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Home > Magazines > Proceedings Magazine - January 2015 Vol. 141/1/1,343 > Close the R&D Gap

Close the R&D Gap

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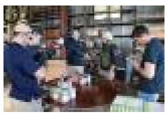
-  [2]
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Proceedings Magazine - January 2015 Vol. 141/1/1,343 [6]
By Alfred G. Stern and Robert E. Kaczmarek

Knowledgeable energetic-materials experts are retiring faster from naval warfare centers than they can be replaced. This trend must be reversed.

In July 2007, all F/A-18 aircraft were grounded across the U.S. Navy and Marine Corps when a rocket in the ejection-seat system of an F/A-18D parked at China Lake, California, activated. Dispatched experts found its propellant had destabilized and initiated in the cockpit at around 165 degrees Fahrenheit—a concern for naval aircraft in hot climates such as the Middle East. (Near- and long-term fixes are under development and being implemented.)

These experts didn't come from industry, which largely regards such support as unprofitable. They came from naval warfare centers that perform research and development (R&D) on energetic materials, a field involving rocket scientists, explosive experts, counter-bomb technologists, and more. Today, these experts are busy sustaining weapon systems across undersea, surface, land, and air warfighting domains, but they are retiring faster than they can be replaced. In the future, energetic materials expertise will be needed even more by the Navy, other services, and federal agencies to meet a growing number of energetics-related challenges. Nearterm readiness and a multitude of capabilities in defense and homeland security will depend on being able to quickly address ever widening R&D and technological gaps.

Energetic Materials 101

Technology rules modern warfare. In the U.S. Navy, the Fleet employs the technologies, and naval-warfare centers serve as the gateways and keepers of those technologies. Scientists and engineers at these research centers understand warfighters' present and future needs, develop or find technical solutions to solve ordnance-related problems and issues, and often contract industry to produce systems and items for the Department of Defense (DOD) and the Fleet. As stated by the naval maxim, "Fire effectively first," which is considered key to tactical success at sea, technology is especially critical. [1] We must have firepower that hits farther, faster, and harder than any opponents' can, a continually changing contest. Such firepower depends on energetic materials, which are energy-releasing chemicals including propellants, explosives, and pyrotechnics developed and engineered to release requisite energies when needed. Energetic materials are to firepower what the Intel chip is to computing power.

These resources are also developed and sustained by naval warfare centers. Naval Air Warfare Center, Weapons Division, at China Lake focuses primarily on energetic materials for air-launched munitions. In Maryland, Naval Surface Warfare Center Indian Head Explosive Ordnance Disposal Technology Division (NSWC Indian Head) provides energetic materials for subsurface, surface, and selected air systems, and develops technologies to render explosives safe.

These centers' energetic-materials technologies permeate the Fleet. As a case in point, an *Arleigh Burke* –class destroyer has 10 to 12 weapons systems supported by energetic materials and well over 20 types of aviation ordnance are deployed on carriers. Other examples include the submarine-launched, Trident ballistic missile, which uses a propellant that allows it to reach its target thousands of miles away in minutes. Certain torpedoes can create a huge, underwater bubble that can break a ship's keel. And a low-collateral-damage bomb can engage enemies in semi-hardened structures while minimizing damage to nearby buildings.

Less noticed are ubiquitous cartridge- and propellant-activated devices that initiate small explosive or propellant charges that yield millisecond functions. As just one example, an F/A-18 has 66 such devices for rapidly releasing bomb racks, activating fire extinguishers, and launching ejection seats.

One defense official described energetic materials as the "goo" that goes into a munition after its development, as if they were afterthoughts. Yet before these systems were on drawing boards, their energetic materials R&D was initiated, driven by requirements like range and target effects. Chemists began to design them at the molecular level, followed by ingredient synthesis, and then chemists and engineers developed formulations—combining additives to increase or decrease energy-release rates, and to bind and stabilize materials and processing technologies to produce these unique propellants and explosives. Then they are scaled up to larger amounts and tested to determine if they perform as intended.

And that's just for energetic-material development. Engineers and detonation scientists design systems to initiate or detonate propellants and explosives, respectively, and to withstand high pressures, temperatures, and firing rates. The overall effort has made munitions increasingly more insensitive to mechanical insult, shock, and fire, particularly after more vulnerable ones caused horrific events on the USS *Oriskany* (CV-34) in 1966 and the USS *Forrestal* (CV-59) in 1967.

Industry often produces energetic components, but in some cases it is unwilling to do so due to expense, environmental impact, or risk. Thus, warfare centers produce when needed. Today, NSWC Indian Head produces Otto fuel II for all domestic and foreign allies' torpedoes, propellant for Trident missile gas generators, and other specialty energetic materials and related technologies.

Energetic-materials R&D, from start (molecule development) to fielding, can take decades, much like pharmaceutical development. Chemistry-based R&D is predominantly by trial and error. Energetic-materials R&D requires substantial experience—around ten years working in the field with mentoring to reach a journeyman level. Today, many naval energetic-materials experts spend 90 percent of their time supporting fielded weapon systems, troubleshooting problems that can stop Fleet-wide use. They know how to sustain these systems because they worked in the R&D process developing them. They also innovate to meet emerging needs, like converting the unguided 2.75 rocket into a guided one that hits moving targets; this is also because of their R&D work. As Massachusetts Institute of Technology Professor Judy Hoyt has said, "To innovate in products, one has to understand the processes by which these products are made." [2]

The Navy's Growing Demand

Naval experts will be needed to sustain existing energetic-materials-powered weapon systems. Some believe that railguns and lasers will replace all energetic-materials munitions on ships. As stated in one report in *Scientific American* , "By equipping ships with railguns rather than standard artillery, the Navy could eliminate the hazards of having high explosives on board ships." [3] The same has been implied for lasers. [4] However, even if lasers and railguns replace 2 to 3 of the 10 to 12 existing weapon systems on a destroyer in several years, the elimination of energetic materials is extremely unlikely, as they support a plethora of functions that require large amounts of chemical energy to be produced in a microsecond to more than several minutes.

Moreover, energetic-materials-powered weapons will complement shipboard lasers and railguns. Ones that are longer ranged must engage threats beyond the ranges of lasers and railguns, which are line-of-sight and/or up to 100 miles, respectively. Also, energetic-materials-powered munitions will be needed for more varied and tailored target effects, relative to lasers' and railguns' specific effects. These weapons will continue to dominate undersea warfare.

Sustaining existing naval weapons requires doing the same for a naval-energetic-materials workforce—which is in need of continued support. As the 2010 Naval Research Advisory Committee's study of the naval R&D enterprise said, "Many critical skill areas are only one or two deep with experienced technologists." [5] This has also been the case for naval energetics-material R&D. In 2013 a wave of federal civilians retired—138,039, the highest since 2000—and more than a third of the workforce will be eligible to retire in 2016. [6] Retirements include proportionate numbers of the naval energetic-materials workforce (such as one of the authors of this article, who has just retired). But retiring experts are not being replaced in the time needed for the ten years of mentoring in this defense-unique R&D area because of financial constraints and generational issues.

This workforce is also needed to meet a growing need for "Navy-after-Next" energetic-materials R&D, while still continuing to improve existing weapon systems. "We too often have considered munitions as an afterthought or, more worrisome, as a bill payer. This is a mistake," said the *Defense Budget Choices and Priorities Fiscal Year 2014* report. "Our military's weapons must be invulnerable to countermeasures and be able to out-reach our enemy's defenses. Potential adversaries continue to improve their capabilities, challenging our ability to project power, especially in anti-access environments." [7]

Energetic-materials R&D will also be needed to develop new weapons. The Fleet's existing weapons are snapshots in time based on technological breakthroughs that occurred 50 and even 70 years ago; they can only be improved so much and will inevitably be supplanted by weapons that hit farther, faster, and harder. Warfare trends point to this. Our warfighters increasingly need such improved weapon systems—and other nations are pursuing them.

Energetic-materials R&D will be needed for the following:

Extended ranges . Early in the 20th century, naval guns ranged 15 miles. By its end, naval aircraft and missiles ranged over 600 miles. [8] According to naval analyst Wayne Hughes, this growth in range has increased land-sea interaction. Today one nation's fielded land-based, antiship ballistic-missile ranges over 900 miles and reportedly, it and other countries seek longer-range antiship missiles. [9] Navy warfighters also seek longer range, ship-based, and air-launched missiles.

Expanded range requires sustained energetic-materials R&D. As a general rule, doubling missile speed quadruples range. This is easier to do for land-based missiles than for ship- and air-launched ones. Land-based missiles can be made bigger with more propellant. More volume constrained ship- and air-launched missiles need denser, more powerful propellants to achieve greater speeds and ranges. Also, the rocket motors must be designed to withstand greater temperatures and pressures. Unlike land-based weapon systems, sailors must "sleep with their weapons," so they must have improved insensitive munitions properties without loss of performance. Furthermore, there is nowhere to run in the event of an explosive incident.

Higher volumes of fire . A major criterion for a warship commander is how much effective combat power the ship can deliver over a period of time. [10] Relative to past capabilities, today's warfighters seek ships with higher volumes of fire and greater magazine capacity. These require smaller, lighter, more lethal, and more precise munitions than the ones that exist today. Such munitions would increase surface ships' firepower; on carriers, they would speed the arming of aircraft and help increase sortie rates. They could also positively affect ship designs. Reducing the size of submarine-launched ballistic missiles could reduce the size of submarines, thus reducing costs. Weapons could be developed with more powerful propellants, tiny micro-fuzes, and in some cases, highly energetic materials that could replace inert munitions casing.

Varied and tailored target effects . Previously, most munitions produced blast and inert fragmentation against personnel, equipment and structures. Increasingly, warfighters need explosives that do much more against an expanding target and in varying environments—all demanding energetic-materials R&D. These munitions must:

• *Defeat high-altitude and space threats* . This includes kinetically engaging targets at the edge of the Earth's ionosphere—about 30 miles—and extending outward. [11]

• *Defeat sea-skimming missile threats at long and medium ranges* . Instead of mainly point kills, intercept missiles might detonate in close proximity, dispersing wide patterns of fragments that "explode" on impact with threat missiles. Such exploding fragments are in development.

• *Defeat increasingly harder and deeper buried targets* . This requires continued development of munitions that survive intense shocks, penetrate prescribed depths, and sense and detonate in intended voids. [12]

• *Destroy chemical and biological storage facilities* . This cannot be done effectively with high explosives, which lack sufficient heat to completely burn up agents. [13] Also, shock pressures can disperse remaining agents. It requires munitions producing flame temperatures over several thousand degrees, for several minutes.

Undersea warfare . A joint warfighting goal is the kinetic engagement of targets below depths of 200 feet. [14] Submariners seek torpedoes that prowl at slow speeds, reconnoiter areas, and quickly engage targets, with different payloads. [15] Such undersea munitions will require specialized energetic-materials mixtures designed to release energy differently than many surface munitions.

Arming unmanned systems . Today's warfighters use unmanned systems that have been equipped with weapons designed for larger manned systems, limiting what they can do. The DOD envisions unmanned systems being armed for more demanding missions than they do today, and having relevance to overcoming anti-access capabilities. Such missions include:

• Mine-laying and mine-neutralization missions in the maritime domain

• Air-to-air combat and suppression and defeat of enemy air defense [16]

• Swarming unmanned attack systems from multiple directions [17]

For these and other missions, unmanned systems will need smaller munitions specifically developed for different environments. Optimizing potential, though, will require energetic-materials development to be at the center of systems engineering for these munitions and future unmanned systems.

Homeland Security Needs Them, Too

The naval energetic-materials workforce will be needed for more than sustaining and developing Navy weapons. It possesses a comprehensive understanding of energetic materials, ranging from development at the molecular level, to use in all applicable warfighting domains. Thus, the other services draw on this expertise for their weapon development. The naval workforce has developed 13 different types of explosives used in 47 Army, Air Force, Marine Corps, and Navy weapon systems. Overall, it has developed 75 percent of the explosives in U.S. weapons. Today this workforce sustains 550,000 cartridge-/propellant-activated devices on more than 11,000 military aircraft.

The energetic-materials workforce is critical to informing systems' survivability in defense and homeland security. It has developed high-fidelity simulation tools that predict weapons' effects—ours and theirs—and help develop weapons such as the counter-torpedo torpedo. They also foresee weapon survivability, and have assessed varying weapons' effects on ships, ground vehicles in Iraq and Afghanistan, and even blast effects on the human brain. Recently, these tools assessed explosive effects on critical U.S. infrastructure, such as dams and underwater pipelines.

U.S. homeland security increasingly will need the naval energetic-materials workforce, which is central to defending against the IED threat. NSWC Indian Head is the DOD Explosive Ordnance Disposal Technology Program lead. In developing counters to IEDs, the division also supports the Departments of Justice and Homeland Security. Their subordinate agencies rely on the Navy's comprehensive understanding of energetic materials as well.

While readily known in other countries, the IED threat in the United States became apparent with the 15 April 2013 Boston Marathon bombing. Less known were the 172 IEDs reported in the country six months prior. [18] This threat likely will increase in sophistication, according to the Joint Improvised Explosive Device Defeat Organization's Counter-IED Strategic Plan 2012-16:

> Future bomb makers will seek to incorporate such enhancements as peroxide- and hydrogen-based explosives; nanotechnology and flexible electronics; new forms of power, e.g., microbial fuel cells, non-metallic and solar; advanced communications (Bluetooth, 4G, Wi-Fi, broadband); optical initiators (using laser or telemetry more than infrared); and highly energetic and molecular materials. [19]

Then there is the threat of the Islamic State of Iraq and Syria. Reportedly, no other group has more expertise in making improvised explosive devices. [20]

The naval energetic-materials workforce will become more and more vital to the intelligence community as well. Naval energetic-materials experts work with intelligence agencies to analyze threat energetic materials such as the composition of the Taliban's homemade IEDs to determine possible countermeasures. They also help agencies assess other nations' claimed capabilities. A nation recently claimed its missiles use a new solid propellant that provides a faster boost in the initial flight phase, making it less vulnerable to U.S. missile defense. [21] Verifying this requires energetic materials expertise.

Ways to Replenish the Workforce

Naval energetic-materials experts sustain and improve the weapon systems its workforce developed for the Navy and across the services. However, the general thought on science and technology was perhaps best described by naval scientists Timothy Coffey, Jill Dahlburg, and Elihu Zimet: "We have become so mesmerized by our enormously successful exploitation of past S&T [science and technology] breakthroughs that we have forgotten how they happened." [22] This is evidenced by the dwindling ranks of naval energetic-materials experts, who are needed not only to sustain existing systems but make S&T breakthroughs happen again.

The following measures can address the widening gaps in this workforce:

• Improve the hiring and retention of energetic-material scientists and engineers for the sustainment of current energetics technologies and future R&D needs. Replacing retiring scientists and engineers and therefore retaining their knowledge, skills, and abilities is critical for sustaining existing weapon systems, and will be needed for future Navy missions and warfighter needs.

• Document energetics procedures and technical data at the Defense Technical Information Center for archive retrieval. This will address knowledge gaps resulting from scientist and engineer attrition and retention misalignment.

• Sustain energetic-materials R&D funding to support and meet current and future Navy warfighting requirements as well as to attract and retain next-generation scientists and engineers. This will not only support critical naval technical authority requirements; it will reduce the possibility of technological surprise by adversaries.

Our competitors saw the superior performance of U.S. weapons in Afghanistan and Iraq and now pursue breakthroughs for weapons that hit farther, faster, and harder. Some are already emerging. [23] More asymmetric enemies are also pursuing increasingly sophisticated IEDs. U.S. energetic-materials R&D is key to countering these growing threats and maintaining warfighting advantages. The naval energetic-materials workforce is the core of U.S. research and development. It must be maintained into the future.

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1. CAPT Wayne P. Hughes Jr., USN (Ret), *Fleet Tactics and Coastal Combat* , second ed. (Annapolis: Naval Institute Press, 2000), xvii, 40, 206.

2. Larry Hardesty, "How to Corner the MEMS Market," 6 April 2012, http://web.mit.edu/newsoffice/2012/manufacturing-mems-production-0405.html [7] .

3. Larry Greenemeier, "Navy Unleashes Its Electromagnetic Railgun outside of the Lab," *Scientific American* , 28 February 2012, http://blogs.scientificamerican.com/observations/2012/02/28/navy-unleash... [8] .

4. Agence France Presse, “US Navy Shows Off Laser Cannon That Can Shoot Down Drones,” 9 April 2013, www.businessinsider.com/us-navy-shows-off-laser-cannon-that-can-shoot-do... [9] .

5. Naval Research Advisory Committee, “Status and Future of the Naval R&D Establishment: 2010 Summer Study,” slide 23, “Supporting Findings Technical Competency,” 23 September 2010.

6. Office of Personnel Management, “Retirement Statistics,” www.opm.gov/retirement-services/retirement-statistics [10] . Damian Dovarganes, “Wave of retirements hitting federal workforce,” *Washington Post* , 26 August 2013, www.washingtonpost.com/politics/wave-of-retirements-hitting-federal-work... [11] .

7. Office of the Secretary Of Defense, “Defense Budget Choices and Priorities Fiscal Year 2014,” April 2013, www.defense.gov/pubs/DefenseBudgetPrioritiesChoicesFiscalYear2014.pdf [12] , 21.

8. Hughes, *Fleet Tactics and Coastal Combat* , 180.

9. Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People’s Republic of China 2013* , www.defense.gov/pubs/2013_china_report_final.pdf [13] , 5, 6. Mark Stokes, “China’s Evolving Conventional Strategic Strike Capability: The Antiship Ballistic Missile Challenge to US Maritime Operations in the Western Pacific and Beyond,” Project 2049 Institute, 14 September 2009, http://project2049.net/documents/chinese_anti_ship_ballistic_missile_asb... [14] , 2.

10. Hughes, *Fleet Tactics and Coastal Combat* , 164.

11. Joint Staff, www.dtic.mil/futurejointwarfare/cap_areas.htm [15] , “Definitions, paper entitled, “Joint Capability Areas,” JCA 2010 Refinement, approved 8 April 2011, 17.

12. Ibid.

13. Ibid., 16.

14. Ibid.

15. Philip Ewing, “Navy sub adm: We need new weapons,” *DOD Buzz* , 19 October 2011, www.dodbuzz.com/2011/10/19/navy-sub-adm-we-need-new-weapons [16] .

16. DOD, *FY2009–2034 Unmanned Systems Integrated Roadmap* , 2009, 10.

17. Joint Staff, *Major Combat Operations* , Joint Operating Concept, Version 2.0, December 2006, www.dtic.mil/futurejointwarfare/joc.htm [17] , 48.

18. Matthew Schofield and Erika Bolstad, “Bombs frequent in U.S.; 172 ‘IED’ incidents in last 6 months, by 1 count,” *McClatchy Newspapers* , 16 April 2013, www.mcclatchydc.com/2013/04/16/188733/bombs-frequent-in-us-172-ied-incid... [18] .

19. Joint Improvised Explosive Device Defeat Organization, *Counter-IED Strategic Plan 2014–2016* , 4.

20. Paul Cruickshank, “Terror havens in Syria and Iraq: Five reasons the West should worry,” CNN, 26 July 2014, www.cnn.com/2014/07/23/world/meast/syria-iraq-terror-havens [19] .

21. *Russian Times* , “Russia test fires AMD-piercing strategic missile,” 23 May 2012, www.rt.com/news/new-strategic-missile-test-970 [20] .

22. Timothy Coffey, Jill Dahlburg, Elihu Zimet, “The S&T Innovation Conundrum,” Center for Technology and National Security Policy National Defense University, August 2005, VII.

23. For example, Russia’s military closely watched U.S. military performance in the early stage of Operation Iraqi Freedom, as evidenced by *FBIS* , “Russian Academy of Military Sciences Analysis of War in Iraq,” CEP20030911000356 Moscow Voyennaya Mysl (in Russian), 11 July 2003, 55–78.

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