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U.S. ARMY RESEARCH LABORATORY ARL 25 YEARS 1992-2017

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# Sciences for Lethality and Protection Overview

**Mr Dave Lyon**
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Sciences for Lethality and Protection

# Army Operating Concept 2020-2040
# "Win in a Complex World"

## Science and Technology Focus Areas

- **Overmatch (technological superiority)**
  - Lethality and effects
  - Assured position, navigation, and timing
  - Network protection
- **Expeditionary Maneuver (global response in a timely fashion)**
  - Reduced logistics "tooth to tail"
  - Lightweight structural materials
  - Lightweight, high efficiency combat vehicles

## Technology Gaps

- Protection technologies (materials and mechanisms) beyond "hard armor"
- Extended range precision fires (conventional and electric) in contested environments
- Soldier protection from ballistic threats

**<u>What does this S&T Campaign do?</u>**

**Plans and conducts basic and applied research that leads to overmatch capabilities across both lethality & protection domains for US Land Forces**

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# ARL People and Expertise

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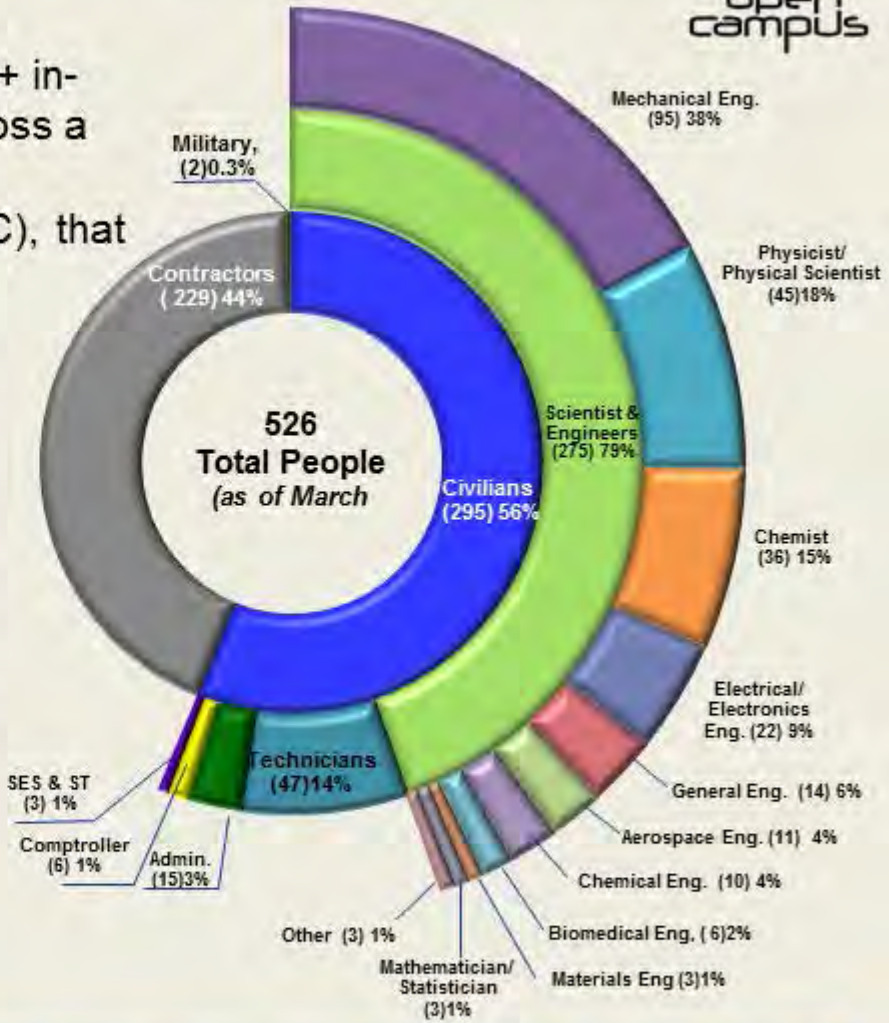
***Why work with us?*** S&T campaign includes 500+ in-house scientists, engineers, and technicians, across a mixture of disciplines, enabled by world-class **experimental and M&S assets** (powered by HPC), that result in **unique research capabilities.**

| | |
|---|---|
| Gov't Civilian | 295 |
| Military | 2 |
| Contractors | 138 |
| Post Docs | 38 |
| Guest Researchers | 16 |
| Emeritus | 13 |
| Students | 24 |
| Total Workforce | 526 |




**ARL is the bridge** between the **Warfighter, S&T, and acquisition** communities, **translating** the needs of Land Forces into scientific gaps, then planning and conducting the research to provide significant advances.



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# Key Initiatives

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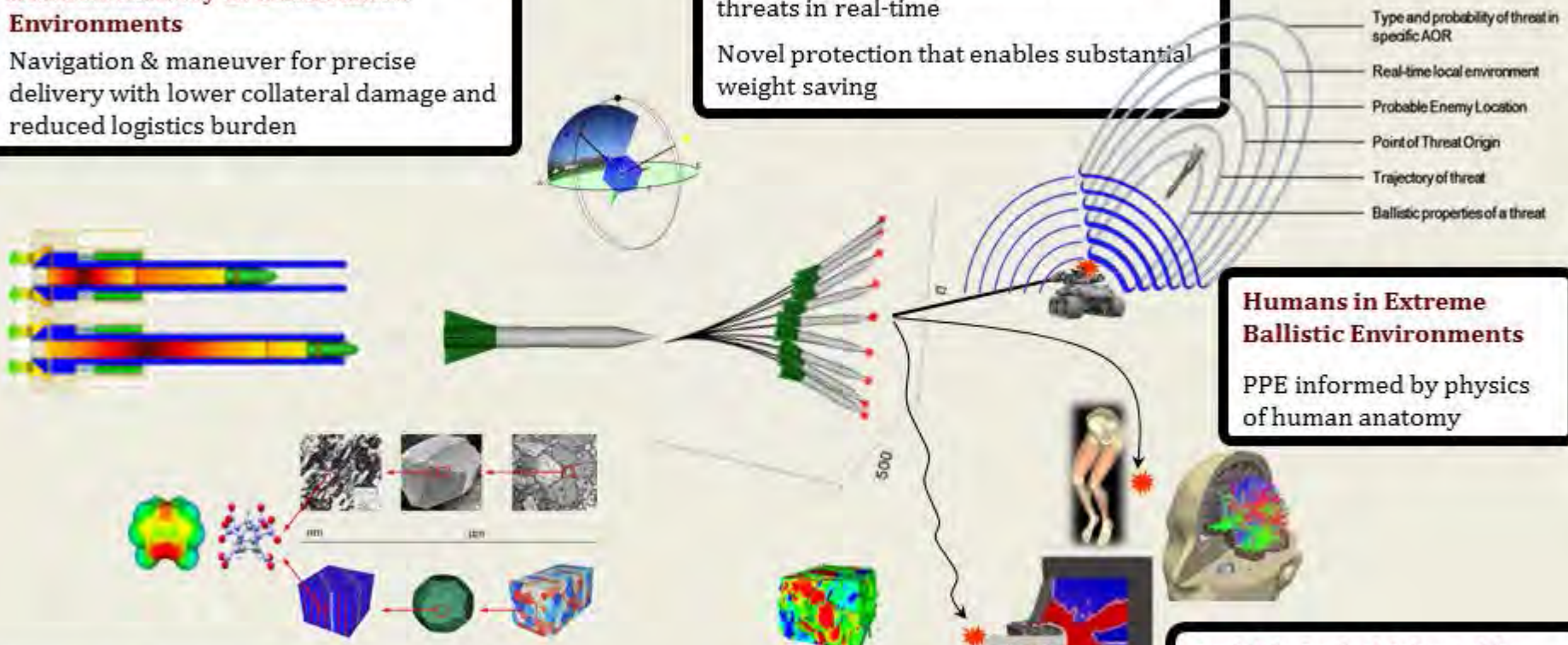
**Assured delivery in Constrained Environments**

Navigation & maneuver for precise delivery with lower collateral damage and reduced logistics burden

**Adaptive and Cooperative Protection**

Ability to predict, detect and counter threats in real-time

Novel protection that enables substantial weight saving




**Humans in Extreme Ballistic Environments**

PPE informed by physics of human anatomy

**Disruptive Energetic Materials**

Understanding a new class of energetics with high-energy density

**Terminal Ballistics & Blast Effects**

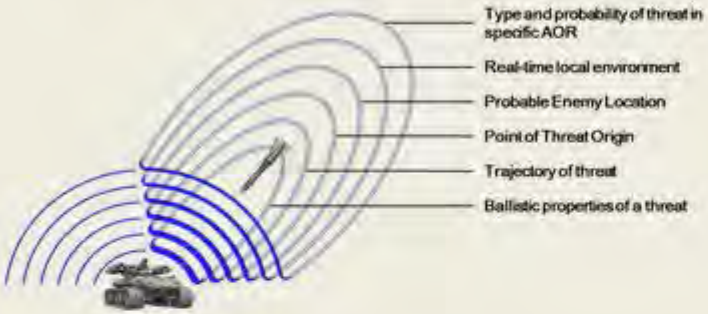
Multi-physical coupling, failure dynamics and energy propagation; algorithms and design capability

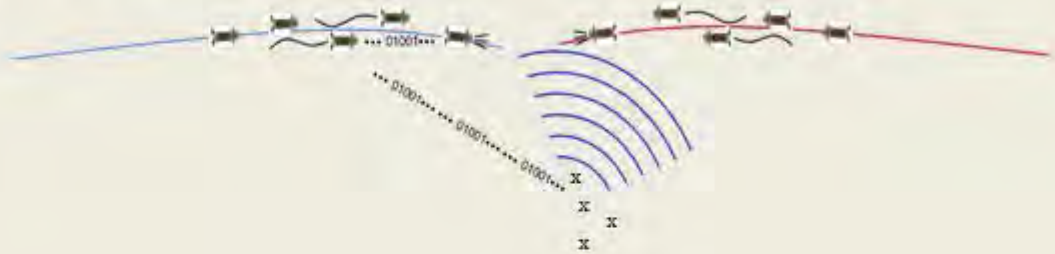
**Scalable Lethal Adaptable Weapons Concepts**

Futuristic concepts for a range of incapacitation.

New gun and missile technologies that deliver increased energy at range with

# Distributed and Cooperative Engagement in Contested Environments



Science that allows:

- Coordination of small number of dispersed entities
- Radical maneuverability
- Efficient payload kill mechanisms
- Protection against complex threats
- Materials that adapt in real time

} Deliver overwhelming kinetic/non-kinetic effects

Imagine a highly capable parent entity that carries and leads echelons of low cost multi-mission agents that either projects or absorbs force. These swarms combines effects and mechanism, autonomy, high speed secure communications and machine learning to deliver/protect from many-on-many to few-on-few bodies.

# Collaborative Opportunities Linked to Areas of Expertise

## Collaborative Opportunities

- **Dynamic Failure & Fracture** (ScLP CCE)
  - Failure and fracture at extreme states
  - Multi-scale behaviors
  - High rate experimental mechanics
  - Diagnostic development for ballistic exp.
- **Desired Lethal Effects at Standoff Ranges in Constrained Environments** (ScLP KCI)
  - Dynamics of launch and flight (flow fields)
  - Guidance, navigation, and control (flight dynamics)
  - High-G environments (structural survival)
- **Energetic Materials** (ScLP KCI)
  - Multi-scale, reactive modeling
  - Disruptive energetics (high yield)
  - Detonation science (high pressure fields)
- **Humans in Extreme Environments** (ScLP KCI)
  - Ballistic and blast insults
- Adaptive Non-Linear Optics

## Academic Disciplines

- Aerospace / Aeronautics Eng.
- Biology / Biomedical Engineering
- Chemistry / Chemical Engineering
- Computer and Information Sciences
- Computer Engineering
- Electrical Engineering
- Materials Science
- Mathematics
- Mechanics / Mechanical Eng.
- Optics
- Physics
- Systems Engineering

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# Dynamic Failure and Fracture

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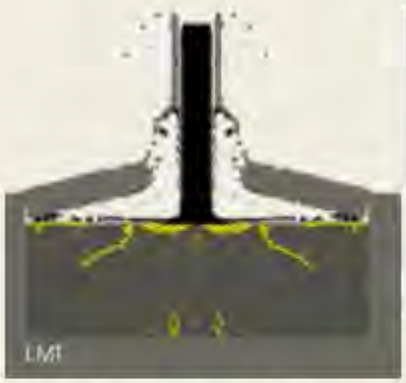
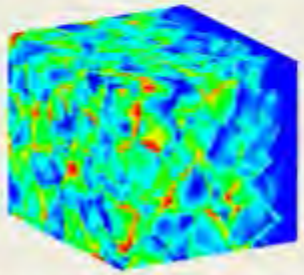
## Objective:

Understand and control material deformation and failure during ultra-high rate loading events

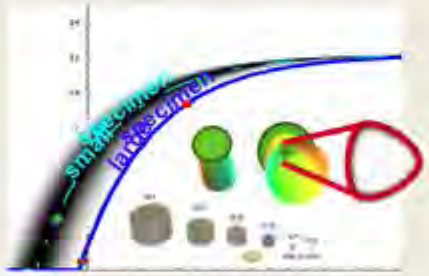
Penetrator impacting confined ceramic



Predictive Computational Tools



Virtual Continuum polycrystal




Volume/scale dependant defect-driven strength

Post-mortem Analysis

## Our Capabilities:

- High rate dynamic loading laboratories (shock, deformation, failure) 500-1M/sec
- Computational Mechanics
- High rate deformation and failure models between 10 GPa and 100 GPa
- Grain-level modeling of materials
- Dynamic Compression Sector (DCS) at Argonne National Laboratory

## What We Are Seeking:

- Advanced instrumentation for in-situ imaging at lower length scales (noninvasive)
- Ability to bridge length scales (defects, inclusions, dislocations)
- Identifying failure mechanisms from recovered specimens
- High pressure isentropic loading
- Novel approaches for modeling discrete failure

## Academic Areas:

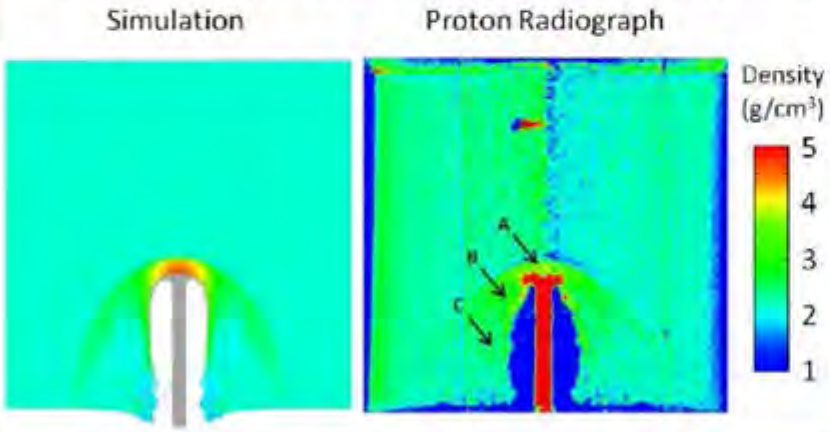
- Solid Dynamics, Computational Mechanics, Shock Physics, Multi-scale Modeling of Mat'l, Numerical Modeling, Ultra High Strain Rate Instrumentation

# Capabilities Supporting Dynamic Failure and Fracture

## High-rate Deformation & Shock at APG

**Dynamic confined compression tests**

Simulation (CTH) & experiment results (LANL)




## Dynamic Compression Sector at Argonne Advanced Photon Source

Observe ballistic phenomena using ultra bright, extremely short light sources

## Computed Tomography

Sub-micron Resolution of defect structures

- Recently established as Center for Impact Physics
- New Cooperative Agreement with California State University to understand the physics of failure of advanced materials under intense ballistic impact and blast

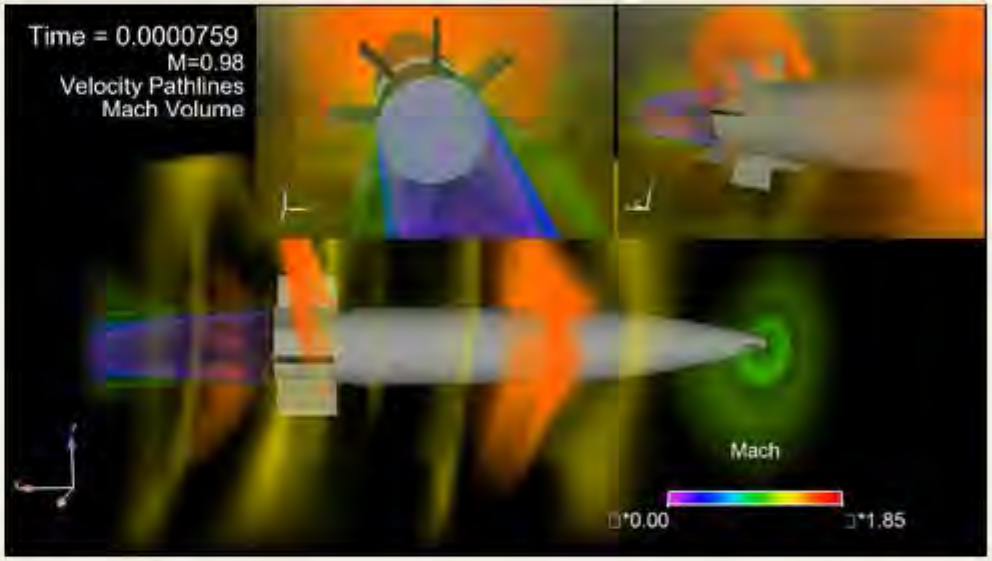
# Desired Lethal Effects at Standoff Ranges in Constrained Environments

## Objective:

Assure delivery of payload even in contested environments (24/7, all weather, GPS denied) while providing increased performance (speed, range & maneuver)

## Technical Areas:

- Maneuver flight physics and experimental validation
- Computational fluid dynamics (CFD)
- Shock-boundary and vortex interactions, nonlinear dynamics and stability
- Nonlinear control laws / theory
- Robust navigation approaches & algorithms




## What We Are Seeking:

- Control mechanisms, nonlinear control algorithms and assessment tools for controlling high maneuverability flight bodies across omnisonic speeds (all Mach regimes)
- Low cost/high accuracy experimental techniques to capture flight maneuvers

## Academic Areas:

- Aerodynamics, Fluids, Flight Dynamics, Numerical Modeling, Computational Science, Controls, Navigation, Experimental Flight Dynamics, Mechatronics

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# Capabilities Supporting Lethal Effects at Standoff Ranges

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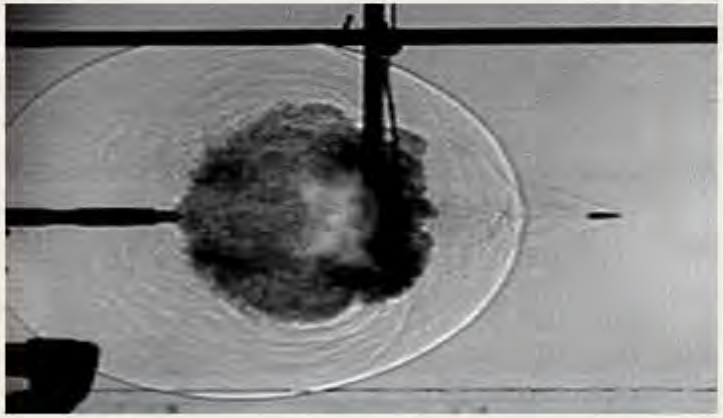
**Guidance Research Facility**
Research and validation for advanced guidance methods

**Transonic Experimental Facility**
Captures flight behavior & flow phenomena

**Muzzle Blast**
High pressure, reacting flows



ARL developed world's fastest rifle using tapered bore technology

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# Energetic Material Research

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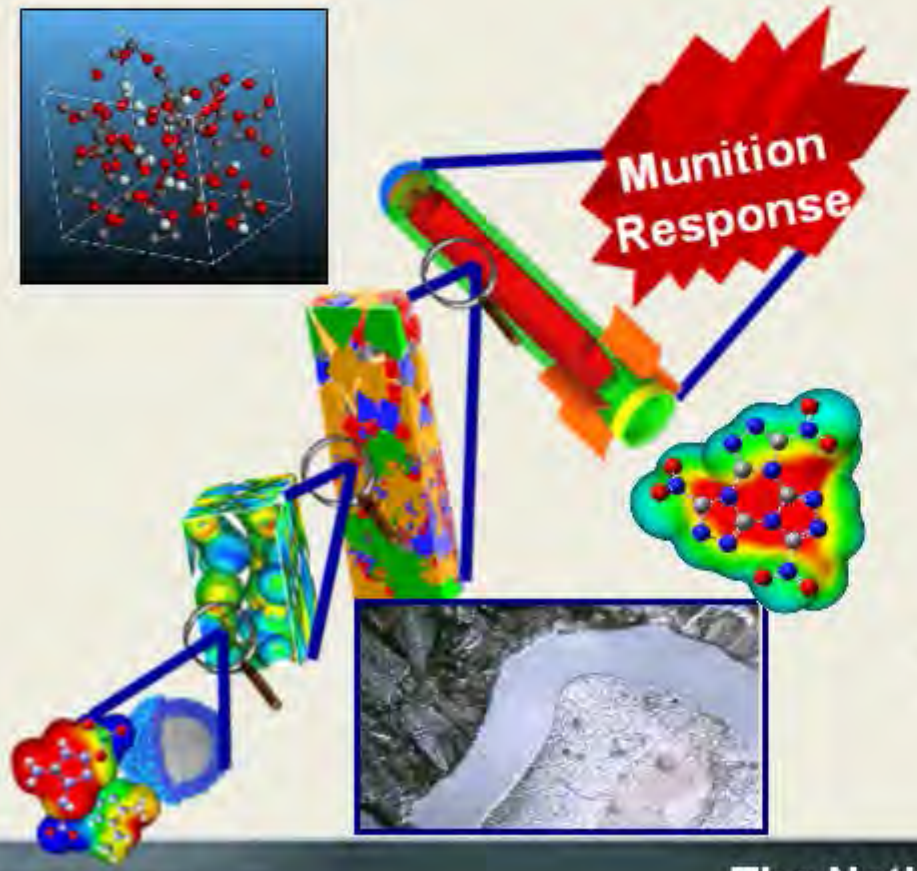
## Objective:

- Understand the multi-scale response of Energetic Materials (atomistic to bulk material)
- Increased performance of conventional explosives (30% increase)
- Discover novel high-yield materials & release mechanism (3-10 times greater)




## Our Capabilities:

Center for Novel Energetic Research

- Synthesis and characterization of advanced novel insensitive energetic ingredients and formulations
- Computationally aided propellant charge design
- Multi-scale reactive modeling of insensitive munitions
- Multi dimensional, multiphase, physics-based gun and rocket propulsion modeling

## What We Are Seeking:

- Enabling experimental technologies for full dynamic range of explosive imaging
- Measurement of species formation and consumption at detonation front

## Academic Areas:

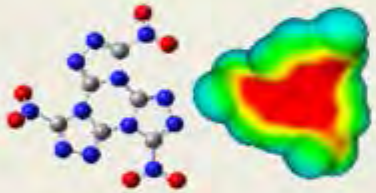
- Molecular Modeling, Formulation Chemistry, High Pressure Synthesis, Experimental Diagnostics

# Capabilities Supporting Energetic Material Research

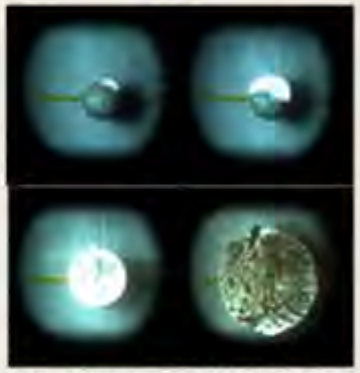
Formulation

Synthesis on Multiple Scales

Characterization



Modeling and Simulation



Experimental Validation

- Recently established the Novel Energetics Research Center
- ARL Scientists Win Best Poster Award at the international Insensitive Munitions & Energetic Materials (IMEM) Technology Symposium in Rome, Italy
- International project agreements under negotiation with Israel Ministry of Defense to study theoretical chemistry and modeling & simulations of energetic materials

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# Humans in Extreme Environments

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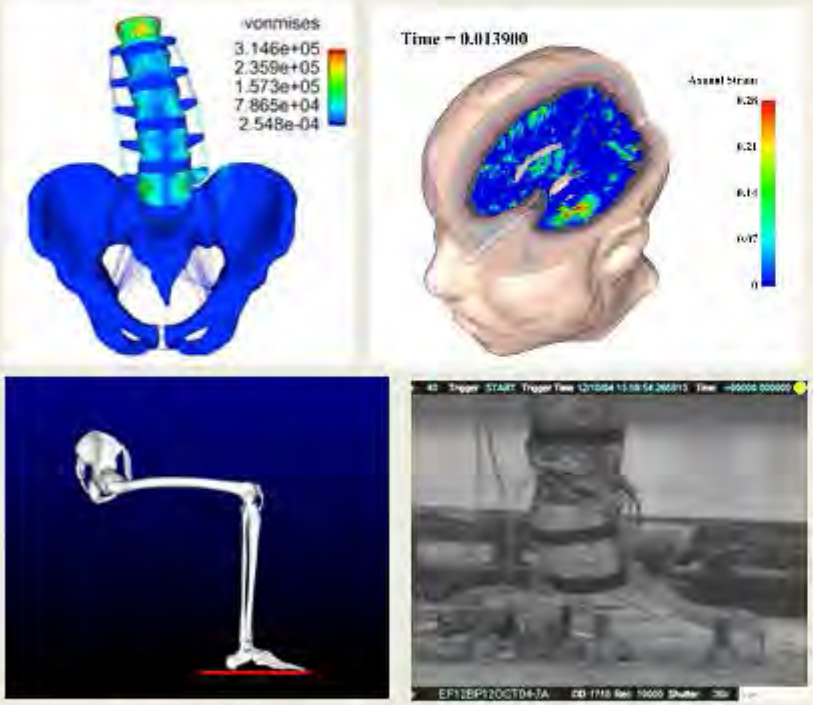
## Objectives:

- Fully understand the human response to ballistic loading conditions (blast, bullets and acceleration) - insult to injury
- Develop improved personal protection systems




Computational Modeling and Experimental Validation

## Our Capabilities:

- In-house expertise in biomechanics, constitutive model formulation, and ballistic event loading
- Suite of DOD, DOE, and COTS software running on multiple high performance computing platforms
- Unique blast and ballistic experimental capabilities for model development and validation

## What We Are Seeking:

- Tissue injury criteria and thresholds for hard and soft tissues
- Biomechanics research facility with experience in high-rate testing of biological tissues (beyond automotive rates)
- Understand the effects of mechanical loading on human physiology and clinical outcome

## Academic Areas:

- Bio Material Characterization, Numerical Modeling, Injury Criterion, Experimental Diagnostics, Anthropomorphic Devices, Neuroscience



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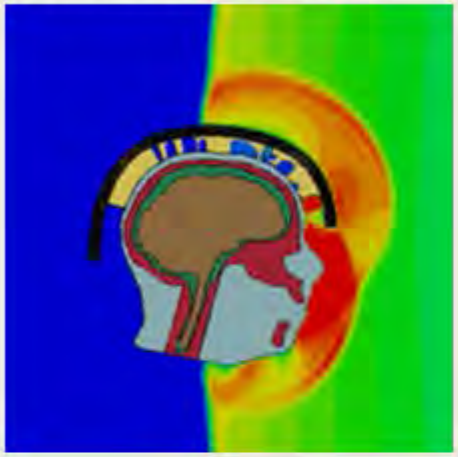
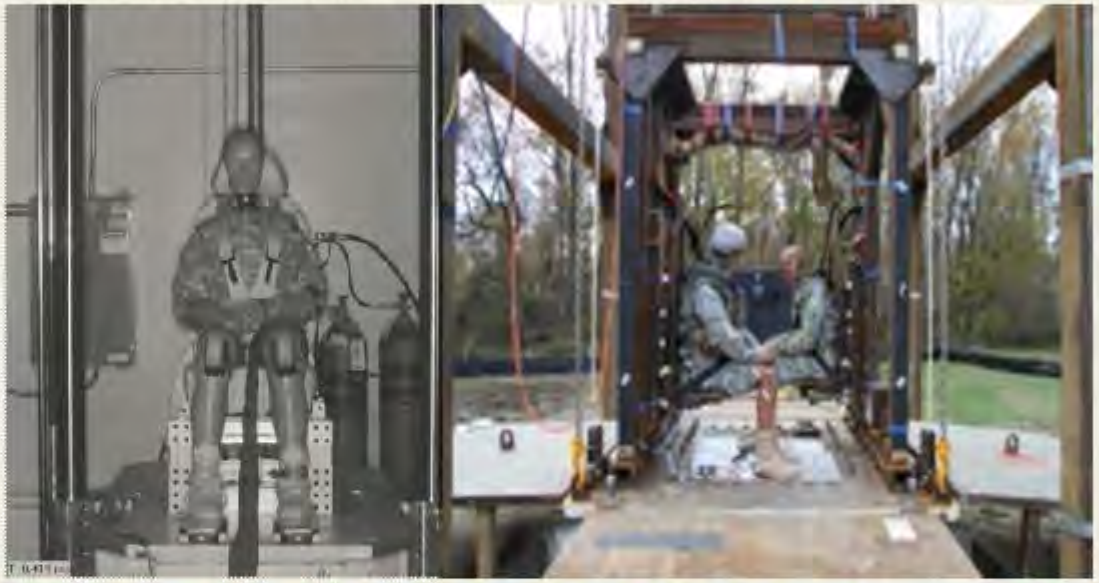
# Capabilities Supporting Humans in Extreme Environments

Model and Experimental Validation of Complex Load/Target Interactions



## Crew and Compartment Protection Facilities

Laboratory simulators replicate loadings from blast threats



- Partnership with University of Alberta to improve head protection through study of blast and impact energy transfer.
- Cooperative agreement with multi-university team lead by Temple U. to study ballistics technology
- ARL Provided Buried Blast Subject Matter Expertise (SME) to NATO Standardization Agreement (STANAG) 4569 Meeting

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# Current Active CRADAs

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## Sciences for Lethality and Protection Poster Locations

### Zahl Building 4th Floor

We are here

| CRADA Partner | CRADA Title |
|---|---|
| Artis (#15-37) | Development of Electric Launcher |
| The Protective Group (#16-59-01) | Development of Next Generation Transparent Materials and Protection Technologies |
| NFL (#14-53-02) | Shear-Thickening Fluids Tethers for Mitigation of Head Acceleration |
| Orbital ATK (#10-06-03) | Demonstration of 0.50-Caliber HE Projectile, CFD Analysis of Guided Projectiles |
| Federal Cartridge (#11-17) | Precision Weapon System Analysis |
| CoorsTek Vista (#12-13) | Development of Advanced Armor Materials |
| DuPont (#12-16-02) | Evaluation of PMMA Polymers as Armor Materials |
| Simmonds Precision Products (#13-06) | Aeroballistics Diagnostic Instrumentation |
| ENSCO (#13-08) | Positioning and Attitude of Weapon Systems |
| Missouri University of Science & Technology (#15-22-01,02) | Emerging Control Theory for Guided Weapons, Prediction of Projectile Aerodynamics |