SAND2008-0047P

A NEW PARADIGM FOR R&D TO IMPLEMENT NEW ENERGETIC MATERIALS IN MUNITIONS

History of R&D and EM Developments

To maintain technologically viable munitions in the 21st century, strictly from the point of view of the energetic materials (EM) used for propellants and explosives in those munitions, we must answer the following questions: Will maintaining the status quo be sufficient?; Will the technology developed in the years following WWII be sufficient to provide energetic materials, propellants, and explosives required for future munitions and weapons to meet new threats and provide needed defenses?; and Will the existing synthesize and test paradigm used for the development of energetic materials be sufficient, or will a new paradigm be required?

Modern development of energetic materials for chemical propulsion and warheads can be traced back to the mid- and late-19th century and the beginning of the mid-20th century with the development of nitroglycerine, nitrocellulose, and other energetic organic nitrate/nitramine compounds, such as RDX, HMX, and TATB. Most sophisticated plastic bonded explosives and propellants were developed just before and during WWII. Most of the "new" solid rocket motor propellants were developed during the first two decades of the Cold War. This era preceded the development of today's computer enabled technologies. Hence, development utilized contemporary methods of the era, which used a cycle of synthesis and test to implement a trial and error approach. This is commonly known as the "Edisonian" method. This paradigm remains the basis for developing new ingredients for munitions.

Many munitions specialists and experts consider this paradigm for the development of new propellants and explosives as too slow (lacking time responsiveness), largely unsuccessful, or with only limited successes, and with high risk. Therefore, it is deemed unworthy of significant investment. In some circles, this paradigm is disparagingly referred to as "tweaking molecules". Historically, the design of new molecules focused on improving thermo-chemistry; i.e., more energy per unit volume. This equilibrium-based concept focused only on improving performance. That approach does not address the issues of reactivity that most often causes a new material to fail safety or aging requirements. Thus, the formulator is, in reality, tasked with creating a material with as much energy content as possible, but is so stable that the energy is not released until desired. The parameter space to design these materials is quite small and not likely to be found by trial and error.

To circumvent the limitations associated with the current "Edisonian" approach requires development of a new R&D paradigm that can facilitate rapid creation of new propellants and explosives, with orders of magnitude less material, and at the same time providing new data that can be used to guide the design of new compounds, composite materials, and applications. This new paradigm must also include development of new experimental methods and diagnostics tools to provide the material scientist and engineer with the experimental tools needed to design new formulations to meet the system requirements of the future.

The design of new materials to satisfy a small and restricted chemical parameter space is not unique to energetic materials. Similar challenges are encountered in the development of new drugs. The pharmaceutical industry must design or identify compounds with high efficacy to treat a specific disease, without detrimental side effects. This is analogous to EM development where efficacy is performance and satisfying safety and aging requirements are akin to avoiding detrimental side effects. Thus, using the pharmaceutical industries R&D paradigm for drug development to guide a new paradigm for EM development may hold promise.

New instruments, new experimental methods, and new computational capabilities will allow and facilitate the investigation of complex reactive systems that heretofore have not been available for use in investigating energetic materials. These tools have been applied to address complex issues in biological and biochemical systems and have revolutionized opportunities in these areas. These tools, however, have not been applied in our overall industry to address the complex reaction issues that underlie the behaviors of propellants and explosives. Our “Implementation Strategy” must be a new paradigm whereby we do not reject, but minimize, trial and error and maximize our current “technological opportunities” while continuing to develop new instruments, methods, and capabilities.

The ultimate goal of the scientific and engineering communities is to understand, measure, model, and predict the complex chemical processes that occur between the ingredients that comprise an EM formulation in response to thermal, mechanical and electrical energy. The heterogeneous nature of these materials makes it necessary to understand their chemical reactivity over a wide range of spatial scales. If these processes can be understood and modeled from the molecular/atomic to macroscopic spatial scales (see Figure 1), the future performance or behavior of macro-sized, orders of magnitude, infinitely more complex systems may be modeled with the advanced computational capabilities now available; and perhaps they may also be understood and their behavior predicted[1]. Table 1 projects the major payoffs that can be expected from future investment in energetic material R&D, as additional focused research is accomplished.

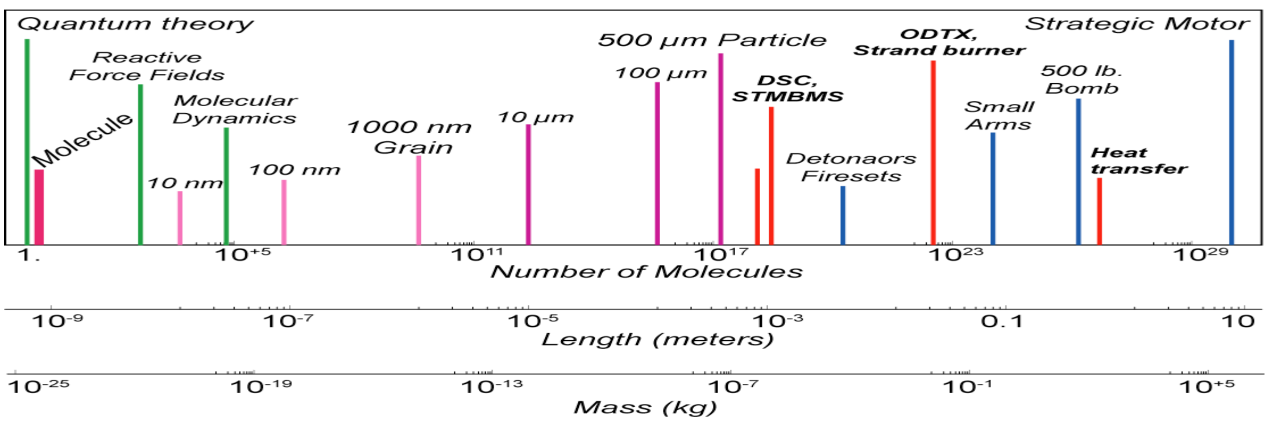

Figure 1. Illustration of spatial scales that may be characteristic of different reaction environments in energetic materials (magenta lines). Experimental methods (red), theory and modeling (green), energetic system articles (blue).

Figure 1. Scale of Issues

A New Paradigm vs. a Shift of the Current Paradigm

Given the large number of requirements that must be satisfied to make a new propellant or explosive that meets very high performance goals while being as safe and as stable as possible, it is not surprising that the slow empirical “Edisonian” paradigm has not been successful for the development of new energetic materials. The pharmaceutical industry, for example, often encounters similar problems of having to satisfy many different types of requirements, ranging from efficacy to safety[2] and cost. It has overcome these obstacles by developing new scientific methods to probe the chemical, biological, and medical issues and requirements for new materials, including new methods to enhance screening and to develop a better understanding of diseases, in our terminology—requirements to guide the development of new drugs, vaccines, and treatment therapies.

Compared to the energetics product area, the pharmaceutical industry has somewhat clearer requirements statements, such as the development of drugs for well-described diseases. Their quest for product improvement in efficacy, safety and cost, however, can be seen as very similar to the need for the resolution of energetics products limitations that are well known and apparently acceptable status-quo (Table 1). Effective development of new energetic materials for munitions in the future must use a requirements-driven approach similar to that used by the pharmaceutical and biotechnology industries. This approach will require the development of a new paradigm that can develop new propellants and explosives much more rapidly, with orders of magnitude less material, and providing new data that can be used to guide the design of new compounds and composite materials.

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.

Table 1: R&D Expectations

Conclusions

There is a critical need to create a plan for R&D investment strategies that would enable the rapid implementation of new energetic ingredients, e.g., high nitrogen compounds, energetic binders, ionic liquids, and future materials, while meeting insensitive munitions (IM), aging, quality assessment and cost requirements. The disparity is growing between the availability of new energetic material technology and the need for increased functionality and preparedness in the future weapons arsenal. The transition from the current “paradigm” of the propellant and explosive material design and development process requires an ability to leap ahead of war-planners and weaponeers to provide futuristic possibilities that can both elevate performance levels and provide new warfare tactics and strategies.

That “leap ahead” can only be achieved with a new paradigm; one that embraces new sense, test, analyze, and design technology opportunities and developments and relies less and less on the “Edisonian” approach of the past. To achieve these ends we must develop near (2 year), mid (5 year) and long-term (10+ year) strategies that seek to accomplish the following:

(1) Establish an ongoing 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.

(2) Develop initiatives to provide the material scientist/engineer with the experimental tools needed to design new formulations required to meet system requirements of the future.

(3) Develop strategies that produce the capability to design weapons for advanced land, air, and naval conflicts and space-based military encounters.

We should also explore the concept of a 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.

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