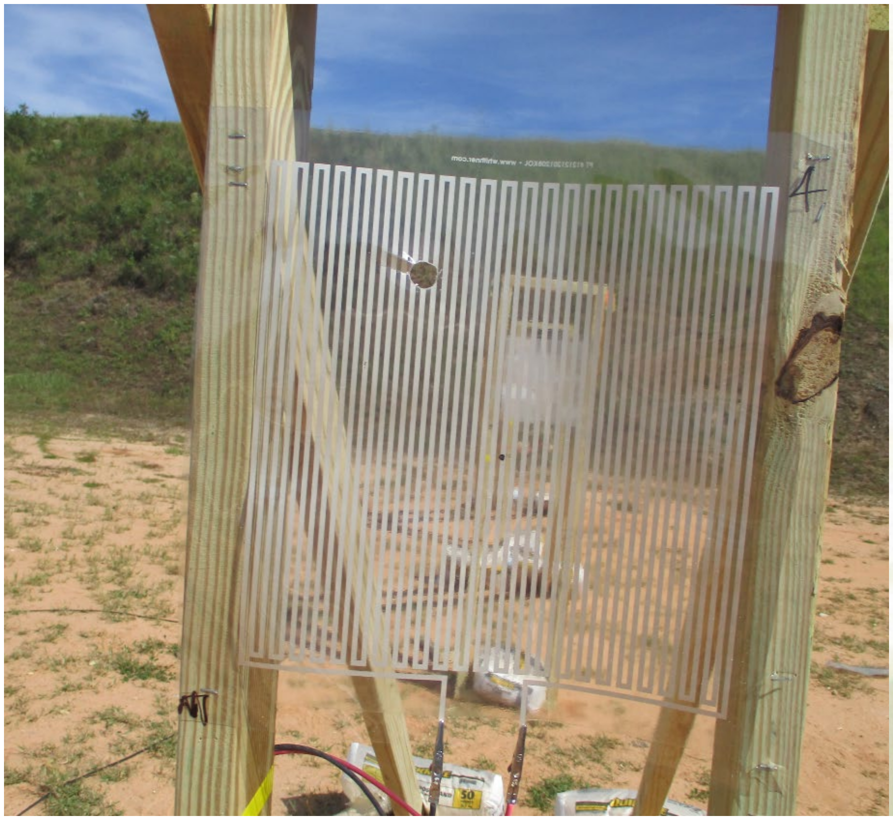
- Long story short, optimal spacing is half the stations at range midpoint, 1/4 of them at each range endpoint
- We used 6 equally spaced TOA gauges over ~75ft

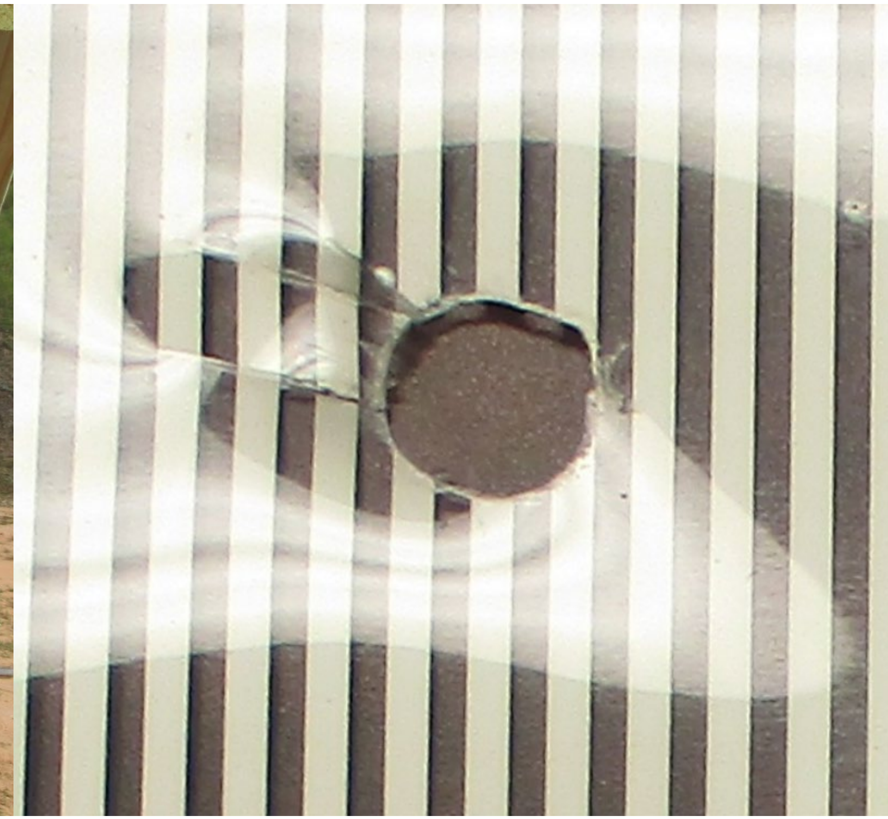
DRAG COEFFICIENT MEASUREMENT TESTING

	Test 1 (RT21463)		Test 2 (RT21464)		Test 3 (RT21465)		Test 4 (RT21466)		Test 5 (RT21467)		Test 6 (RT21468)	
	TOA (ms)	X (in)	TOA (ms)	X (in)	TOA (ms)	X (in)	TOA (ms)	X (in)	TOA (ms)	X (in)	TOA (ms)	X (in)
GUN-TOA1	25.4180	120.0000	24.7467	120.2500	22.6041	103.5000	21.9282	104.0000	23.0228	104.0000	22.0304	104.0000
TOA1-TOA2	26.6044	120.0000	25.9591	119.2500	24.4072	179.3750	23.6915	179.3750	24.7955	180.3125	23.8304	180.8750
TOA2-TOA3	27.8177	120.0000	27.1960	119.2500	26.2653	180.1250	25.5208	178.8750	26.6321	178.8750	25.6687	178.2500
TOA3-TOA4	29.0660	120.0000	28.4682	120.8750	28.1943	179.1250	27.4107	179.0000	28.5503	179.1250	27.5918	178.9375
TOA4-TOA5	30.3597	120.0000	29.7834	120.8750	30.2280	181.1875	29.4085	181.1875	30.5653	181.1875	29.6188	181.3125
TOA5-TOA6	31.6837	120.0000	31.1328	120.0000	32.3423	178.8125	31.4505	178.8125	32.6443	178.5625	31.7180	178.5000

DRAG COEFFICIENT MEASUREMENT TESTING

DRAG COEFFICIENT MEASUREMENT TESTING





TOA gauges a little heavy…

UNCLASSIFIED

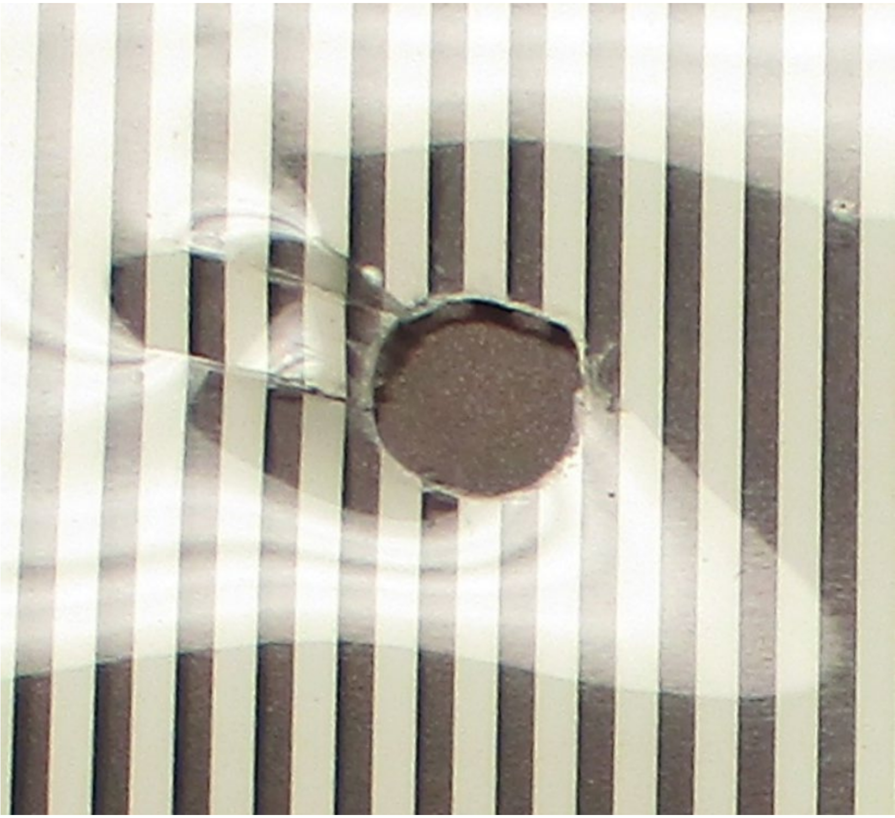
DRAG COEFFICIENT CALCULATION

	Test 1 (RT21463)		Test 2 (RT21464)		Test 3 (RT21465)		Test 4 (RT21466)		Test 5 (RT21467)		Test 6 (RT21468)	
	TOA (s)	x(m)	TOA (s)	x(m)	TOA (s)	x(m)	TOA (s)	x(m)	TOA (s)	x(m)	TOA (s)	x(m)
TOA1	0.0254180	-7.6200	0.0247467	-7.6099	0.0226041	-11.4128	0.0219282	-11.3900	0.0230228	-11.4104	0.0220304	-11.4102
TOA2	0.0266044	-4.5720	0.0259591	-4.5810	0.0244072	-6.8567	0.0236915	-6.8339	0.0247955	-6.8305	0.0238304	-6.8159
TOA3	0.0278177	-1.5240	0.0271960	-1.5520	0.0262653	-2.2815	0.0255208	-2.2905	0.0266321	-2.2871	0.0256687	-2.2884
TOA4	0.0290660	1.5240	0.0284682	1.5182	0.0281943	2.2683	0.0274107	2.2561	0.0285503	2.2627	0.0275918	2.2566
TOA5	0.0303597	4.5720	0.0297834	4.5884	0.0302280	6.8704	0.0294085	6.8583	0.0305653	6.8649	0.0296188	6.8620
TOA6	0.0316837	7.6200	0.0311328	7.6364	0.0323423	11.4123	0.0314505	11.4001	0.0326443	11.4004	0.0317180	11.3959

	a3	a2	a1	a0	V0	CD	dV/dx
Test 1	1.5761E-08	1.9406E-06	4.1023E-04	2.8439E-02	2437.6	1.79	23.062002
Test 2	5.4435E-08	1.7083E-06	4.1568E-04	2.7835E-02	2405.7	1.55	19.77285
Test 3	2.9361E-08	1.9223E-06	4.2280E-04	2.7223E-02	2365.2	1.72	21.507083
Test 4	6.6191E-09	1.7185E-06	4.1697E-04	2.6464E-02	2398.2	1.56	19.76768
Test 5	5.7707E-09	1.9215E-06	4.2105E-04	2.7585E-02	2375.0	1.73	21.677254
Test 6	1.8829E-08	1.9283E-06	4.2235E-04	2.6626E-02	2367.7	1.73	21.620883

Seems high!

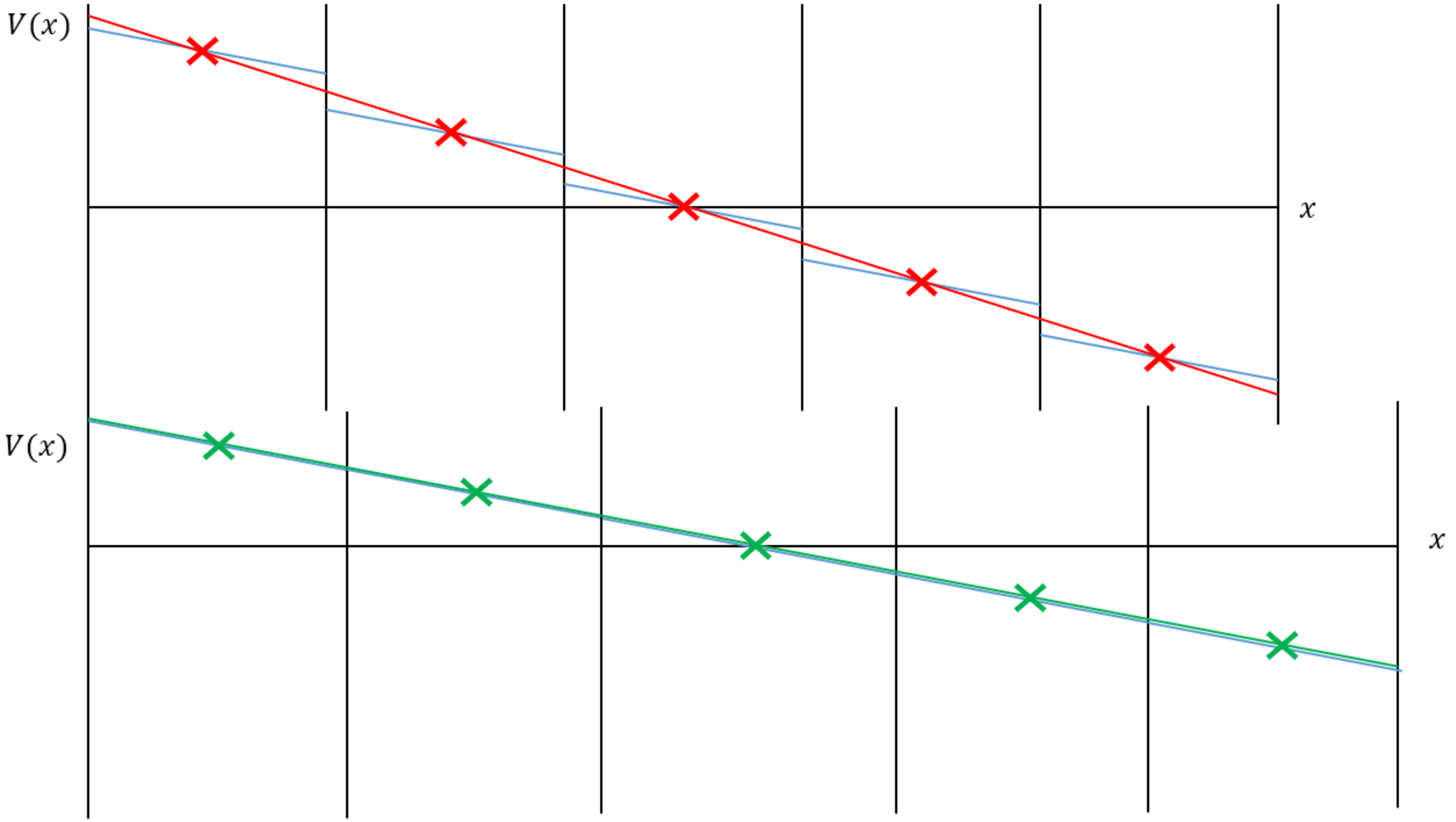
DRAG COEFFICIENT CALCULATION



	TOA Gauges	
	15in x 15in	
	657 grains	
	~0.010" thick	
lb	0.093857143	TOA mass, lb
kg	0.042572849	TOA mass, kg
S	0.000160606	Fragment Presented Area, m^2
m1	0.0186	Fragment Mass, kg
v1	2367.7	Measured Midpoint Velocity, m/s
A	0.145161	TOA Total Area, m^2
m2	4.71026E-05	Mass of Punched Out TOA, kg
v2	2361.71919	Residual Velocity, m/s
dv	5.980810401	Velocity Reduction, m/s
dVdx	**18.907529**	m/s per m
dx	0.316318986	Equivalent Distance, m
dxin	12.45351011	Equivalent Distance, in
dt	0.133597578	Equivalent Time, ms

Velocity drop equivalent to ~12" of travel!

DRAG COEFFICIENT CALCULATION



TOA gauge velocity drop acts as equivalent range length and time delay

DRAG COEFFICIENT CALCULATION

	dtms	dxin	dtms	dxin	dtms	dxin	dtms	dxin	dtms	dxin	dtms	dxin
	0.1342937	12.887973	0.1626238	15.402528	0.134371	12.5124	0.1485344	14.02423	0.1332225	12.45684	0.1335976	12.45351

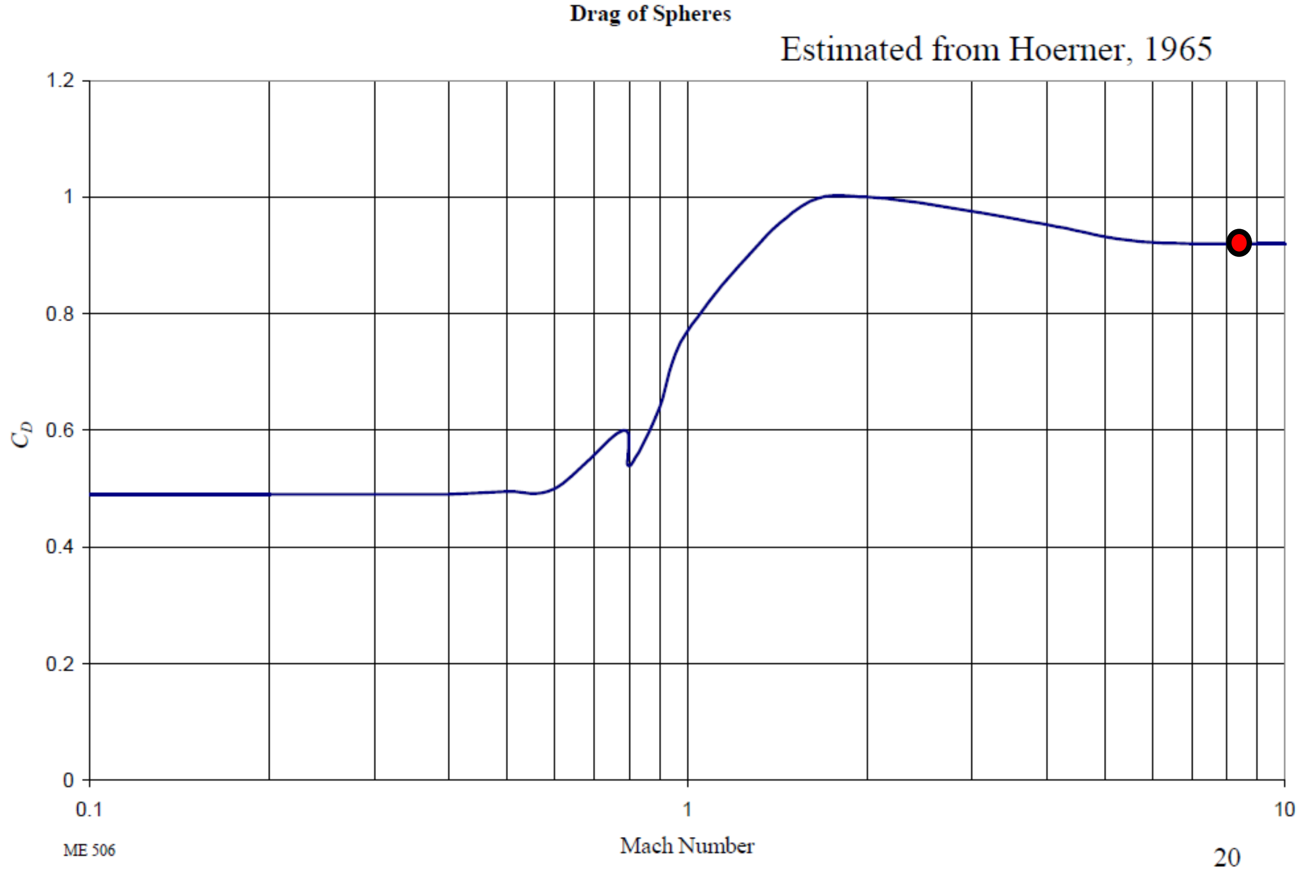
	Test 1 (RT21463)		Test 2 (RT21464)		Test 3 (RT21465)		Test 4 (RT21466)		Test 5 (RT21467)		Test 6 (RT21468)	
	TOA (ms)	X (in)	TOA (ms)	X (in)	TOA (ms)	X (in)	TOA (ms)	X (in)	TOA (ms)	X (in)	TOA (ms)	X (in)
GUN-TOA1	25.4180	120.0000	24.7467	120.2500	22.6041	103.5000	21.9282	104.0000	23.0228	104.0000	22.0304	104.0000
TOA1-TOA2	26.7387	132.8880	26.1217	134.6525	24.5416	191.8874	23.8400	193.3992	24.9287	192.7693	23.9640	193.3285
TOA2-TOA3	28.0863	132.8880	27.5212	134.6525	26.5340	192.6374	25.8179	192.8992	26.8985	191.3318	25.9359	190.7035
TOA3-TOA4	29.4689	132.8880	28.9561	136.2775	28.5974	191.6374	27.8563	193.0242	28.9500	191.5818	27.9926	191.3910
TOA4-TOA5	30.8969	132.8880	30.4339	136.2775	30.7655	193.6999	30.0026	195.2117	31.0982	193.6443	30.1532	193.7660
TOA5-TOA6	32.3552	132.8880	31.9459	135.4025	33.0142	191.3249	32.1932	192.8367	33.3104	191.0193	32.3860	190.9535

	a3	a2	a1	a0	V0	CD	dV/dx
Test 1	1.1606E-08	1.5824E-06	4.1023E-04	2.8775E-02	2437.6	1.46	18.805598
Test 2	3.7964E-08	1.3419E-06	4.1568E-04	2.8241E-02	2405.7	1.22	15.532698
Test 3	2.3976E-08	1.6802E-06	4.2280E-04	2.7559E-02	2365.2	1.50	18.79808
Test 4	5.2756E-09	1.4784E-06	4.1698E-04	2.6836E-02	2398.2	1.34	17.005553
Test 5	4.6791E-09	1.6804E-06	4.2106E-04	2.7918E-02	2375.0	1.51	18.956255
Test 6	1.5344E-08	1.6863E-06	4.2235E-04	2.6960E-02	2367.7	1.51	18.906947

Iterative procedure corrects for velocity drops across thick TOA gauges – C_D appears to be 1.2-1.5

RESULTS AND DISCUSSION

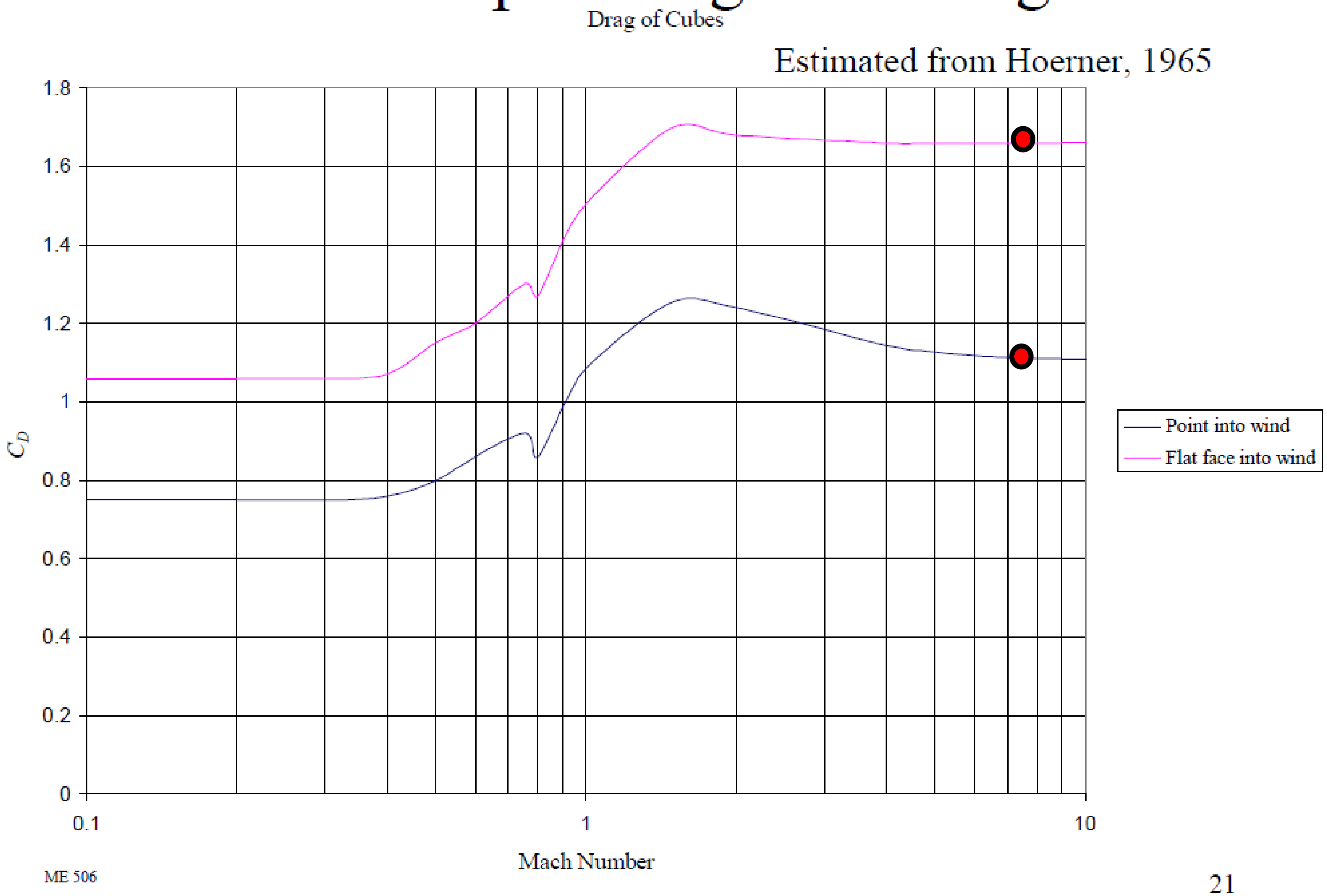
Spherical Fragment Drag



Spherical fragment expected C_D~0.9

RESULTS AND DISCUSSION

Cube Shaped Fragment Drag



Cube shaped fragment C_D expected to be 1.1-1.65

SUMMARY AND CONCLUSIONS, FUTURE WORK

- 6 drag coefficient measurements performed for NATO IM fragment at approximately 2530 m/s
- ~80ft (~25m) range length with 6 TOA gauges
- Drag coefficient measured to be 1.22-1.51 when corrected for TOA gauge thickness
- Looks to be about what we expected; agrees with Dunn and Porter too
- Possible sources of error: TOA spacing error, trajectory curvature, fragment yawing motion, deformation from TOA gauge impacts
- Future work: perform measurements with rifled gun, thinnest possible TOA gauges, and more optimized timing station distribution

QUESTIONS

REFERENCES

[1] Murphy, C. H. “Free Flight Motion of Symmetric Missiles”. BRL-R-1216, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1963.

TNO innovation for life

MITIGATION OF FLAT 2-DIMENSIONAL SHOCKS TO PREVENT SYMPATHETIC REACTIONS

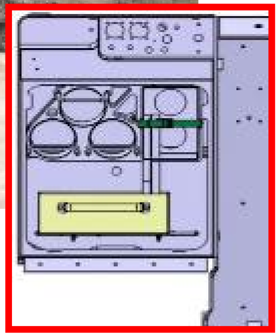
DR. S.A.L. DE KOSTER & J.H.G. SCHOLTES

10 October 2022

PLATFORM SAFETY
LIFE-CYCLE MUNITIONS - THREATS



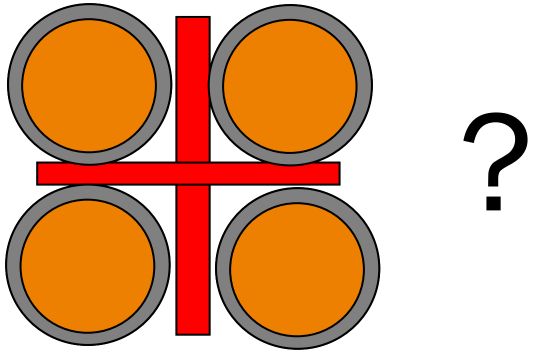




- Fragments
- Shaped charge jet
- Bullets
- Cook-off
- **Sympathetic reaction**

MUNITION RESPONSE MITIGATION
BULLET IMPACT AND SYMPATHETIC REACTION

- MOD identified items of interest for testing
- Some tested munition types showed violent response
  - Ranging from type 1 (detonation) to type 3 (explosion)
- Test programme at ‘t Harde to find mitigation solutions
  - Latest series: 3 munition types available
  - Unique solution for every munition type
- This presentation: plastic explosive

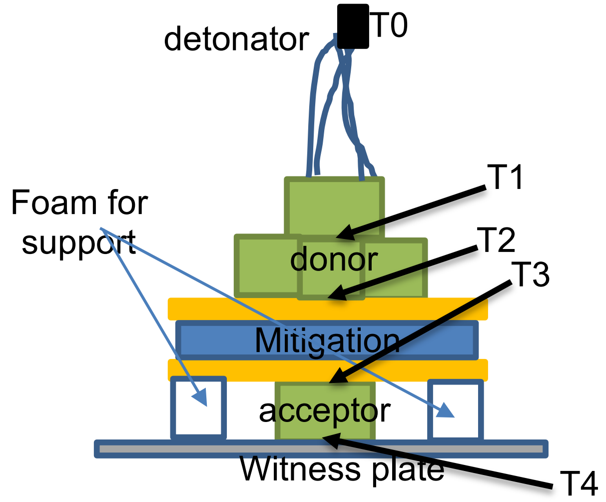


PLASTIC EXPLOSIVE
WOODEN BOXES OF 25 KG

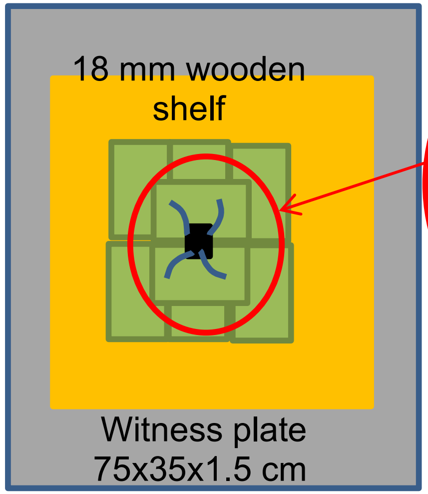
SYMPATHETIC REACTION TESTS
DESIGN

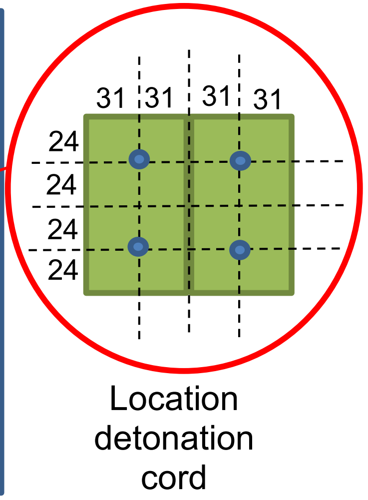
- Donor: product a **large, flat detonation wave**
  - Wood - Mitigating material wood
- Acceptor: just two blocks
- Trigger wires to understand response mechanism
- Steel witness plate to confirm detonation response

Plastic explosive block
Length 95 mm
Width 62 mm
Height 58 mm
v_D 7.35 mm/µs



Side view





Top view

Distribution Unlimited

SYMPATHETIC REACTION TESTS
MITIGATING MATERIALS

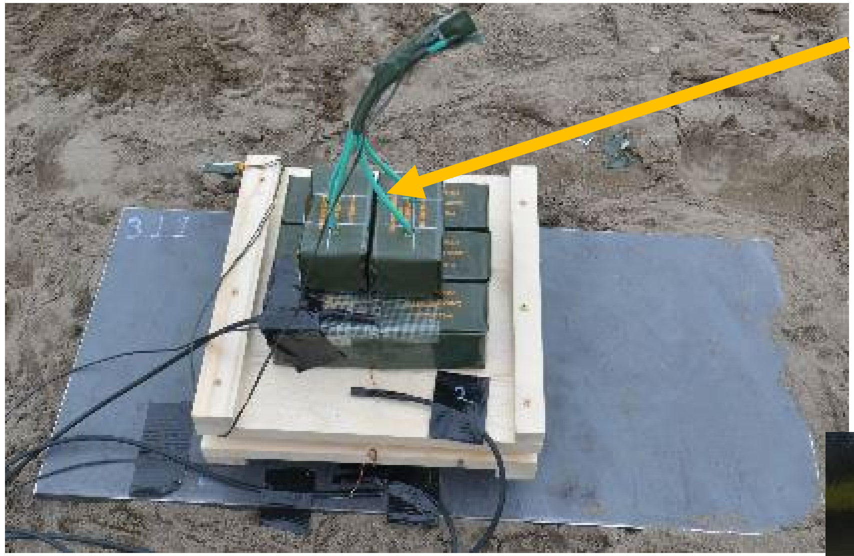
- Several types of mitigating materials:
  - Air (with wooden spacers at edge)
  - PIR foam with density of 0.3 kg/dm^3 (35 and 70 mm)
  - Aerated concrete (35 and 70 mm)
  - Aluminium-rubber layers (5 and 9 layers with 3 mm AL7075 and 4 mm NBR-Rubber)

- 300x300x18 mm pine wood board to simulate box

- However, tests did not go as planned
  - Flat detonation wave more effective than anticipated!

SYMPATHETIC REACTION TESTS

SET-UP (18 MM AIR GAP)

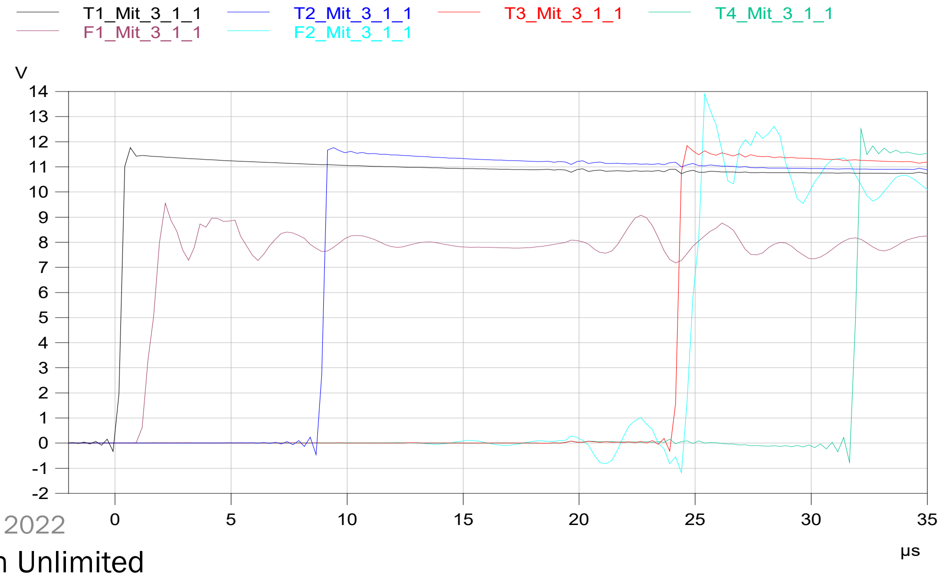


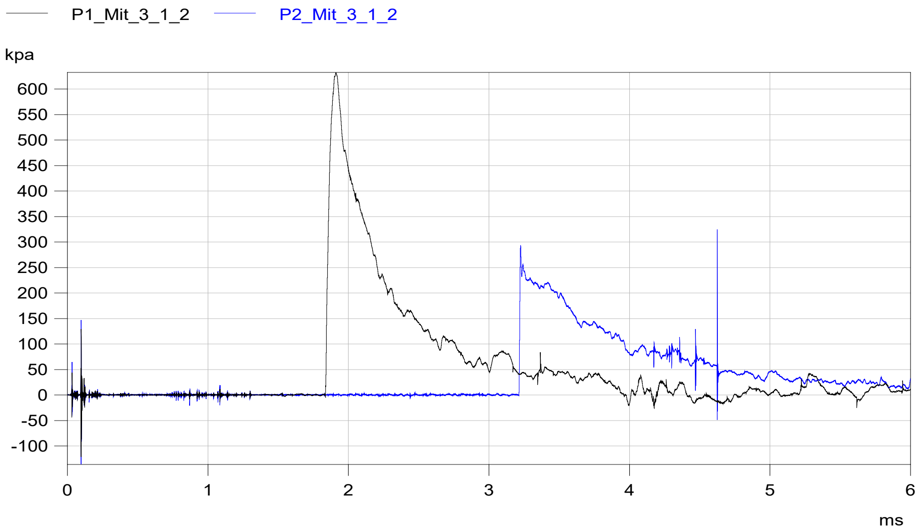
SYMPATHETIC REACTION TESTS

INTERPRETATION OF THE RESULTS (18 MM AIR GAP)

Plastic explosive block
Length 95 mm
Width 62 mm
Height 58 mm
v_D 7.35 mm/µs

T1-T2 = 8.73 µs
T2-T3 = 15.29 µs
T3-T4 = 7.69 µs
SDT





OTHER TESTS WITH AIR GAPS
36 MM AND 210 MM

ALUMINIUM/RUBBER
5, 9 AND 13 LAYERS




AERATED CONCRETE
70 AND 2X140 MM

AERATED CONCRETE
210 MM AND 2X70 MM WITH 16 MM STEEL

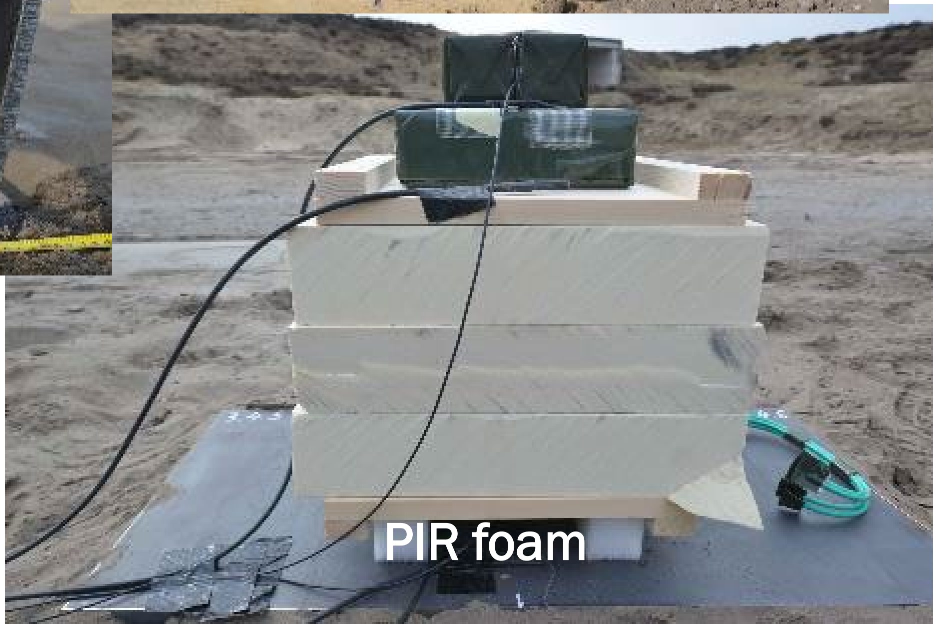
No detonation

Distribution Unlimited

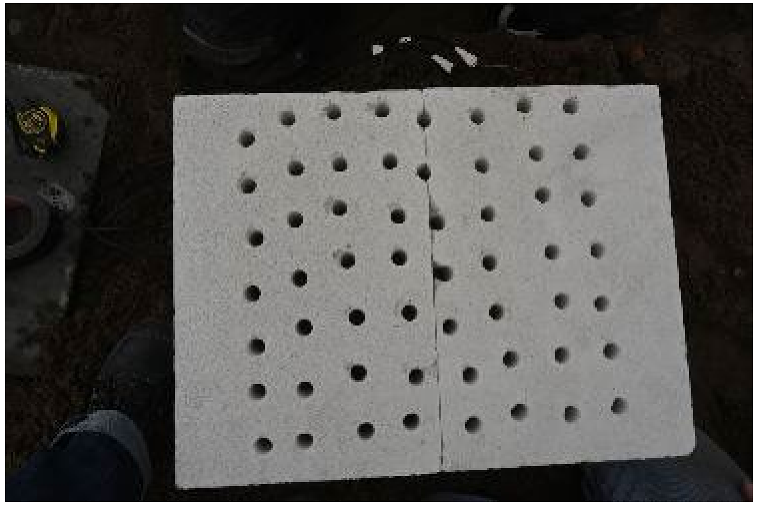
OTHER TESTS

CAN WE MAKE IT LIGHTER?

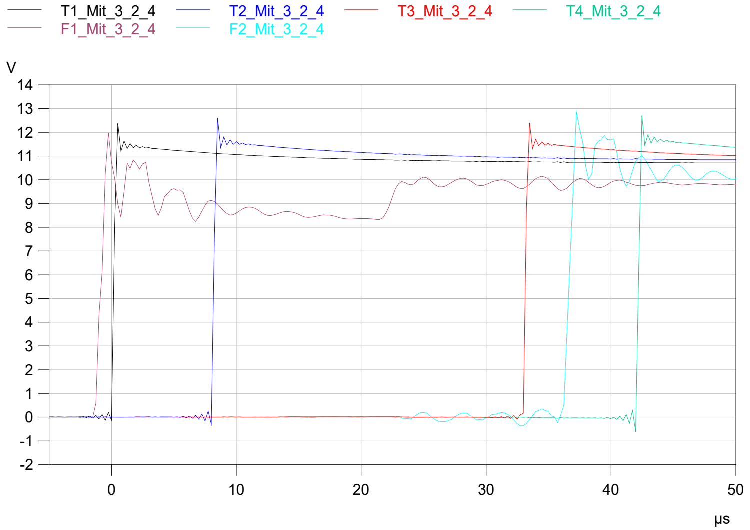
All detonations



OTHER TESTS
LESS IS BETTER?



Indentation of the plastic explosive!



T1-T2 = 10.27 µs

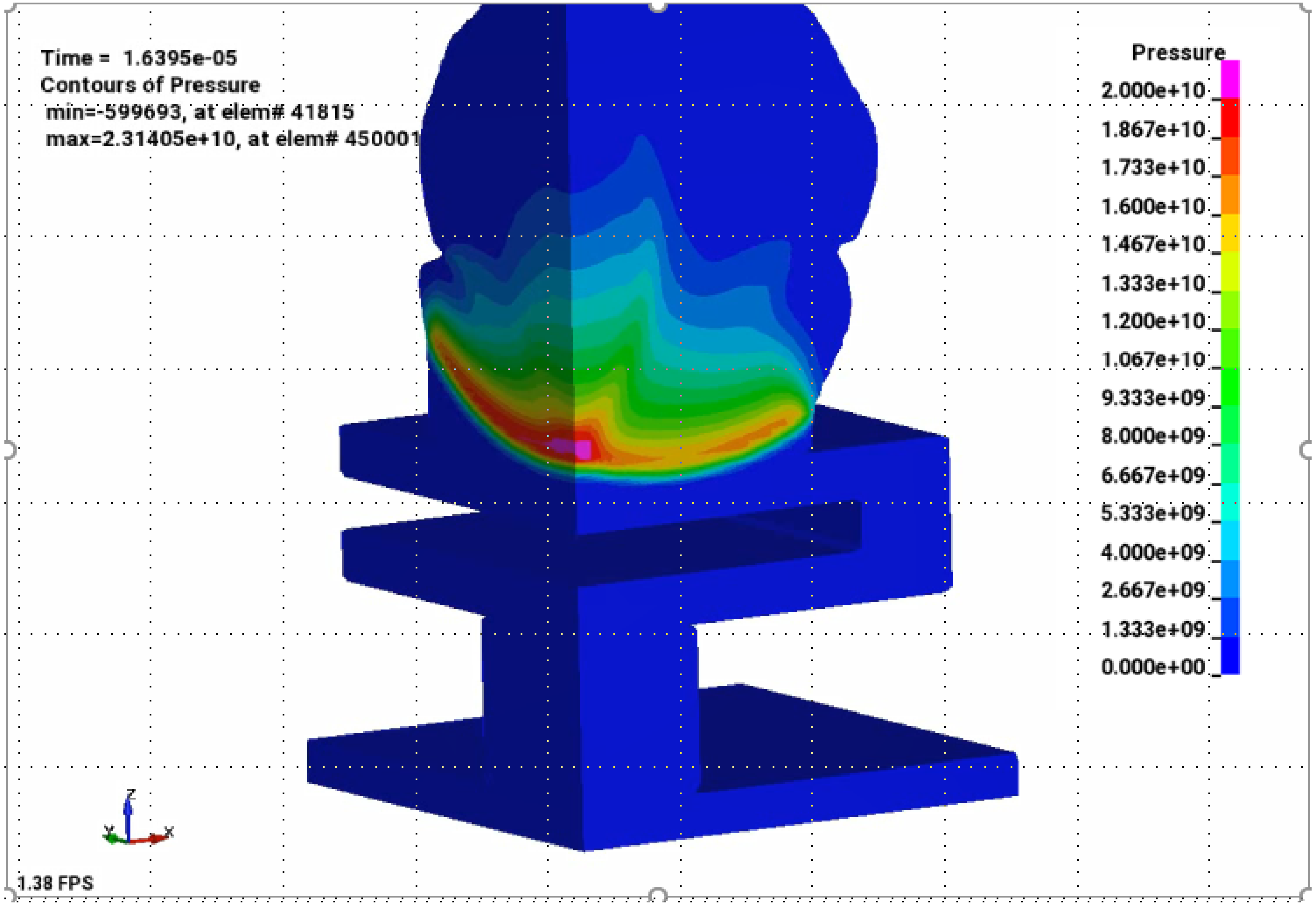
T2-T3 = 37.99 µs

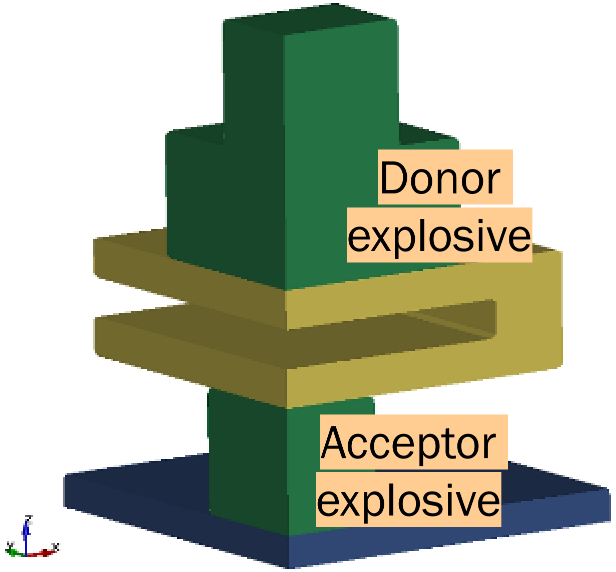
T3-T4 = 122.89 µs

No detonation!

Distribution Unlimited

SIMULATIONS TO SUPPORT INVESTIGATIONS
PRELIMINARY RESULTS





NEW TEST SERIES
FOCUS ON BREAKING UP THE SHOCK WAVE

Spoilers:

- Several types of mitigating materials:
  - Aerated concrete to determine minimum thickness ← 190 mm
  - Aerated concrete with 13 mm holes (40 mm spacing)
  - Aerated concrete with 13 mm holes (40 mm spacing), staggered
  - Aerated concrete with 8 mm holes (30 mm spacing)

- Additionally, ceramic blocks

← These did not work

AERATED CONCRETE WITH HOLES
13 MM, 40 MM SPACING

In-line

Staggered

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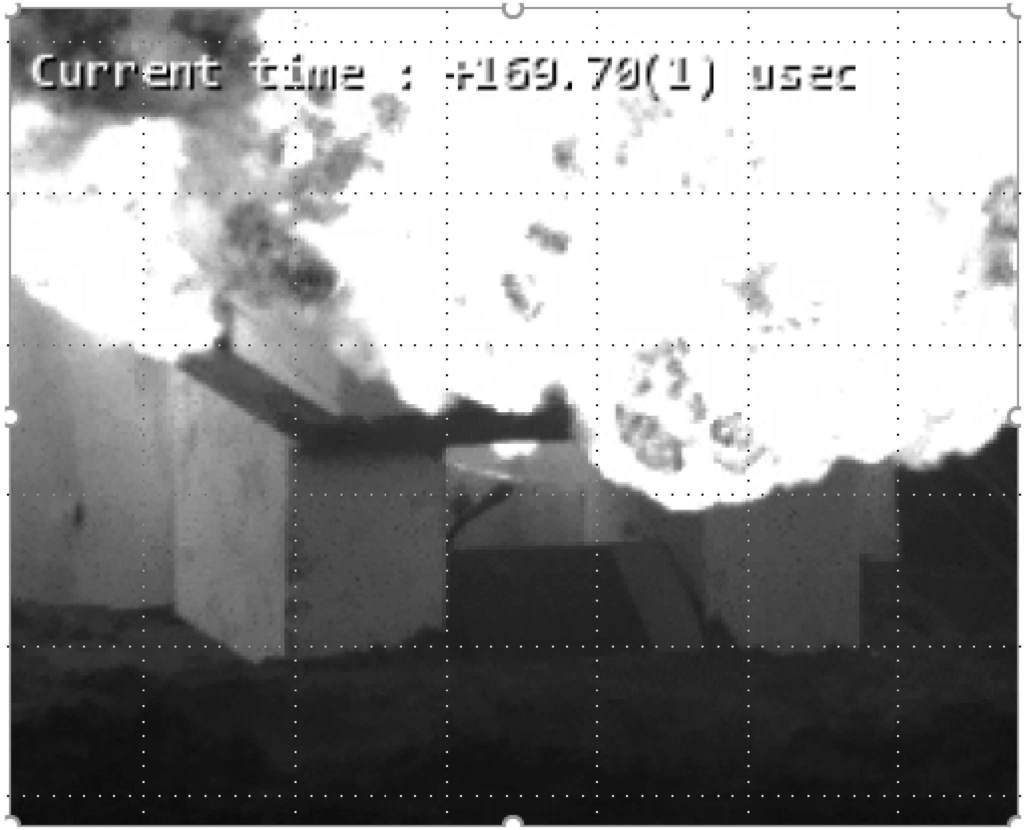
AERATED CONCRETE WITH HOLES
13 MM, 40 MM SPACING, STAGGERED

190 mm



170 mm

AERATED CONCRETE WITH HOLES
8 MM, 30 MM SPACING

120 mm

100 mm

AERATED CONCRETE WITH HOLES
8 MM, 30 MM SPACING

120 mm

100 mm

CONCLUSIONS
MITIGATION OF PLASTIC EXPLOSIVE SYMPATHIC REACTION

- **Flat detonation waves are challenging to mitigate!**

- Ineffective
  - Air gap (210 mm)
  - Aluminium/rubber (46 mm)
  - PIR foam (210 mm)
  - Wood (210 mm)
  - Ceramic blocks (175 mm)

- Effective
  - Aerated concrete 190 mm
  - Aerated concrete with 13 mm holes 170/190 mm (in-line/staggered)
  - Aerated concrete with 8 mm holes 120 mm


THANK YOU FOR
YOUR TIME
TNO innovation for life
Distribution Unlimited

Continuous ResonantAcoustic® Synthesis and Crystallization

Joseph Mayne, Ph.D.

Senior Chemical Engineer

Resodyn™ CORPORATION

Building Value through Discovery and Innovation®

Problem Statement

Product Formulation:

- Many Constituent Components
- Specified Chemical Composition
- Optimized Material Properties
- Unique Synthesis, Processing Challenges

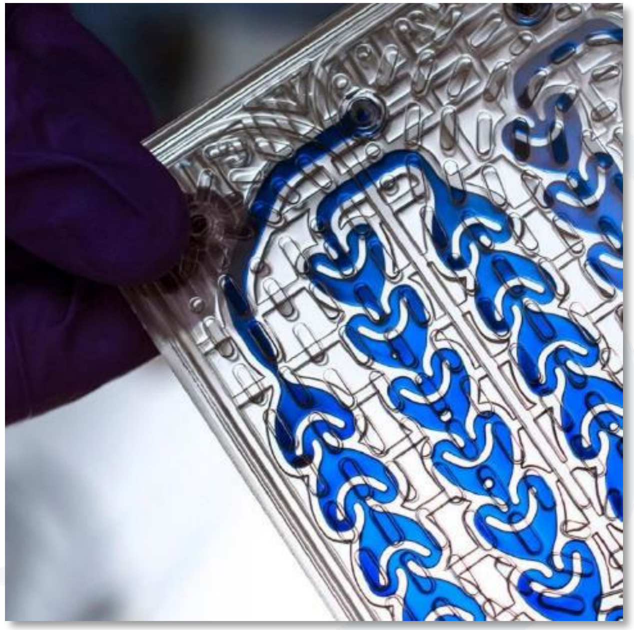
Continuous Chemical Synthesis Goals:

- **Flexibility:** Adapt to synthesis of broad range of chemicals
- **Tunability:** Able to control the physical properties of the product
- **Consistent Control:** Eliminate variability, decrease waste
- **Scalability:** Bench-scale discovery to world-scale production

Legacy Batch vs. Advanced Continuous Flow Reactors

Chemglass 10L Reactor

Corning AdvancedFlow^{TM} Reactor



Conventional Batch Reactors:

+ Inexpensive and Flexible
+ Multiphase Processes
- Variability on product quality
- Mixing and Heat-Exchange Limitations

Microfluidic Reactors:

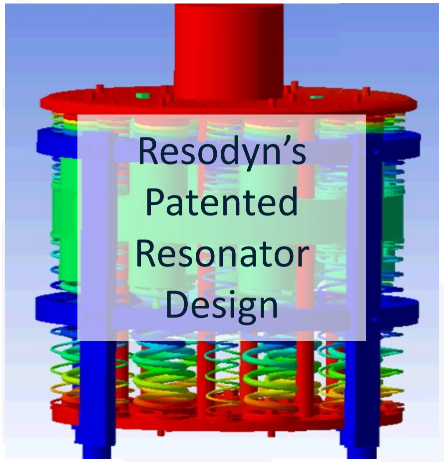
+ Improved Mixing and Temp Control
+ Control and Tunability of Product
+ Decreased Waste
- Complexity and Cost
- Difficulty Processing Solids

ResonantAcoustic® Mixing Phenomenon

RAM Features:

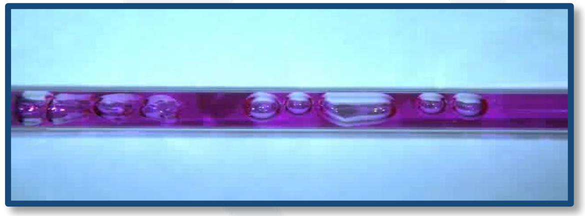
- Oscillates Contents at ~60 Hz, 100g
- Intense material interaction driven by uniform acoustic energy
- Broad mixing application base:
  - Liquids, Pastes, Solids, Multi-phase
  - Energetics, Chemical, Pharmaceutical, Energy Storage
- Seamlessly scalable from bench to industrial-scale processes

Bench-Scale Energetic Mixer
Hazardous Materials Rated

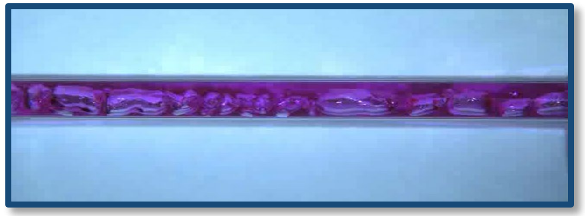


Multiphase Visualization in RAM Continuous Flow Cell

Compressive Regime vs. Splitting and Combining Regime



0 *g* Acceleration, 150 mL/min
4 mm Inner Diameter
Re = 780 → laminar flow



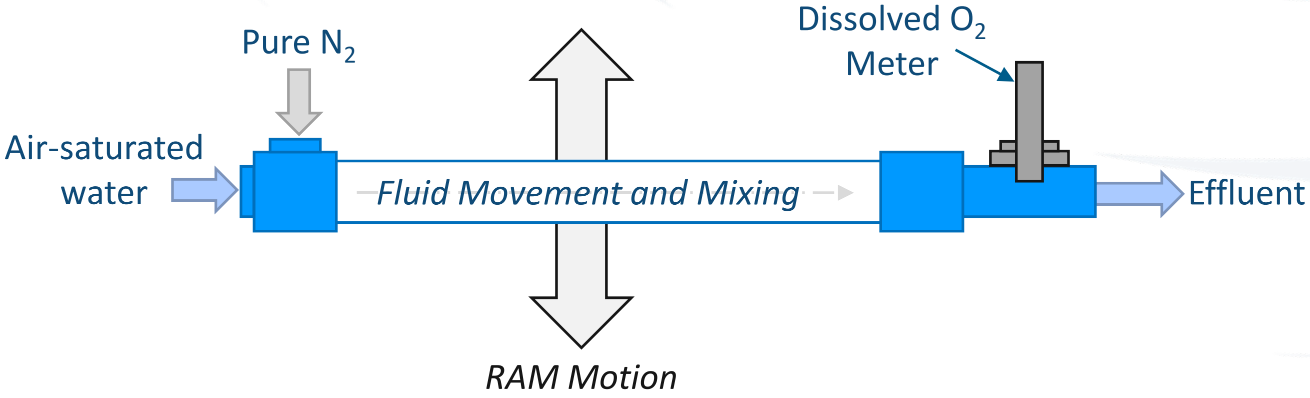
40 *g* Acceleration,
150 mL/min

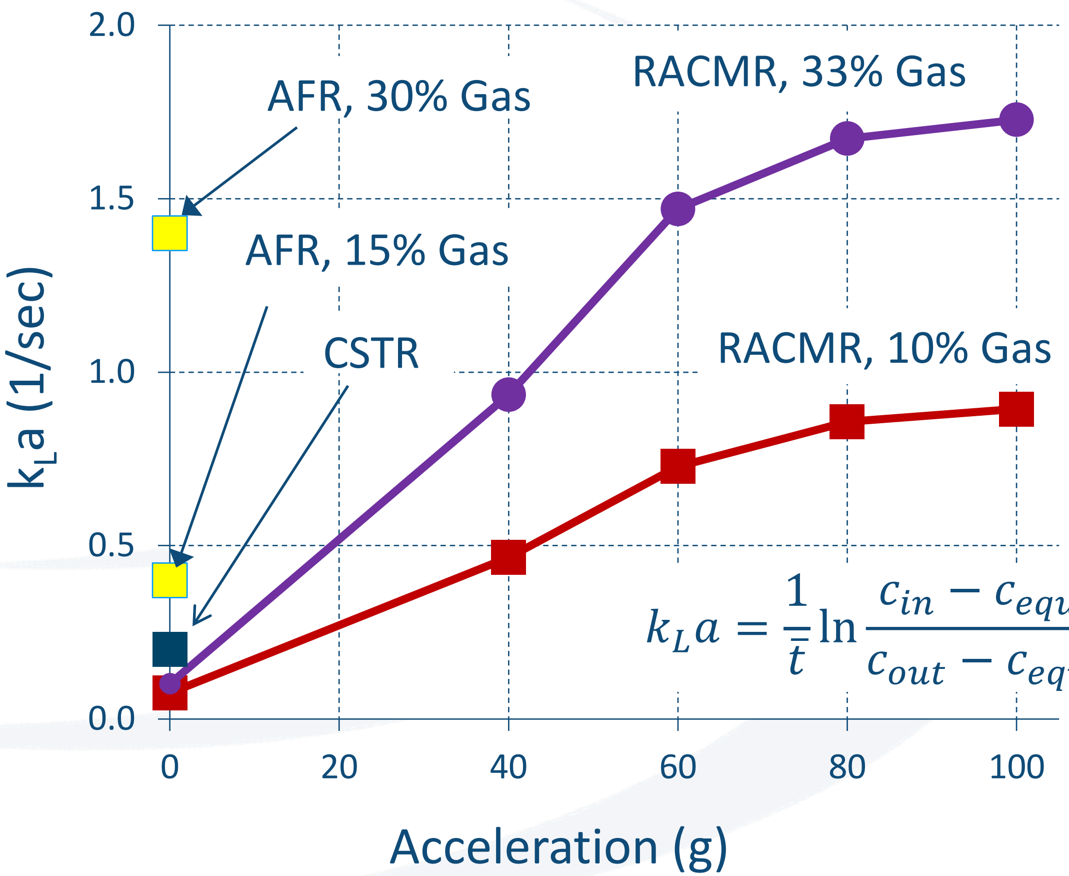
100 *g* Acceleration,
150 mL/min

Gas Headspace is Required for RAM Enhanced Mixing

Mass Transfer Coefficient Measurement

- **Dissolved Oxygen Experiments:**
  - Air-saturated water fed with pure N_2
  - Dissolved-oxygen meter measures transfer of O_2 to gas phase
  - Corning AFR is 7-fold improvement in Mass Transfer compared to legacy CSTR
  - Continuous ResonantAcoustic® Mixing is a further 35% improvement in Mass Transfer with an 88% lower residence time





$$k_L a = \frac{1}{t} \ln \frac{c_{in} - c_{equ}}{c_{out} - c_{equ}}$$

Model Reaction Study: Mixing Time Measurement

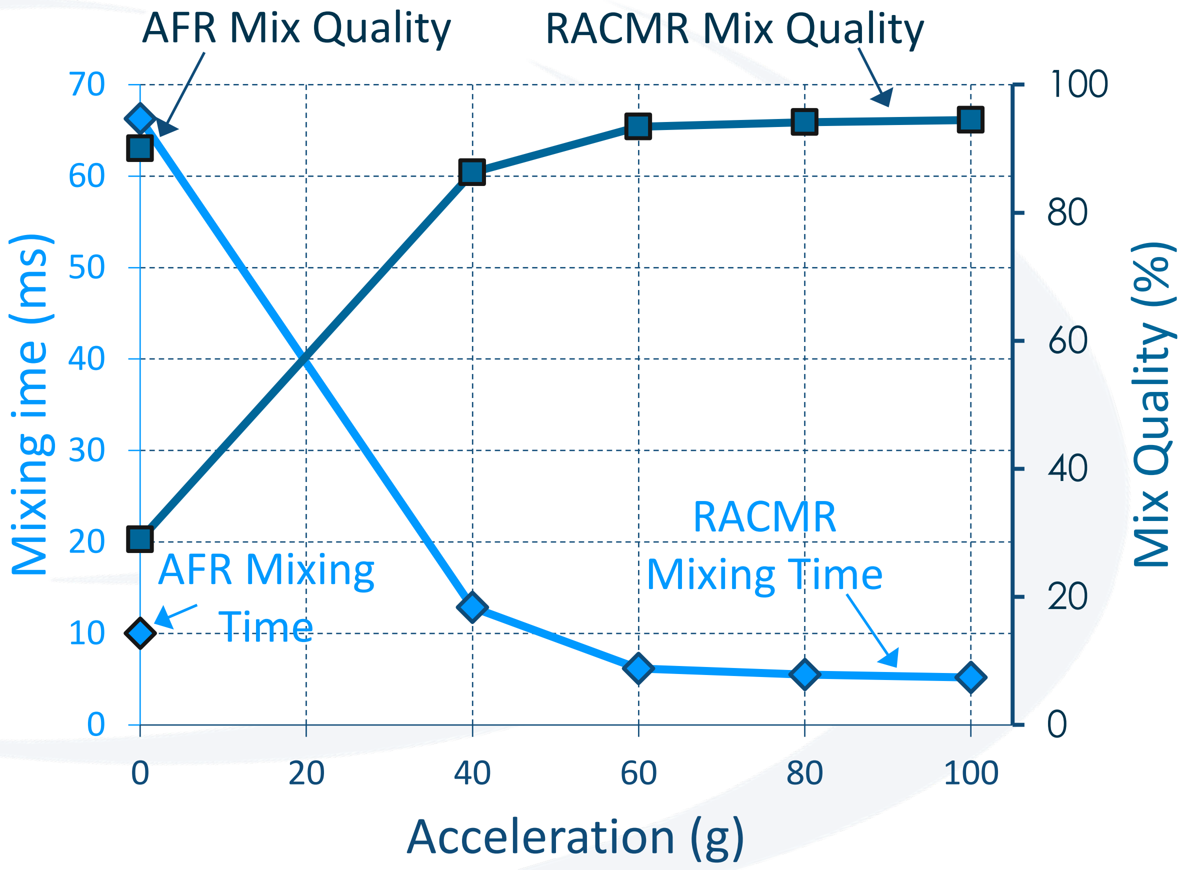
- Parallel Competitive Reactions to quantify mixing time

$$H_2BO_3^- + H^+ \overset{fast}{\longleftrightarrow} H_3BO_3$$

$$IO_3^- + 5I^- + 6H^+ \overset{slower}{\longleftrightarrow} 3I_2 + 3H_2O$$

$$I_2 + I^- \leftrightarrow I_3^-$$

- Fast reaction consumes acid when perfectly mixed
- Any degree of poor mixing, side reaction will form I_2 formation
- UV/VIS measurement of $[I_3^-]$ in product, used to calculate mix quality and mixing time



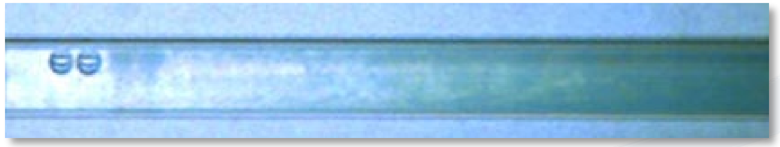
Precipitation Reaction Demonstration

- Advanced microreactors easily clog in the presence of solids
- Continuous ResonantAcoustic® process can handle solids

- Example: Formation of Basic Copper Carbonate solids

$$2\,Cu^{2+}(aq) + 2CO_3^{2-}(aq) + H_2O \rightarrow Cu_2(OH)_2CO_3(s) + CO_2(g)$$

0 g Acceleration

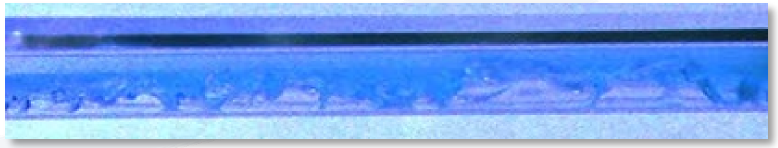


40 g Acceleration

60 g Acceleration

80 g Acceleration

100 g Acceleration

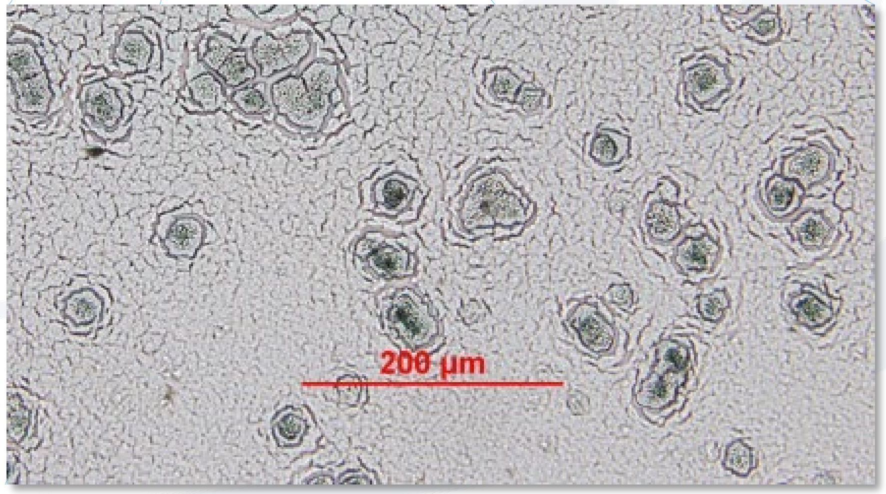


Precipitation Reaction Demonstration

Sample collected from microreactor
80-100 *g* acceleration

After Centrifuging

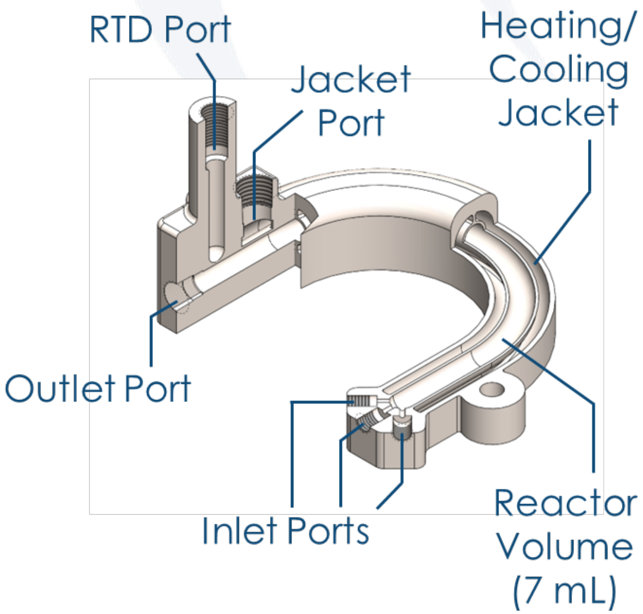
Solids Recovered from Centrifuge Vial



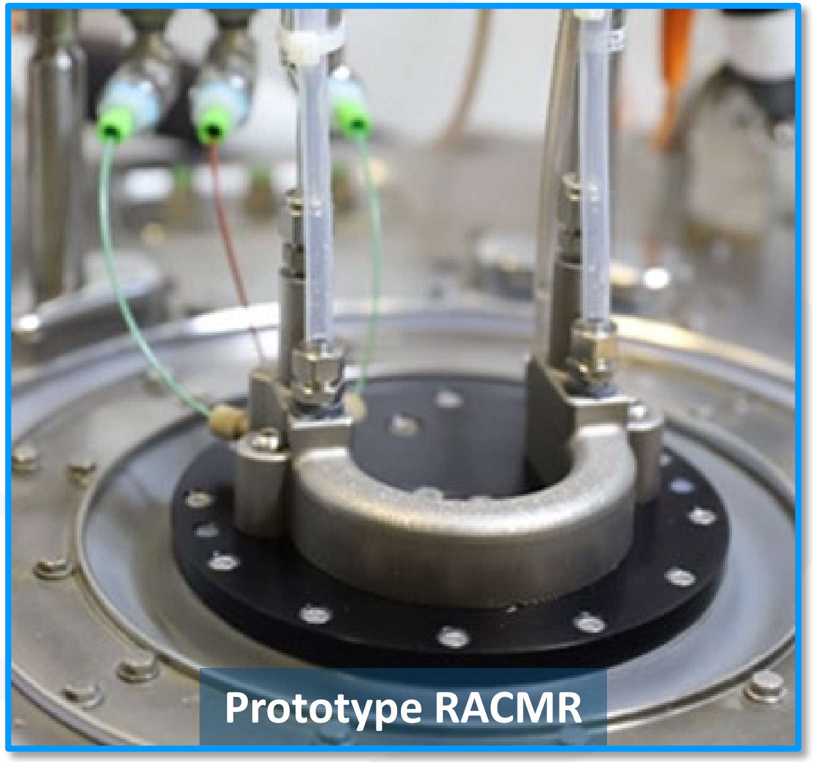
Microscope Images Reveal Basic Copper Carbonate Particles

ResonantAcoustic® Continuous Microreactor (RACMR)

- RACMR Prototype:
  - Incorporation of up to three reactants
  - Immediate and complete mixing of reactants
  - RAM results in plug flow fluid profile
  - Jacketed for cooling or heating of reaction mixture

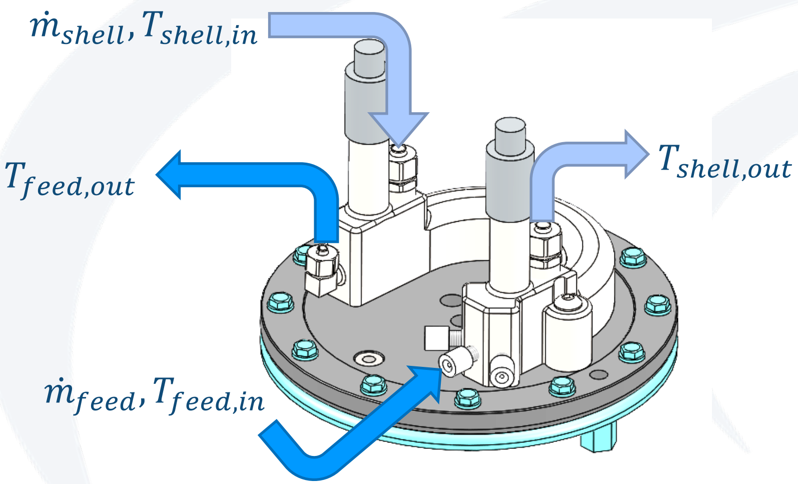


RACMR Design



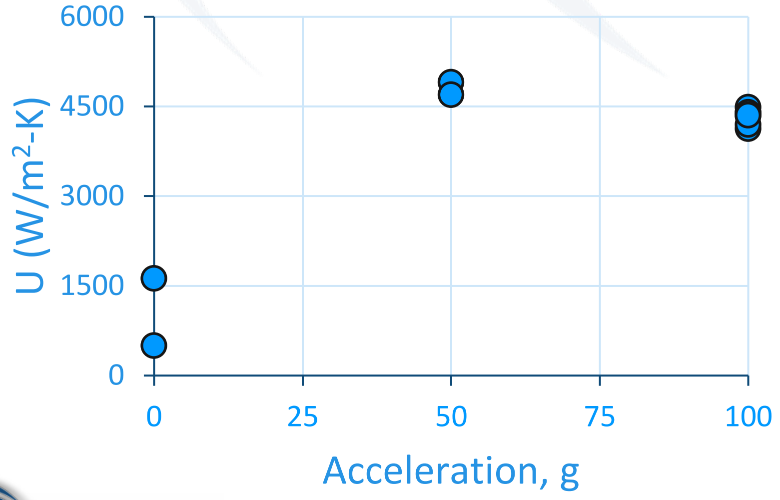
Prototype RACMR

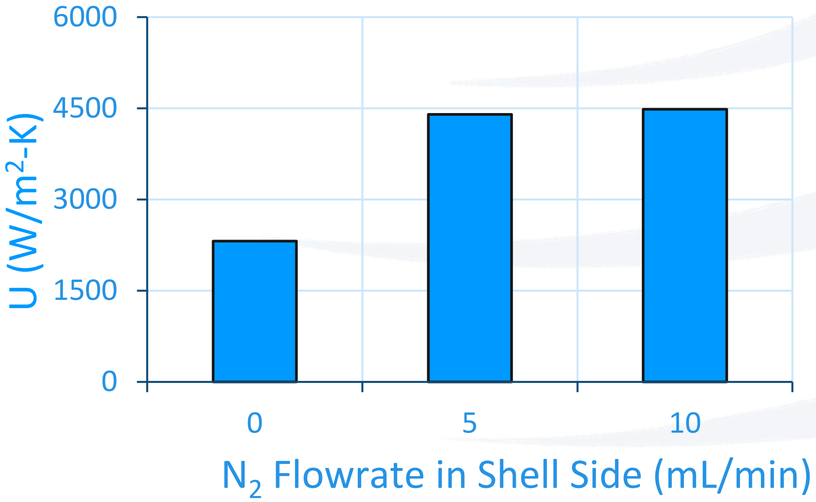
Heat Transfer Coefficient Measurement

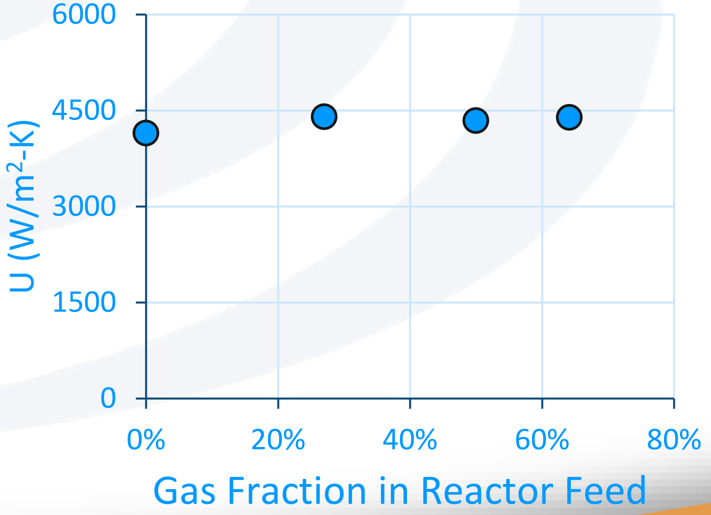


$$\dot{q} = \dot{m}_{feed} C_{p,feed}\left(T_{feed,in} - T_{feed,out}\right)$$
$$= \dot{m}_{shell} C_{p,shell}\left(T_{shell,in} - T_{shell,out}\right)$$

$$\dot{q} = UA\Delta T_{LM} = UA \frac{\left(T_{shell,out} - T_{feed,in}\right) - \left(T_{shell,in} - T_{feed,out}\right)}{\ln\left(\left(T_{shell,out} - T_{feed,in}\right) / \left(T_{shell,in} - T_{feed,out}\right)\right)}$$



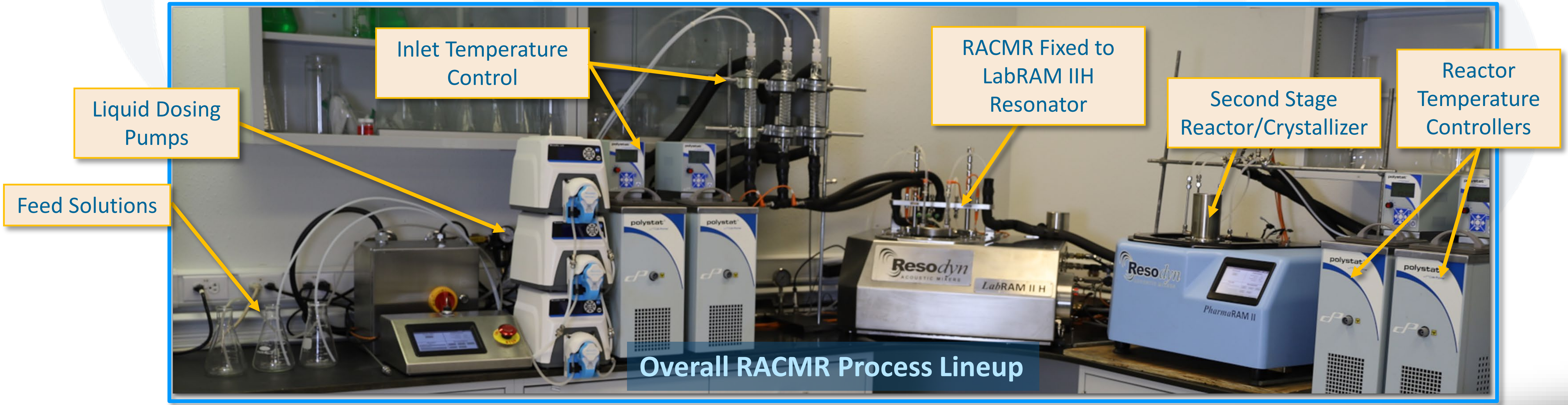




Demonstration of RACMR Flow Process

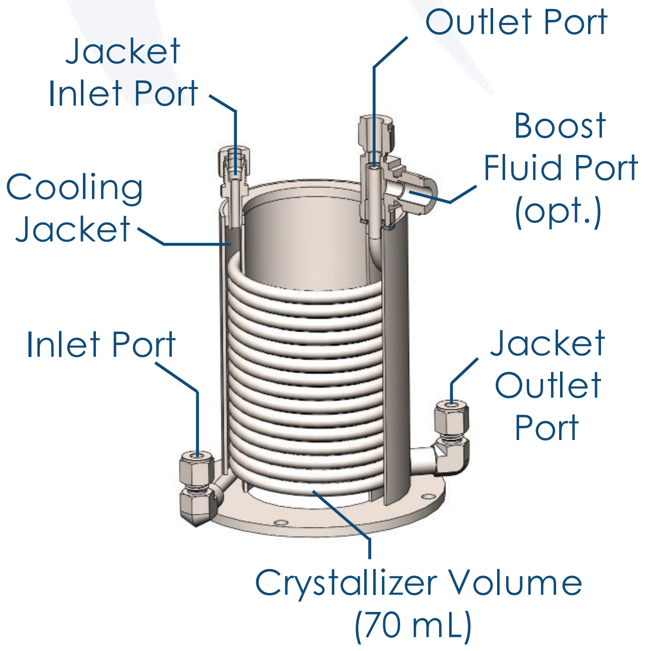
Highlights:

- Demonstrated synthesis of energetic precursors
- Continuous synthesis with high purity and yield
- Delivery of >1kg of >99% pure product

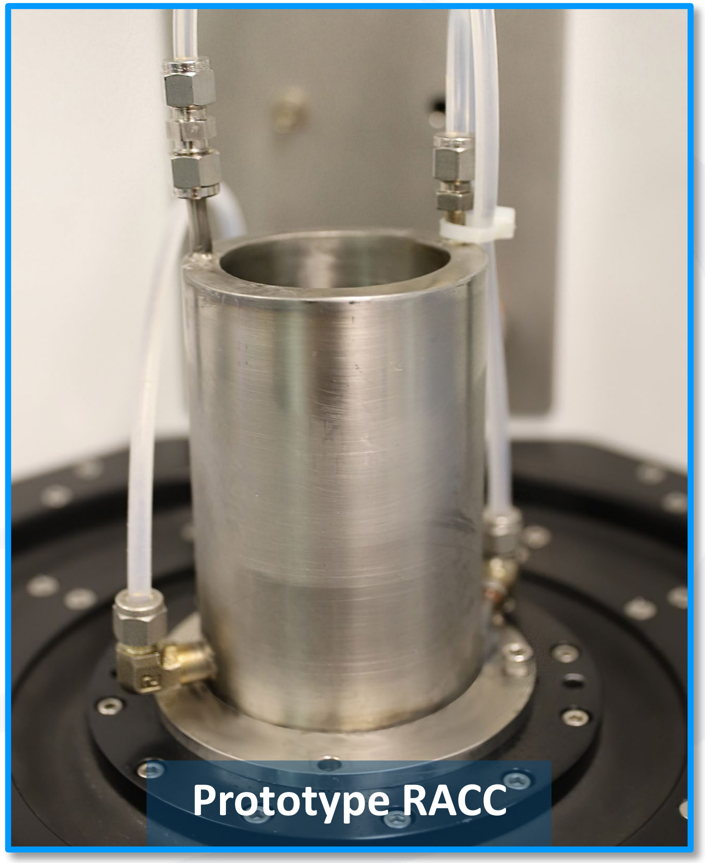


ResonantAcoustic® Continuous Crystallizer (RACC)

- RACC Prototype:
  - Optimized for Cooling Crystallization
  - Saturated solution fed through coil
  - Jacket supplied with coolant
  - Slurry product filtered



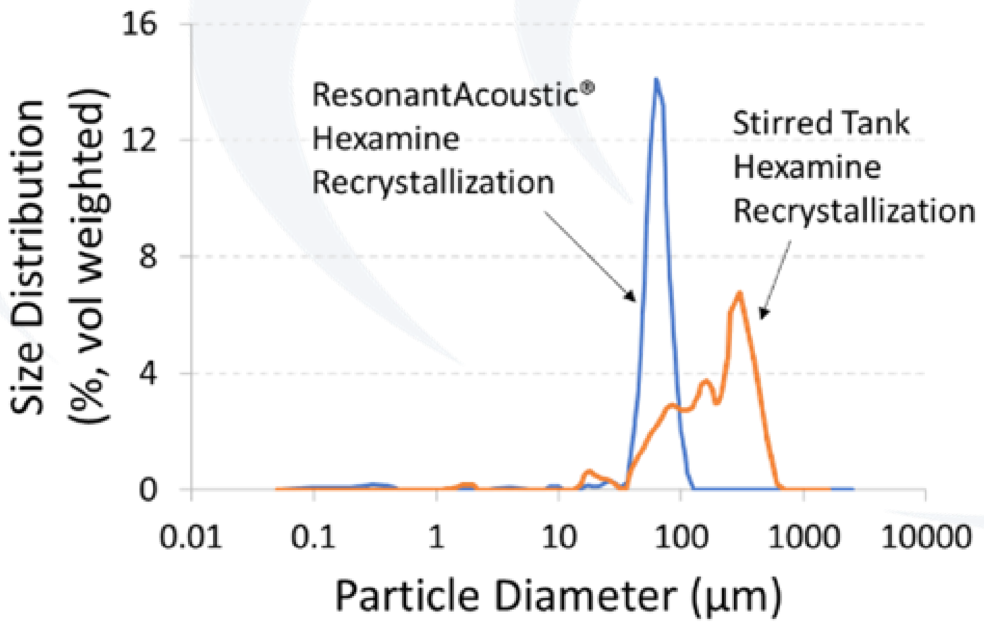
RACC Design

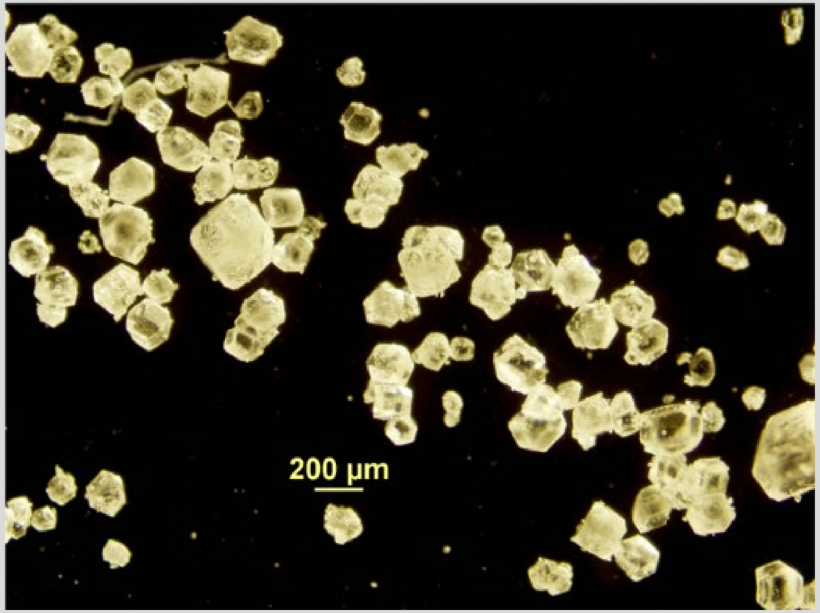


Prototype RACC

Recrystallization of Hexamine

- RACC provides 90% narrower Crystal Size Distribution

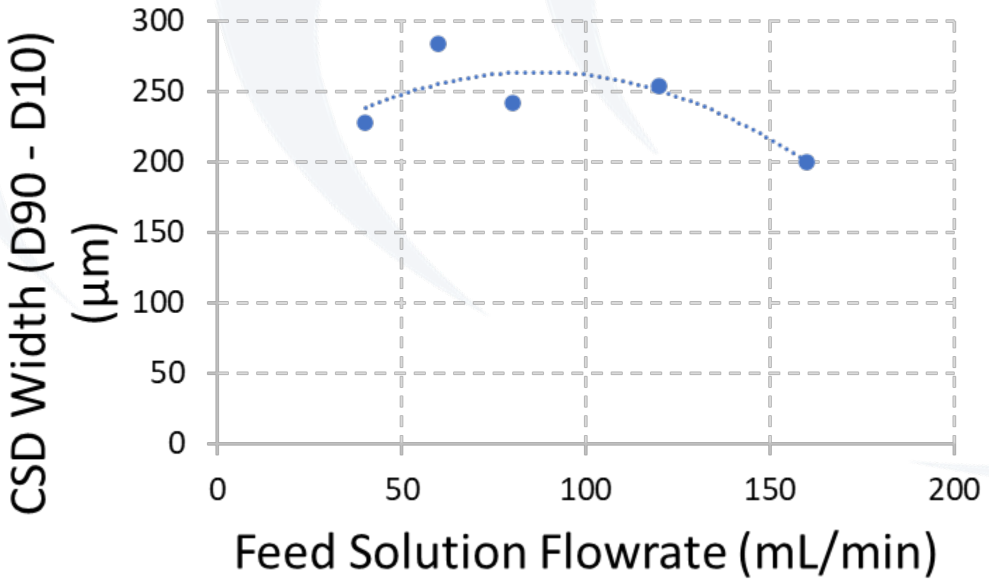




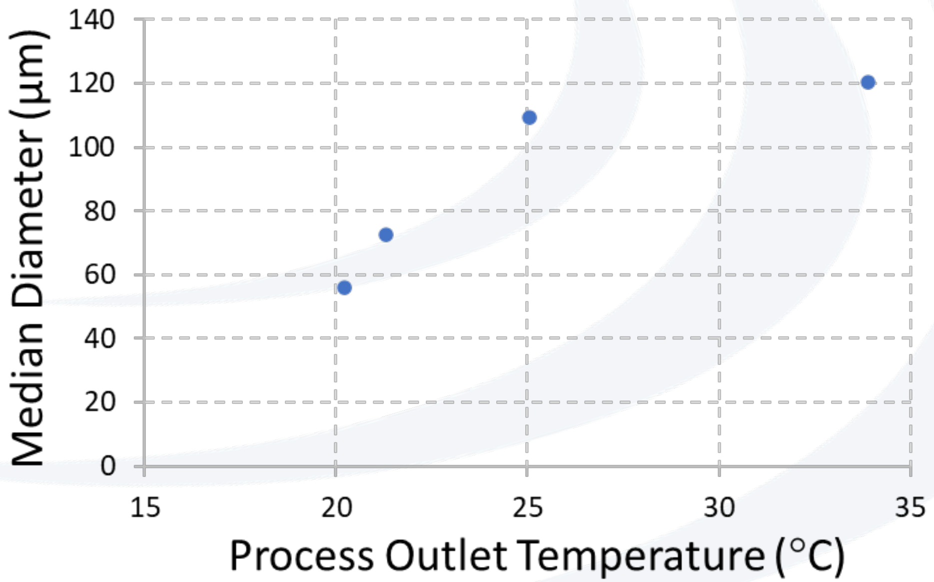
Hexamine recrystallized via RACC

Recrystallization of Hexamine

- Narrow CSD across broad inlet RACC flow range

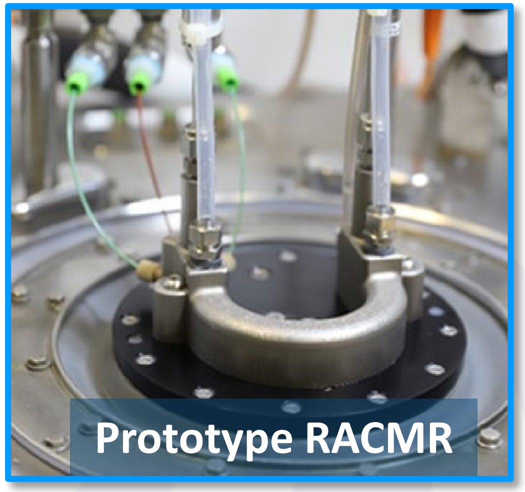


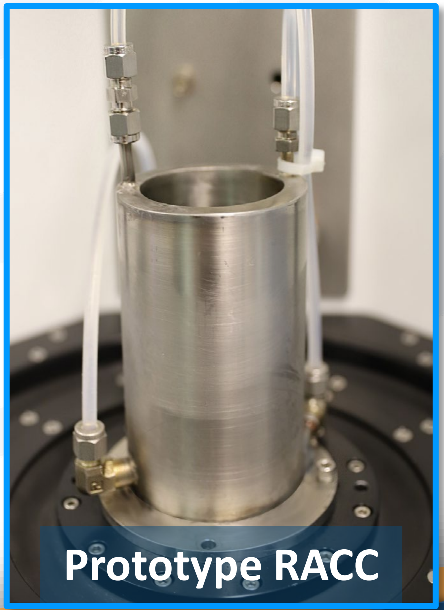
- Mean Particle Size is tunable based on Jacket Temperature



Summary

- Continuous Chemical Processing Benefits:
  - Rapid and complete incorporation of feeds (mixing time: 6 ms)
  - Highly effective heat transfer (U = 4,400 W/m^2-K)
  - Mass/Heat Transfer independent of flow velocity
  - Ability to handle slurries, viscous flow, multi-phase processes etc.
  - Scalable process from bench-scale to industrial-scale reactors
- ResonantAcoustic® Continuous Microreactor:
  - Demonstrated synthesis of energetic precursors
  - Continuous demonstration with consistent high yield
- ResonantAcoustic® Continuous Crystallizer:
  - 90% narrower crystal size distribution than legacy crystallizer
  - Ability to tune crystal morphology to desired range based on shell temperature


Prototype RACMR


Prototype RACC

Acknowledgements

Thank you for your time and attention.

Process Improvement of Melt Pour Explosive 3,4-Dinitropyrazole (DNP)

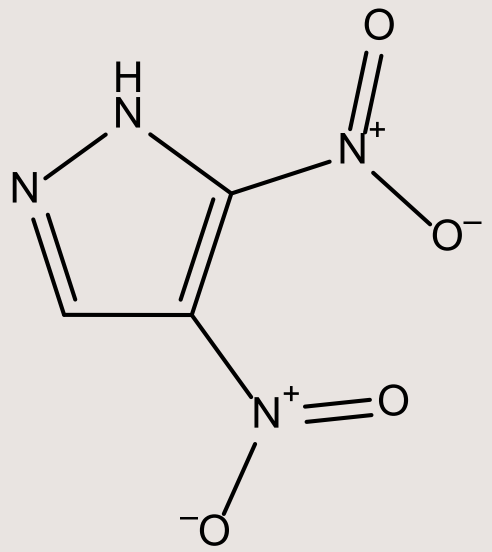
Tomasz Modzelewski PhD. (BAE), Neil Tucker PhD. (BAE), Philip J. Samuels (CCDC-AC), Keyur Patel (CCDC-AC) and Christopher Y. Choi (CCDC-AC)

October 2022

BAE SYSTEMS

Background

- Recent shift towards IM explosives resulted in a need for a less sensitive replacement for TNT (classic melt pour explosive filler)
- Material required to have similar melting profile and explosive performance
- 3,4-dinitropyrazole (DNP) identified as a highly promising candidate
  - Commercially available starting material
  - Easily nitrated to final product
  - Similar melt temperature



DNP

DNP Performance

- Better explosive performance than Comp-B
- Higher density than both Comp-B and TNT
- Increased stability towards external stimuli

Property	TNT	MIL-C-401E Comp-B	DNP
DSC Exotherm (°C)	288	214	276
P_{CJ} (GPa)	18.91	29.22	30.2
Density (g/cc)	1.63	1.71	1.87
VOD (km/s)	6.63	8.02	8.25
√2E (mm/µs)	6.94	7.91	
BAM Friction (N)			246 (164[1])
Naval Impact (cm)	157 (27[1])	59	55 (39[1])
ESD (J)	0.19		0.2625
DSC Melt (°C)	80.9	79.0	87

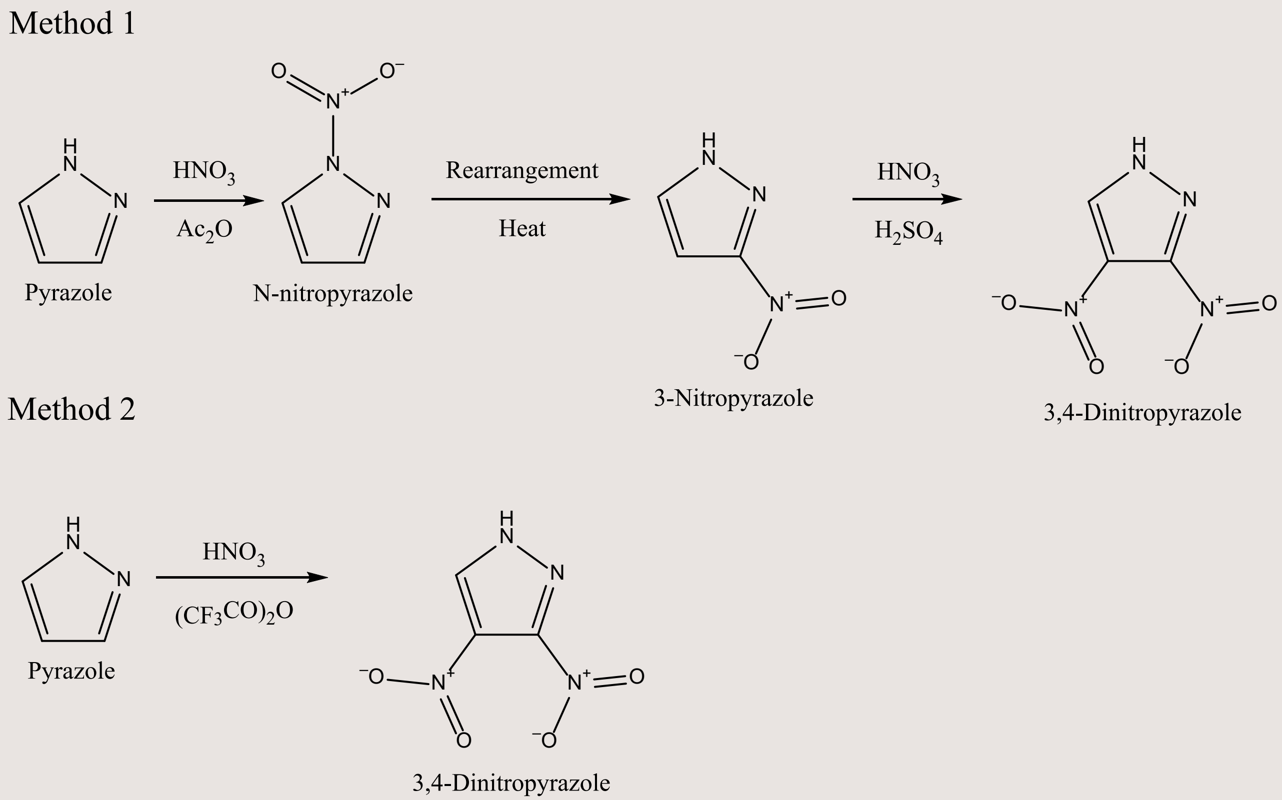
[1]RDX Class 5 Standard

BAE SYSTEMS

DNP Legacy Synthesis

- Two primary synthetic routes

1. Mixes Sulfuric / Nitric acid
   - Not scalable at HSAAP due to limited ability to recover spent sulfuric acid
2. Trifluoroacetic anhydride
   - Not scalable at HSAAP due to inability to recover trifluoroacetic anhydride / trifluoroacetic acid

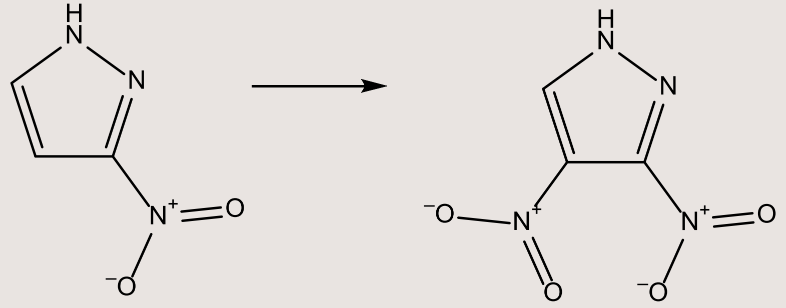


Project Goals

1. Simplify DNP synthesis to:
   1. Allow it to be manufactured at HSAAP
   2. Limit operator exposure
   3. Reduce overall labor cost
2. Decrease / Eliminate waste streams
   1. Eliminate need for off-site disposal
   2. Decrease final cost of DNP

Initial Exploration of Alternative Nitration Protocol

- Initial trials (-43, -44, -45) were sampled at end of reaction, not fully worked up
  - New chemistry showed promise
  - Inconsistent nitration
- Second set (-48, -50, -52) showed increased efficacy
  - 2-step single-pot process
    - nitration and sample workup/purification
  - No organic solvents required
  - More reliable conversion
  - High nitrate content of final product
- Required a modification to final product to eliminate remaining nitric acid in the solid material



Trial	Yield (%)	Purity (%)	Nitrate Content (wt%)
1190-43	NA	2.5	NA
1190-44	NA	100 (oil)	NA
1190-45	NA	12.4	NA
1190-48	78.4	99.9	0.24
1190-50	51.2	100.0	0.25
1190-52	100.0	96.8	0.33

BAE SYSTEMS

Optimization of New Protocol

- DOE process optimization (17 trials)
  - Variation of 5 reaction parameters
- System showed dependence on only one 1 parameter, with remaining 4 providing minor/no influence
- Optimal reaction parameters: Trial 17
  - Highest yield and purity
  - Acceptable nitrate concentration

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Yield (%)	12.6	40.0	62.5	62.8	0.12	62.5	0.33	0.09	22.7	30.9	2.45	63.2	0.14	62.62	65.4	1.98	67.9
Purity (%)	0.66	99.8	99.9	99.9	0.29	99.9	3.36	0.27	67.5	65.4	16.0	98.8	0.37	99.8	98.5	5.36	99.9
Nitrate (wt%)	0.02	0.00	0.11	0.12	0.01	0.00	0.01	0.02	0.01	1.28	0.01	0.01	0.02	0.02	0.02	0.01	0.03
DSC Melt (°C)	175.6	85.9	87.3	87.9	176.3	87.5	172.8	175.0	67.9	oil	64.8 156.6	87.3	175.2	86.5	83.8	171.1	86.5

BAE SYSTEMS

Effects on Explosive Sensitivity

- All trials which formed DNP showed similar explosive sensitivity
- No discernable difference between samples
- Samples which showed poor/no conversion were not tested

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Purity (%)	0.66	99.8	99.9	99.9	0.29	99.9	3.36	0.27	67.5	65.4	16.0	98.8	0.37	99.8	98.5	5.36	99.9
Nitrate (wt%)	0.02	0.00	0.11	0.12	0.01	0.00	0.01	0.02	0.01	1.28	0.01	0.01	0.02	0.02	0.02	0.01	0.03
Holston Impact (cm)	NA	>85 (45.8)	>85 (45.8)	>85 (45.8)	NA	>85 (45.8)	NA	NA	>85 (47.5)	NA	NA	>85 (47.5)	NA	>85 (50.8)	>85 (47.5)	NA	>85 (50.8)
BAM Friction (N)	NA	>221 (221)	>221 (221)	>221 (221)	NA	>221 (221)	NA	NA	>247 (247)	NA	NA	>247 (247)	NA	>234 (234)	>221 (221)	NA	>234 (234)
ESD (J)	NA	0.138 (0.074)	0.138 (0.089)	0.101 (0.089)	NA	0.138 (0.074)	NA	NA	0.138 (0.074)	NA	NA	0.165 (0.074)	NA	1.165 (0.089)	0.138 (0.089)	NA	0.138 (0.089)

BAE SYSTEMS

Initial Scaleup: RC1e

- Procedure scaled up to run in Mettler Toledo RC1e unit
  - 2L primary reaction vessel
  - Completely computer controlled
  - Provides continual monitoring of reaction parameters and calculation of heats of reaction
- Two trials
- Good reproducibility
- 100% yield when accounted for DNP remaining in final waste stream

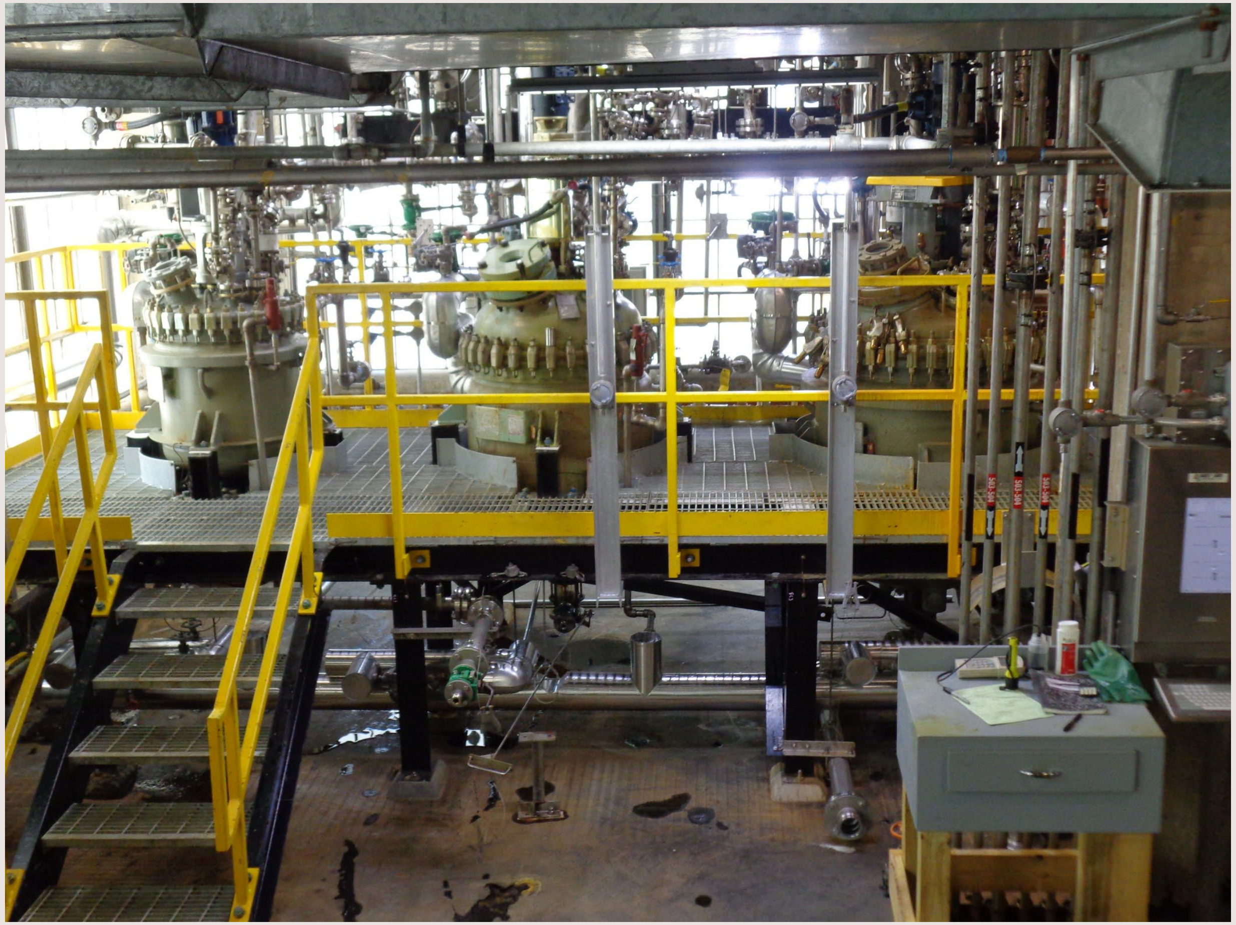
Sample	Yield (%)	Purity (%)	Nitrate (wt%)	T_{melt} (°C)	ESD (J)	BAM Friction (N)	Holston Impact (cm)
1203-30	73	99.70	≤0.02	87.3	0.165 (0.074)[1]	278 (212)[1]	>85 (53)[1]
1203-32	73	99.87	≤0.02	85.3	0.138 (0.074)[1]	268 (212)[1]	>85 (53)[1]

[1]RDX Class 5 Standard

BAE SYSTEMS

Upcoming Effort: Pilot Plant

- Transitioning new manufacturing process to HSAAP Pilot Plant facility
  - Multiple batches will be produced
  - Process challenges will be fully addressed
  - Final material provided to customer for evaluation



Summary

- DNP is a leading candidate for next-generation melt pour IM explosive
  - Legacy synthesis routes not scalable at HSAAP
- New synthesis process developed
  - Fully proved out on lab scale and able to be scaled based on HSAAP infrastructure
  - Waste streams easily managed on site
- Process to be scaled up to HSAAP pilot plant facility
  - Allow for final process challenges to be addressed
- Ready for full scale production at HSAAP

Continuous ResonantAcoustic® Production of Energetic Material

Stephanie Trant

Process Development Engineer

Resodyn™ CORPORATION

Building Value through Discovery and Innovation®

Project Overview

Objectives

- Design, Fabricate and Test an Energetics Rated Continuous Acoustic Mixing – Clean In Place (CAM-CIP) system
- Demonstrate Energetic PBX Production at NAWCWD China Lake Using the Energetics Rated CAM-CIP system

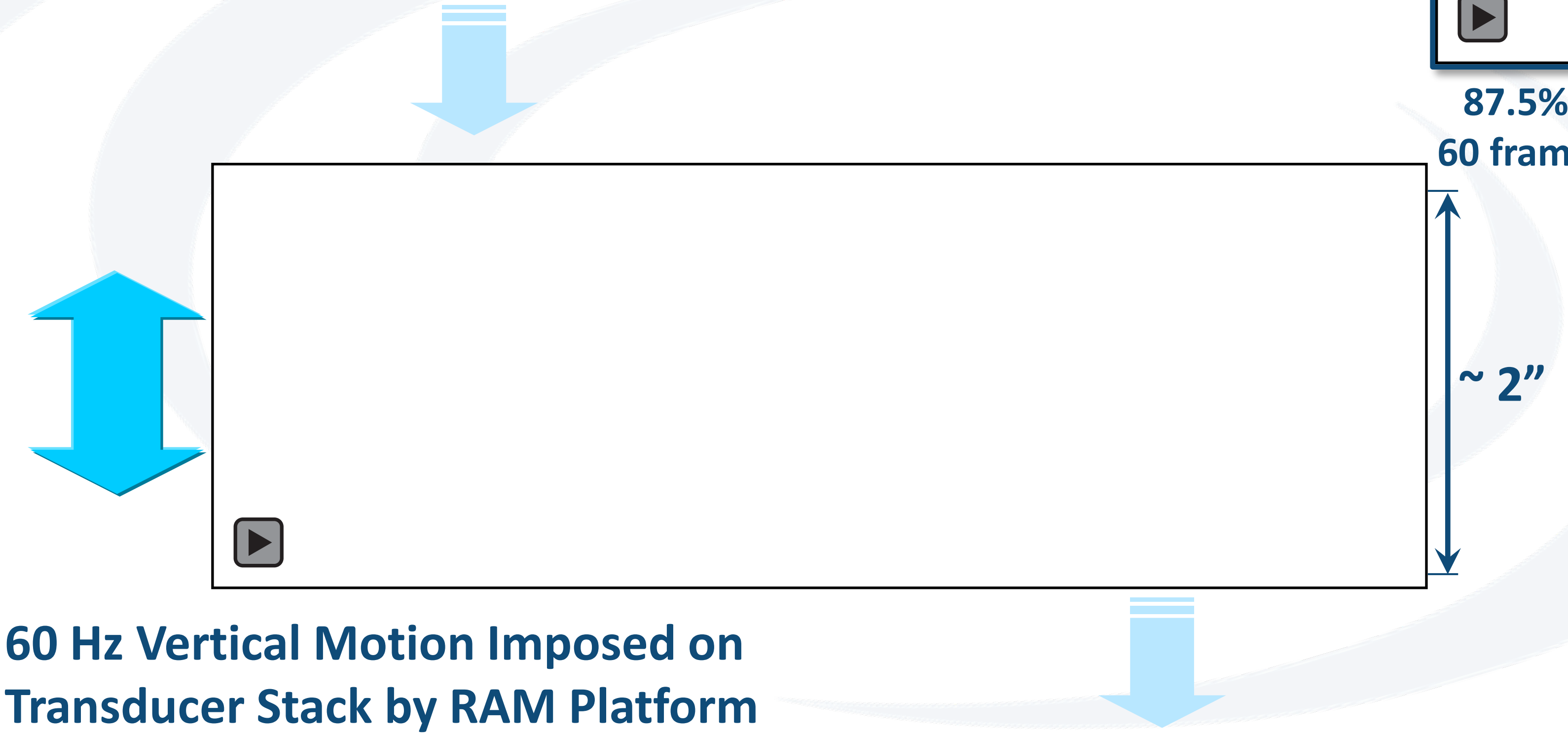
Results

- CAM-CIP Module Completed and Tested
- Testing of Energetics Rated Ancillary System Ongoing
- Expect to Produce Energetic PBX Material once set up at China Lake

Continuous Acoustic Mixer - Paste

87.5% Solids Paste
60 frames per second

Continuous Module Inlet



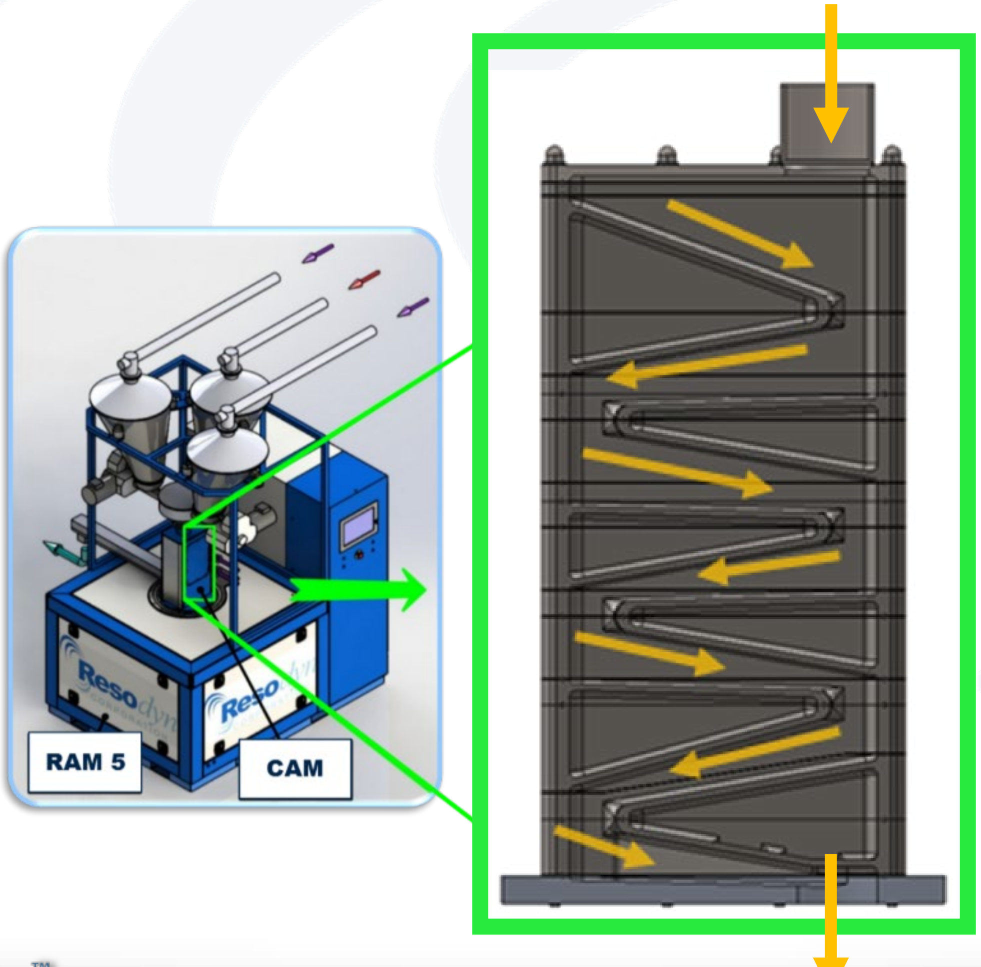
60 Hz Vertical Motion Imposed on Transducer Stack by RAM Platform

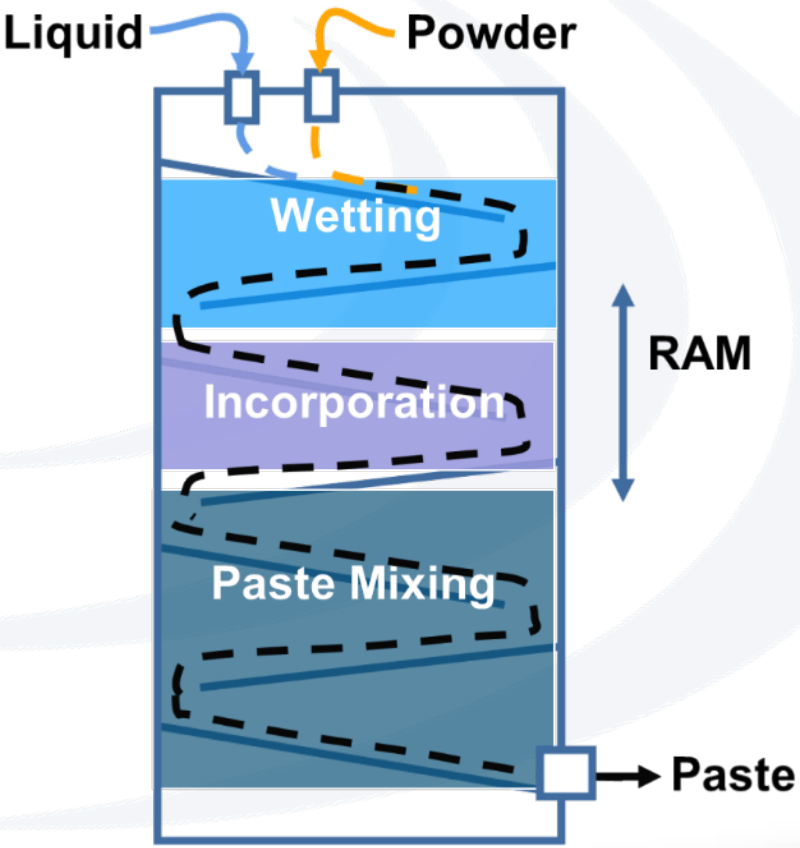
Continuous Module Outlet

Upper and Lower Acoustic Transducers Continuously work on the Materials being Mixed

Continuous Mixing Schematics

Continuous Acoustic Mixer (CAM)

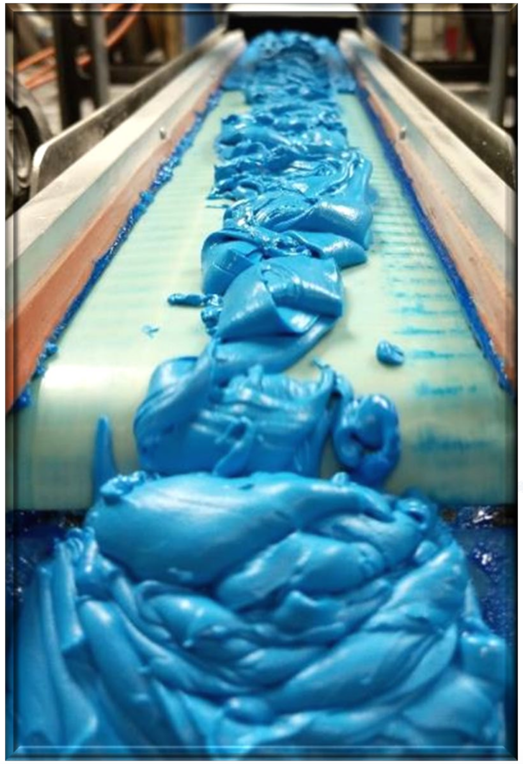




Mixing Pastes Continuously

CAM-CIP for RAM 5

- Paste Viscosities: >1,000,000 cP at Room Temperature
- Tested at: 3.0 kg/min or 180 kg/hr



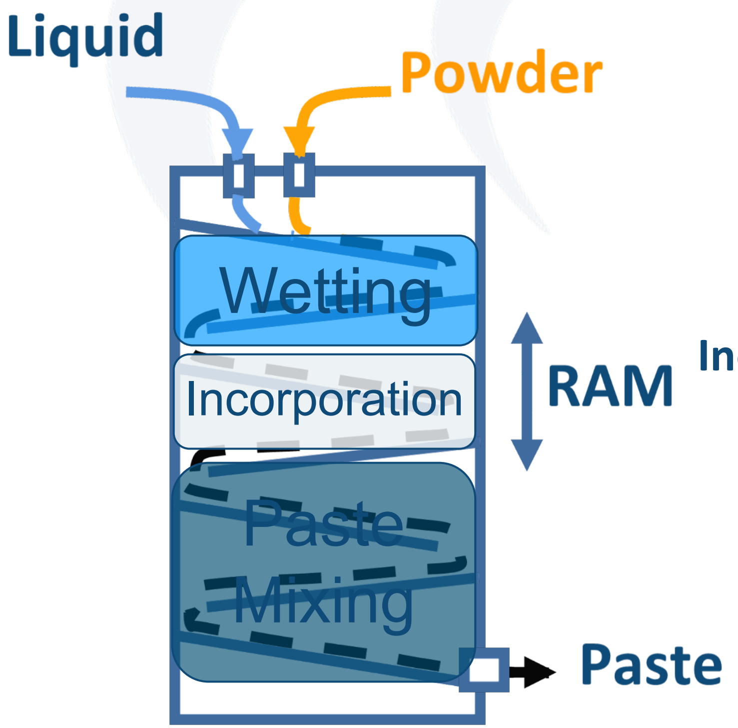
Continuous Mixing System

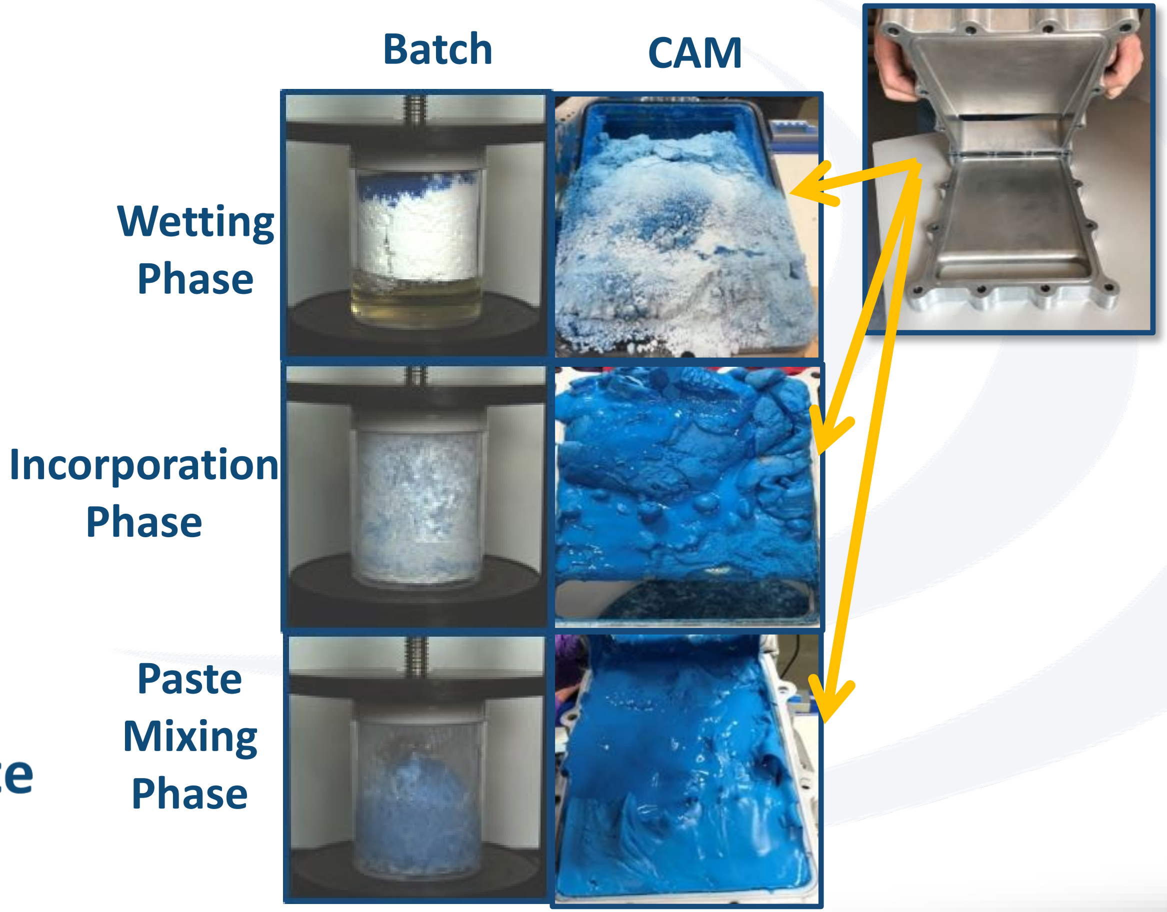
Unclassified. Distribution Unlimited.

Resodyn™ ACOUSTIC MIXERS

Continuous Module Mix Regimes

Mix Regimes are the Same within the CAM as in Batch





Characterization of the CAM-CIP

Test	Solids Loading %	Acceleration *G*	Flow Rate gm/min	Solids Loading Range %
1	92.6	60	932	0.4097
2	92.6	80	932	3.175
3	88.6	70	535	1.044
4	89.0	60	970	0.5808
5	89.0	80	970	0.6595
6	86.0	70	1,500	0.00989
7	87.5	60	1,760	0.1824
8	89.0	70	2,500	0.1230
9	87.5	80	2,500	0.5012
10	86.0	60	2,500	0.4531
11	87.5	70	1,250	0.1617

Plastic Bonded Surrogate Explosive Paste

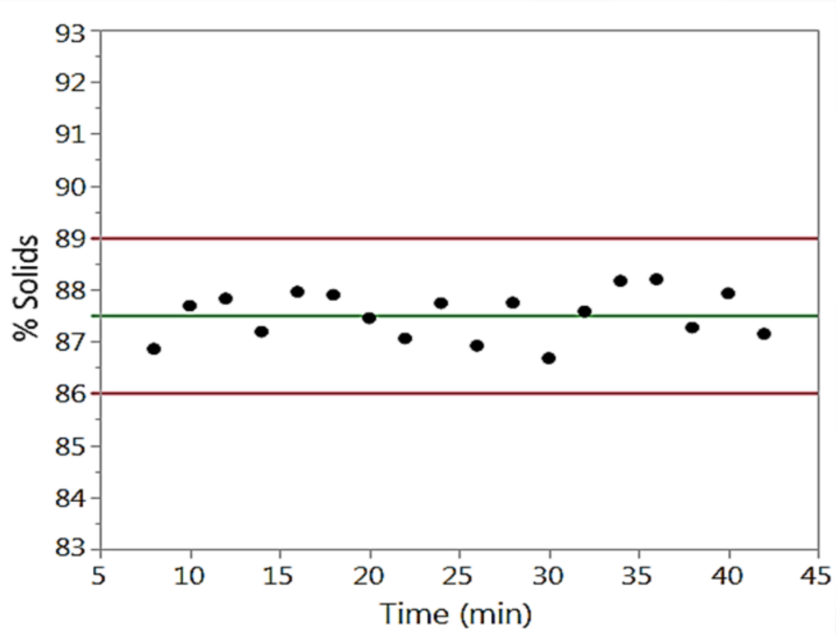
Regression Analysis:

- JMP Software was utilized
- All source interactions are statistically significant
- The interaction between solids loading and acceleration is the most significant

Source Interactions	p-value
Solids Loading (%)	0.0233
Acceleration (g)	0.0408
Flow Rate (gm/min)	0.0150
Solids Loading (%), Acceleration (g)	0.0016
Solids Loading (%), Flow rate (gm/min)	0.0236
Acceleration (g), Flow Rate (gm/min)	0.0264

Mixed material was tested for consistency using:

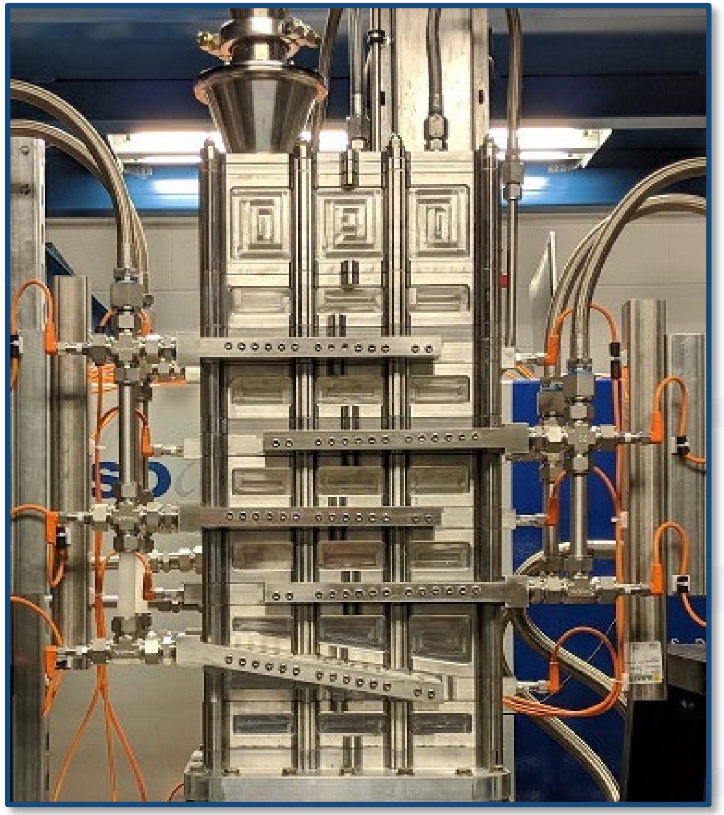
- Thermal Gravimetric Analysis



Temperature Control – Heating or Cooling

Embedded Heat Transfer Channels within CAM Modules

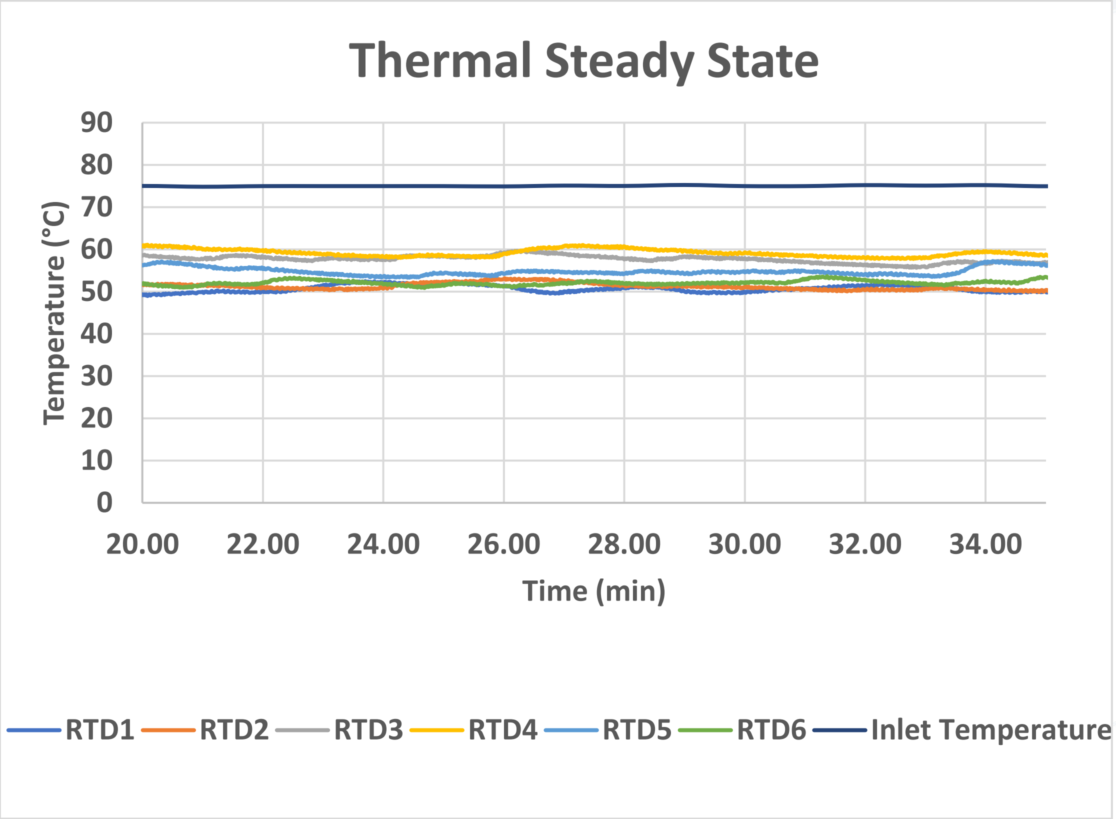
Through Plate Channels
For Cooling, or Heating
Fluids

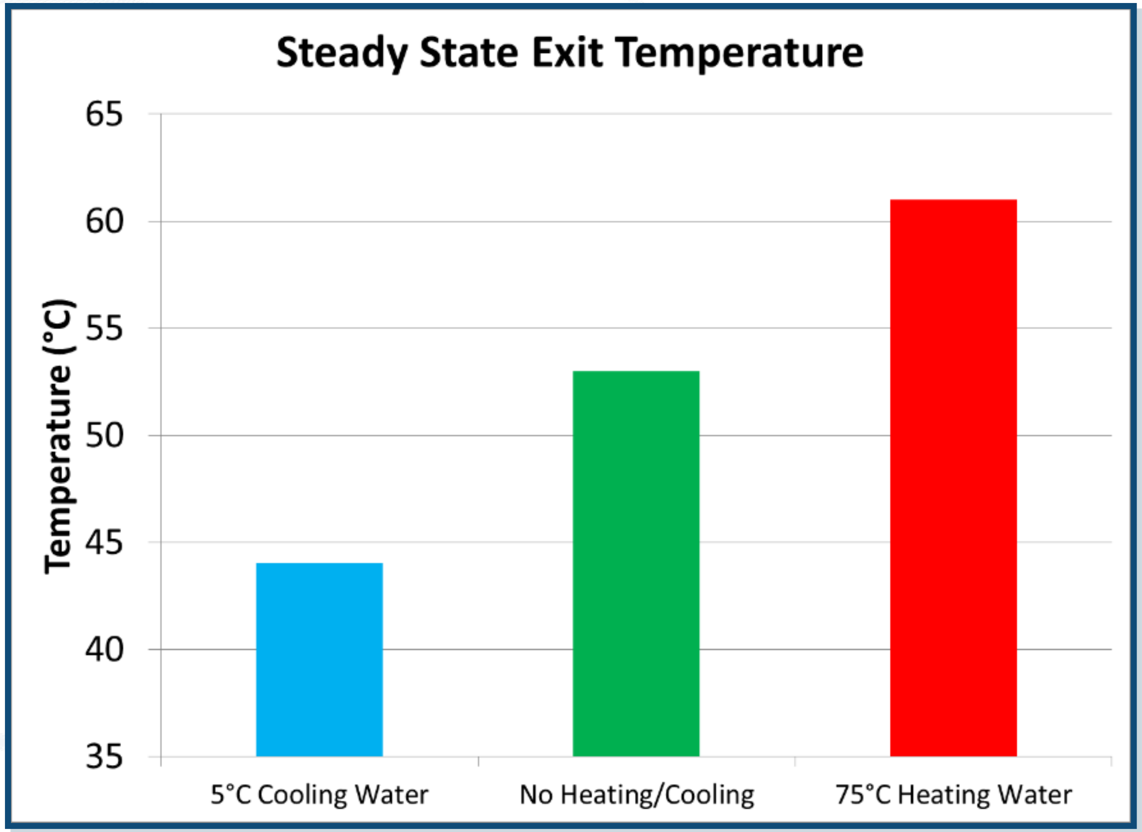


Temperature
Control Manifolds

Thermowells
Several Plate
Locations to Measure
Mix Temperature Progress
Through the Stack

CAM-CIP Temperature Control



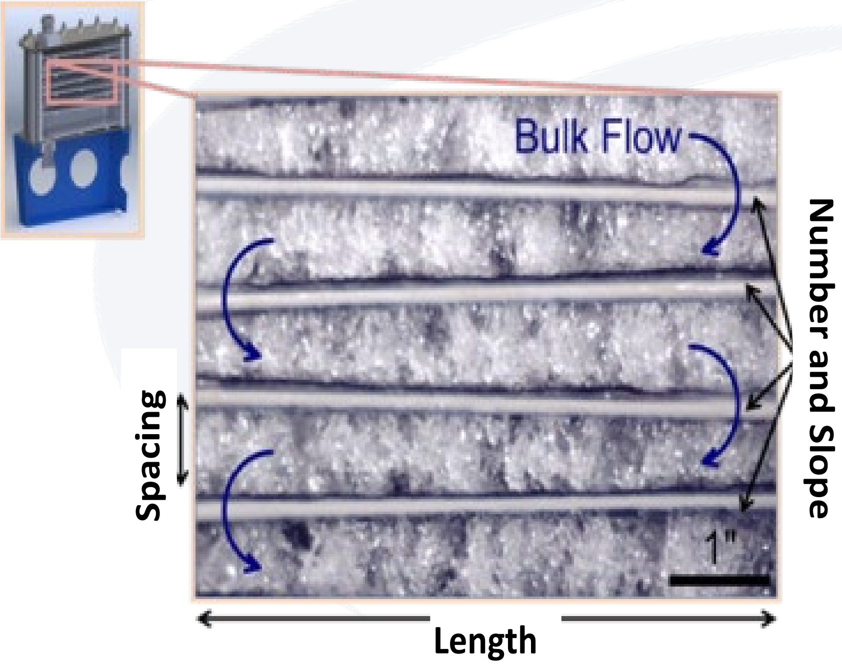


Clean-in-Place (CIP)

Current Typical Batch Cleaning

- Uses Organic Solvents
  - Hazardous Air Pollutants (HAP)
  - Exposure source for workers
- Creates Waste
  - Residual material ≈ 5% by mass
  - Cleaning supplies and PPE ≈ 10% by mass

Clean-in-Place (CIP)



Prototype CAM Processing

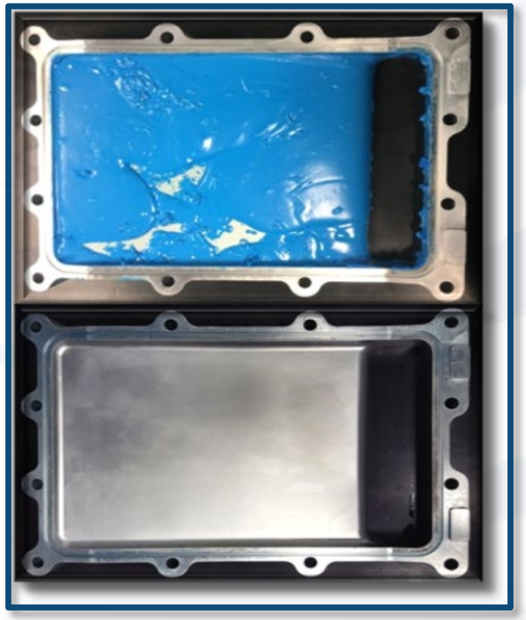
Water and Air

CAM Clean in Place (CIP)

- Cleaning Inert PBX Surrogate from CAM using Clean-in-Place
- 5 kg of Material Wasted
- Less than 9 L of Aqueous Waste
- 100% Removal Efficiency Achieved

After Runout
Before Cleaning

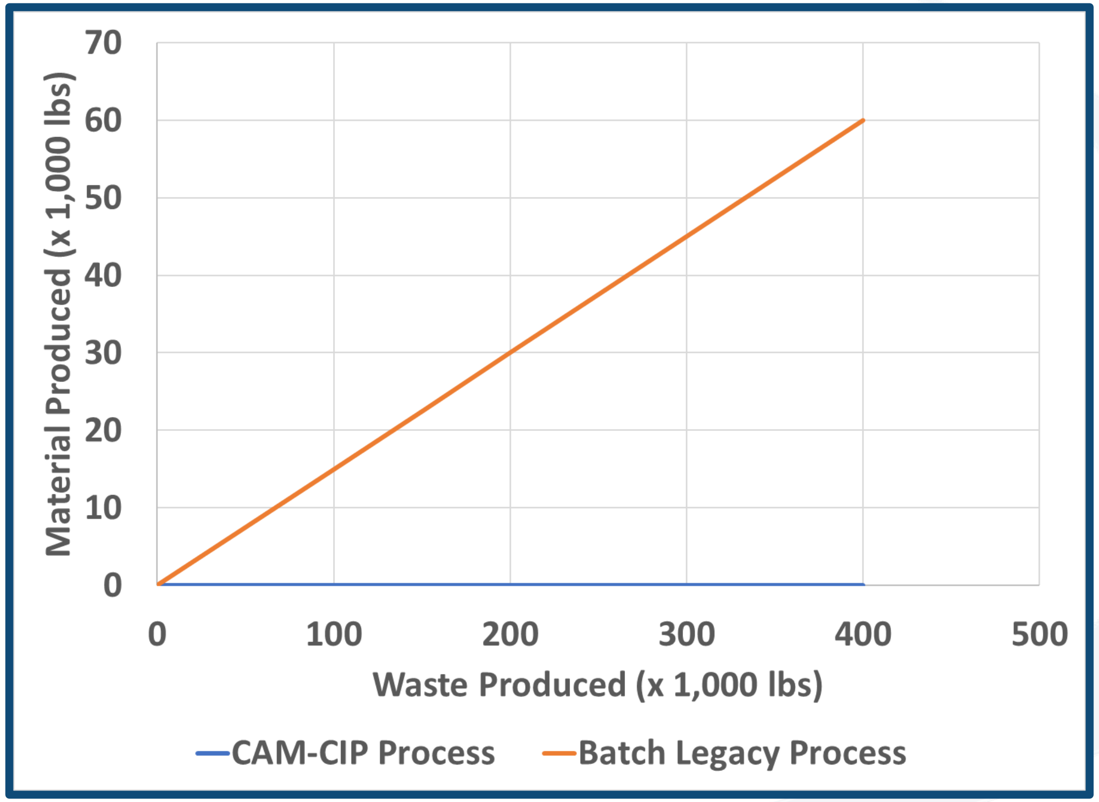
After Clean-in-Place



RAM CIP Results in Less Waste

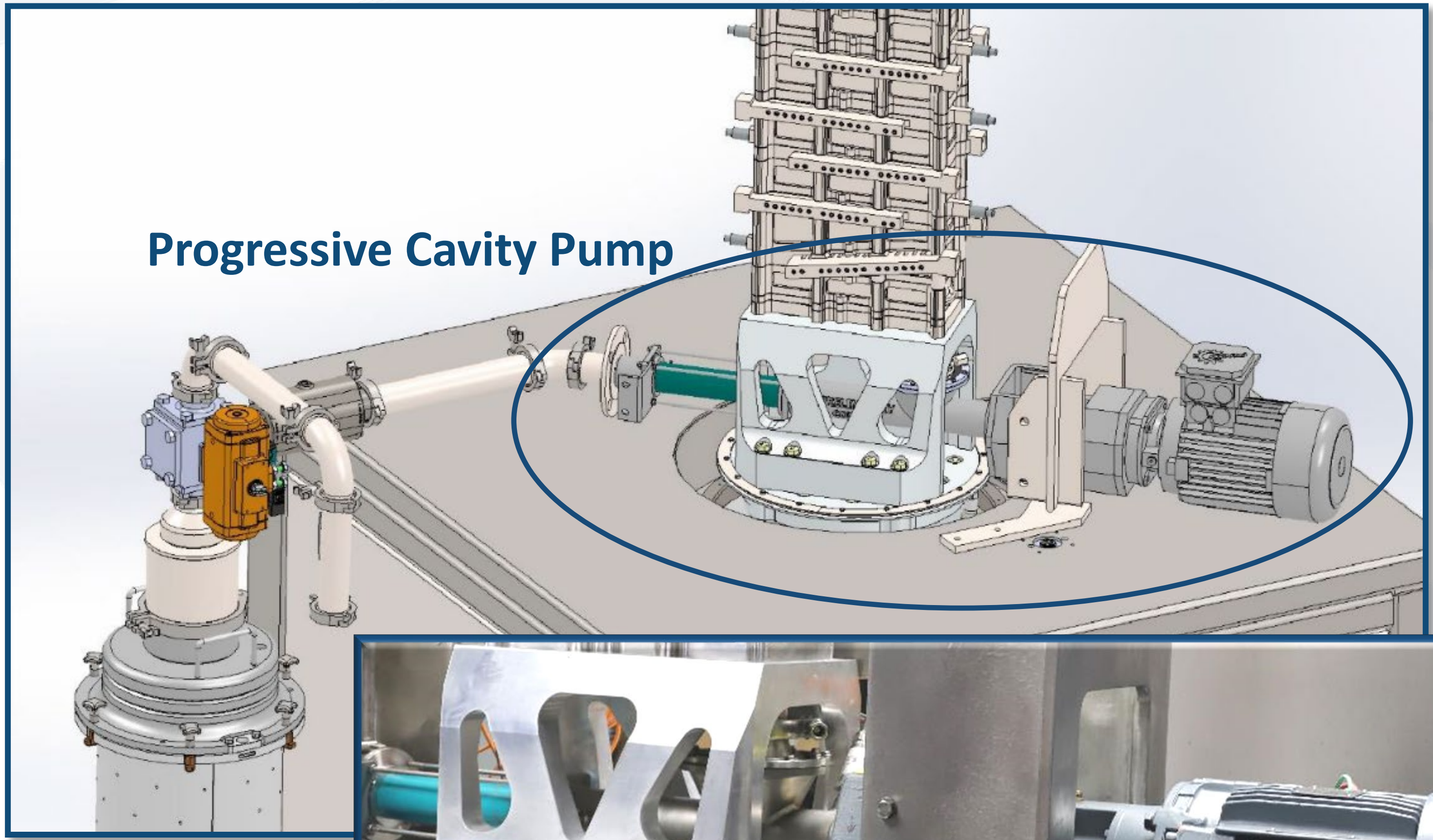
- Waste Produced is Independent of Run Time

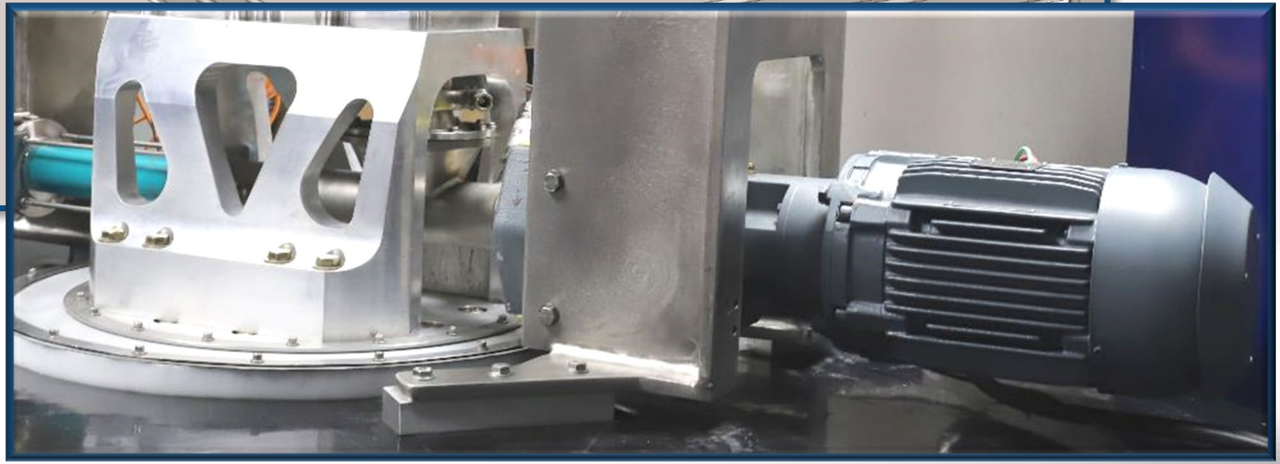
- No Material is Wasted Due to Batch Overrun



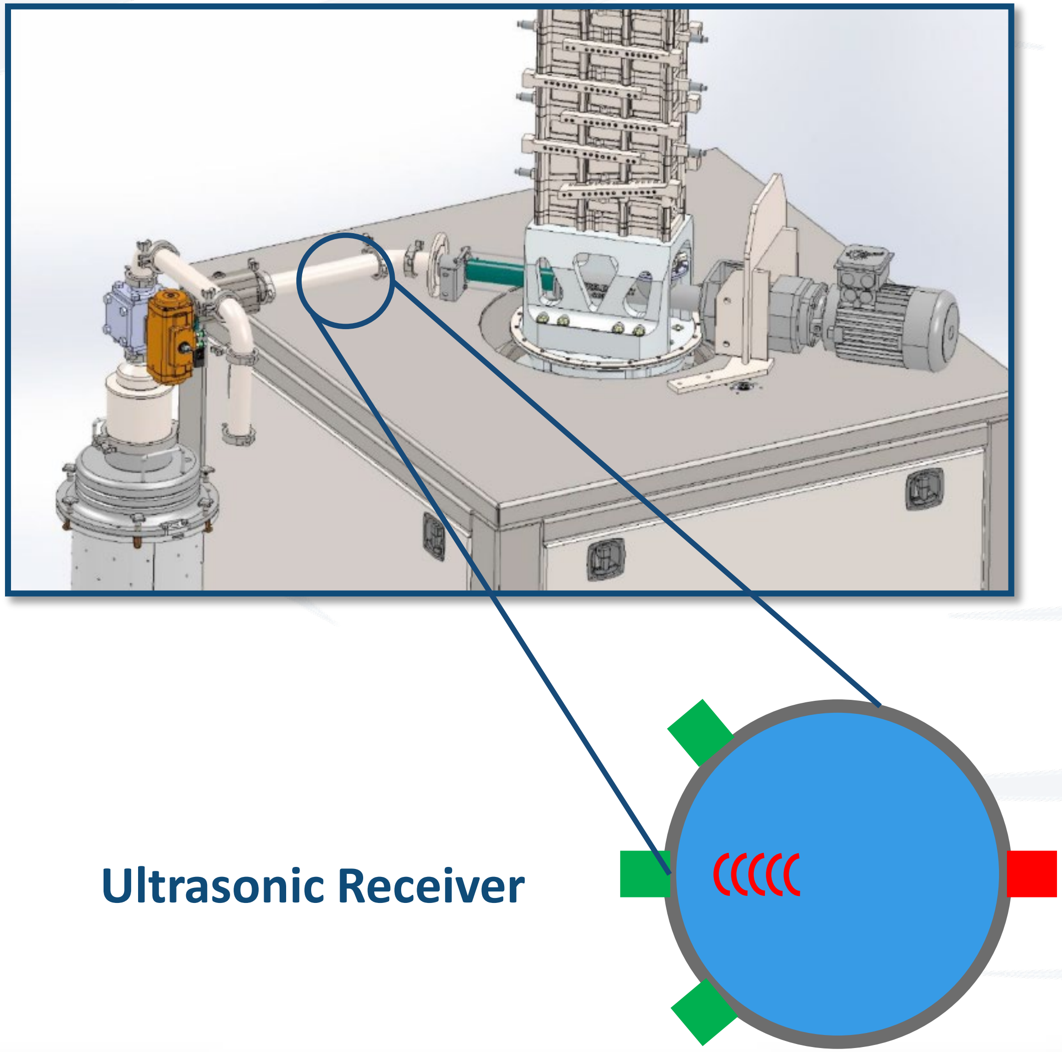
Transition to an Operational Environment

Material Transport





Mixedness Sensor

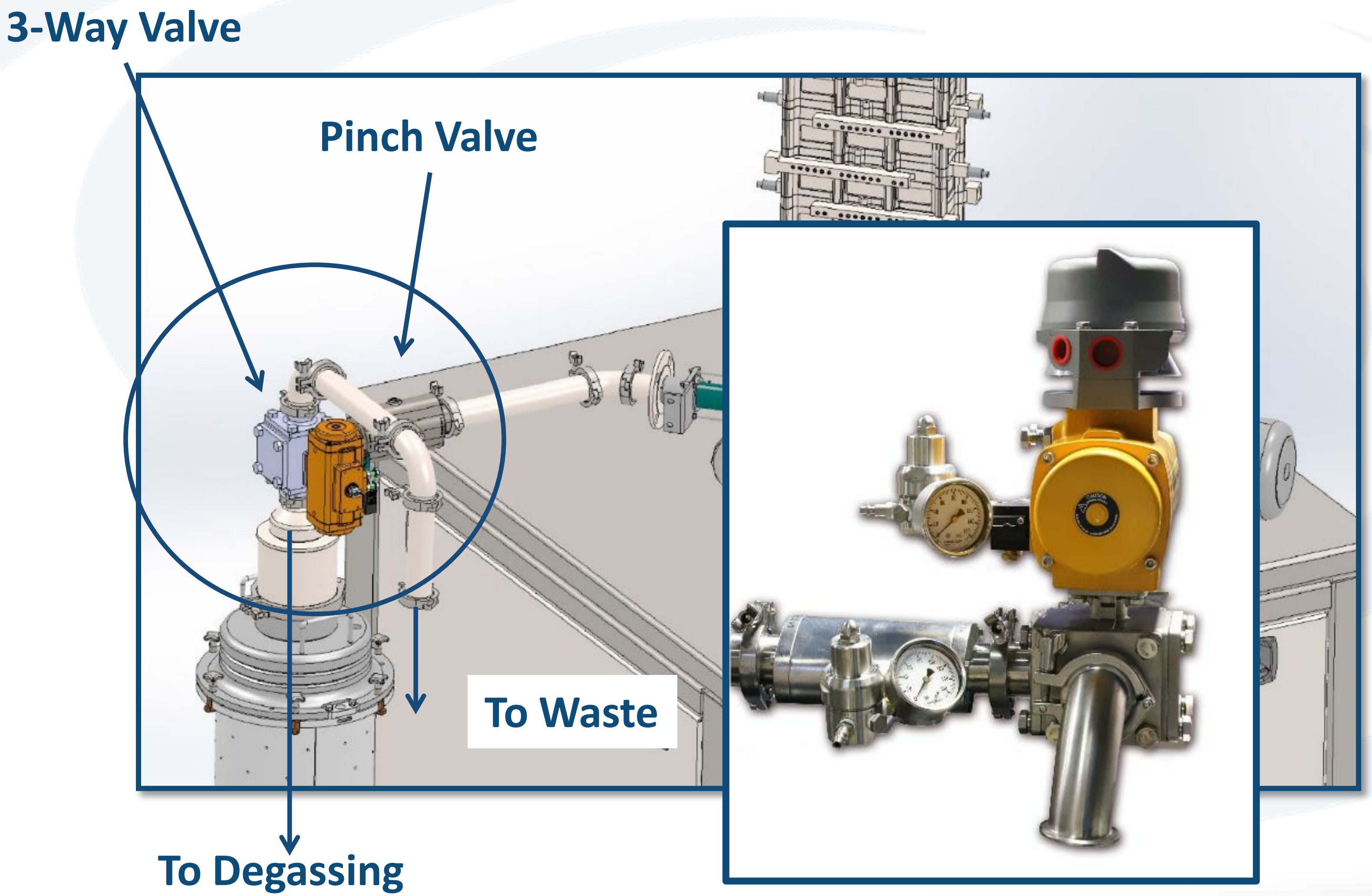


One Transmitter and
One Receiver can
Measure Composition
and Mixedness by analyzing
the Time of Flight Against a
Standard and to Each Other

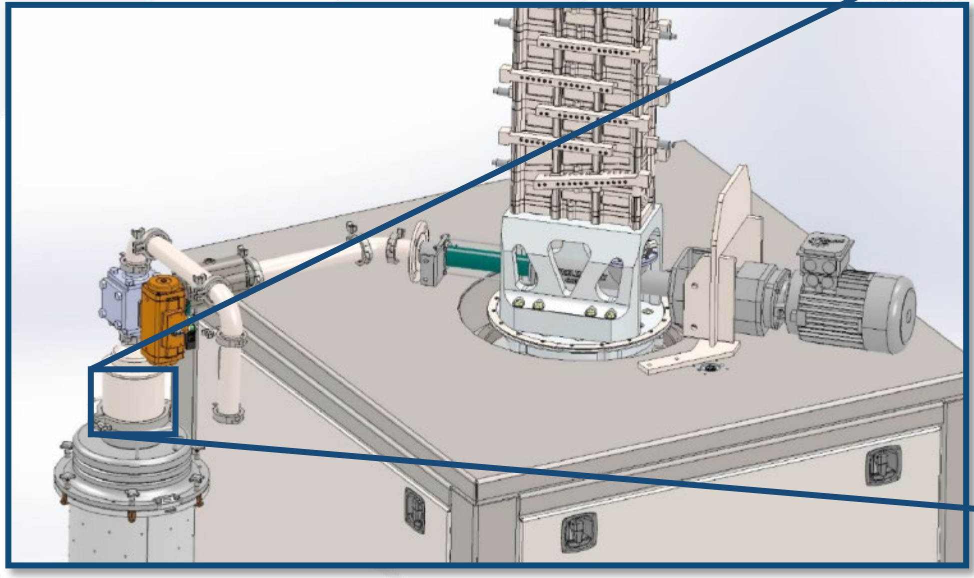
Ultrasonic Receiver

Ultrasonic Transmitter

Automatic Diversion System



Continuous Degassing System

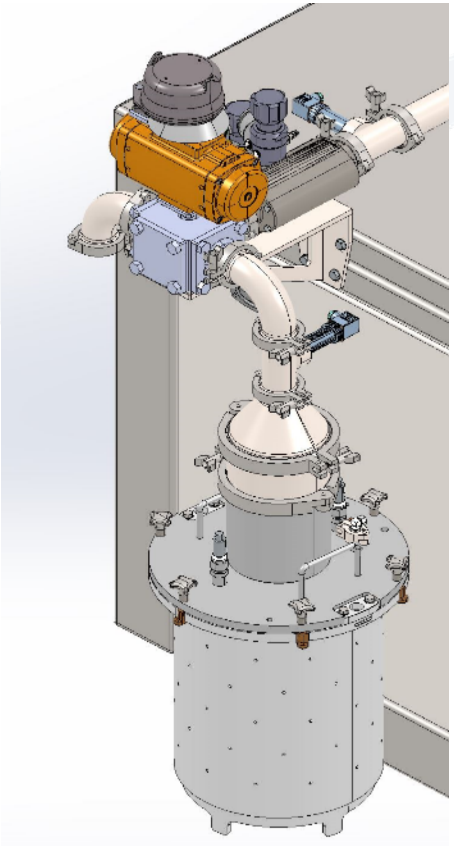


Adequate Surface Area for Production Rate

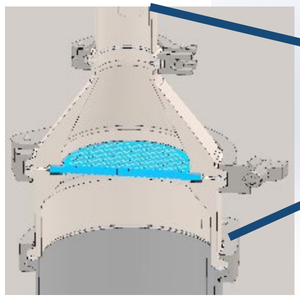
Spacing to Allow Strand Expansion

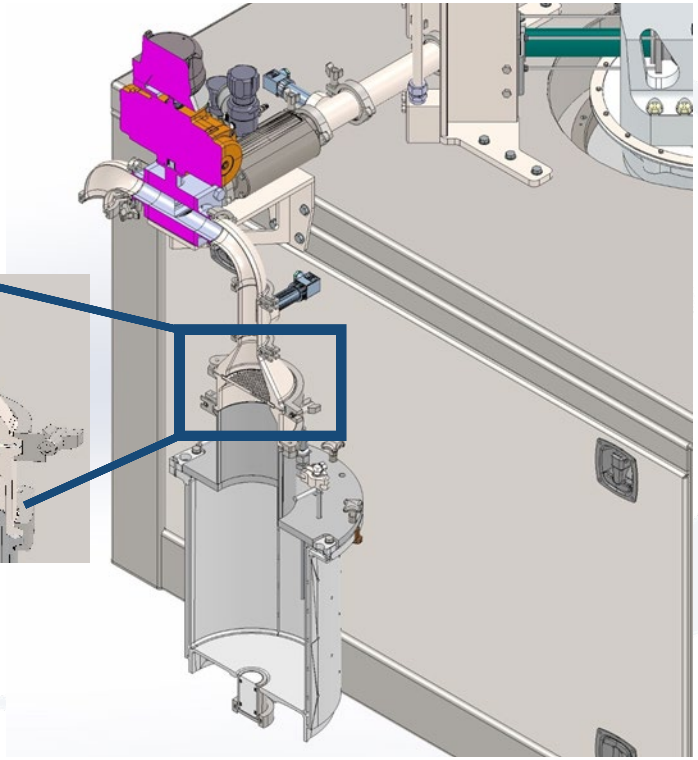
Continuous Degassing System Assembly

View of Degas Assembly



Degassed Mix Material Collection Vessel





Cross-section View of Degas Assembly

Continuous Mixed Material Degassing System in Operation

Degas Strainer Assembly

Degas System in Operation

Acrylic Cylinder Inside
Diameter 7.5 inches

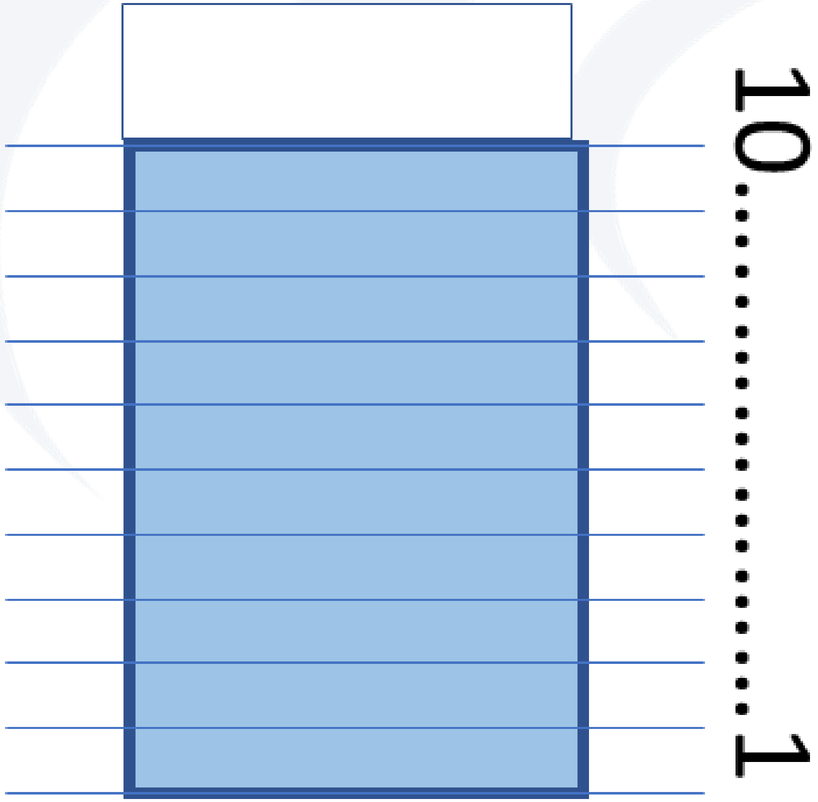
Degassed Mixed Material Collection at End of Run

Mixed and Degassed Material Production Rate

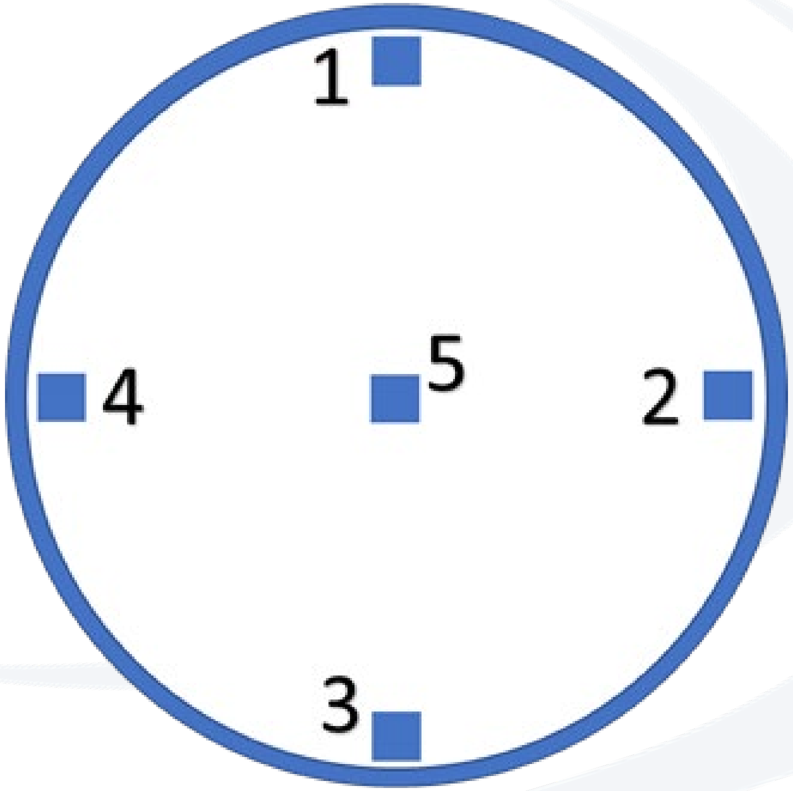
60 kg/hour

Energetic Rated System Testing

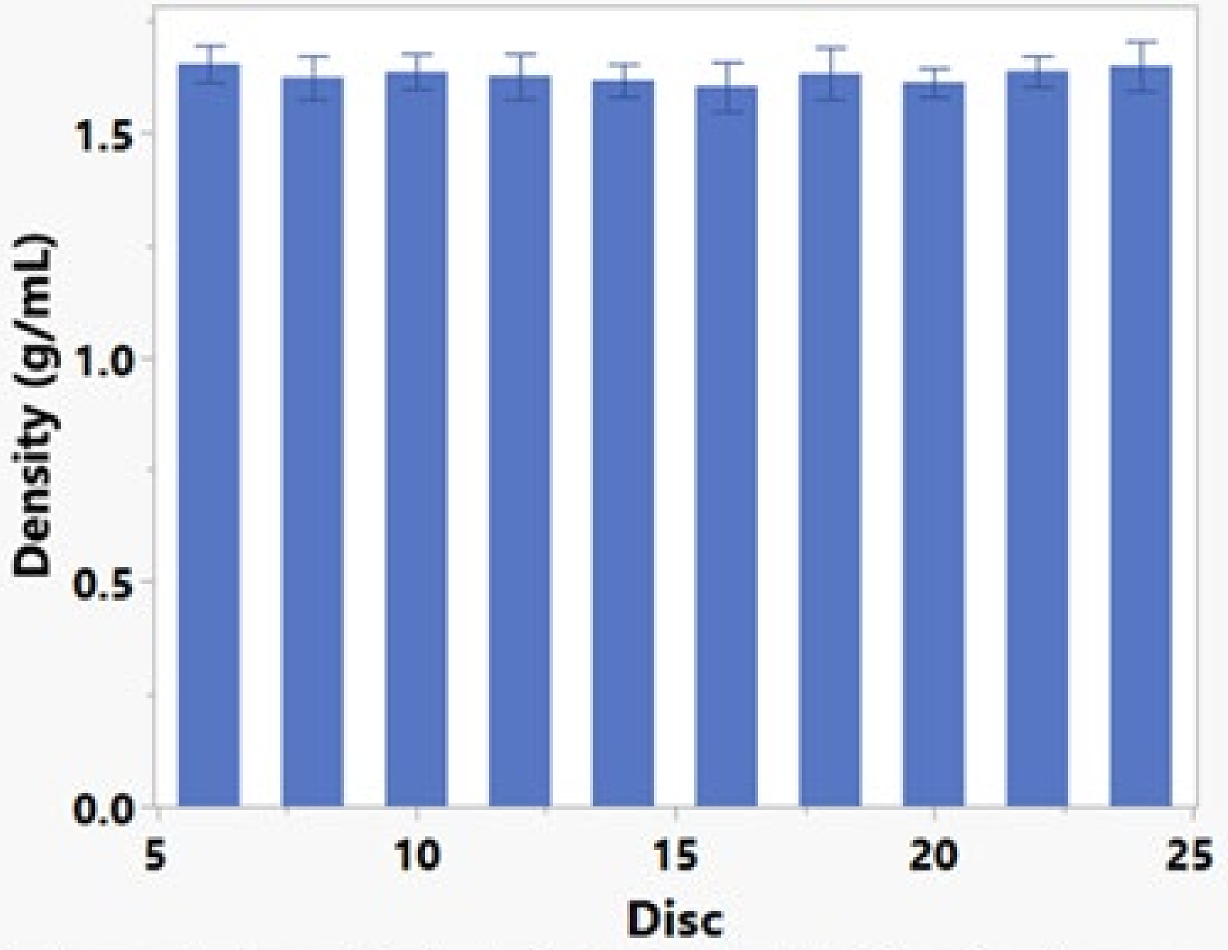
Mold



Disc

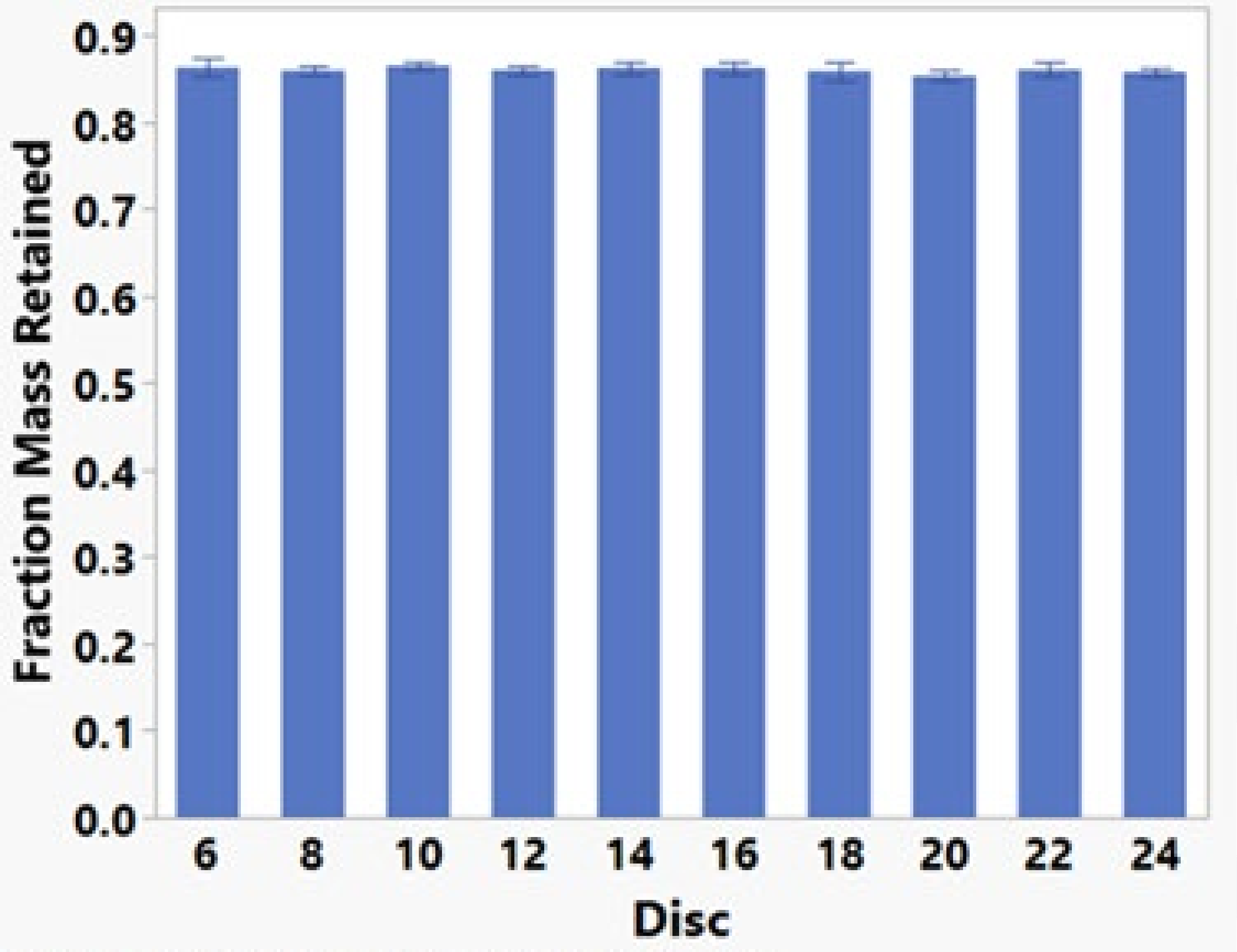


Energetic Rated System Testing



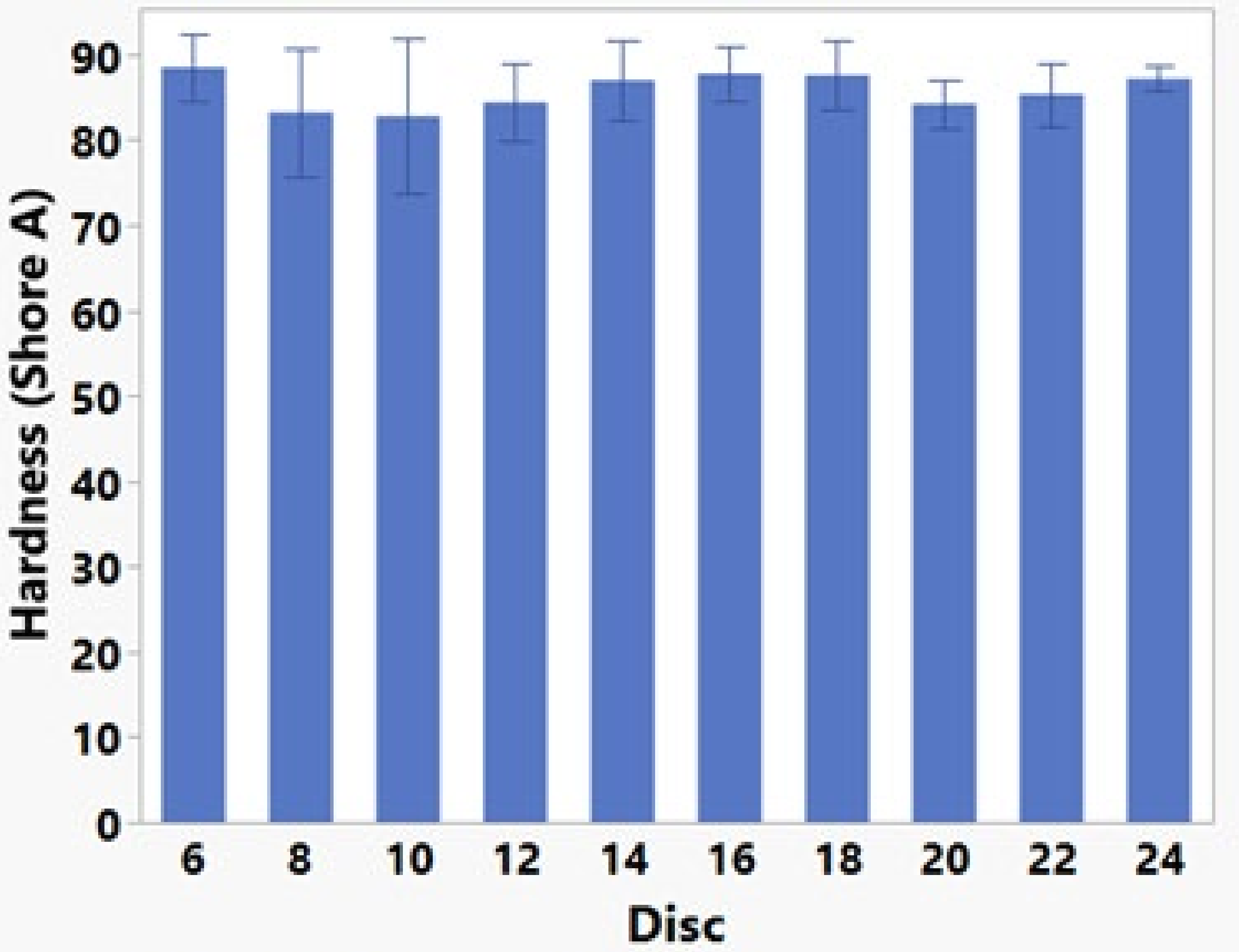
Each error bar is constructed using 1 standard deviation from the mean.

Energetic Rated System Testing



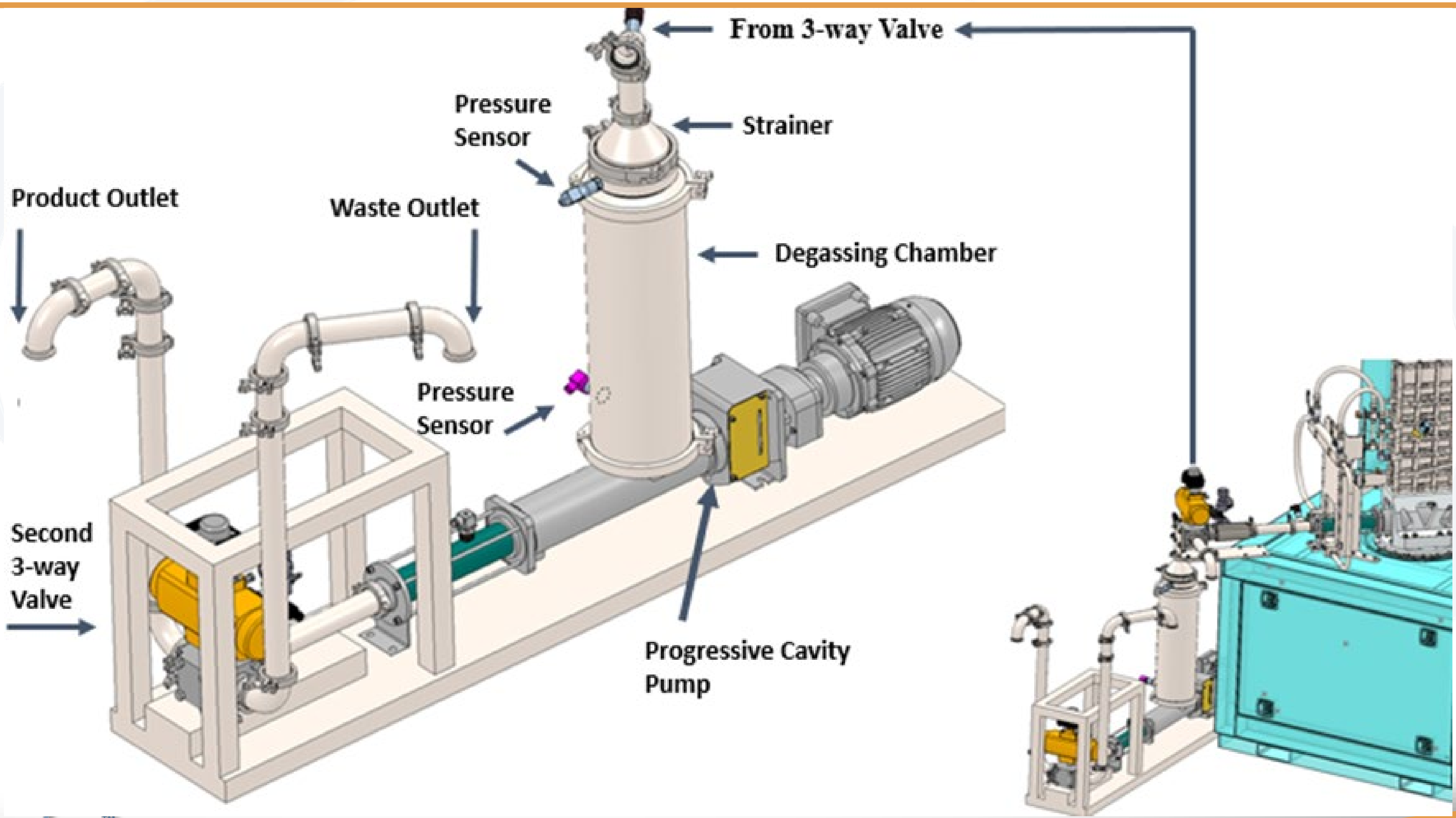
Each error bar is constructed using 1 standard deviation from the mean.

Energetic Rated System Testing



Each error bar is constructed using 1 standard deviation from the mean.

Continuous Mixed Material Degassing System for Continuous Filing



Summary

Accomplishments

- Energetics Rated CAM-CIP Ready for Energetics Testing
- CAM-CIP Demonstrated with 100% Efficiency
- Temperature Control, Degassing

Next Steps

- Production of Mixed Energetic Material from this System at NAWCWD China Lake
- Development of Inline Mix Quality Sensor
- Development of a Continuous Degassing System

Thank you for your time and attention.

19 October 2022

Paths for EM/IM to Provide Strategic Differentiation

How many lines can I cross in one talk?

or

Can we create a path to technical superiority?

Robert B. Wardle

2022 Insensitive Munitions & Energetic Materials Technology Symposium

Please, don't say IM is not relevant today

- It's a threat as a system question
    - Perhaps more than IM on an individual munition?
- Do we need to ask if we are doing the right analysis for meeting the IM policy?
  - Avoiding unwanted ignition…..

The case for technical superiority

- WWI
  - Technical parity across fronts (can cite more examples)
- WWII
  - Technically behind (allies) but got better – aircraft, armor
- Cold War
  - Strategy of superior technology rather than match numbers
- Gulf Wars I and II
  - Show what happens with a technical overmatch (not a commentary on other aspects of either war)
- Global War on Terror
  - Precision, low collateral damage, stealthy delivery
  - Adaptations that were successful may have made us vulnerable to another kind of warfare
    - For example, had air dominance – not attacked in depth
- Our technical superiority has been focused on the world situation of the last 30 years – that status quo has been upset

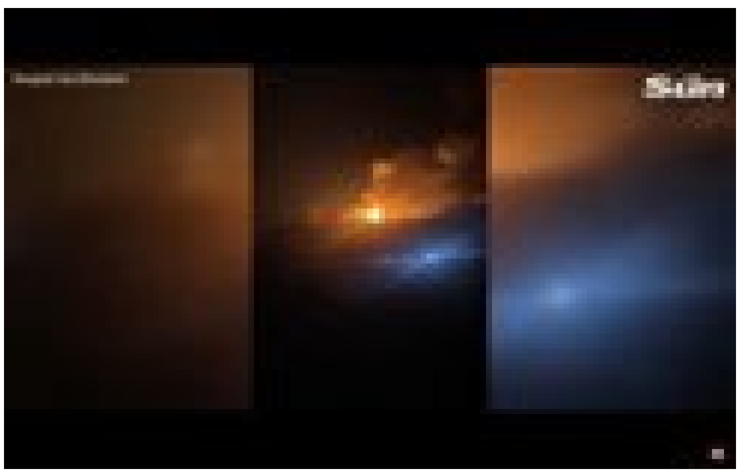
Aggressive Russia

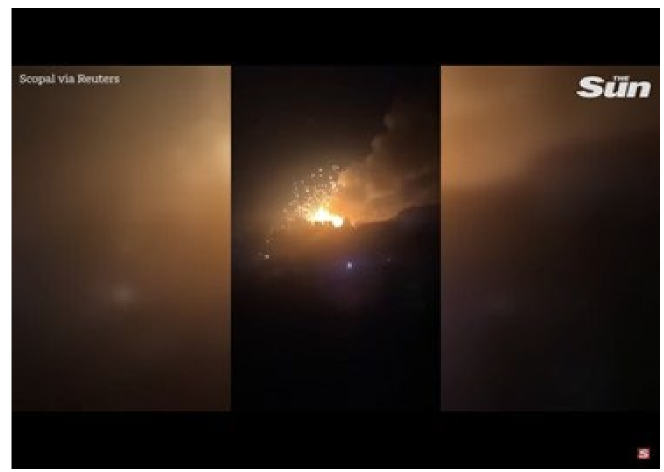
- Willing to use weapons
  - Have used hypersonic weapons in Ukraine….and others
- Overall military of Russia has not impressed
  - Is this a technical fault? Certainly not exclusively
- Playing on foreign soil against a determined enemy is hard – did we not learn that a number of places against much less well armed foes?

- What are we learning (early) about weapons?

Case for Performance and IM

https://youtu.be/hoo-mTsSD4Y





- Battlefield scenario shows vulnerability of munitions that are not IM and value of range and inherent "IM" in increased performance (e.g. range)
- Takata air bag recall: need to get it "right" not default to conservatism

China military capability expanding rapidly

- Clear goals
- Focused and driven from the top
- Designed to neutralize capability of western powers to exert influence/dominance in Asia/Pacific, initially
- Numbers are scary – doubt we can count on weaknesses seen elsewhere

- Taiwan support presents key challenges and a good scenario to study

China technical numbers are amazing

- Publication examples:
  - CL-20 (since 1987 via Sci-Finder)
    - >18,000 Technical Journal publications
    - 5,873 patents
    - 1806 reviews
    - 157 books
    - Top 5 publishing organizations are in China (7 of top ten)

  - Carbon -Carbon

    A quick search via SciFinder shows the following open-source literature statistics on Carbon Fiber Composites:

    - 162+K total publications
    - Top ten authors are Chinese
    - 34K publications in Chinese language
    - Of the top ten literature producing organizations, 8 are Chinese

From Energetics Technology Center

Let's not forget…..

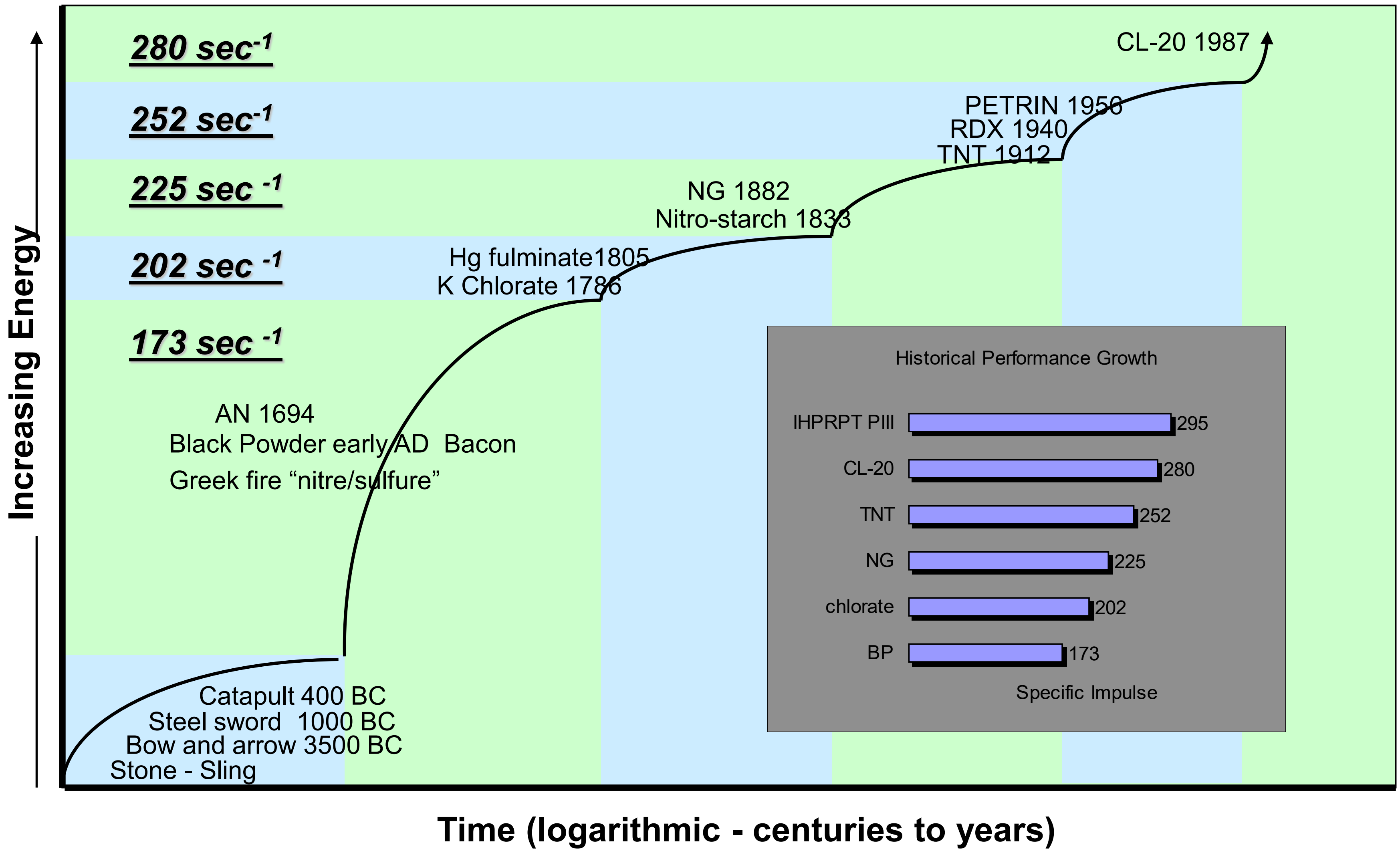
- North Korea
- Iran
- Non-state terrorist organizations
- More…..

Here's the problem

- We aren't particularly efficient right now (development, acquisition, sustainment). Does anyone want to argue that?
  - All through our system – not one part – all are contributing
  - Examples
- We off-shored too much of our industry
  - Economics drove much of change…..and is a barrier to bringing back
  - Sad reality of shipping pollution off-shore
- Just plain getting buried by R&D and production in China – we appear to be losing both quantitative and, maybe, qualitative advantages.
  - Does not bode well for our future…..
  - …….and change is really hard

Historical Performance Growth

Energy asymptotically approaches a physical limit for a given technology followed by a dramatic technology change and a period of rapid increase
– today we are again on the cusp of such a change



Changing the Pallet

<u>Weapons in the US have been built with a stationary pallet for over 70 years</u>

- The primary energetic materials in all US military (and civilian) propellants, explosives and pyrotechnics (PEP) were developed in the 19th or first half of the 20th Century
- The weapons systems we have today are designed based on the capabilities of this limited pallet of materials – any improvements are incremental, at best

<u>How could even a few new energetic materials impact PEP and munitions?</u>

- Much emphasis is placed on simple energy increase – it is relevant and significant
- However, the larger benefit is that the trade spaces will be opened with new combinations of density, energy, oxidation index, molecular weight available to the creative formulator and designer of munitions
- Trade space can include lethality mechanism, lethality at target, range of munitions, time to target, signature/plume, size of component
- **Effects at the weapon system are more than additive – they multiply each other**
  - *Example: lower weight warhead with higher performance propellant increases range, speed, lethality by more than either of the individual numbers suggest*

We don't have to invent a magic powder to provide the latitude for revolutionary increases in weapon capability and a strategic advantage

Example of winning at performance <u>and</u> sensitivity

- Castable CL-20 formulation provides energy of pressed composition with reduced sensitivity
- Pressed CL-20 formulation shows both improved performance and reduced shock sensitivity compared to baseline formulations

Win-win scenarios are possible

Formulation	Density (g/cc)	Gurney Constant @V/V_0=7 (m/s)	Gurney Energy @V/V_0=7 (kJ/g)
DLE-C038	1.805	3005	4.515
PBXN-110	1.680	2780	3.864
LX-14	1.835	2948	4.345

Bullet Impact in generic hardware
No damage to end closure or copper liner
Mild response to 0.50 cal round

Slow Cook-off
No damage to main body, end closure, or copper liner
Heating rate was 3.3°C/hr

Historical example of using the existing pallet

- Start with single base: Nitrocellulose
- Add a little more energy: Nitroglycerin
- Want improved dimensional integrity, add: PEG
- Add a curative for the polymer: diisocyanate
- Improve freezing point of the NG, add: BTTN
- Same to amend Tg of PEG, add: PCP
- Maybe a bit more energy, add: nitramine monopropellant
- Need to better control the burning rate, add: lead catalyst

Result:

- Move from relatively low performance single base gun propellant to a high energy, minimum smoke tactical rocket motor propellant

Conclusion:

- Effects are more than additive when applied creatively to create a differentiated technology for weapons

The Case for Change

- What would it take?

- "…must believe that change is the lesser evil, and that a failure to change will realistically produce catastrophic, near-term consequences, such as the loss of a major war."
  - Christian Brose in "The Kill Chain", 2020

Are we there, yet?

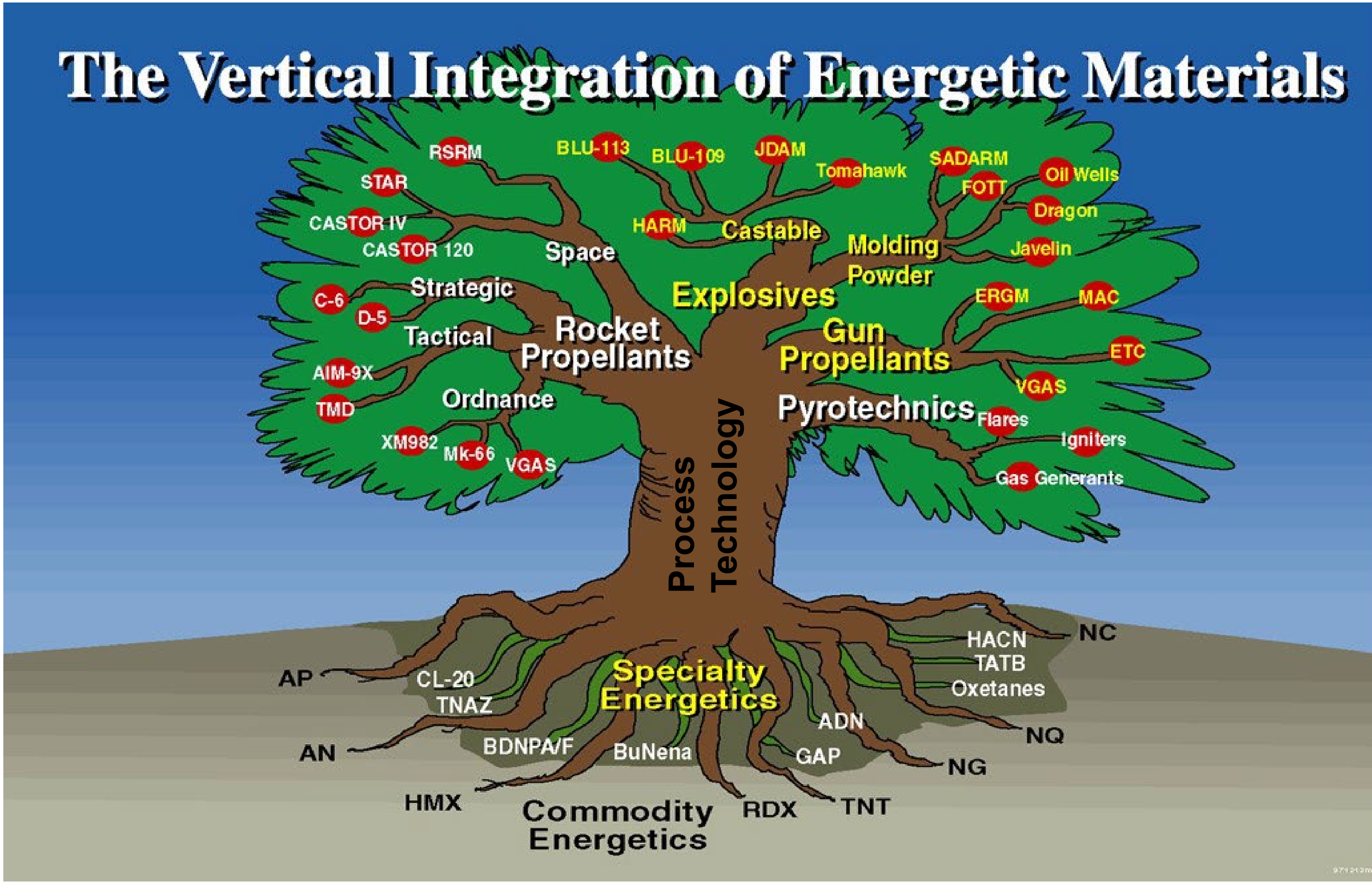
Western Democracies have advantages

- Vibrant, creative economies
  - Not top driven with fake data
  - Much better able to respond to signals than we give them credit
  - People are willing to take some major risks (examples)
- Alliances of the willing
  - If we can stay together – causes make a difference
- Remarkable militaries
  - Professional, committed, remarkable people
  - Equipped with effective systems that overwhelmingly work
- Political systems that I believe are an enduring advantage
  - Personal freedoms that are worth protecting
  - Less fear of overthrow as in autocracies (don't waste energy oppressing)
  - Not as fast making decisions, but many voices should result in better outcomes and fewer massive blunders
  - Messy, slow, ponderous, confusing, frustrating – it can be a good thing

Here's a couple of ideas

- Unleash the creativity that is possible only in a free, democratic society
  - Let errors and inefficiencies of autocracy accumulate…..they always do
    - Cost of maintaining domestic control
    - Cost of bad decisions because of top-down decisions
  - We need to open the flood gates in energetics
    - Provide environment with challenging goals
- Look hard at where we can reduce the inefficiencies in our system
  - Support the best – wherever it may come from
    - Parts of our system drives towards "novel" rather than "optimal"
  - Advocate for technology creativity – not our home base
    - Structure hurts – everyone needs to pay bills
  - IM based on hazards analysis – let's create advantages that count on the battlefield – and not hold back technology unnecessarily
    - How do you get many kbar into a large rocket motor being shipped by truck/train or stored versus improving stimulus expected on the battlefield for tactical munitions
  - Micro-bureaucracy, we can each break down in our own home
    - Building barriers to others competing with us is a natural…..it's hard
- Help expand what is on the pallet
  - Improve acceptance of new materials even if not yours
  - A little bit does go a long way

We can have a healthy enterprise



Final Products are Complex

Distribution Unlimited

AFRL

Characterization of Impact Induced Reaction of Explosives Using the AFRL High Explosive Survivability Test (HEST)

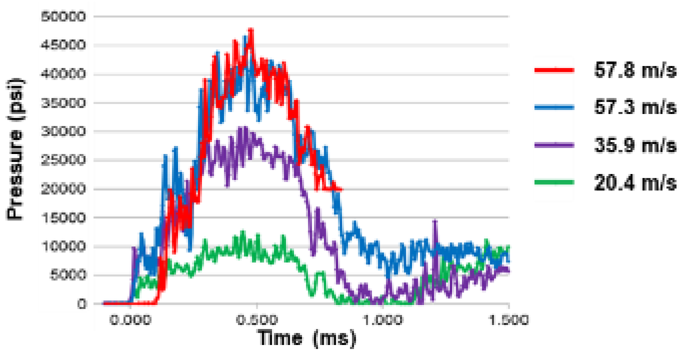
Jesus Mares Jr., AFRL/RW
Stephen Thornton, IS4S
Matthew Neidigk, AFRL/RW
Michael Nixon, Torch Technologies

2022 IMEM Technology Symposium
October 18-20, 2022

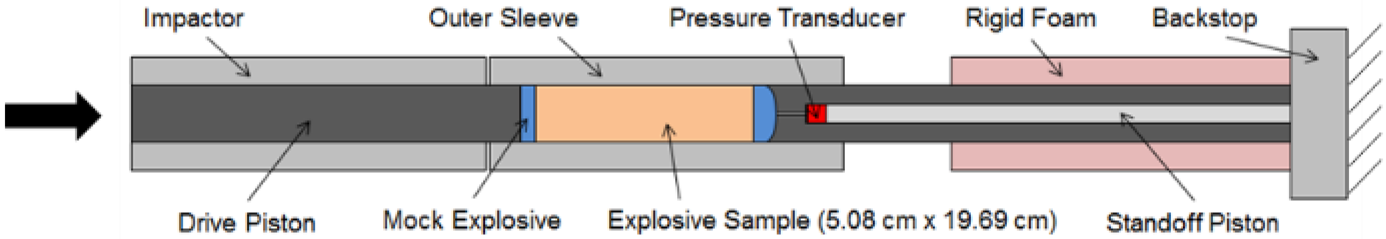
High Explosive Survivability Test (HEST)

- Measure the propensity of an explosive to yield reaction (*deflagration*) under complex (*pressure and shear*) impact loading conditions at lab scale.
- Comparable to Steven Test or Navy Setback Simulator
  - ❑ Designed for "longer" time pressure, larger charge mass (~2 lbs.), and controllable shear/friction on explosive charge
  - ❑ Idealized loading conditions on charge to aid modeling of stress conditions
- Utilize high speed videography to observe occurrence of reaction and motion of hardware
- Vary impact conditions to identify threshold of explosive material following Neyer D-Optimal Sensitivity Test
- Measured pressure pulse and M&S to estimate loading conditions of materials
  - ❑ Allows for filter or ordering system of proposed explosives

High Explosive Survivability Test (HEST)



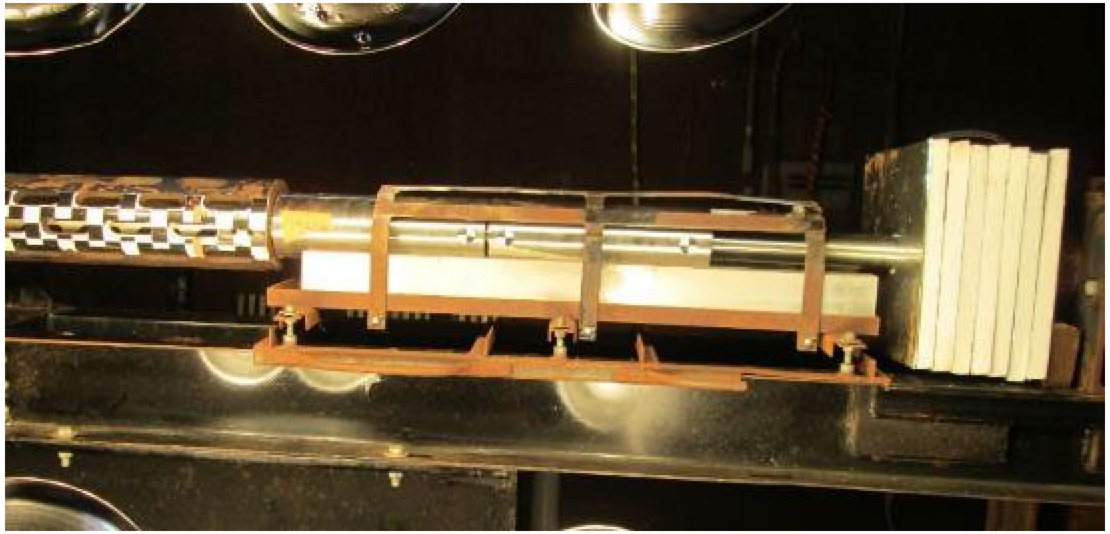
Example of long time pressure pulse in HEST



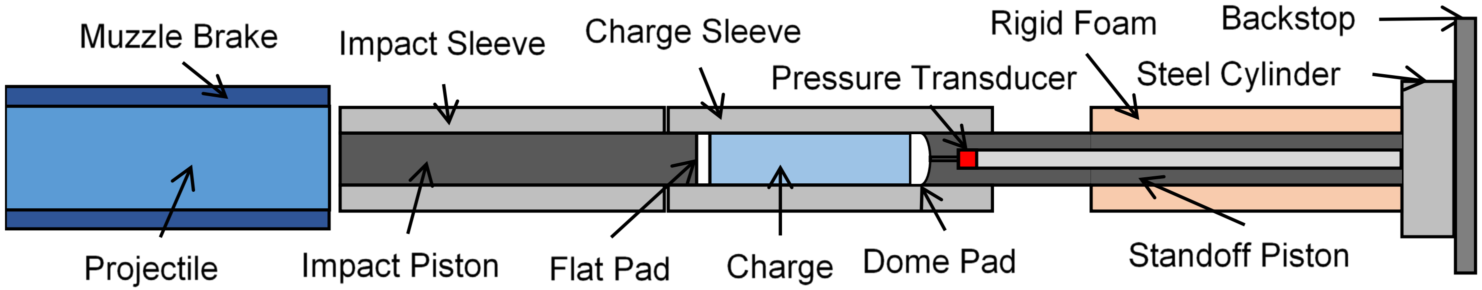
Dynamic loading mechanisms of charge in HEST

High Explosive Survivability Test (HEST)

HEST gas gun



HEST test assembly



HEST assembly diagram cutaway

Typical "GO" result

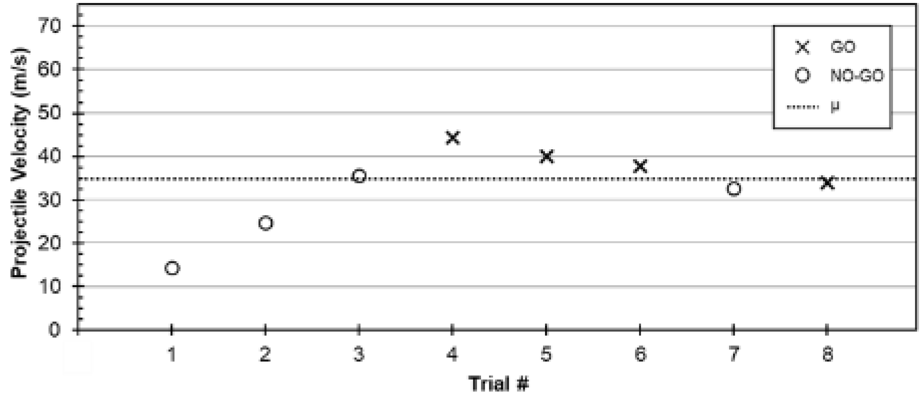
Typical "NO-GO" result

High Explosive Survivability Test (HEST)

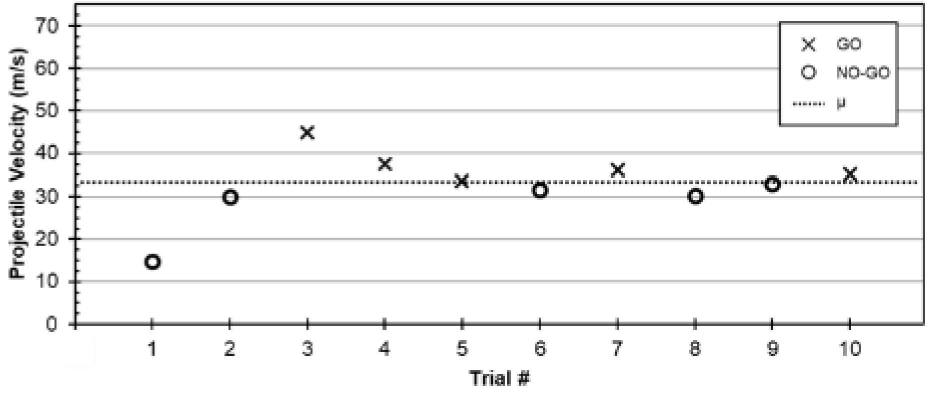
Initial Test Series

- Two test series (Material A and Material B) have been conducted since implemented changes:
  (1) Switch to Teflon pads
    - Overfit pads (2.020” diameter)
  (2) Ensure no adhesion at explosive-wall interface
    - Fit slip charge, use of lubricant at wall

Material	Projectile Velocity (m/s)	Result	Observed Reaction Type	% Mass Recovered	Friction Coefficient
Material A	14.38	No-Go	None	-	0.050
Material A	24.72	No-Go	None	100%	0.025
Material A	35.67	No-Go	None	100%	0.025
Material A	44.43	Go	Vigorous	87%	0.025
Material A	40.11	Go	Full Burn	-	0.025
Material A	37.73	Go	Vigorous	79%	0.025
Material A	32.70	No-Go	None	100%	0.025
Material A	33.97	Go	Mild	100%	0.010
Material B	14.67	No-Go	None	100%	0.100
Material B	29.94	No-Go	None	100%	0.010
Material B	44.84	Go	Vigorous	98%	0.010
Material B	37.44	Go	Mild	100%	-
Material B	33.61	Go	Mild	100%	0.010
Material B	31.71	No-Go	None	100%	0.010
Material B	36.04	Go	Full Burn	21%	0.010
Material B	30.25	No-Go	None	100%	0.010
Material B	32.93	No-Go	None	100%	0.025
Material B	35.30	Go	Full Burn	11%	0.025



Material A



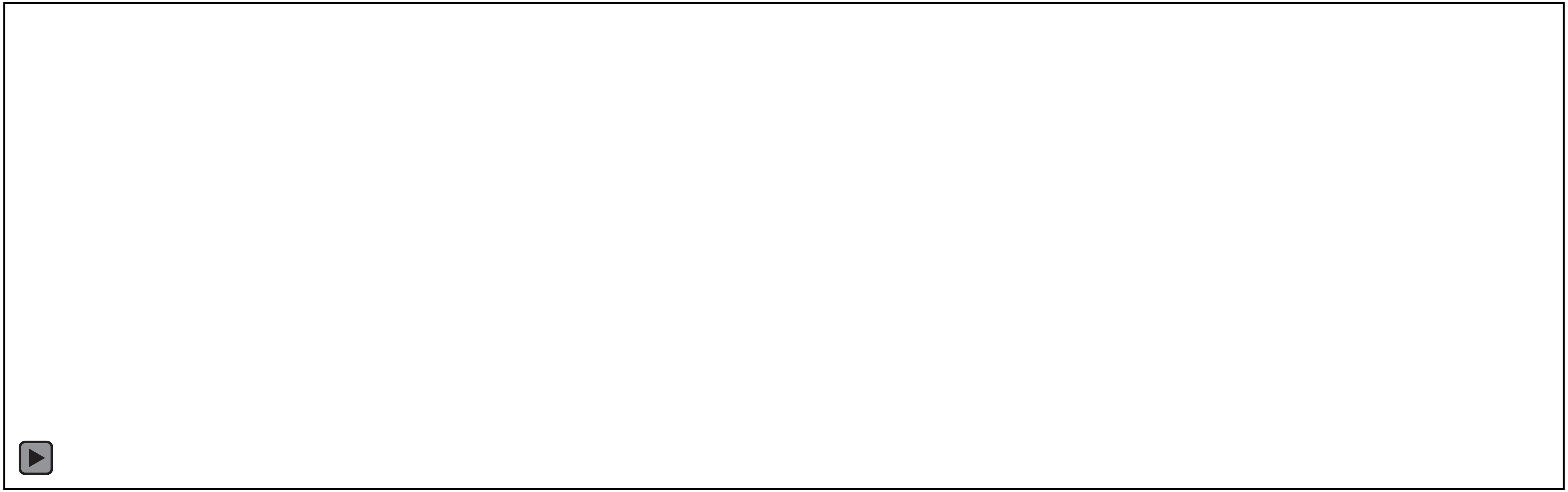
Material B

Explosive	μ (m/s)	σ (m/s)
Material A	34.90	2.56
Material B	33.27	0.68

Example of No-Go

Example of Go (Mild Reaction)

Example of Go (Full Burn)

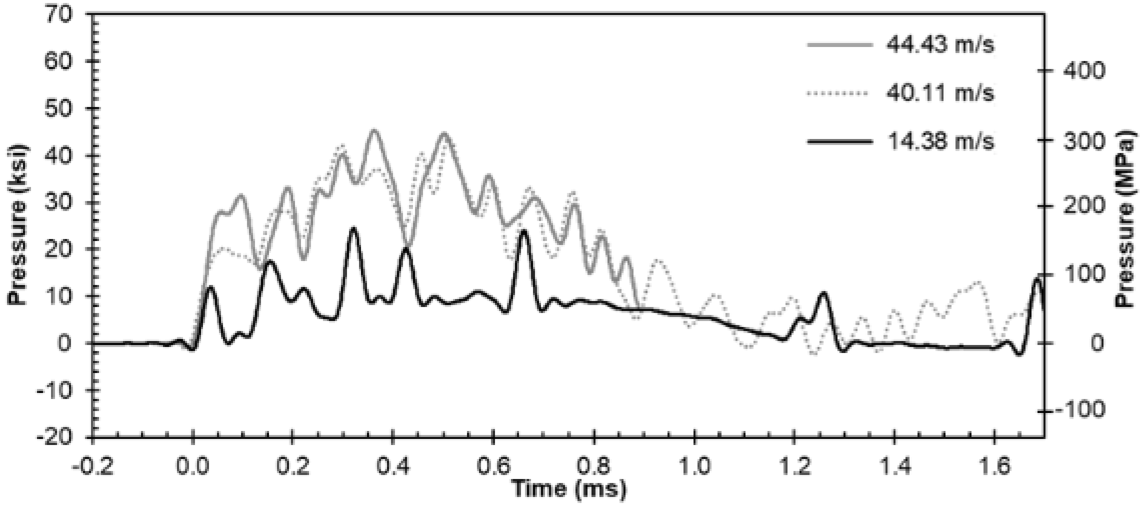


Example of Go (Full Burn) – Chamber View

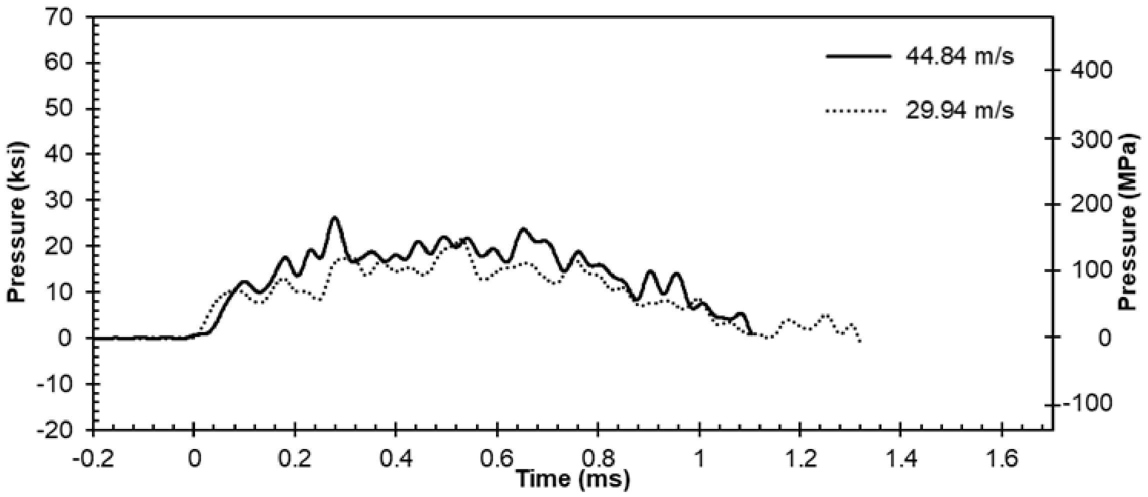
Example of Go (Vigorous)

Example of Go (Vigorous) – Chamber View

Diagnostics: pressure measurement



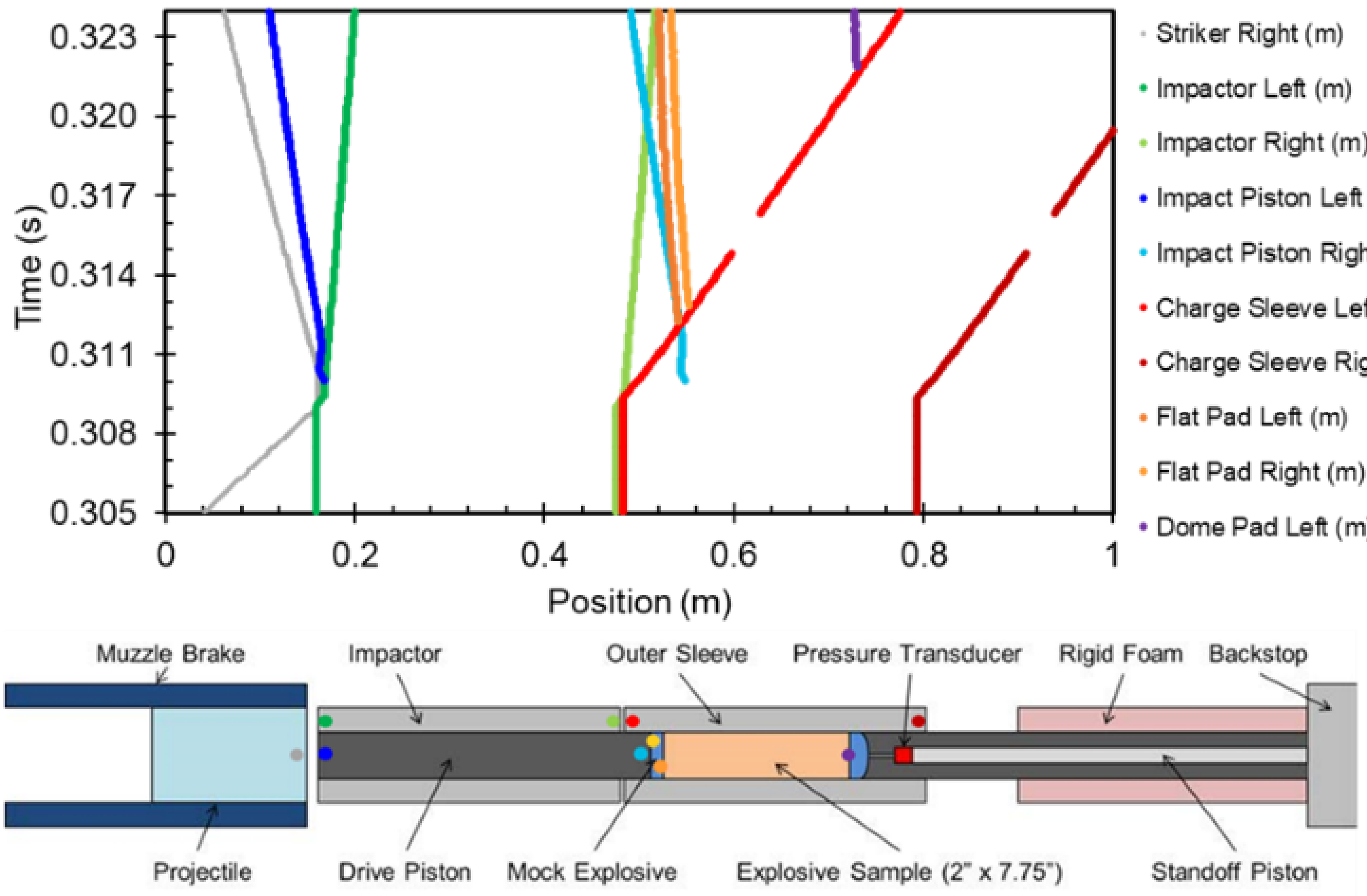
Dynamic pressure measurement for material A



Dynamic pressure measurement for material B

- Poor probability for successful pressure measurement

Diagnostics: *x-t* diagram

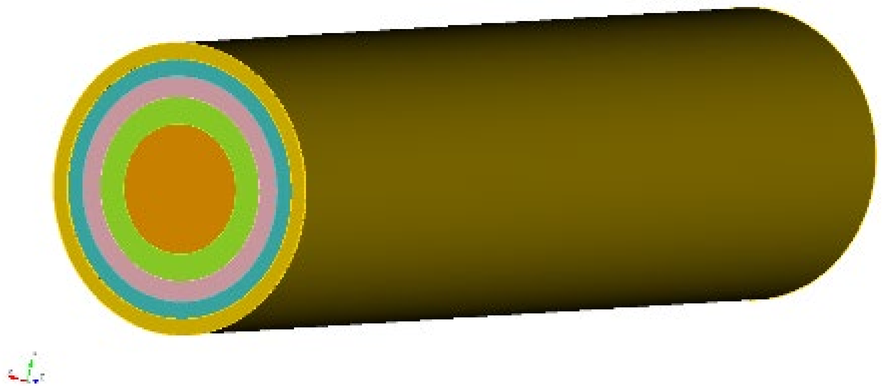


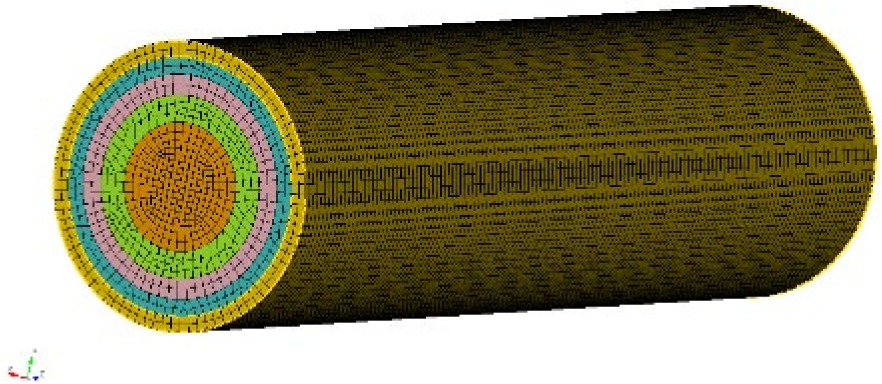
x-t **diagram information of moving hardware and charge**

Simulations

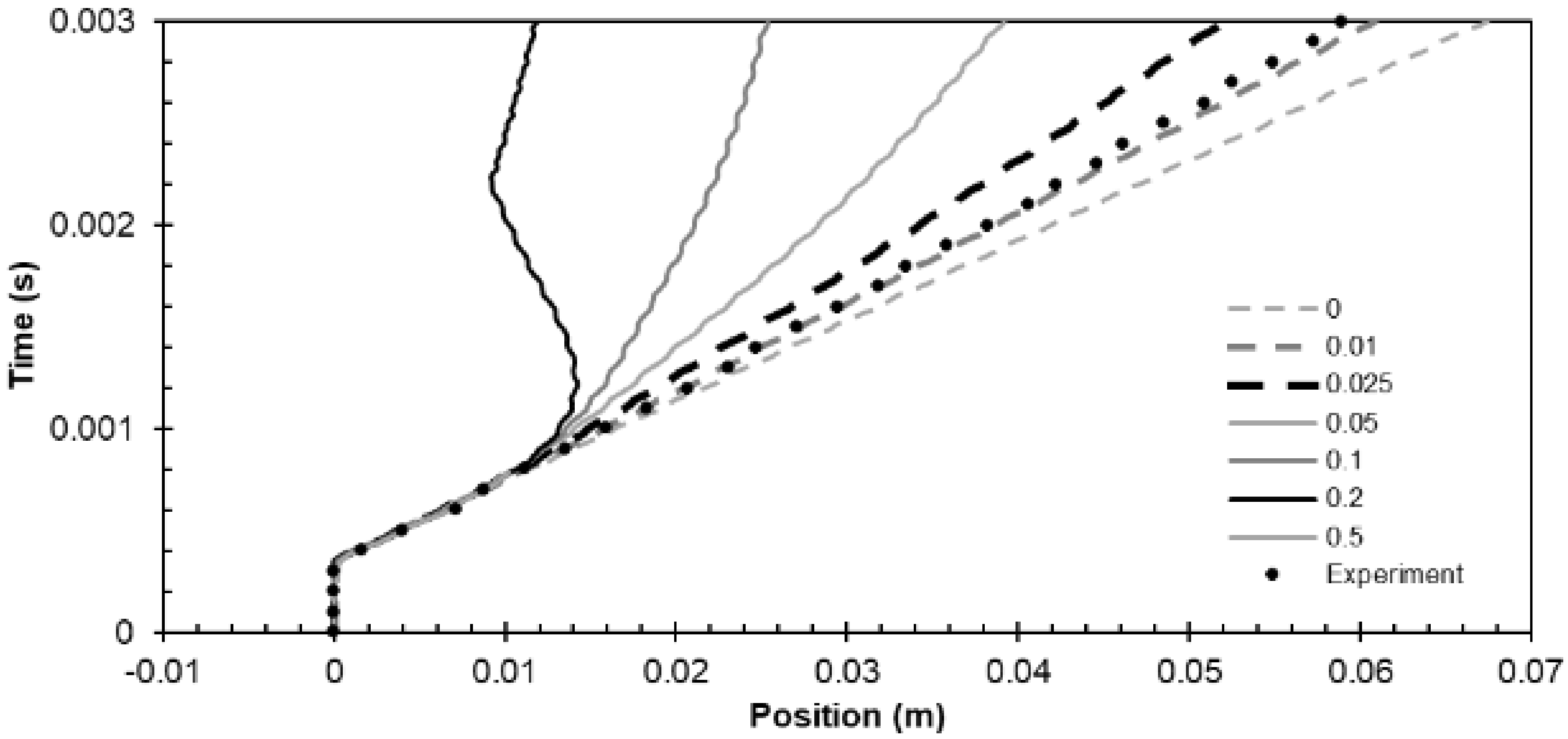
Simulations were run using SIERRA Solid Mechanics code version 5.2

- Computational mesh of 275,006 8-noded hex elements
- HE modeled with 127,127 hex elements of equi-weighted concentric rings
- Mechanical model for HE was Simplified Potential Energy Clock (SPEC) model
    - Required shear and bulk thermal and mechanical viscoelastic data
    - Supported by DMA, TMA, Tri-ax measurements
    - Bulk modulus assumed to be constant



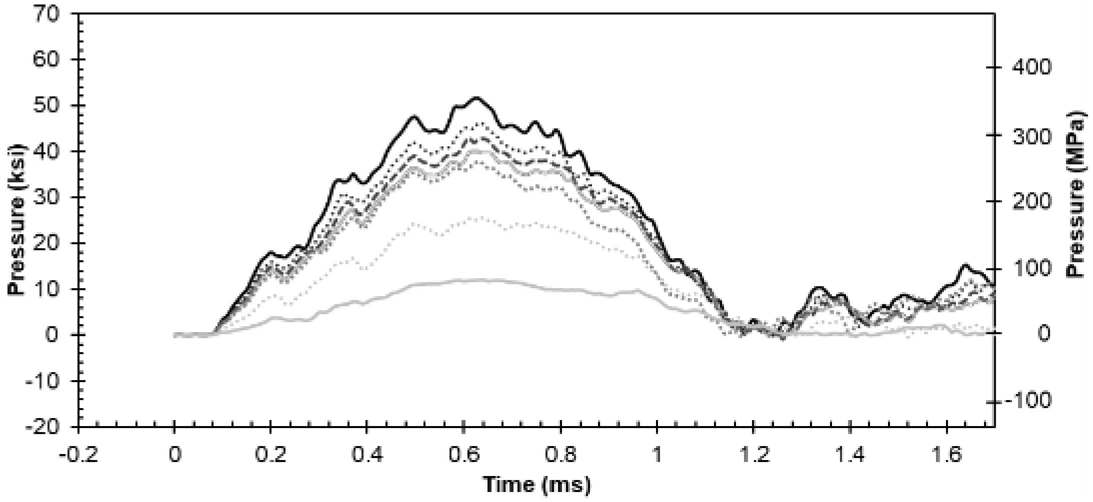


Simulations: friction study

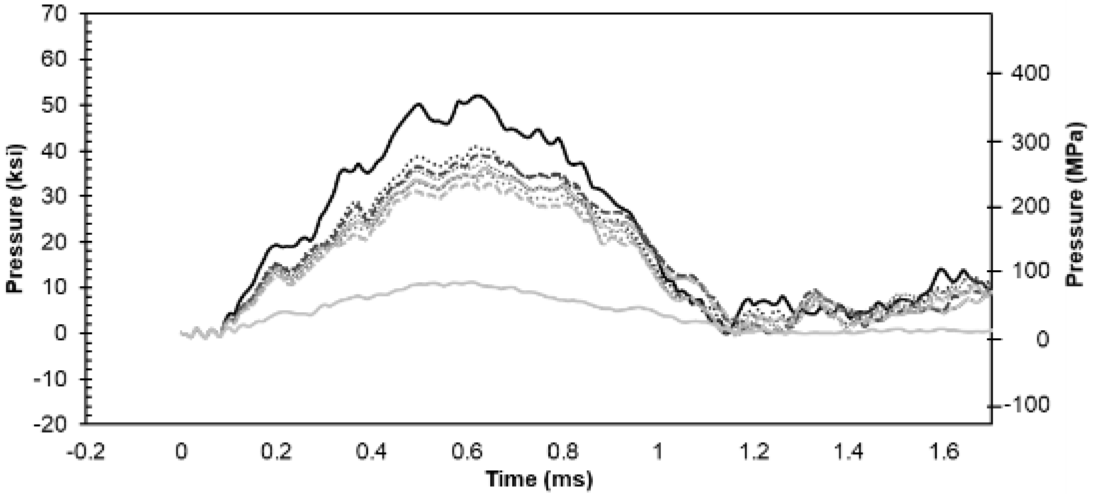


- Varied friction between HE and wall to determine *position data of charge sleeve*
- Effect of bulk modulus had little effect *on charge sleeve position*
- Effect of friction for Teflon pads had little effect *on charge sleeve position*

Simulations: predicted pressure history



Predicted mean pressure histories for material A



Predicted mean pressure histories for material B

Future Work

(1) Investigate the predicted stress distribution over time to better determine stress history required for reaction
- Leading into deflagration prediction modeling

(2) Investigate role of adhesion at the wall on complex loading behavior and resulting impact sensitivity
- Tearing/High Friction/Frictionless
- Different material may be more resilient to different ignition mechanisms

(3) Additional materials

Questions?

Evaluation of Critical Temperature via Thermal Runaway Models and Slow Cook-Off Testing

Matt Hathaway, Jeremy Headrick, Virgil Fung & Sara Lowry

IMEMTS 2022 (October 2022)

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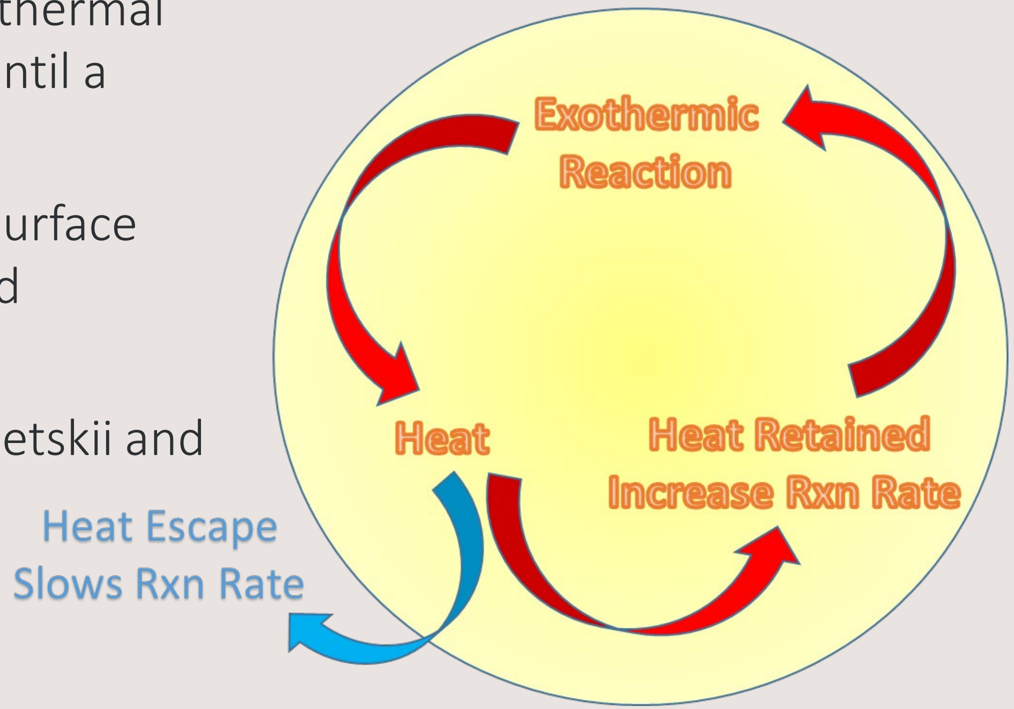
Briefing Outline

- Background – Self Heating & Critical Temperature
- Background – Predictive Models
- Validation of Predictive Models via Slow Cook Off (SCO) Testing
- Results
- Summary
- Acknowledgements

Background – Self-Heating & Critical Temperature of an Explosive Material

- Self-heating is a process where thermal energy is liberated from a material as a results of a slow chemical decomposition.
- If the rate of thermal heat generated from this chemical decomposition exceeds the systems ability to dissipate the thermal energy then the temperature of the material will increase until a catastrophic event occurs.
- The Critical Temperature is defined as the lowest constant surface temperature at which a material in a specific shape, size and composition can begin to self-heat catastrophically.
- Two predictive models of critical temperature Frank-Kamenetskii and Semenov



Background – Frank-Kamenetskii and Semenov Predictive Models

- Frank-Kamenetskii Model
  - Assumes conductive heat transfer
  - Temperature gradient in the reacting mass
  - Worst-case predictive model
  - Mimics a viscous melt with no stirring

$$T_c = \frac{E_a/R}{ln\left[\frac{A^2 \rho Q Z E_a}{T_c^2 \lambda \delta R}\right]}$$

- Semenov Model
  - Assumes perfect stirring
  - Convective heat transfer
  - Uniform temperature in the reacting mass
  - Heat loss to thermal gradient at vessel boundary

$$\frac{E_a}{T_c} = R \ln\left[\frac{V \rho Q Z E_a}{S \alpha R T_c^2}\right]$$

R – gas constant
Q – heat of decomposition
ρ – density
E_a - activation energy
Z – frequency factor
λ – thermal conductivity
A – radius of sphere, cylinder or slab
δ – shape factor
V- volume of charge
S- surface area of charge
α- heat flow coefficient at boundary
T_c- critical temperature

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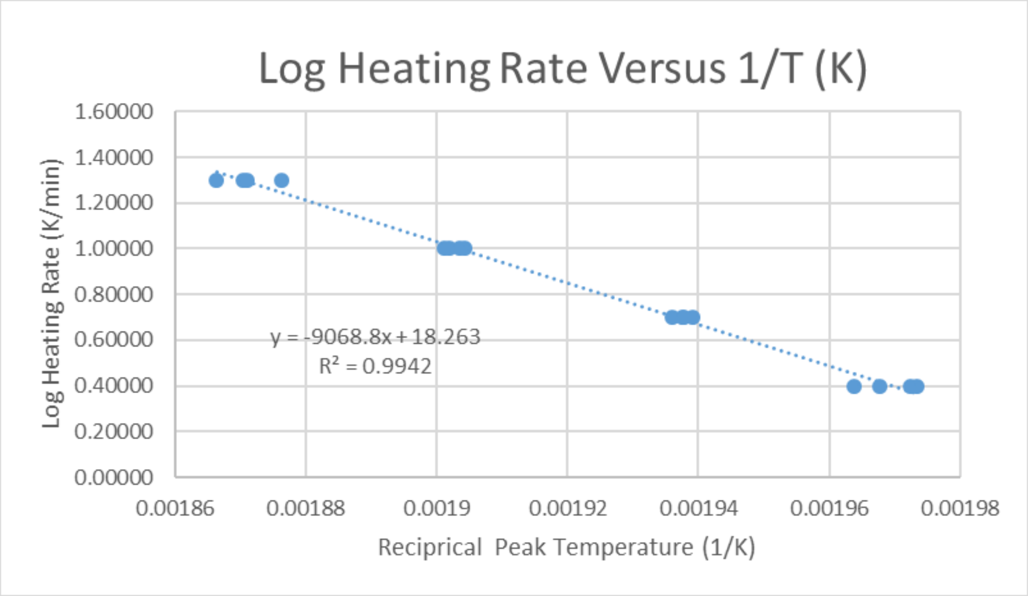
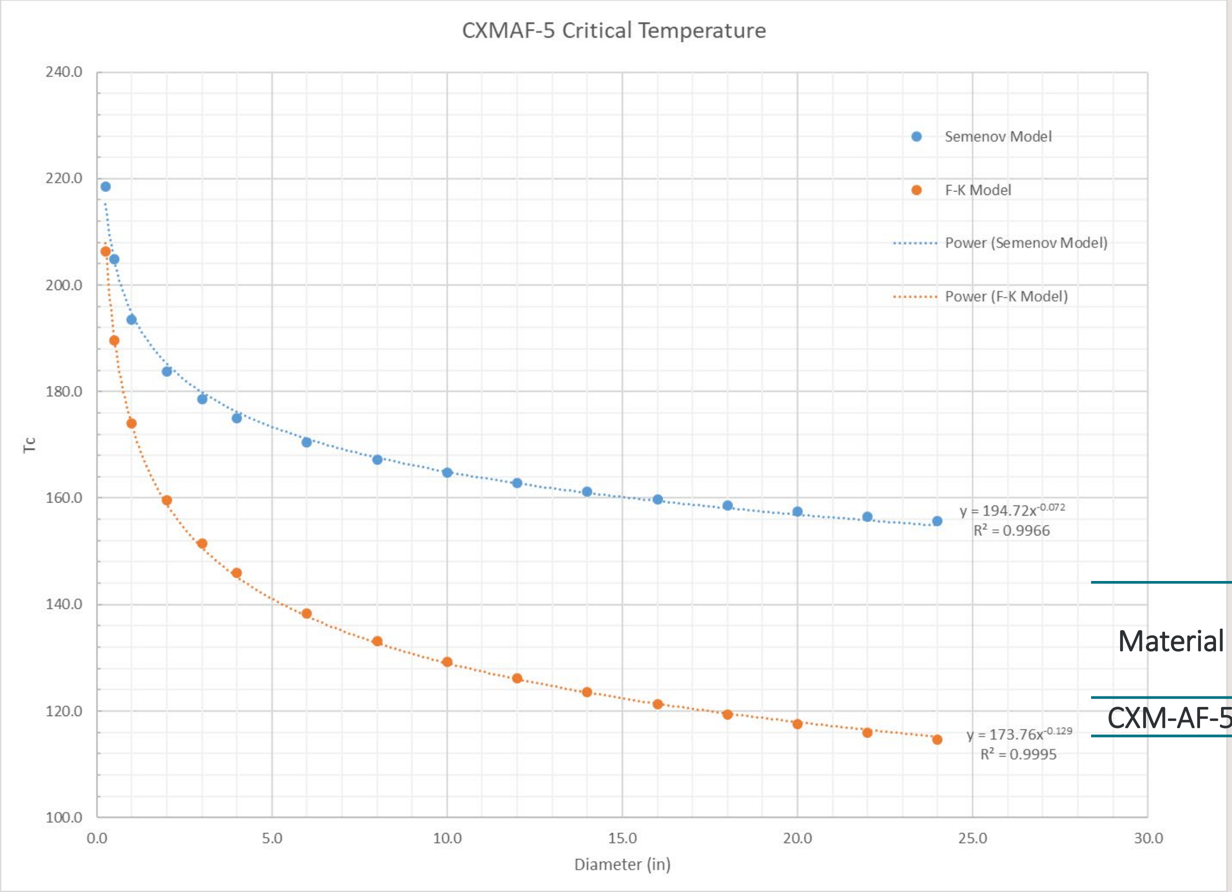
Critical Temperature via Predictive Models

- Heat of decomposition used as 500 cal/g
- Density used were bulk densities for the material.
- Decomposition Kinetic Parameters (E_a & Z) determined by variable ramp rate DSC.



*R – gas constant - 1.987 cal/(mol*K)*
Q – heat of decomposition – 500 cal/g
ρ – density - 1.00 g/cm³
E_a - activation energy – From DSC
Z – frequency factor – From DSC
*λ – thermal conductivity – 0.000507 cal/cm*S*C*
A – radius of sphere, cylinder or slab
δ – shape factor - 2.75 for right cylinder
V- volume of charge
S- surface area of charge
*α- heat flow coefficient at boundary – 0.0022 cal/(cm²*s*C) steel*
T_c- critical temperature

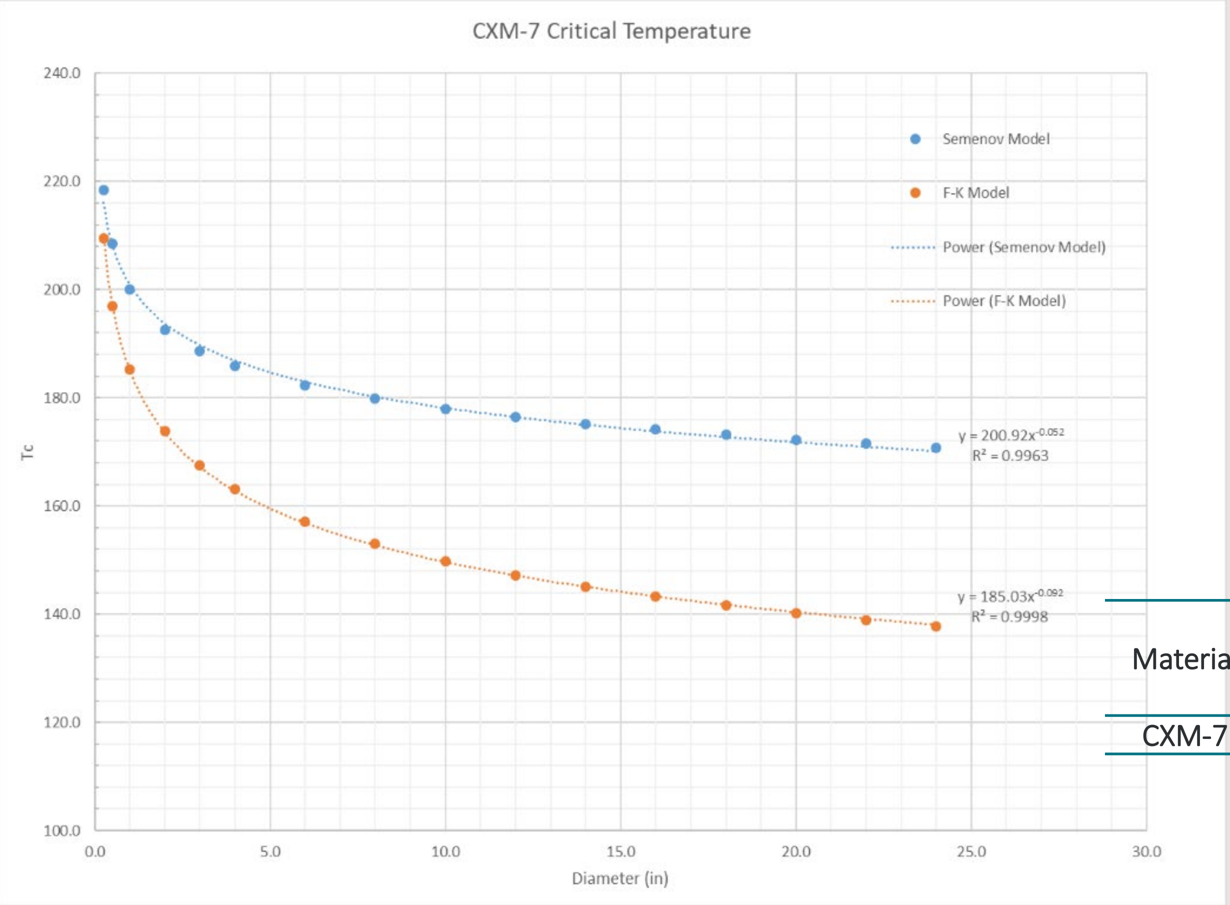
Critical Temperatures via Predictive Models: CXM-AF-5



- From parameters the critical temperature for increasing sample diameters were calculated.
- Estimates from the Frank-Kamenetskii model predict at a 20” diameter the critical temperature for this material was 117.5℃
- Estimates from the Semenov model predict at a 20” diameter vessel the critical temperature for this material was 157.5℃

Material	Tc (°C) 1.0” Diameter		Tc (°C) 2.0” Diameter		Tc (°C) 3.0” Diameter		Tc (°C) 20.0” Diameter	
	F-K	Semenov	F-K	Semenov	F-K	Semenov	F-K	Semenov
CXM-AF-5	174.0	193.5	159.5	183.7	151.5	178.6	117.5	157.5

Critical Temperatures via Predictive Models: CXM-7



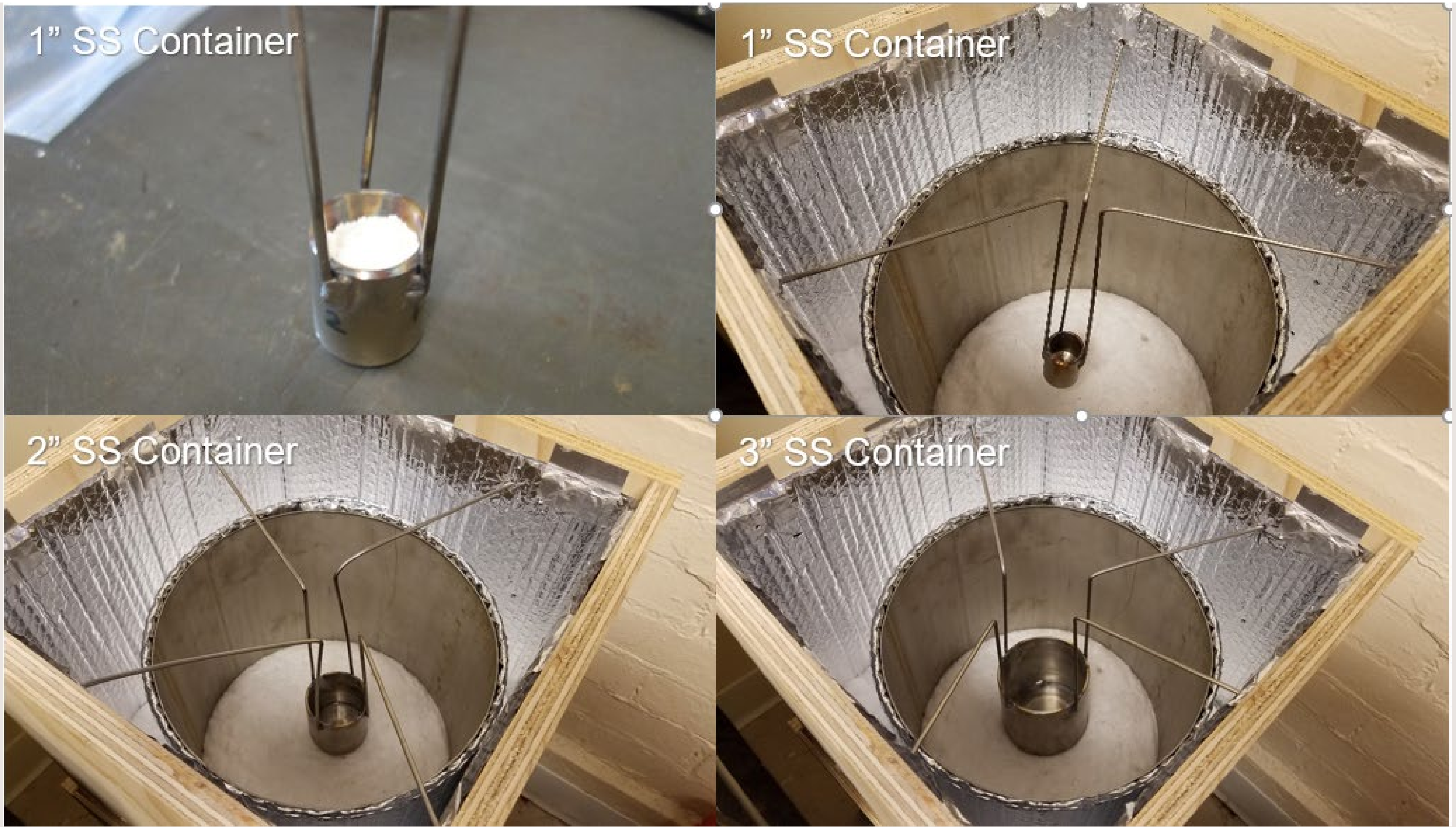
- From parameters the critical temperature for increasing sample diameters were calculated.
- Estimates from the Frank-Kamenetskii model predict at a 20" diameter the critical temperature for this material was 140.2℃
- Estimates from the Semenov model predict at a 20" diameter vessel the critical temperature for this material was 172.3℃

Material	Tc (°C) 1.0" Diameter		Tc (°C) 2.0" Diameter		Tc (°C) 3.0" Diameter		Tc (°C) 20.0" Diameter	
	F-K	Semenov	F-K	Semenov	F-K	Semenov	F-K	Semenov
CXM-7	185.2	200.0	173.9	192.6	167.6	188.6	140.2	172.3

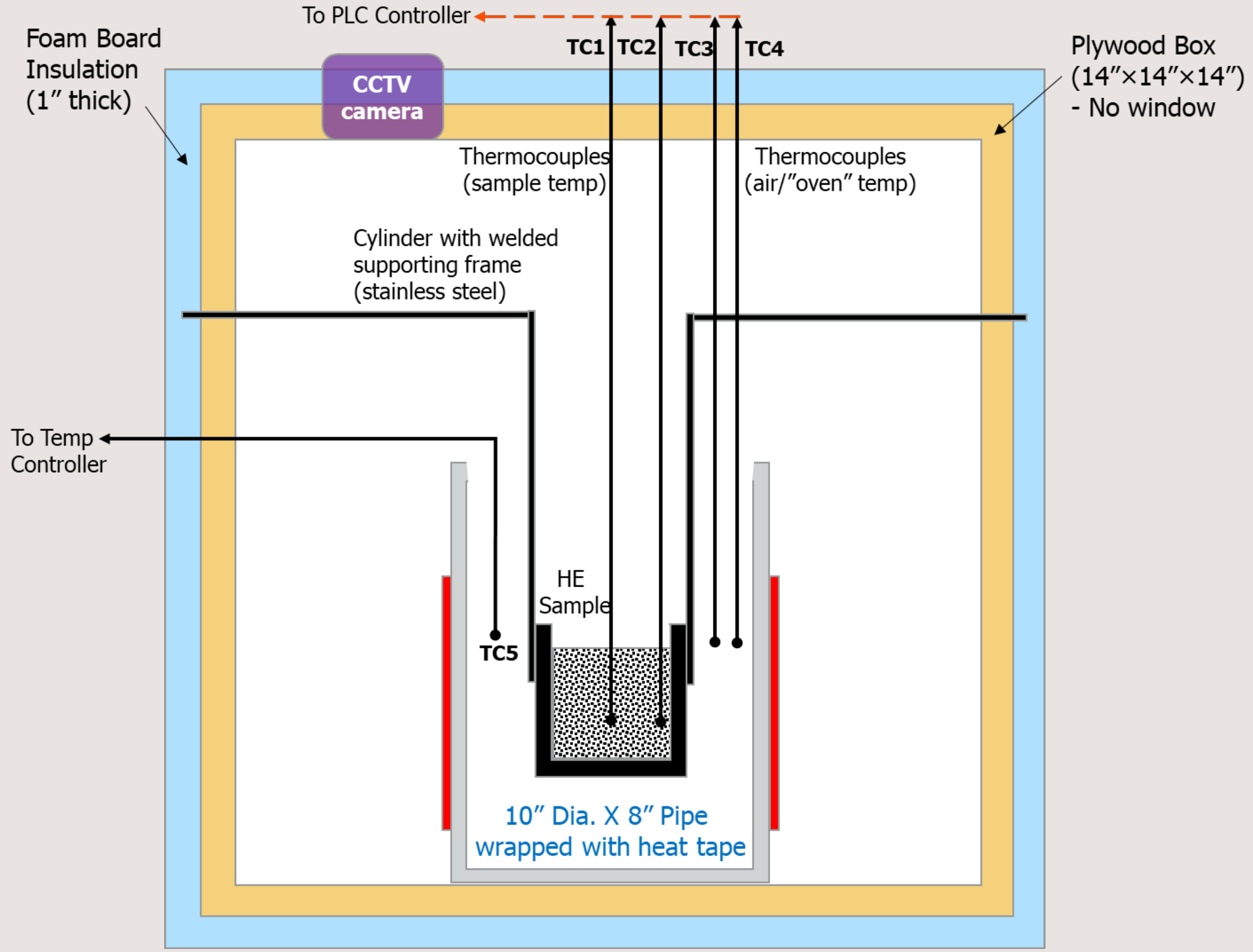
Validation of Values from Thermal Prediction Models

- The results from the predictive models were validated using a series of Slow Cook Off tests.
- In this series of tests the size of the containment vessel used for the explosive was increased between tests.
- The vessel used were right cylinders of 1 in., 2 in., and 3 in. diameters.
- Samples were initially heated to 120 ℃ and then allowed to equilibrate for 6 hours.
- Samples were then heated at 3.3 ℃/min. until an event occurred.
- Post test evaluation of the differences between the oven and sample temperatures were evaluated to measure onset of self-heating within the samples for comparison to the predictive models.

Slow Cook-Off Testing (SCO) – Test Apparatus Setup



Slow Cook-Off Testing (SCO) – Test Apparatus Setup



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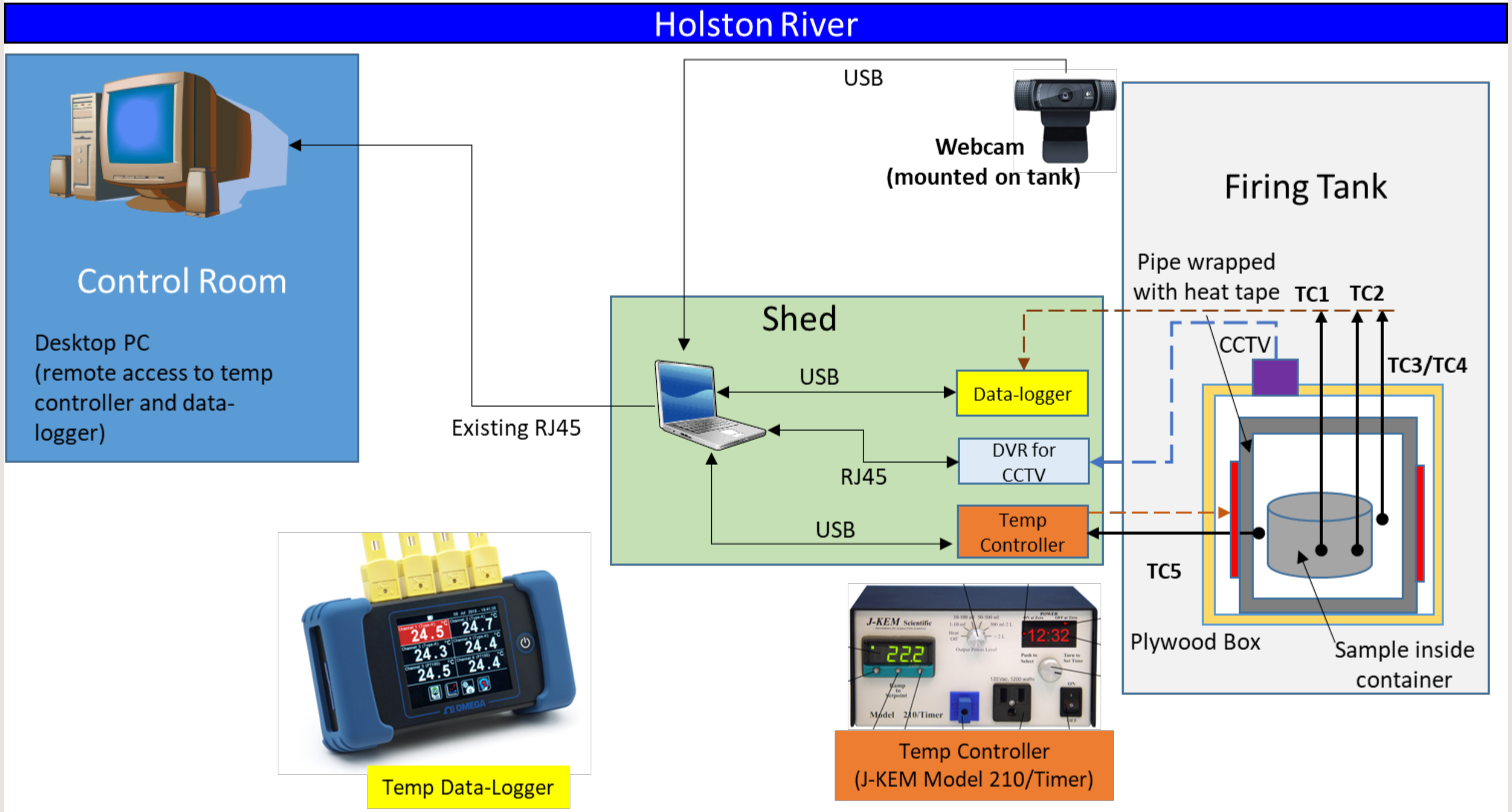
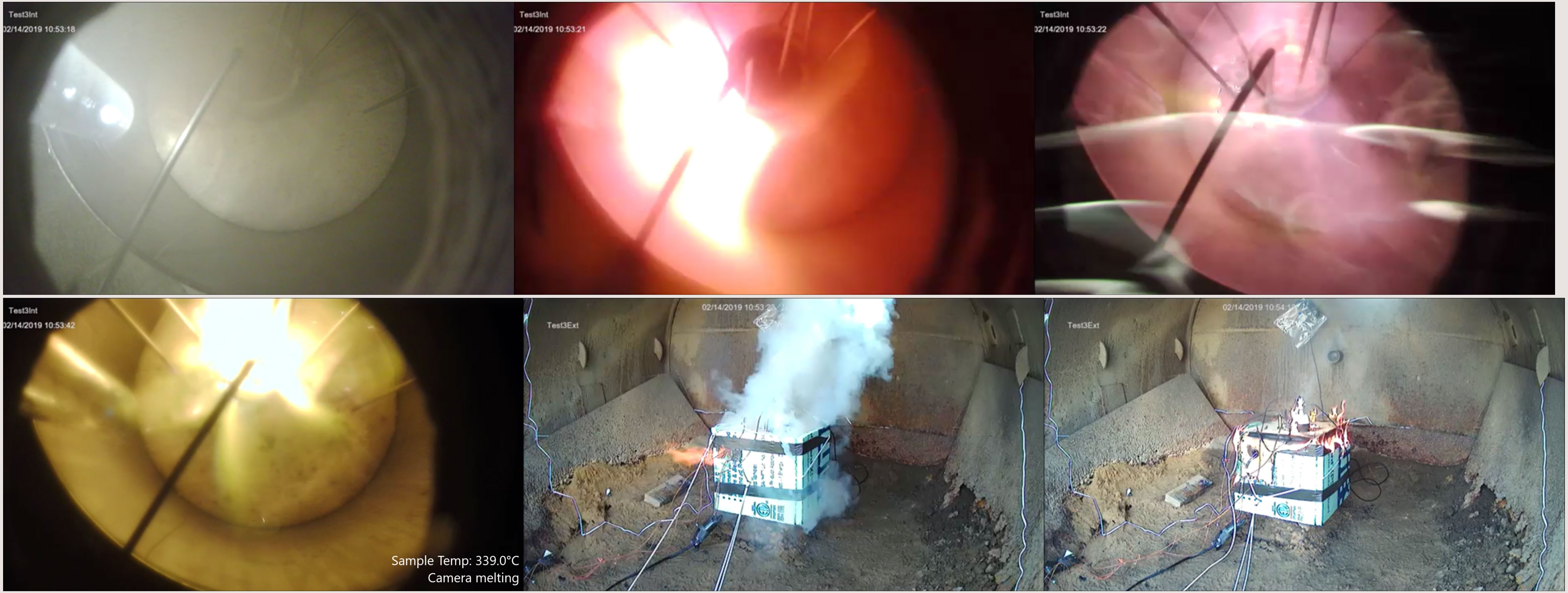
Slow Cook-Off Testing (SCO) – Test Facility Setup



Slow Cook Off (SCO) Test Pictures

Slow Cook Off (SCO) Test Pictures



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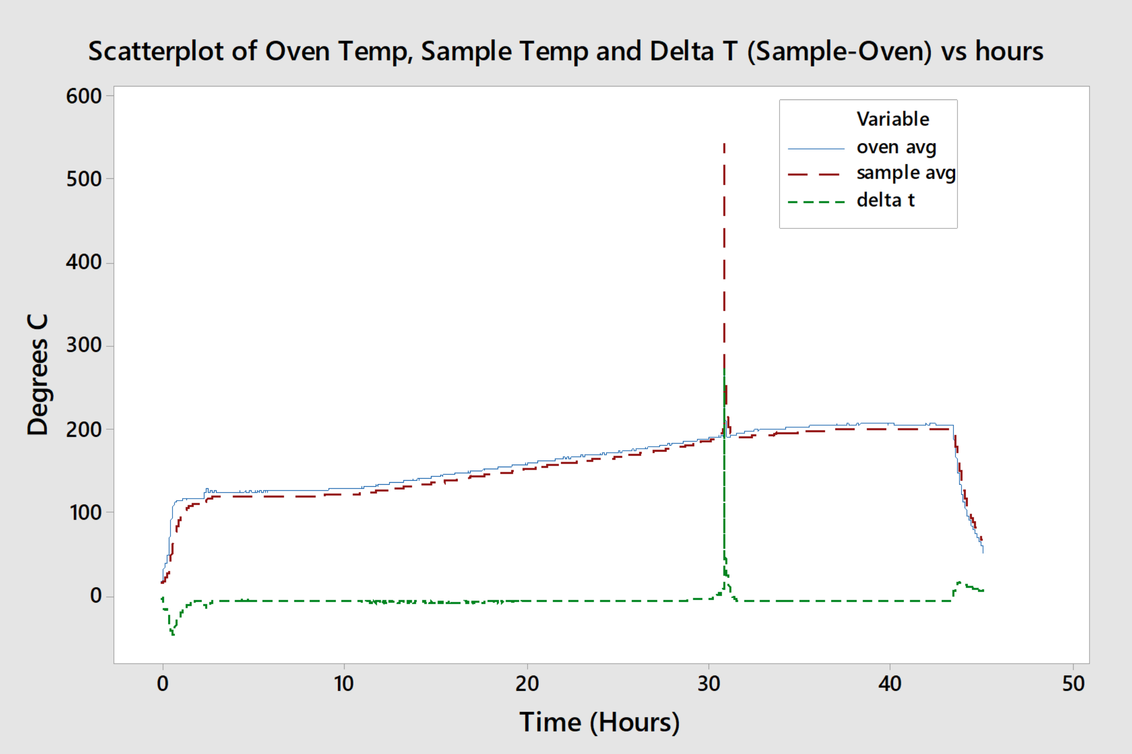
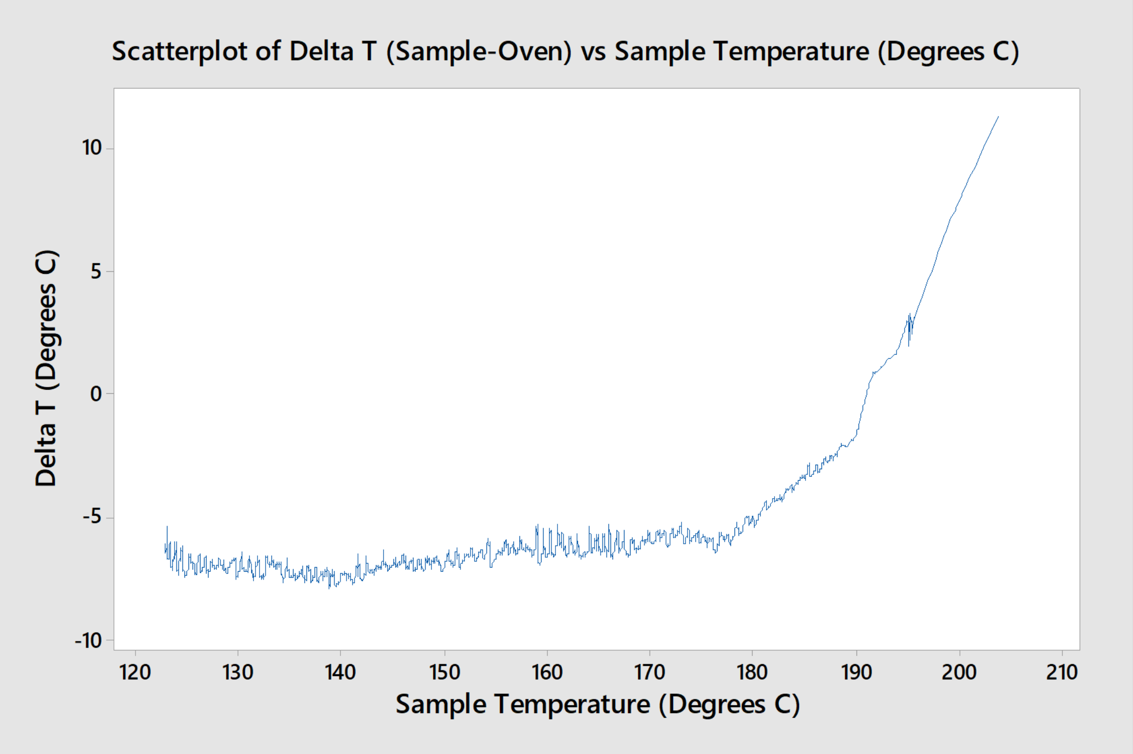
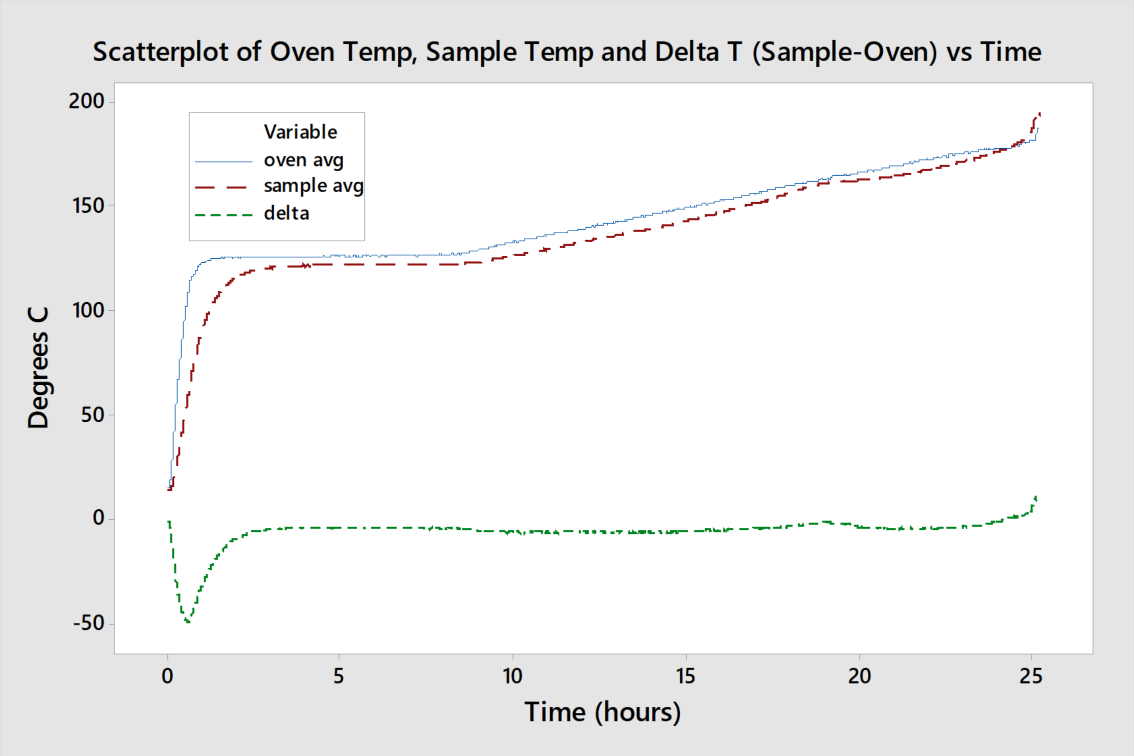
Slow Cook Off (SCO) Test Pictures – Post test

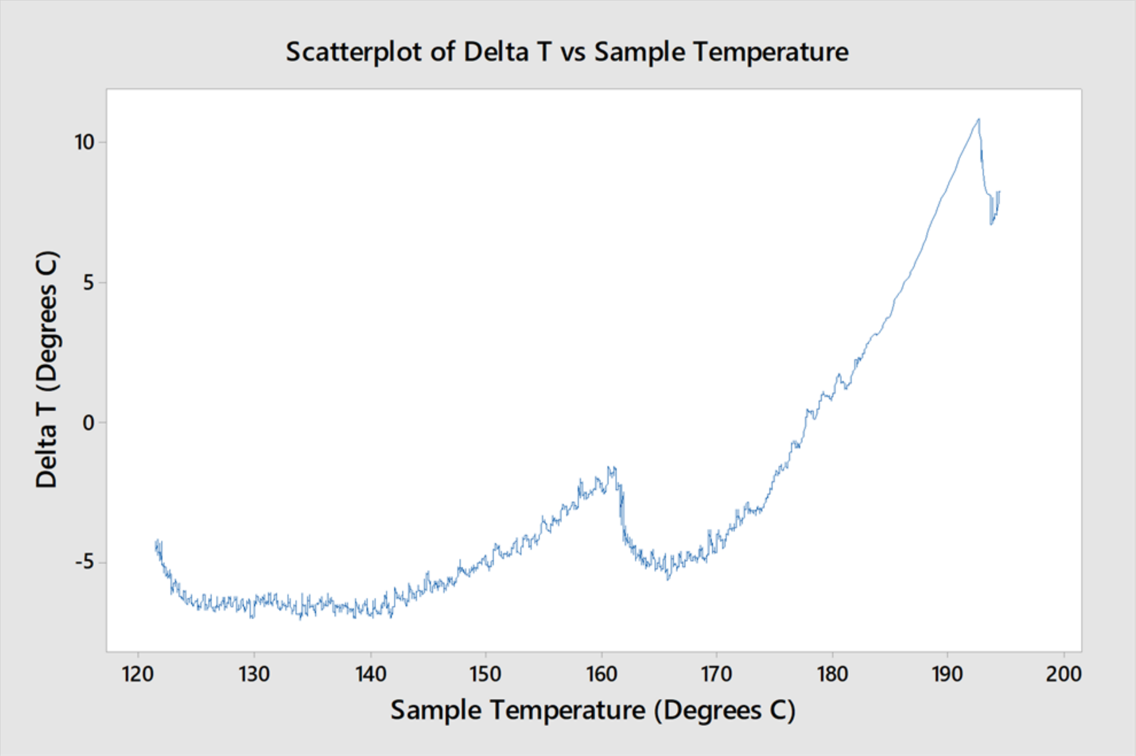
Slow Cook off (SCO) with 1" Diameter Right Cylinder Test Sample





Slow Cook off (SCO) with 2” Diameter Right Cylinder Test Sample





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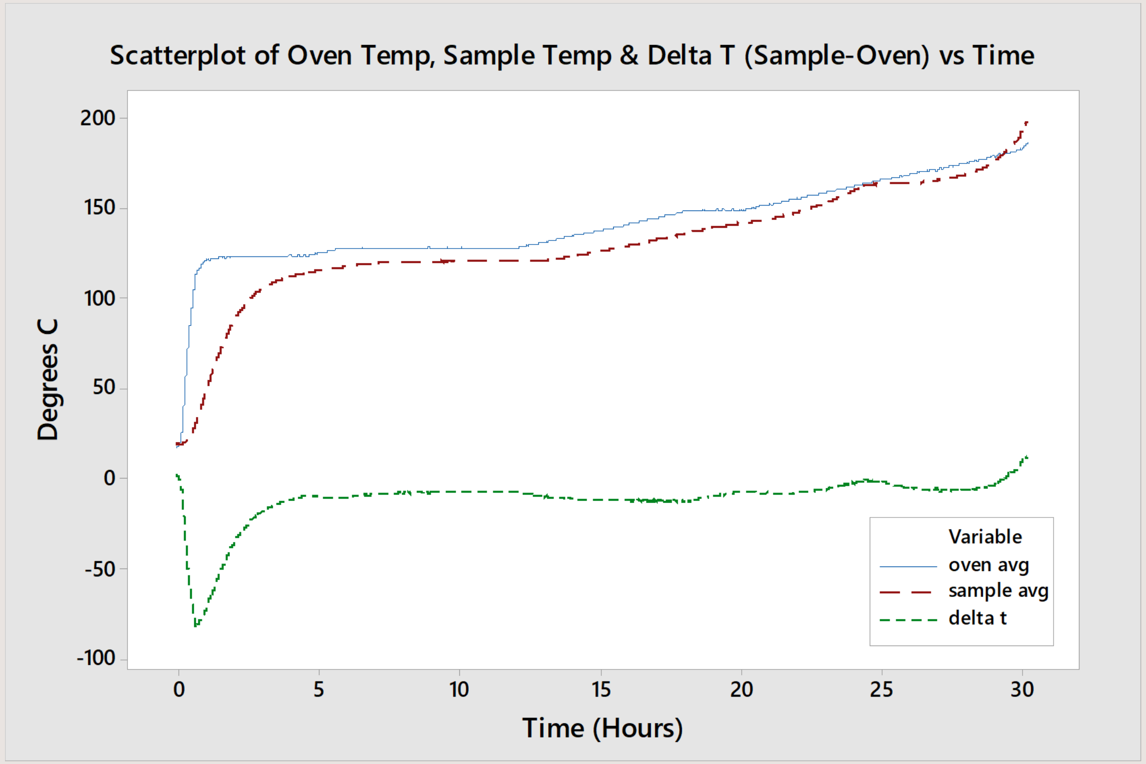
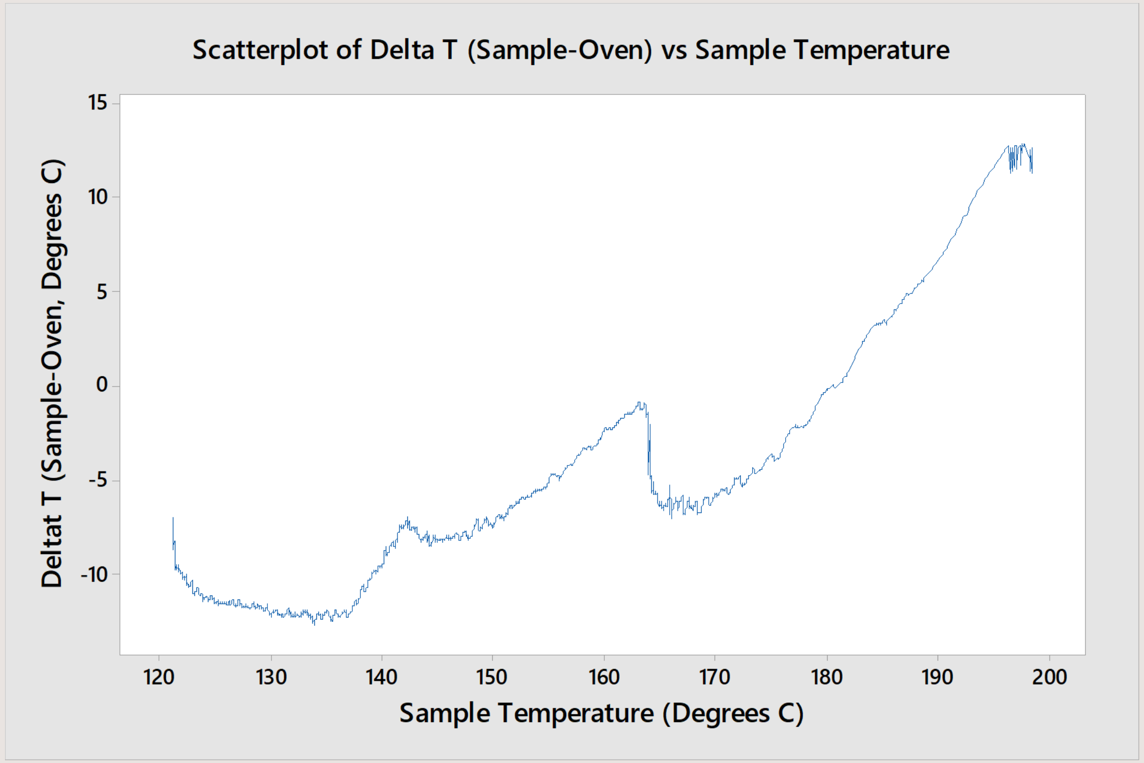
Slow Cook off (SCO) with 3" Diameter Right Cylinder Test Sample





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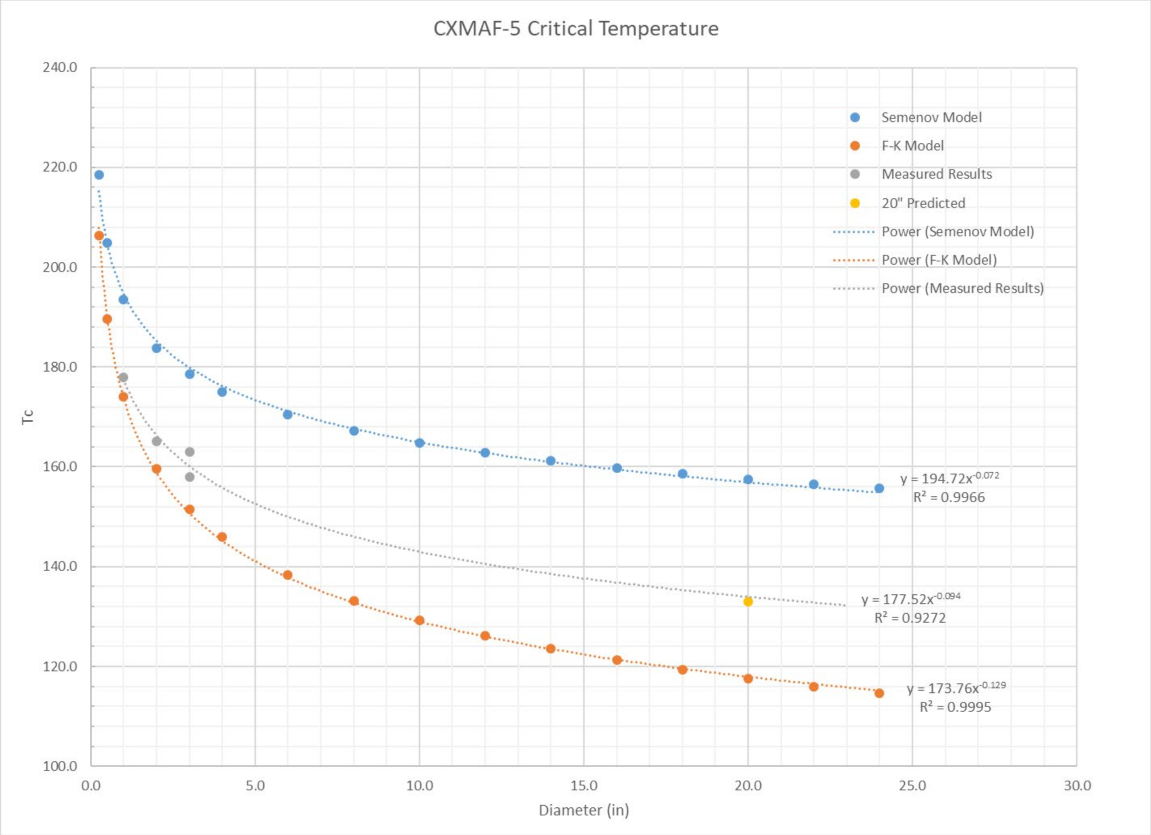
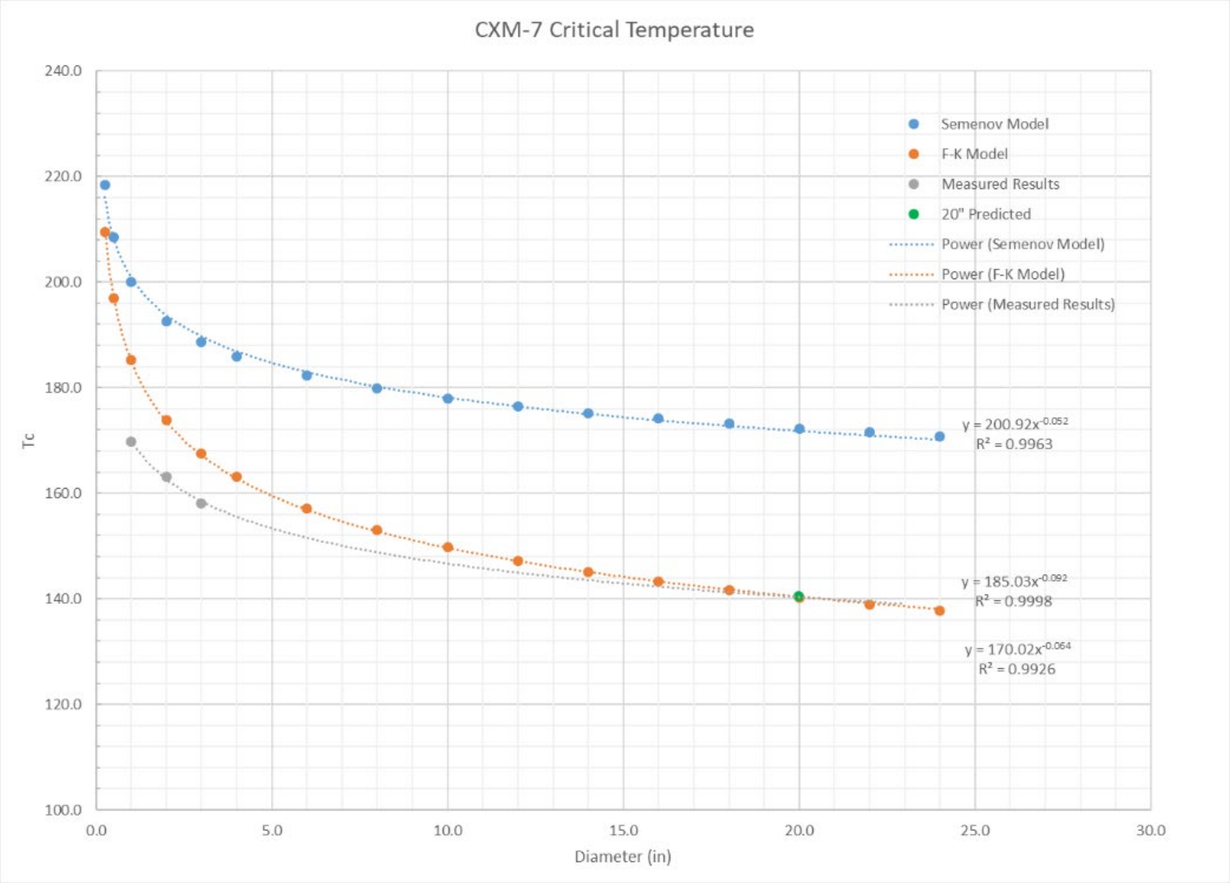
Comparison of SCO Testing to Predictive Models: CXMAF-5



Diameter	F-K Model (T_c °C) Predicted	F-K Model (T_c °C) Measured	% Error from Predicted
1 inch	174.0	178.0	2.3
2 inch	159.5	165.1	3.5
3 inch	151.5	158.0	4.3

Diameter	F-K Model (T_c °C) Predicted	F-K Model (T_c °C) Predicted via Measured values	% Error from Predicted
20 inch	117.5	133.0	13.2

Comparison of SCO Testing to Predictive Models: CXM-7



Diameter	F-K Model (T_c °C) Predicted	F-K Model (T_c °C) Measured	% Error from Predicted
1 inch	185.2	169.8	8.3
2 inch	173.9	163.2	6.2
3 inch	167.6	158.1	5.7

Diameter	F-K Model (T_c °C) Predicted	F-K Model (T_c °C) Predicted via Measured values	% Error from Predicted
20 inch	140.2	140.4	0.1

Summary

- Semenov and Frank-Kamenteskii Models were used to estimate critical temperatures of increasing diameter vessels
- Slow Cook-Off Testing was performed to validate the predicted results from the models
- The SCO test setup performed well throughout the testing. For future testing, it is suggested that the data collection rate be slowed from two data points per second to a data point every 5 seconds to reduce the amount of data collected and to potentially reduce noise in the data due to oversampling.
- The measured Tc values for all RDX based samples were within 15% of the theoretical Tc calculated from the F-K equation.
- The measured Tc values for HMX based samples were within 16% of the theoretical Tc calculated from the F-K equation.
- The general agreement between these two methods supports the screening of the Tc of future products via determination of the Arrhenius equation kinetic parameters using Differential Scanning Calorimetry (DSC) and application of the F-K equation.

Acknowledgements – to be updated

- Dr. Jeremy Headrick
- Dr. Neil Tucker
- Mr. Virgil Fung
- Ms. Kelly Smith
- Ms. Denise Painter
- Mr. Todd Dye
- Mr. Tracy Kelly

Naval Surface Warfare Center Dahlgren Division

Concept For Improving Cook-off Performance of Propellants and Explosives

Presented by

Jon Yagla, PhD

Senior Member, International Ballistics Society
Integrated Engagement Systems (E) Department

WELCOME

Insensitive Munitions and Energetic Materials Technology Symposium

Indianapolis, Indiana

October 2022

The Leader in Warfare Systems Development and Integration

Introduction and Background

A concept for improving the cook-off performance of munitions is explained. The performance improvements could be preventing reactions, delaying the time to reactions, and/or and reducing the violence of reactions.

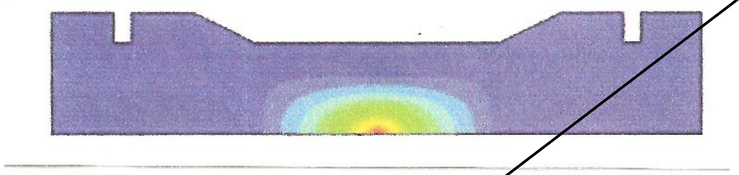
A reactive cook-off occurs due to an instability that occurs when heat is evolved from exothermal decomposition, and the heat produced exceeds the ability of the explosive material to conduct it away from the reaction zone. The rate of reaction increases exponentially as temperature increases. The decomposition rate and release rate of thermal energy rate is completely unstable and a violent reaction results.

The concept involves introducing heat conduction paths that wick the heat out of interior points of the energetic material. Reactions could be prevented, or at least made to occur near the outer surface of the munition, where there is less confinement and much less violence.

Modeling Results for Cook-off of PBX at Two Heating Rates

Slow Heating,

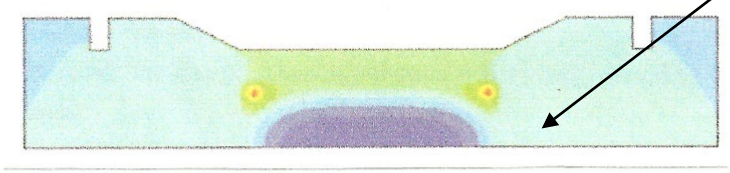
3.3° C / hr



Slow heating
Bulk temperature elevates to the point where the heat from the thermal decomposition cannot get out fast enough and leads to an explosion. The centerline is the place where heat has the most trouble diffusing out fast enough to prevent a thermal runaway.

Fast Heating,

3.3° C / min



Faster heating
Bulk temperature elevates to the point where the heat from the thermal decomposition cannot get out fast enough at some interior point well away from the centerline, and leads to an explosion at some point well away from the center.

The faster the heating, the closer to the surface the reaction is, and the less violent the explosion.

J.C. Gois et. al, Cook-off Test Models and Results, Laboratory of Energetics and Detonics, University of Coimbra, Portugal

Example of Solid Propellant Rocket Motor Insensitive Munitions, Testing and Simulation

Heat trapped in dome of rocket motor leads to reaction ahead of rest of propellant

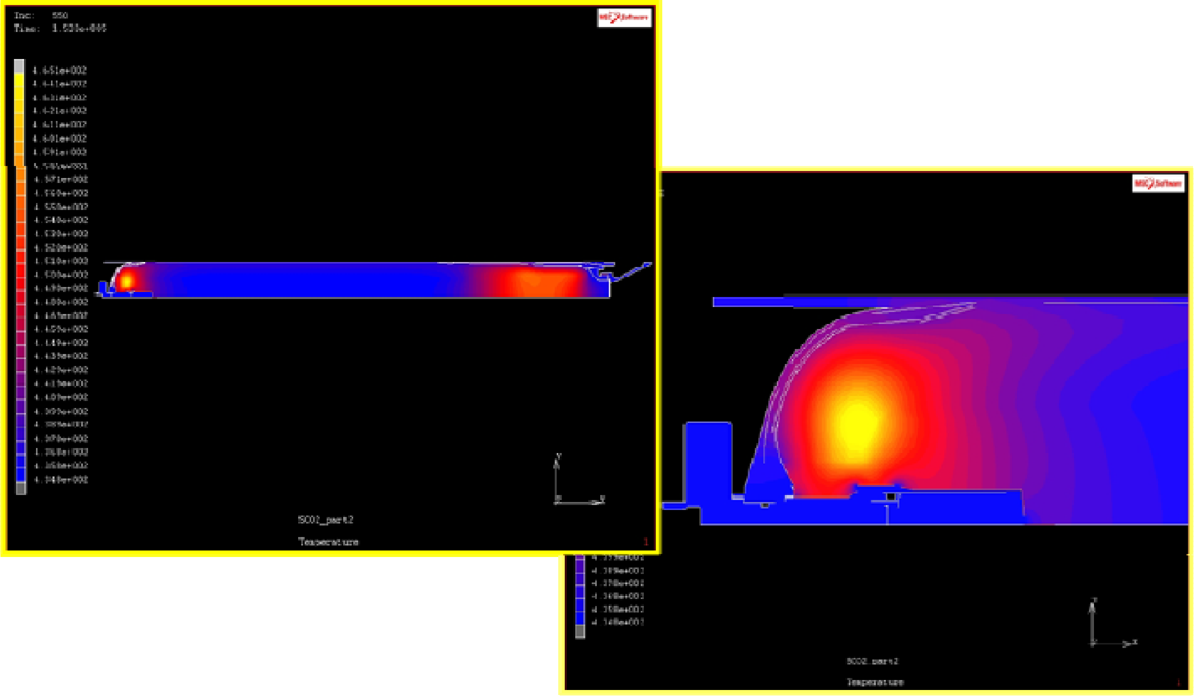


Figure 11: FE-temperature distribution of the HBR-motor just before the SH-reaction

Dr. A. Weigand*, G. Unterhuber*,
K. Kupzik**, Dr. T. Eich***, B. Bucher***

Solid Propellant Rocket Motor Insensitive Munitions, Testing and Simulation

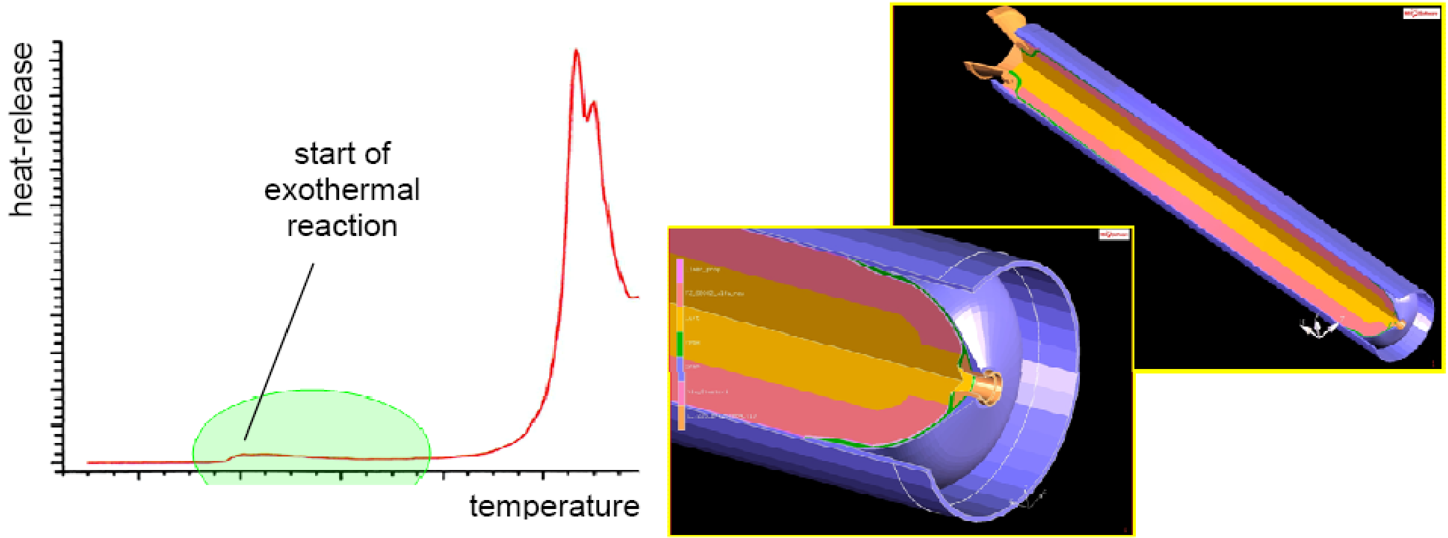


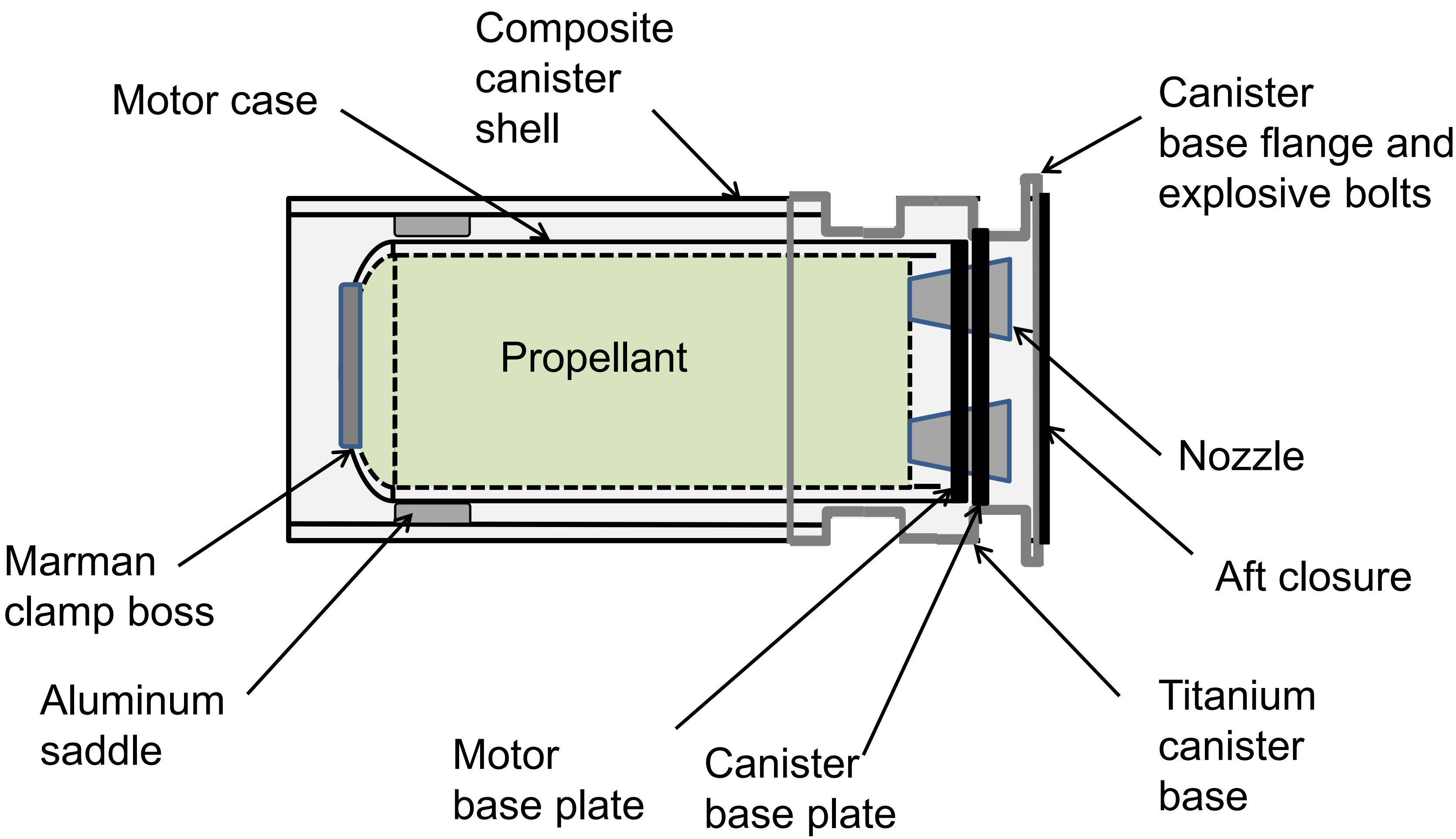
Figure 10: Results of DSC calorimetry and FE-model of the HBR motor.

Figure 11 shows the computed temperature distribution in the HBR rocket-motor and the air in the bore just before the SH-reaction. The computation is two-dimensional and used a measured 3.3℃/h oven-temperature profile as bounda ry condition. The results indicate the formation of a hot spot in the dome region close to the bore surface. At that location, the SH-reaction would actually start. While the temperature of the hot-spot is only 10K higher than that of the hot region in the rear of the motor, the residual part of the grain remains at oven-temperature level. The physical meaning of the hot-spot location is that this is the thermally best insulated region in the motor with the least amount of heat loss through conduction.

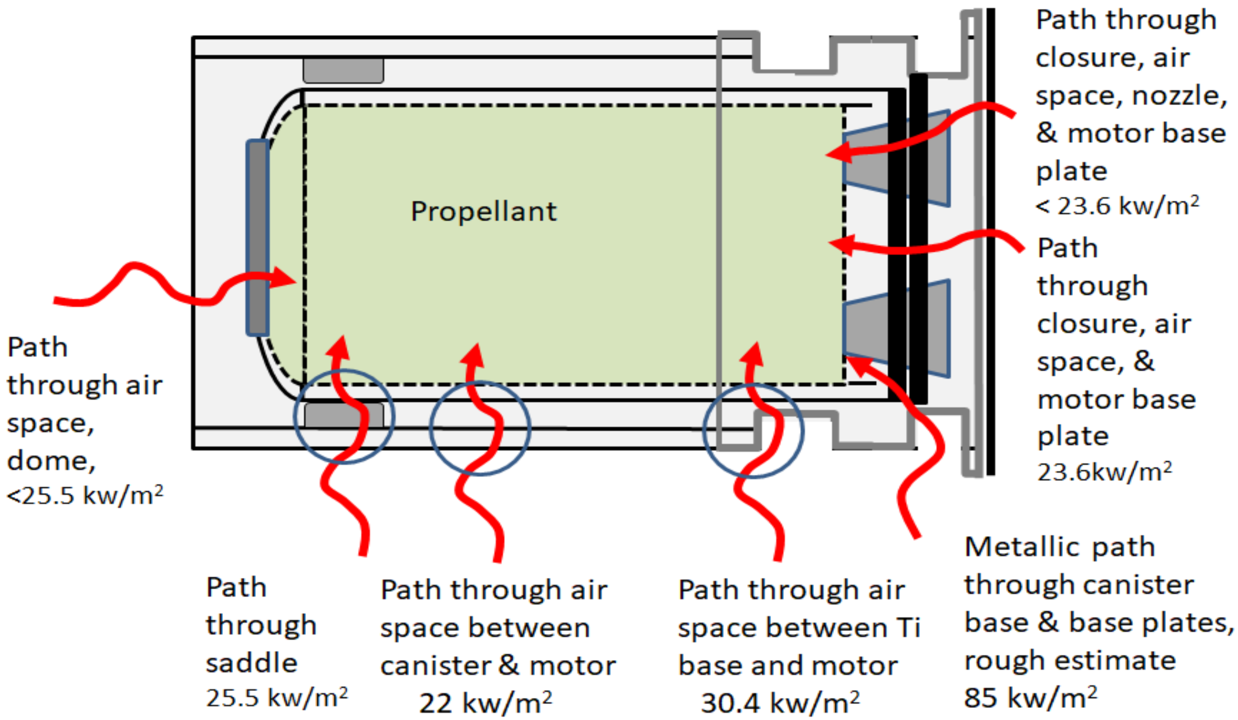
Dr. A. Weigand*, G. Unterhuber*,
K. Kupzik**, Dr. T. Eich***, B. Bucher***

Heat Flows Along Several Thermal Paths Into a Rocket Motor Propellant in a Fast Cook-Off Casualty and Test

The new concept is to find a way to get unwanted heat out of the rocket motor.



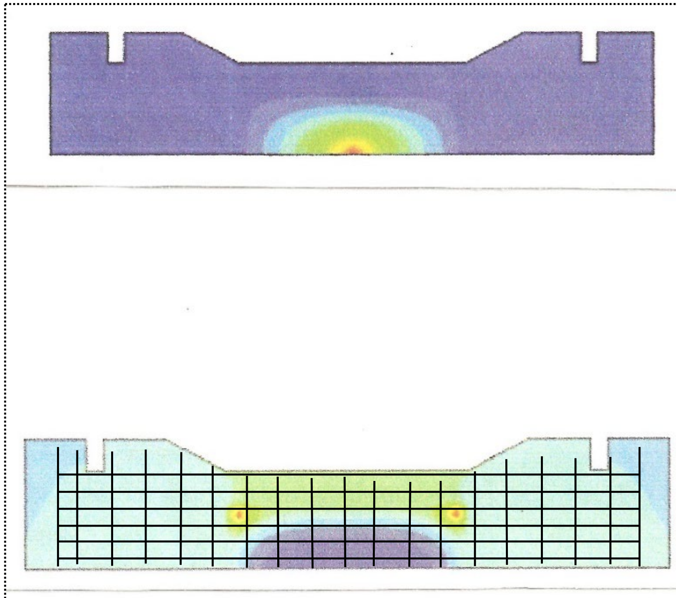
Thermal Paths to Propellant Leading to a Cook-Off Event

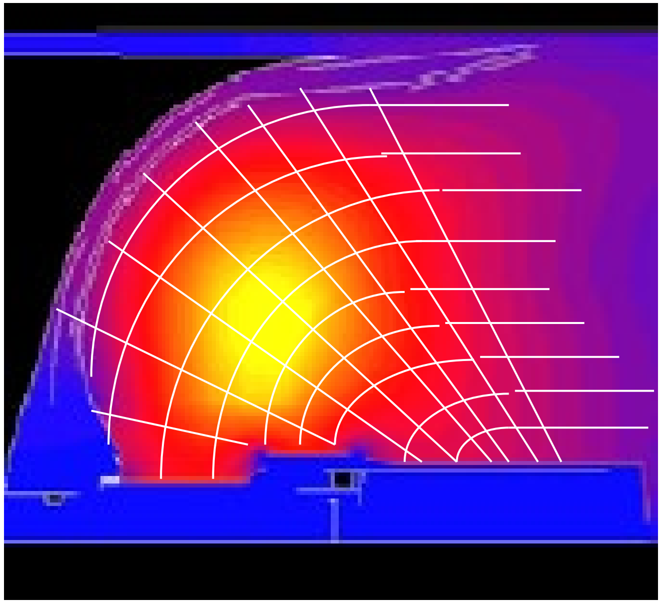


Heat fluxes into the propellant range from
22 to 85 kW/m^2 for fast cook-off in realistic scenario

Mitigation Concept - Meshes

Uniform and lowest possible temperature maintained





Wire meshes imbedded in energetic material conduct heat away from hot spots to outer surface where reactions would be less severe. Wires terminate short of outer surface to assure minimum confinement of reaction.

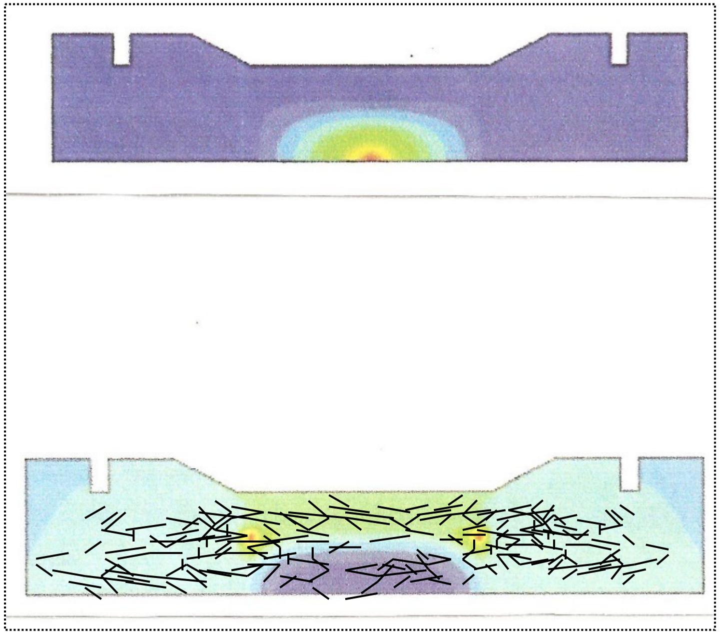
Aluminum and magnesium wires have high thermal diffusivity and can be used as a reactant so there is no weight penalty.

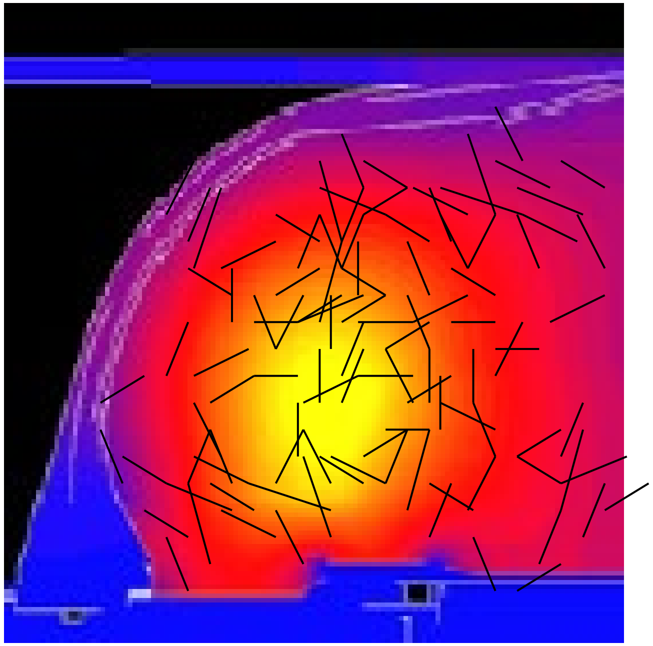
Grids produced in 3-D metal printers could simplify manufacturing and create precise flow paths and variable diameter conductors.

3-D Finite element models could be used to design grids that follow isotherms and heat flux vector fields for optimum performance.

Mitigation Concept - Fibers

1. Use fiber meshes to diffuse incoming heat throughout energetic material to allow uniform and lowest possible temperature.

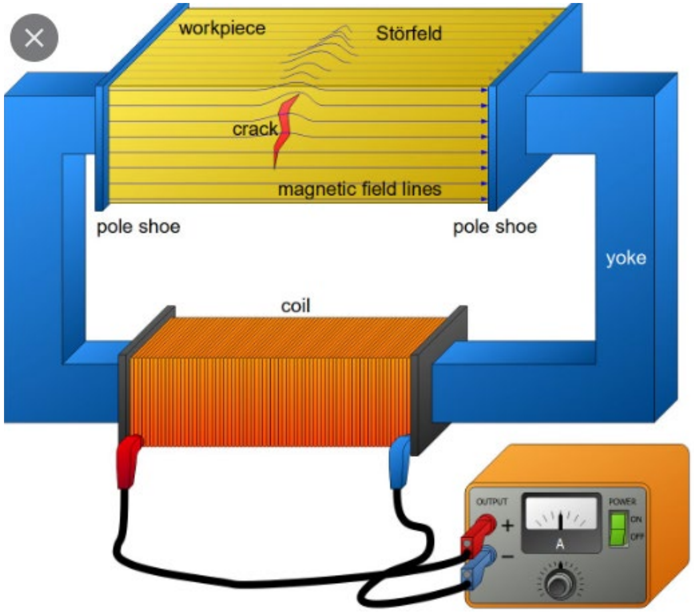


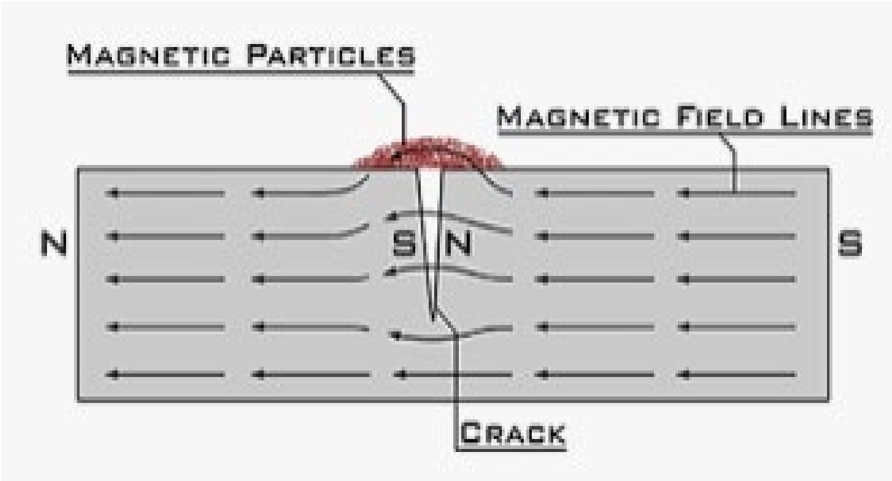


2. Fibers imbedded in energetic material conduct heat away from hot spots.
3. Aluminum and magnesium fibers have high conductivity and can be used as a reactant, and strengthen material for shock and vibration.
4. Synthetic and stainless steel fibers are routinely used to reinforce materials, e.g. concrete.
5. Fibers could be aligned in a magnetic field while casting propellant or explosives.

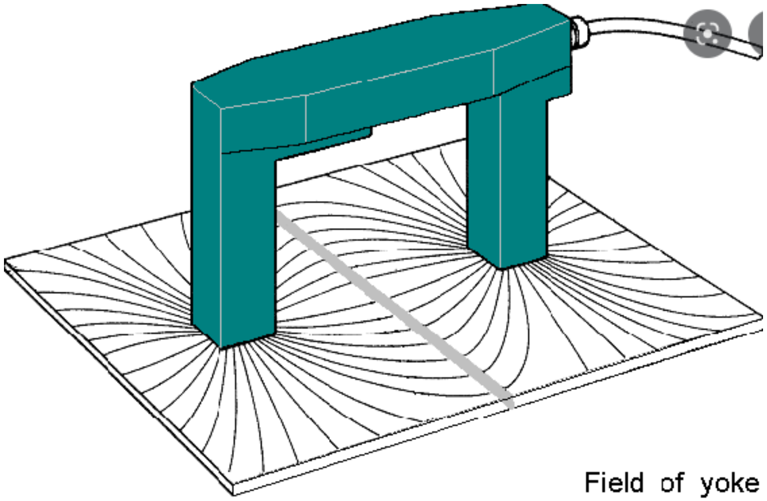
Magnetic Particle Testing

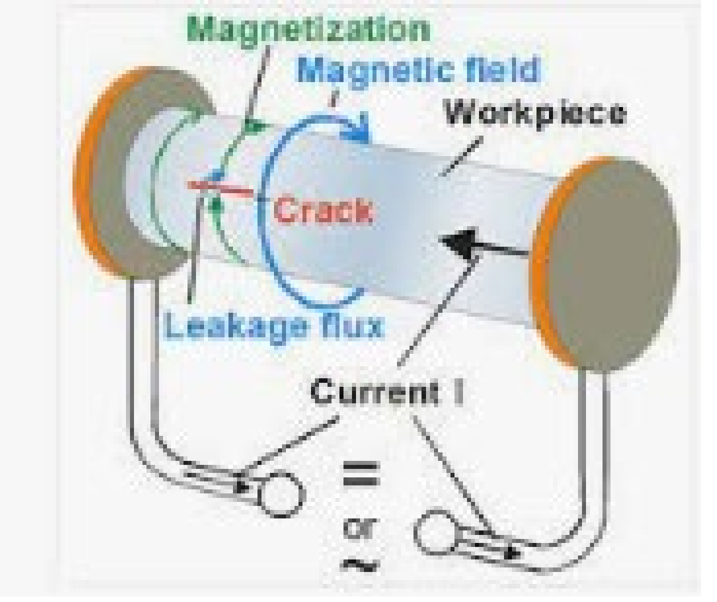
Idea comes from author's personal use of magnetic particle (MT NDT) of gun parts inspection, and use of stainless steel fibers to achieve super high strength (>10ksi) concrete structures



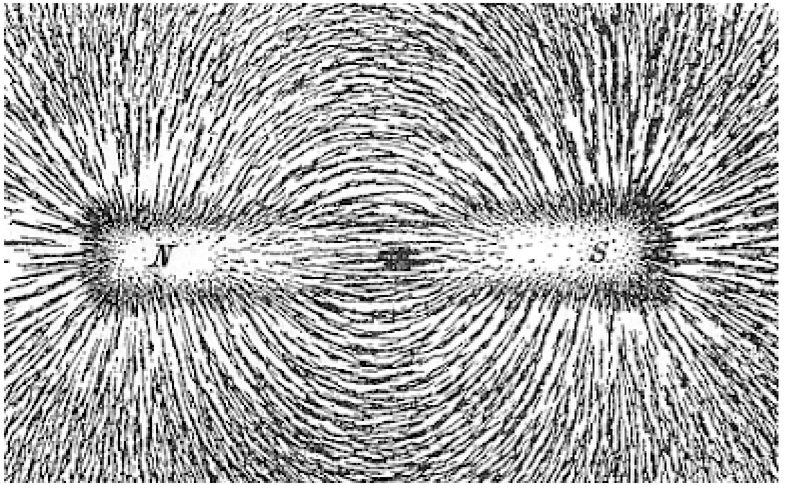


Ordinary MT technique

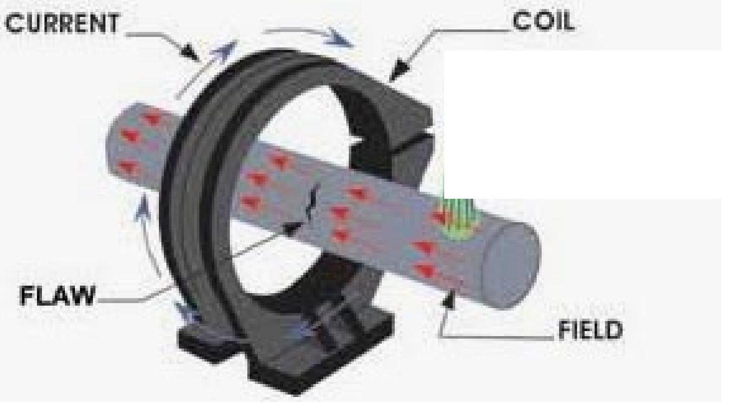




Axial technique



Iron particles align with magnetic field on bottom side of plate



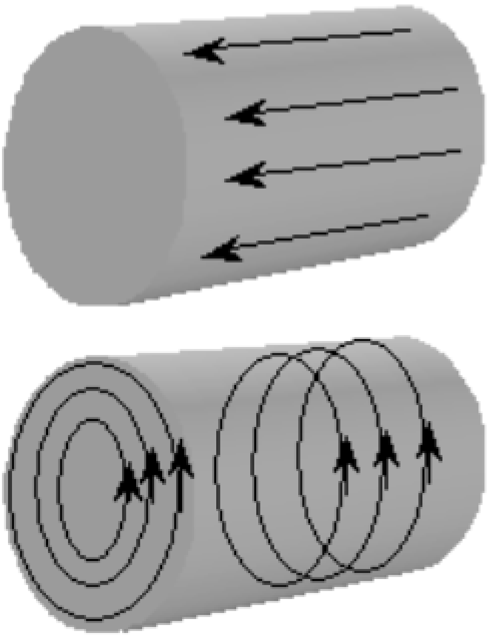
Circumferential technique

A Look Into The Math

Magnetized particles can be aligned in any direction by superposition of a longitudinal field with a circular field

A **longitudinal magnetic field** has magnetic lines of force that run parallel to the long axis of the part. Longitudinal magnetization of a component can be accomplished using the longitudinal field set up by a coil or solenoid. It can also be accomplished using permanent magnets or electromagnets.

A **circular magnetic field** has magnetic lines of force that run circumferentially around the perimeter of a part. A circular magnetic field is induced in an article by either passing current through the component or by passing current through a conductor surrounded by the component.

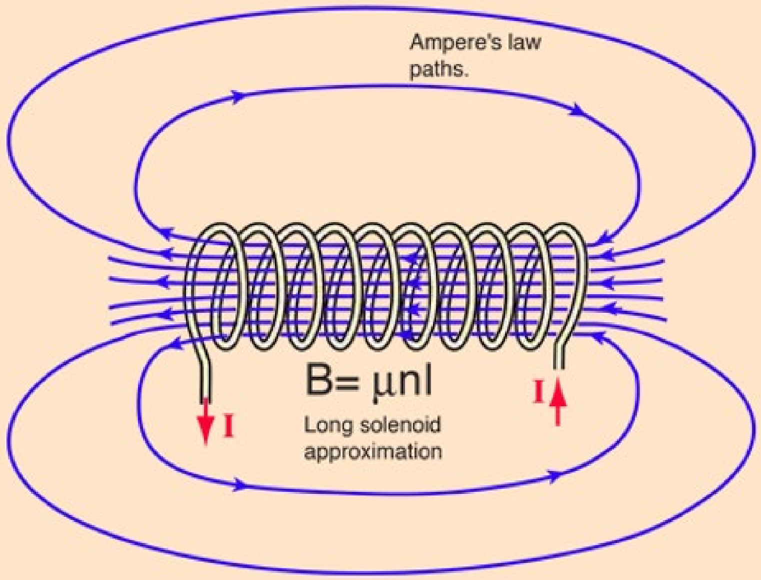


A computer field theory solver can compute path lines along which the particles will align themselves

Solenoidal fields are fundamental to electricity and magnetism

Partial differential equations theory allows superposition (adding) of solutions in different coordinate systems to solve complex problems

A long straight coil of wire can be used to generate a nearly uniform magnetic field similar to that of a bar magnet. Such coils, called solenoids, have an enormous number of practical applications. The field can be greatly strengthened by the addition of an iron core. Such cores are typical in electromagnets.



The magnetic field is concentrated into a nearly uniform field in the center of a long solenoid. The field outside is weaker and the lines representing the magnetic field are further apart.

In the above expression for the magnetic field B, n = N/L is the number of turns per unit length, sometimes called the "turns density". The magnetic field B is proportional to the current I in the coil. The expression is an idealization to an infinite length solenoid, but provides a good approximation to the field of a long solenoid.

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Thermal and dipolar interaction effect on the relaxation in a linear chain of magnetic nanoparticles

We will use these new analysis methods and results to align the conductive fibers

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ARTICLE INFO

Keywords:
Dipolar interaction
Magnetic relaxation
Thermal effect
Random anisotropy

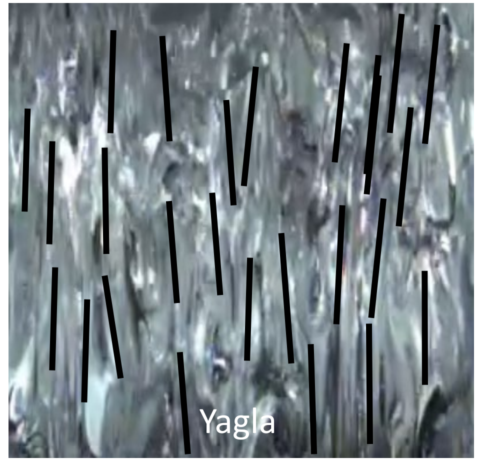
ABSTRACT

We perform computer simulations to study the relaxation in a one-dimensional chain of dipolar interacting magnetic nanoparticles (MNPs). Using the two-level approximation of the energy barrier, we perform kinetic Monte Carlo simulations to probe the relaxation mechanism as a function of dipolar interaction strength and temperature. The anisotropy axes of the MNPs are assumed to have random orientations. At high temperatures, the magnetization decay curve is exponential for weak dipolar interactions. It is found that dipolar interactions slow down the magnetic relaxation and increase the effective Néel relaxation time τ_N, which is affected by thermal fluctuations. In the weak dipolar limit, there is a perfect agreement between simulated and analytically evaluated values of τ_N for a wide range of temperatures. Microscopic analyses such as magnetic moments correlations and dynamic domain formation also suggest an increase in ferromagnetic coupling with an increase in dipolar interaction strength or decrease in thermal fluctuations. We believe that the concepts presented in this work are relevant in the context of applications such as data storage, digital data processing, and magnetic hyperthermia, in which the linear chain of MNPs are pervasive.

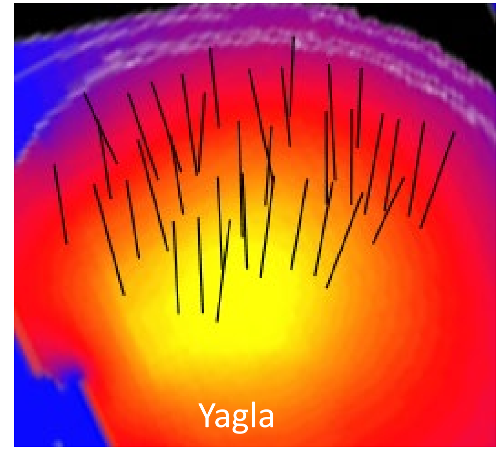
NSWCDD-PN-19-00318; Distribution Statement A: Approved for Public Release

Possible Fiber Alignment In Acoustic Field

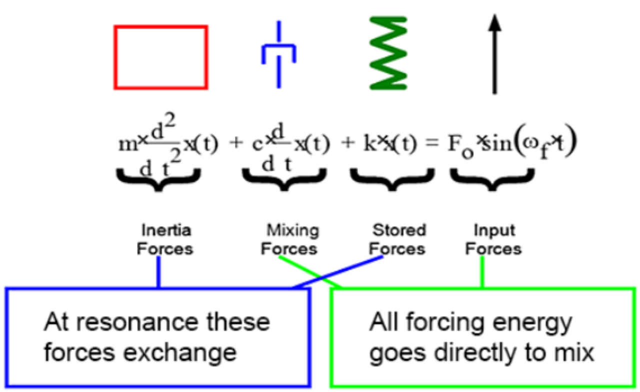
Propellant strands in alignment



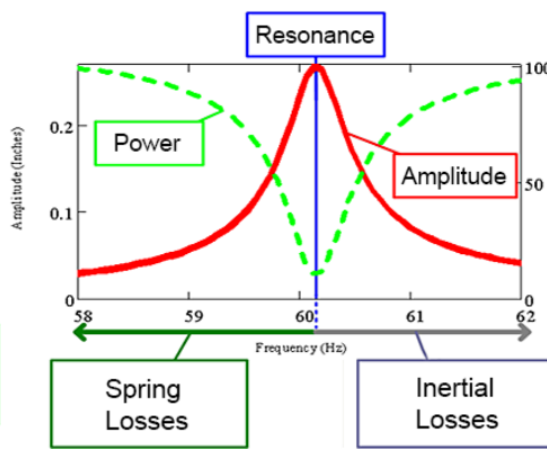
Long fibers in alignment



Alignment in radial acoustic field



Resodyn Corp

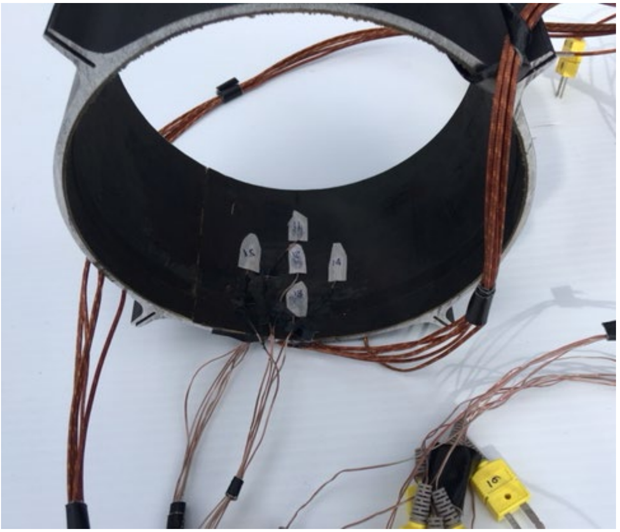


25-100 Hz Frequency
12mm Displacement
100 g Acceletation

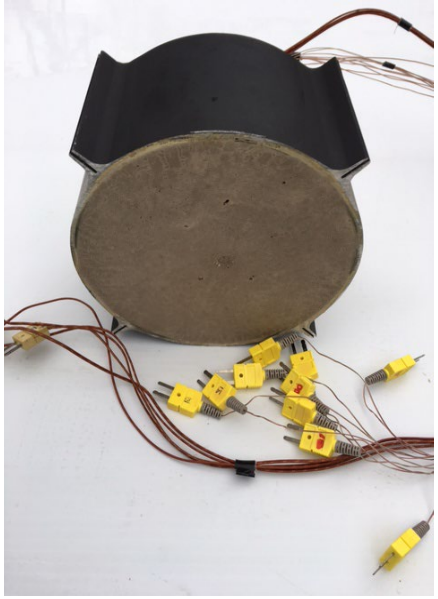
Resodyn Corp

Test Method: Buildup Used for Fast-Heating Test of Rocket Motor

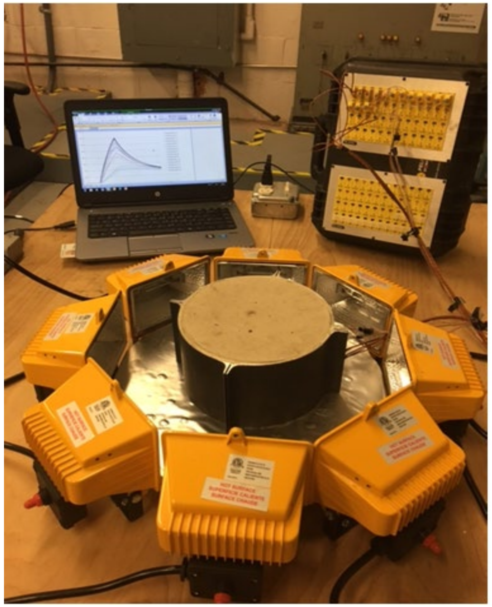
Empty Rocket Motor Casing



Motor Case Filled with Inert Propellant



Full Setup with Instrumentation



- A section of the real motor was used for this test
- Inert propellant simulant was cast into the section
- TCs placed along five thermal paths into the propellant
- TCs placed on outer casing, between case and insulation, between the insulation and the propellant

Laboratatory Test with 30mm Cartridge in Radiant Chamber in 2022

The cartridge has thermocouples on the interior surface of the case and interior of the projectile.

A wide range of heat fluxes, from slow cook-off to fast cook-off, and beyond are available.

The heating is mostly radiative and very uniform.

Computer models and mitigation schemes could be tested economically and quickly in purpose-built radiant chambers.

The 30mm round shown has six internal thermocouples and recorded temperatures comparable to FCO.

The radiant chamber will be used to to external heat loads to instrument test specimens

Start Up Program Plan

Analysis Phase
Scope problem with analytical solutions
Finite element modeling
Refine model to optimize a point solution for a system of interest

Experimental Data Gathering Phase
Interpret existing FCO data in context of a mitigation scheme
Interpret existing SCO data in context of a mitigation scheme
Interpret hot gun experimental data
Augment hot gun test instrumentation
Attempt 3-D printing of representative mesh
Attempt acoustic alignment
Measure heat flows with and without fibers in radiant chamber

System Concept Development
Select a system of interest with sponsor willingness to participate
Detailed program plan

Recent Advancement on Enhanced Blast Explosives Manufacturing at Holston Army Ammunition Plant

Kyle Bittner, Brian Alexander, Neil Tucker, Virgil Fung & Matt Hathaway

IMEMTS 2022 (October 2022)

BAE SYSTEMS

Briefing Outline

- Background - EB Explosive Overview
- Background – EB Explosive Processing
- EB Explosive Process Development
- EB Explosive Manufacturing at HSAAP
- EB Explosive Manufacturing Capabilities
- Other EB Explosive Manufactured at HSAAP
- Summary
- Acknowledgements

Background – Enhanced Blast Explosives Overview

- Enhanced Blast (EB) Explosives offer performance characteristics of both aluminized and non-aluminized formulations for target defeat
- Incorporation of aluminum powder achieved high shock overpressure for longer duration than non-aluminized composition
- EB Explosive is formulated to optimize the balance of detonation velocity and total mechanical energy, resulting in desirable metal pushing capability as well as high blast energy
- EB Explosives are typically selected for multi-purpose warheads in shoulder-launched weapon or direct-fire applications
- EB Explosives of interest:
  - PBXIH-18 (Aluminized HMX Based EB with plasticizer)
  - PAX-3 (Aluminized HMX Based EB with plasticizer)
  - PAX-30 (Aluminized HMX Based EB with plasticizer)
  - PAX-42 (Aluminized RDX Based EB with plasticizer)

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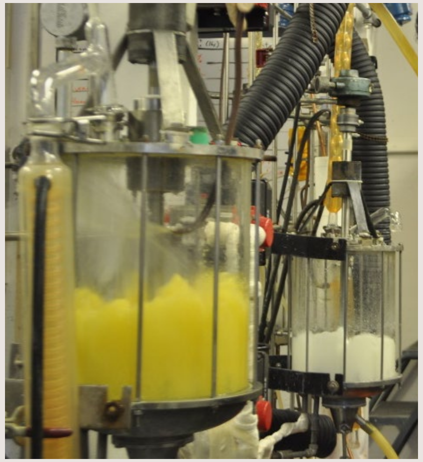
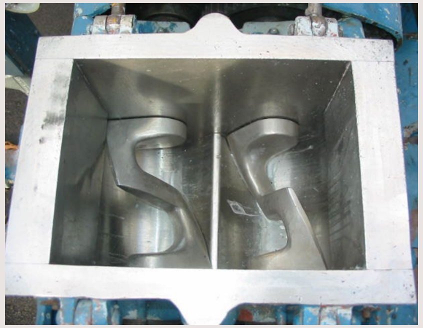
Background – EB Explosive Processing Techniques

- Granulation via Aqueous Slurry Coating with organic lacquer
  - One step process similar to standard Holston pressed explosive process
  - Production equipment readily available
- Twin Screw Extrusion (TSE)
  - Multi-steps process; incorporation of aluminum powder with nitramine precursor; granulator
- High Shear Mixer
  - Multi-steps process; dry or coating nitramine required
  - High Shear Mixer not available at HSAAP





Background – EB Explosive Processing (2)

- Aqueous Slurry Coating is preferred at HSAAP
  - Most efficient and cost effective process
    - Most suited for existing infrastructure without major investment
    - All processing steps conducted at HSAAP
- Choice between Water Replacement (WR) Fluid & Water
  - WR Fluid
    - Non reactive with aluminum powder
    - similar boiling point as water
    - High cost (purchase/recovery) for Production
  - Water
    - Significantly lower cost than WR Fluid
    - No special delivery or handling equipment
    - Standard aqueous source for HE manufacturing at HSAAP

EB Explosive Process Development

- H_2 Generation from Aluminum/Water Interaction

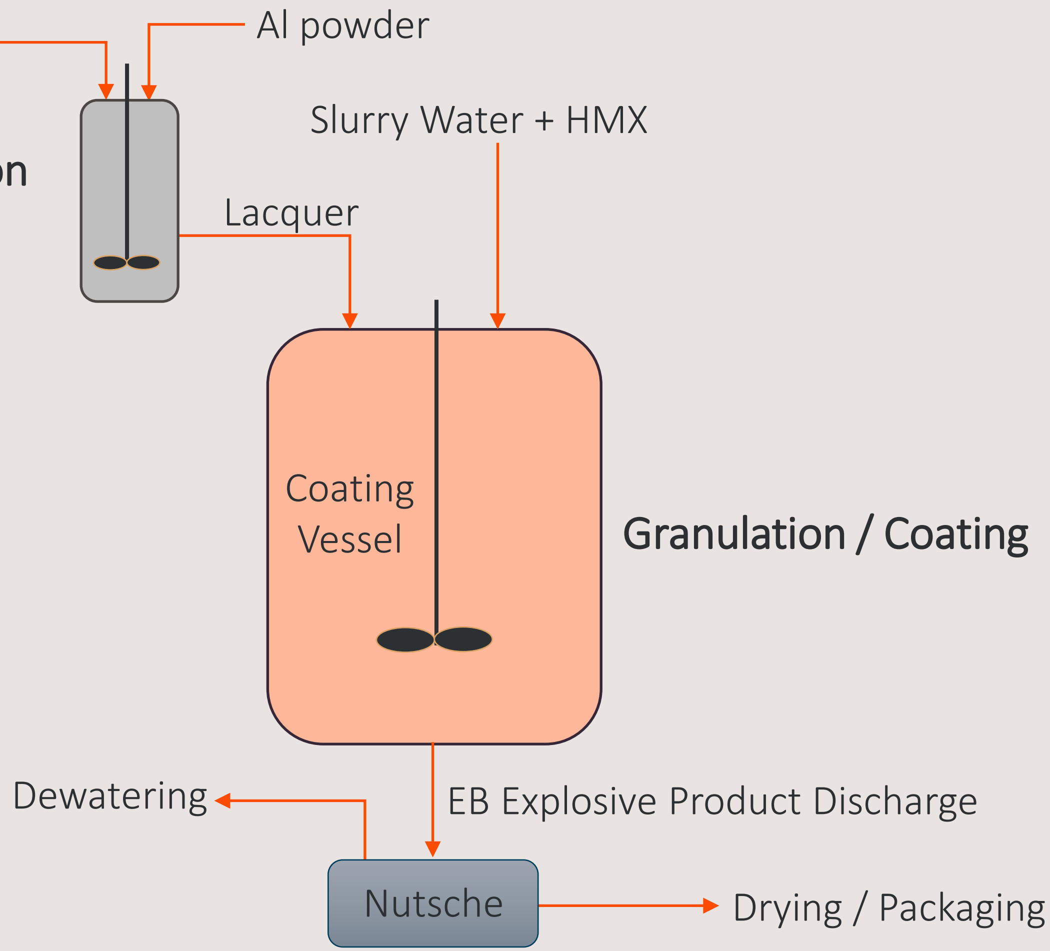
$$2Al + 6H_2O = 2Al(OH)_3 + 3H_2 \qquad (1)$$

$$2Al + 4H_2O = 2AlO(OH) + 3H_2 \qquad (2)$$

$$2Al + 3H_2O = Al_2O_3 + 3H_2 \qquad (3)$$

- BAE Systems developed a water slurry coating process to address potential Hydrogen generation via
  - Suitable additives
  - Specific temperature at key stages (granulation & distillation)
  - Process Configuration Changes (e.g. solvent removal / lacquer preparation)
- H_2 monitoring conducted throughout the process
- The new EB Explosive Water Slurry Process was successfully scaled from Lab (5 lbs.), Pilot (100 - 150 lbs.) to Production (300 – 350 lbs.)

EB Explosive Water Slurry Process - Overview



EB Explosive Manufactured in Production at HSAAP (1)

PAX-3

- Developed & Qualified by US ARMY DEVCOM at Picatinny Arsenal
- HMX based EB with aluminum and energetic plasticizer
- Previously manufactured via Slurry Coating with WR Fluid & TSE
- Robust Process for Slurry Coating with Water developed in 2015
  - PAX-3 made via this technique known as Type III
- Over **25,000 lbs.** manufactured in Production to date
- Fielded/Qualified in the 120mm Advanced Multi-Purpose (AMP), M1147 Tank Cartridge
- Under evaluation in the other weapon systems

M1147 Photo courtesy of Northrop Grumman

EB Explosive Manufactured in Production at HSAAP (2)

PAX-3 (from 2017 Production Campaign)

EB Explosive Manufactured in Production at HSAAP (3)

PAX-3 vs. PBXN-9

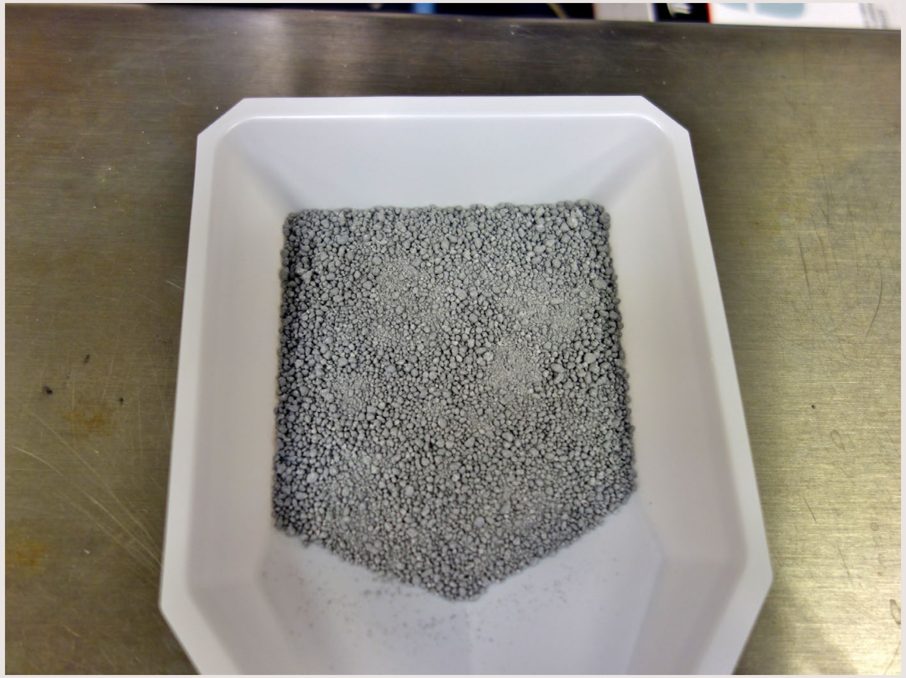
EB Explosive Manufactured in Production HSAAP (4)

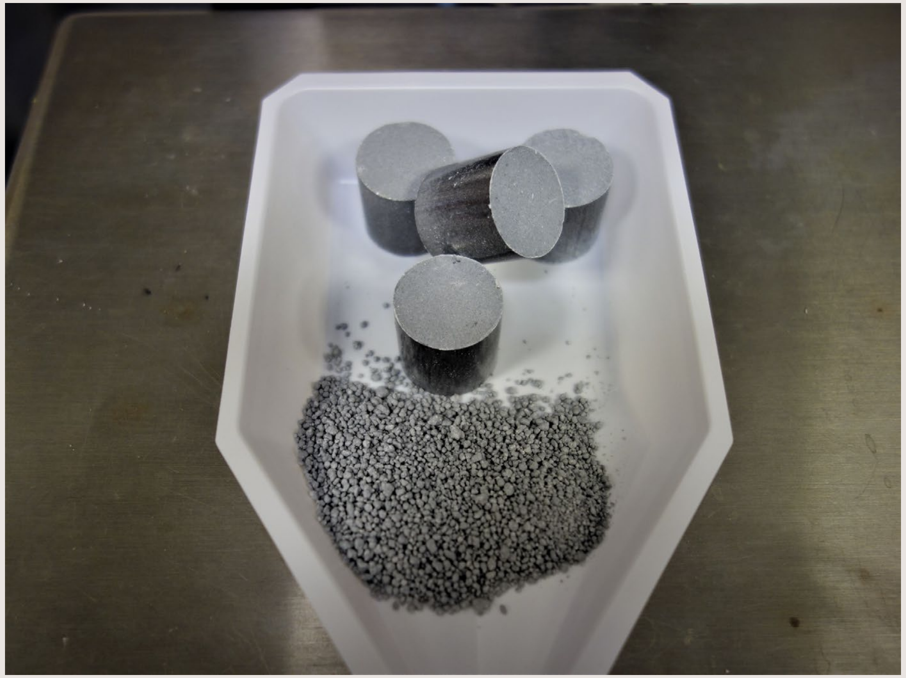
PBXIH-18

- Developed & Qualified by US NAVY Indian Head
- HMX based EB with aluminum and inert plasticizer (DOA)
- Previously manufactured at HSAAP via Slurry Coating with WR Fluid
- Current process involved Twin Screw Extrusion (3rd party facility) of precursor (e.g. PBXN-9)
- Robust Process for Slurry Coating with Water developed in 2016
- Over 2,100 lbs. manufactured in Production to date
- BAE Systems water slurry material performed identically to WR slurry material (presented at IMEMTS 2016)

EB Explosive Manufactured in Production HSAAP (5)

PBXIH-18 (from 2017 Production Campaign)





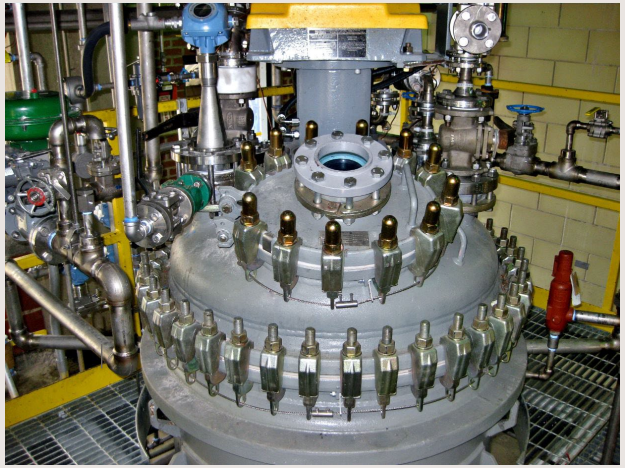
EB Explosive Manufacturing Capability at HSAAP (1A)

R&D Energetics Pilot Plant

- 50-, 100-, 200-Gallon glass-lined reactors (ingredient synthesis)
- 100- and 400-Gallon Formulation Coating Still (pressed explosive)
- Commissioning completed Fall 2013
- Over **74,000-lbs.** of explosives produced in the pilot plant (2013-2022 YTD)
- 38 different materials/products, more expected in 2023 and beyond
  - Energetic Ingredients (e.g. LLM-105, DNP, PYX, NTO, TATB)
  - Formulations (e.g. PAX-3 & PAX-30, reduced sensitivity PBXN-9 and LX-14, LX-17, PBX-9502)

Grams → 1-lb → 100-lb → 1,000-lb → 100,000-lb → 1,000,000-lb +

Laboratory | Pilot Plant | Agile Manufacturing | Manufacturing



EB Explosive Manufacturing Capability at HSAAP (1B)

PAX-3 Manufacturing at the R&D Pilot Plant


Lacquer Preparation Vessel


Coating/Granulation Vessel (Small)
~ 50-100 lbs.


Coating/Granulation Vessel (Large)
~ 300 lbs. or more


Dryer / Oven

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EB Explosive Manufacturing Capability at HSAAP (2)

Manufacturing Equipment – Production Facility

- Continuous PAX-3 manufacturing (24/7 operation)

Lacquer Preparation Vessel

Coating/Granulation Vessel (Large) ~ 300 lbs. or more

Material Handling

Other EB Explosive Manufactured at HSAAP

PAX-3 with Alternative Energetic Plasticizer

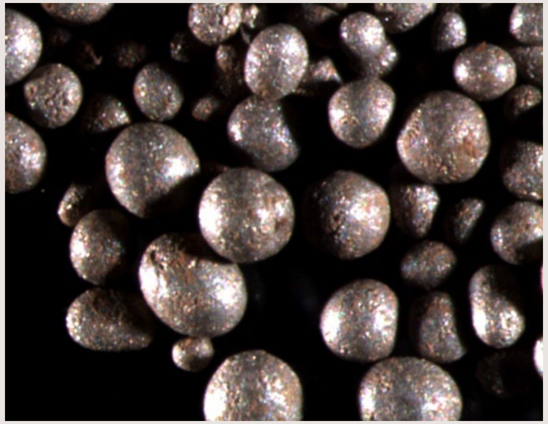
- ~ 2,000 lbs. manufactured with water slurry coating production process (pilot plant)
- Alternative plasticizer replacing current plasticizer (readily available – HSAAP product)

PAX-30

- High HMX Content (>75%) EB Explosive
- BAE Systems developed lab-scale coating process
- ~ 1,500 lbs. manufactured with water slurry coating production process (pilot plant)

PAX-42

- High RDX Content (>75%) EB Explosive
- Robust lab scale process developed under IRAD effort
- 2 lbs. batches made successfully in lab; “scale-up ready” at the pilot plant

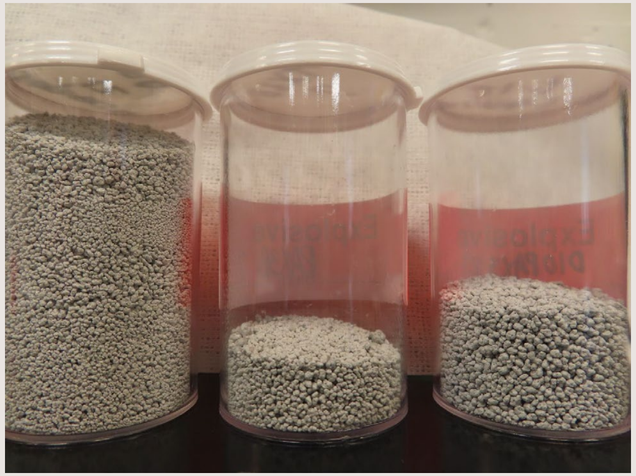


PAX-3 w alt. plasticizer (Production)

PAX-30 (Pilot Plant)

Summary

- BAE Systems had developed a ROBUST, SAFE & COST EFFECTIVE one-step water slurry coating process to manufacture aluminized EB Explosive at HSAAP
- PAX-3, PBXIH-18, PAX-30 and PAX-3 w alt. plasticizer have been successfully manufactured with Production Equipment
- PAX-3 Type III already qualified; PBXIH-18 made in this process will be qualified in 2023
- PAX-30 scale-up process proven; ready to transition to large campaign
- R&D Pilot Scale Coating Vessel available for Process Development and Optimization with current and new EB Explosives
- Other pressed EB Explosive such as PAX-42 ready to “Scale-Up”



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