A New Paradigm for R&D to Implement New Energetic Materials in Munitions

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NDIA 2007 Insensitive Munitions & Energetic Materials Technology Symposium
Miami, Florida
October 15-18, 2007

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Overview

- Challenges for future munition development
- What is the existing development paradigm?
- Why invest in energetic material R&D?
- What strategy should guide the development of new R&D paradigm?
- What are the technical challenges?
- What is the vision for a new R&D paradigm?
- How to address the technical issues and move R --> D
- Summary & Conclusions

A rapidly changing world creates challenges for future munition development

- **Isolation is not an option in a smaller world**
  - Increasing population & competition for resources
  - Conflicts at cultural boundaries
  - Disruptions caused by global climate change
  - Increasing technical prowess in the developing world
- **Life, liberty and the pursuit of happiness across the globe**
  - What is the role of munitions?
  - How to maintain the balance of power.
- **Populous technically capable societies evolve in 21st century**
  - What is the military technology component?

Do we continue to rely on methodologies created in the late 19th and early 20th centuries for future munition development?

History of EM development for munitions reveals context of current EM development paradigm

- **New EM development with high impact ended by 1970**
  - 19th century to WWII -- *nitroglycerine, NC, organic nitramines*
  - WWII - *plastic bonded explosives, early propellants*
  - Cold war to 1970 -- *solid rocket motor propellants*
  - 1970 to present -- *follow-on work built on established development methods*
- **Development during this era based on trial & error "Edisonian" approach**
  - Methodology developed before era of computers & modern instruments
- **EM development since 1970 has very limited success -- CL-20**
  - Creates perception of high risk and unworthy of significant investment

The number of attributes required for new energetic materials to be used in munitions is extensive and comparable to requirements for the introduction of new drugs in the pharmaceutical industry.

JANNAF Workshop on "R&D Required to Implement New Energetic Ingredients in Munitions" considered issues

- **55 participants from DoD & DOE laboratories, academia, and industry -- August 2006**

- **Discussions focused on two areas**
  - Requirements for munitions systems of the future
  - Scientific and technical issues that will enable rapid develop of new energetic materials

- **Conclusions**
  - Investment of funds for EM development is low
    - Defense program managers see high risk -- little likelihood of success
  - Reaction processes in EM are complex and difficult to understand.
    - Not more challenging than other areas, biotechnology, genetics, neuroscience, but difficult.
  - Need new paradigm for munition *development*
    - Must move research capabilities into hands of developers.
  - Implementation may need virtual development laboratory

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Why invest in energetic materials R&D?

- ***Successful*** **R&D will enable major payoffs in propulsion, warheads, high energy IM systems and surveillance.**

Research Area	*Energetic System*	*Major Payoff Projected*
Propulsion		
	Rocket Motors	Enhanced energy in heavy lift systems.
		Energetic binders to increase I_{sp}.
	Guidance Systems	Tailorable burn rates to provide in flight control resulting in more precise target interdiction.
	Guns	Tailorable burn rates to permit reduced gun weight, erosion, corrosive products, and extended gun life.
Warheads	Micro-propulsion	Programmable on-board micro-propulsion devices to steer warheads for increased accuracy/lethality.
	Energetic Payload	Use of controlled payload output utilizing different types of energetic material to permit a desired type of reaction with a particular target.
High Energy IM Systems	Propulsives & Warheads	Enhanced energetics knowledge to optimize tradeoffs between insensitivity and system requirements
	Propulsives & Warheads	Enhanced IM knowledge to provide safer- high performance systems that are less costly to transport, store and maintain.
Surveillance (Aging)	Propulsives & Warheads	New evaluation methods that can provide a better means for understanding aging behavior to optimize the life expectancy, assure safe continued performance and overall lowest life cycle cost.

- **Why is investment likely to be successful now?**
- **What constitutes a successful R&D paradigm?**

What will constitute an R&D paradigm that will enable advanced munition development?

- **What must be understood to design new munitions?**

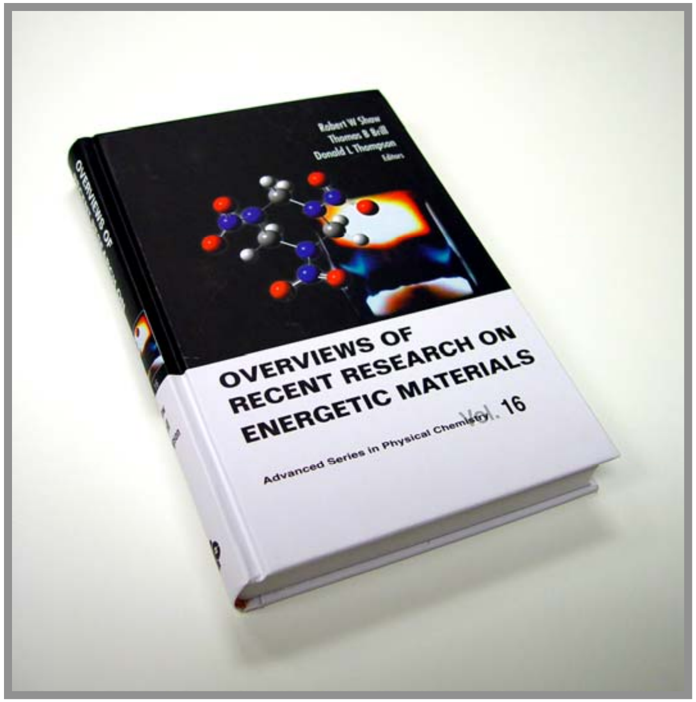
Item	*Prop?*	*Exp?*	*Category*	*Reactive?*
Long-term stability	Y	Y	C	Y
Response in fires	Y	Y	S	Y
Response to impact Š low rate mechanical energy input	Y	Y	S	Y
Response to shock -- high rate mechanical energy input	Y	Y	S	Y
Response to electrical stimuli	Y	Y	S, PF	Y
Coupling of mechanical/thermal in fire. Thermally induced changes alter response to mechanical energy.	Y	Y	S	Y
Toxicity & environmental compliance	Y	Y	S	N
Specific impulse	Y	N	PF	N
Pressure exponent	Y	N	PF	Y
Pressure oscillations	Y	N	PF	Y
Propellant or explosive integrity	Y	Y	PF, S	Y
Erosivity (guns)	Y	N	PF, C	Y
Tailor-able thrust	Y	N	PF	Y
Detonation velocity, detonation pressure	N	Y	PF	N
Processibility	Y	Y	M	Y
Dispersal of active compounds at target	Y	Y	D	Y
Response to Environmental Stressors (T, H, V, & S)	Y	Y	S, PF	Y

C - Compatibility; S - Safety; PF- Performance; M - Manufacturing; D - Disruptive technology Issues

- **Categories:** Performance, safety, compatibility, manufacturing, disruptive technology
- **Understanding *reactivity* is key to future success.**

Research has lead to new understanding of reactions of energetic materials

- **Propellant flame chemistry**
  - Korobeinichev, Parr
- **Reactions in shocks**
  - Greiner, Blais, Dlott
- **Elementary reactions**
  - Dagdigian, Bernstein
- **Molecular theory**
  - Thompson, Fried, Rice, Goddard…
- **Combustion models**
  - Anderson, Yang, Miller, Beckstead
- **Thermal decomposition**
  - Brill, Behrens



R.W. Shaw, T.B. Brill, D.L. Thompson, editors

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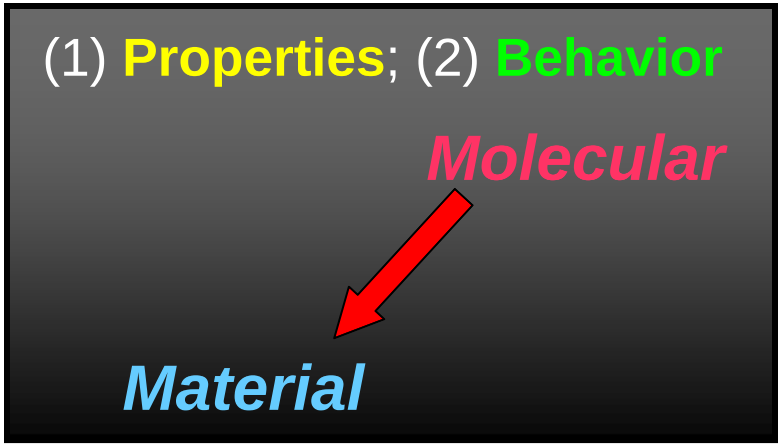
How do we connect current research to EM development?

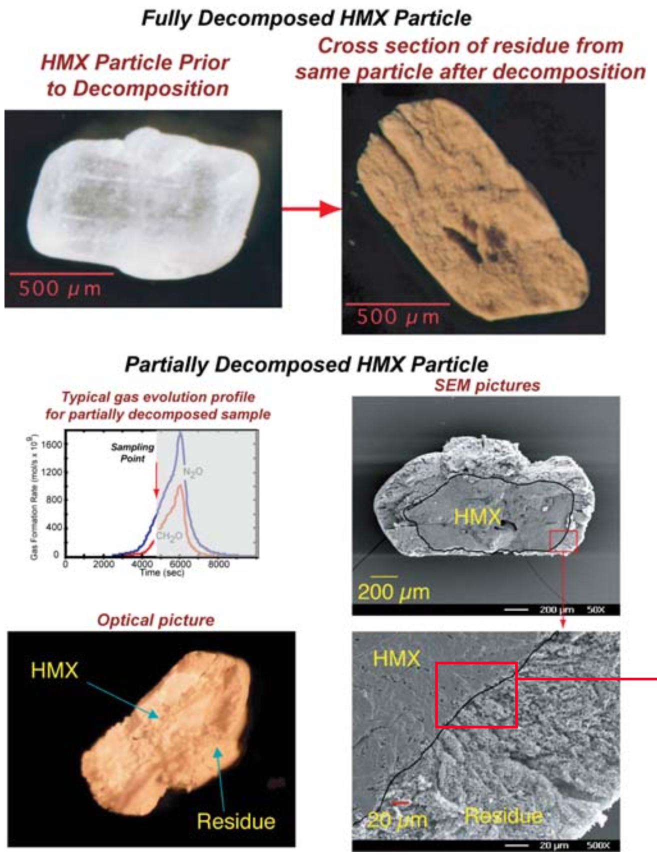
- **Connection between molecular and material properties not established**

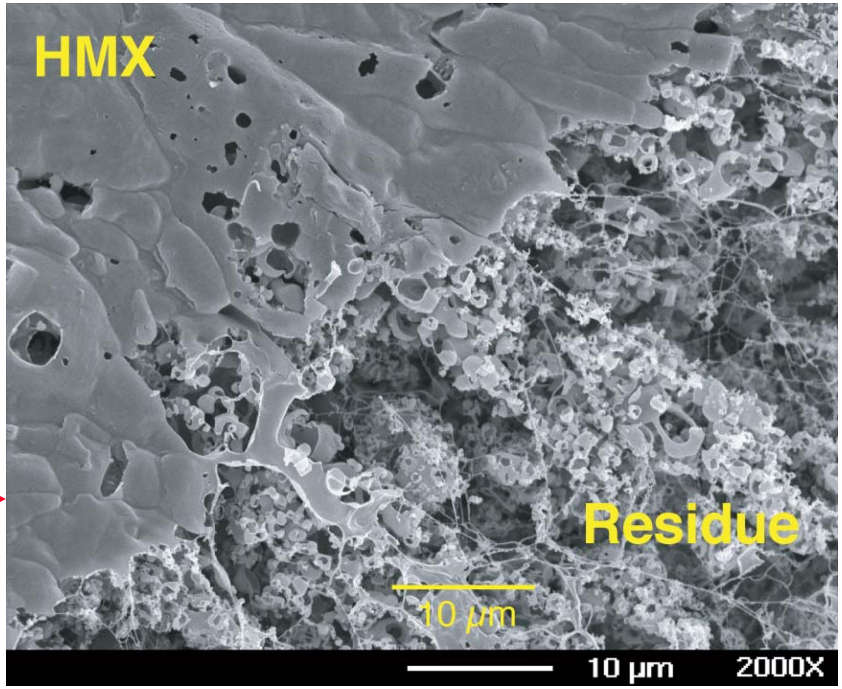


- **Reactions of materials in condensed phase at low and moderate temperatures determine.**
  - Safety
  - Aging
  - Performance -- initial stages
- **Build on work on complex reaction process in chemical, biological and genetic systems -- John Ross (Stanford)**

Thermal decomposition of HMX illustrates importance of spatial features on reactions

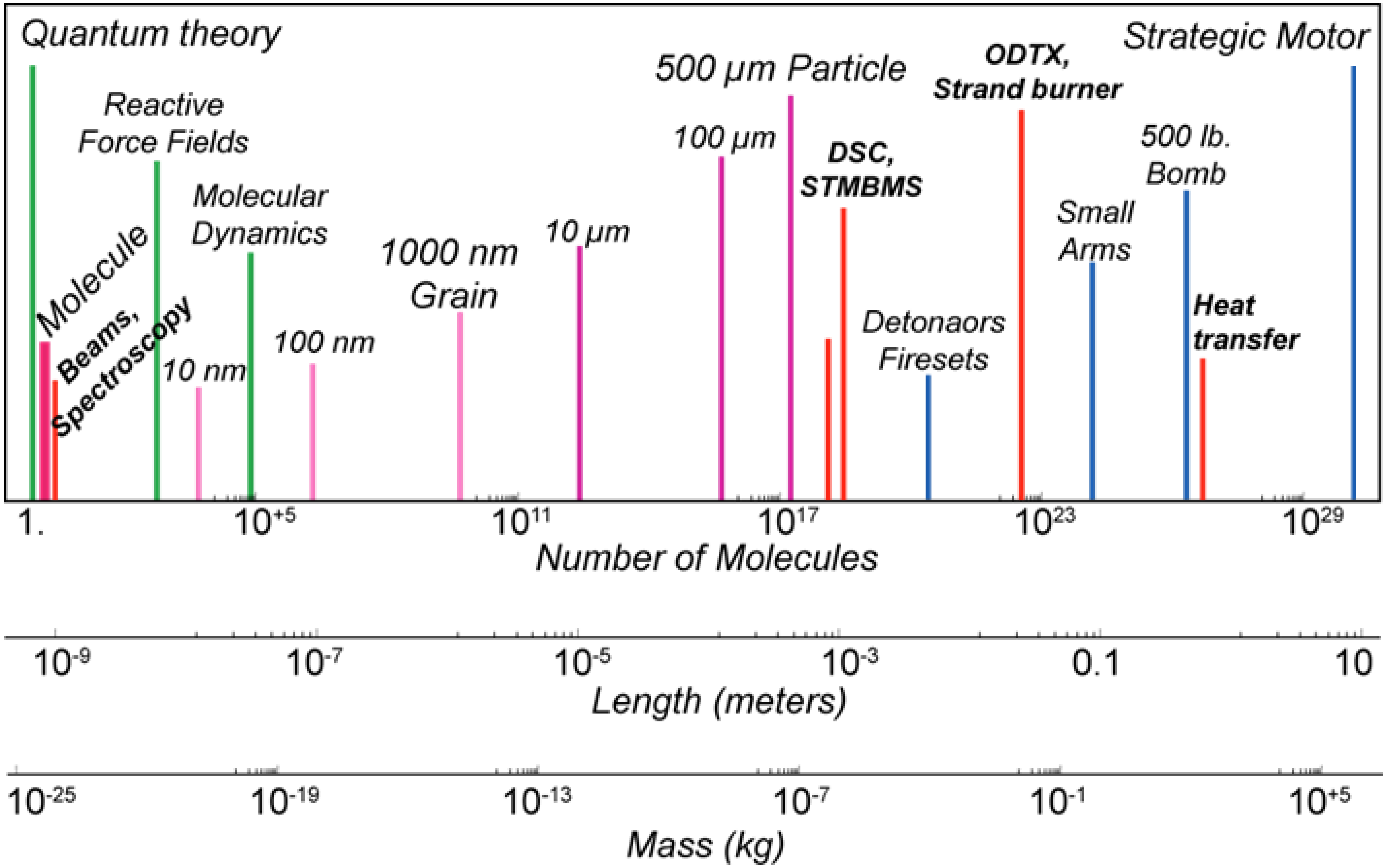
- ***Overall reaction rates are determined by the creation and reaction in localized regions.***





Successful future designs will require controlling reactivity on multiple spatial scales.

At what spatial scales can material be considered homogeneous?



Experiments, diagnostics and modeling must capture data & gain understanding on many scales

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What does the developer need to address?

- **Performance criteria**
  - Burn rates and pressure exponents for propellants
  - Detonation velocity and pressure for explosives
- **IM requirements**
  - Lowest possible impact and shock sensitivity
  - Non-violent response to slow and fast heating
  - Insensitive to electrostatic discharge
- **Manufacturing**
  - Manufacturing process must not introduce new features that affect safety, performance or aging.
- **Life cycle**
  - Materials do not degrade with time, or degrade in predictable manner.
  - An effective and inexpensive means for surveillance.
  - Not present health or environmental compliance issues.
  - Disposal in environmentally sound & cost-effective manner
- **New military requirements --** implement new design concepts**.**

Performance issues comprise only a small portion of the list.

A new requirements-driven paradigm will enable future EM development

- **Current paradigm is perceived as “Edisonian”**
  - Fabricate and test.
- **Pharmaceutical development paradigm would enable EM development**
  - *Requirements driven*: Disease prevention and therapy
  - *Science based*: Knowledge of disease pathways
  - *High-throughput*: Automated data collections, bioinformatics analysis.
- **A new paradigm with requirements -driven approach will require:**
  - Development of propellant & explosives more rapidly
  - Using orders of magnitude less material (grams vs. kilograms)
  - Providing new data to guide design of new compounds and composite materials.

Technical challenges are understanding chemical reactivity and using this knowledge to design new EM

- **Reactivity is determined by complex processes.**
  - Reactions occur at high concentrations in condensed-phase
- **New experimental and diagnostic methods required.**
  - Super-small scale experiments - mg quantities
  - Provide maximum insight into reaction processes
  - Integrated with large scale numerical analysis and simulation
    - Allows tracking of molecular theory to larger spatial scales.
- **Modeling & theory must handle spatial scales beyond molecular level**
  - Identify most important reactions at larger spatial scales.
  - Apply theory to these cases.
- **Use current material design parameters to guide and focus R&D efforts on reactivity.**

Technical opportunities

- **Move successful research methods into development protocols**
  - Thermal decomposition research -- IM, safety & aging issues
  - Combustion -- gas phase & particle combustion
  - Microdetonics -- laser diagnostics
- **Identify where research is still needed**
  - Reactions at important spatial scales
    - Particles, grain boundaries & defects.
  - Localized reactions under shock, impact & ESD.
- **Use new research methods to develop protocols needed for future EM development.**

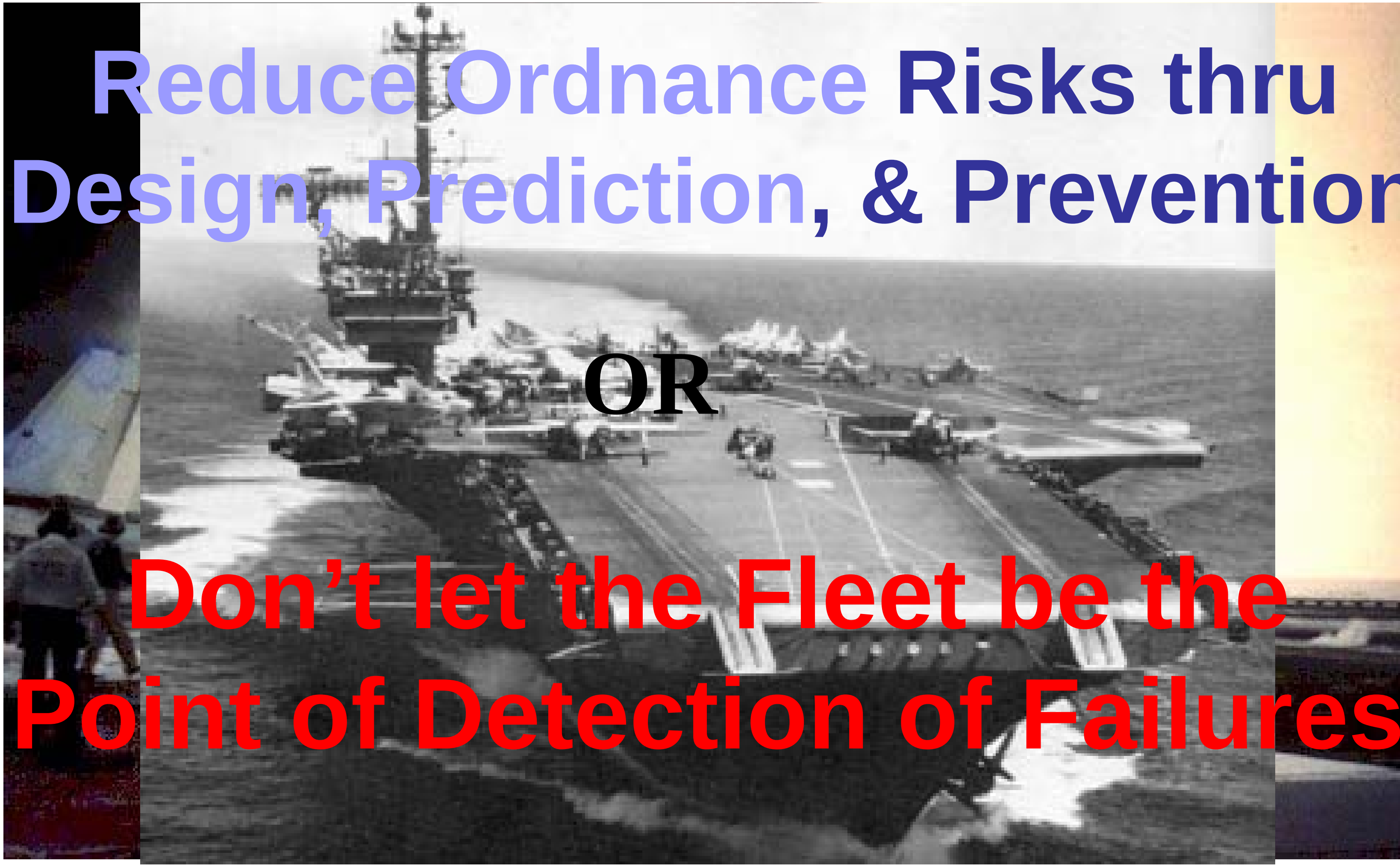
Summary.

- **New R&D Approach to Enable Rapid Development.** There is a critical need to create a plan for R&D investment strategies to enable rapid implementation of new compounds (i.e., high-nitrogen compounds, ionic liquid, energetic binder,etc.) while meeting IM, aging, quality assessment and cost requirements.
- **Current EM Development Technology Does Not Meet Future Needs.** There is a growing disparity between available new energetic material technology and the need for increased functionality and preparedness for future weapons.
- **Provide EM technology to Provide New Warfare Tactics & Strategy:** The transition from the current material design/development paradigm requires the ability to leap ahead of war-planners to provide futuristic possibilities that can elevate performance and provide new warfare tactics and strategy.
- **"Leap ahead" Requires New R&D Paradigm:** The "leap ahead" can only be achieved with a new paradigm: one that embraces new science-based sense, test, analyze and design technology opportunities and developments and relies less on the "black art" or "Edisonian" approach of the past.

Conclusions

- **Establish Dialogue with War-planners**: Establish dialogue with war-planners to permit the early molding of weapons requirements based on reachable energetic material technology growth contributing to the rapid deployment of emerging weapons
- **Develop National Initiatives to Provide New Experimental Tools**: Develop national initiatives to provide the material scientist/engineer with the experimental tools needed to design new formulations required to meet system requirements of the future,
- **Develop National Strategies for Advanced Weapon Design**: Develop national strategies that result in a capability to design weapons for advanced land, air, and naval conflicts and space-based military encounters
- **Explore Concept of Virtual Laboratory**: We should explore the concept of a national virtual laboratory enterprise or consortium to bring the scientific and engineering communities together to understand, measure, model, develop, and most importantly predict the actions and inter-relationships of complex energetic molecular formulations so that application developments can progress at a faster pace with greater assurances of safety, reliability, and performance.

Our work impacts lives and assets



Reduce Ordnance Risks thru Design, Prediction, & Prevention

OR

Don’t let the Fleet be the Point of Detection of Failures