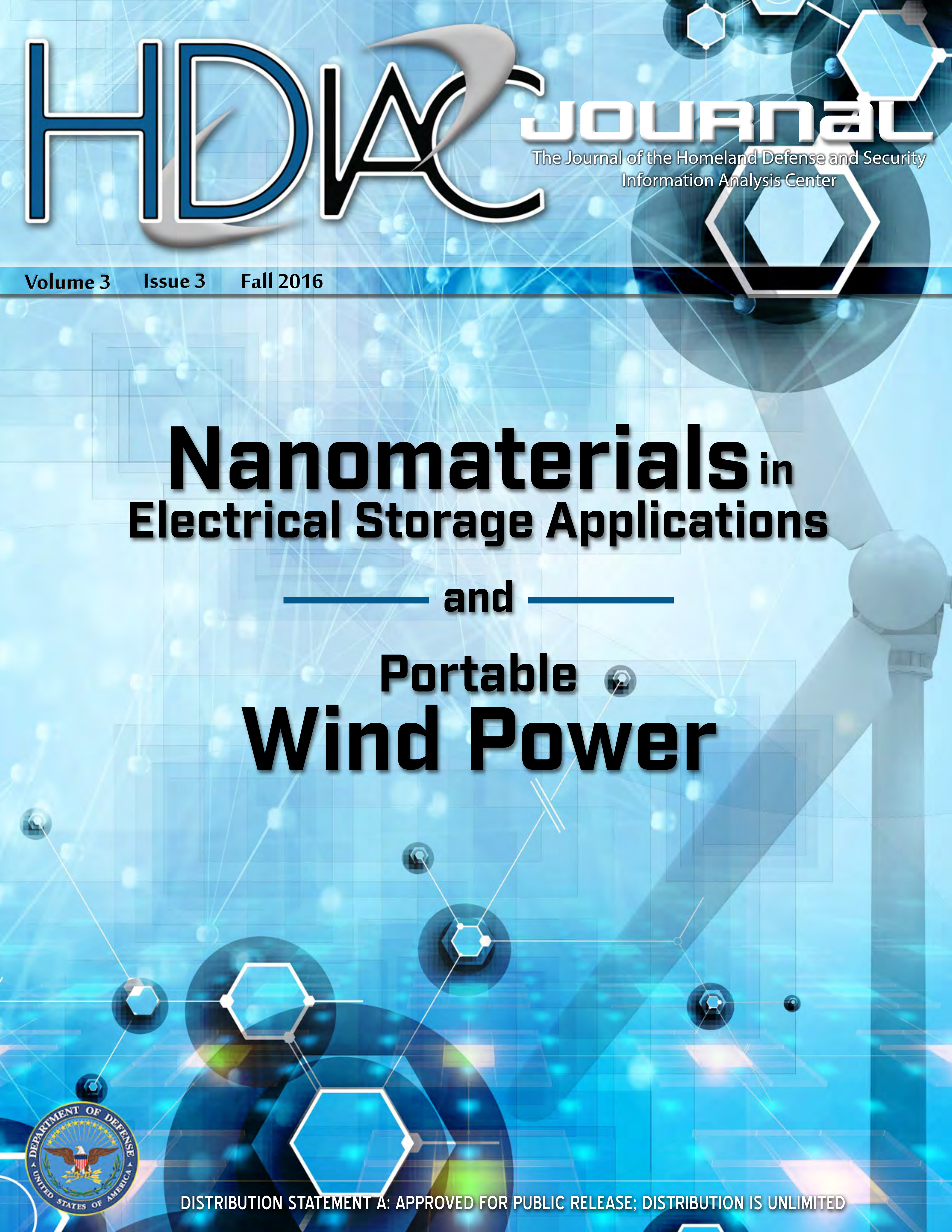

HDIAC JOURNAL

The Journal of the Homeland Defense and Security
Information Analysis Center

Volume 3 Issue 3 Fall 2016

Nanomaterials in Electrical Storage Applications

and

Portable Wind Power

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

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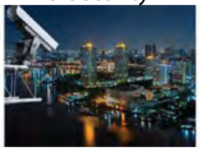

Homeland Defense & Security


Medical


WMD

Message from the Director:

Better Buying Power 3.0

Better Buying Power 3.0 is a Department of Defense initiative to achieve dominant capabilities through technical excellence and innovation. The Homeland Defense and Security Information Analysis Center supports BBP 3.0 by improving affordability, productivity and standardization within defense acquisition. This message touches on two BBP 3.0 focus areas: incentivize productivity and innovation in industry and government; and promote effective competition.

As global threats and national defense objectives change, there is a need for greater agility and responsiveness in U.S. forces. The private sector frequently matures scientific applications faster than the normal development cycle of the DoD, so BBP 3.0 calls for greater leverage of commercial technology.

To incentivize productivity in industry and government, BBP 3.0 seeks to remove barriers to commercial technology utilization, improve the return on investment in DoD laboratories and stimulate corporate independent research and development. To incentivize innovation, BBP 3.0 seeks to increase the use of prototyping and experimentation, emphasize technology insertion and refresh in program planning, and use modular open systems architecture to stimulate innovation. To promote effective competition, BBP 3.0 seeks to improve DoD outreach for technology and products from global markets.

These BBP 3.0 objectives are satisfied by the primary function of HDIAC, which is to leverage the best expertise from industry, other government agencies and academia to solve the government's toughest scientific and technical problems. HDIAC provides cost-effective DoD research and development lifecycle support by acquiring, analyzing and disseminating relevant scientific and technical information; maintaining an extensive database collection; and utilizing a wide-ranging subject matter expert network.

HDIAC recently collaborated with industry, government and academia to support a new DoD initiative, the Third Offset Strategy.

The U.S. offset strategies began in the Cold War to generate and sustain a competitive advantage through technological and operational innovation, while extending conventional deterrence against great world powers. These attempted shifts in advantage became known as "offsets" in response to an adversary's military capabilities. The Third Offset Strategy focuses on five technological-operational components: deep-learning systems; human-machine collaboration; human-machine combat teaming; assisted human operations; and network-enabled cyber-hardened weapons.

In support of this new DoD initiative, HDIAC recently provided a free technical inquiry report on identifying human behavior threat signals using sensor technology. This report touched on multiple components of the Third Offset Strategy within a BBP 3.0 approach.

The Third Offset Human Systems Roadmap identifies current technical challenges that, "lack advanced modeling and complex algorithms to process new data streams for actionable information in real-time." To assist the warfighter in rapidly identifying human behavior threat signals, HDIAC researched a range of physical sensor and identification software technologies, emphasizing those novel sensors capable of determining a subject's threat level. Determining a subject's threat level in an operational environment means assessing both physical (body temperature, disguises and speech dialect) and behavioral (stress markers, nervousness and speech patterns) characteristics in a time-sensitive situation. The system must differentiate between a combatant or non-combatant and alert the warfighter to the subject's presence and intentions.

Software and sensor technologies evaluated by HDIAC include advanced facial recognition and body temperature measurement software, as well as advanced mood, heart rate and stress level sensors. If combined, the technologies have the potential to provide a multimodal sensor system that can assist the warfighter in instantaneously analyzing a subject's threat level.

HDIAC's research and analysis will help the DoD identify leaders in the private and academic sectors, making it easier to incentivize productivity and innovation as well as promote effective competition in support of BBP 3.0.

HDIAC organized a meeting between a military unit pursuing human sensor technologies and leading academic and industry scientists in the field of neuroanalytics to detail the findings in the technical inquiry report. HDIAC also developed and presented a three-pronged approach designed to tackle and inform issues inherent within the Third Offset. This approach included a long-term research plan and a funded working group, followed by prototype development informed by the previous entities.

Stuart Stough
HDIAC Director

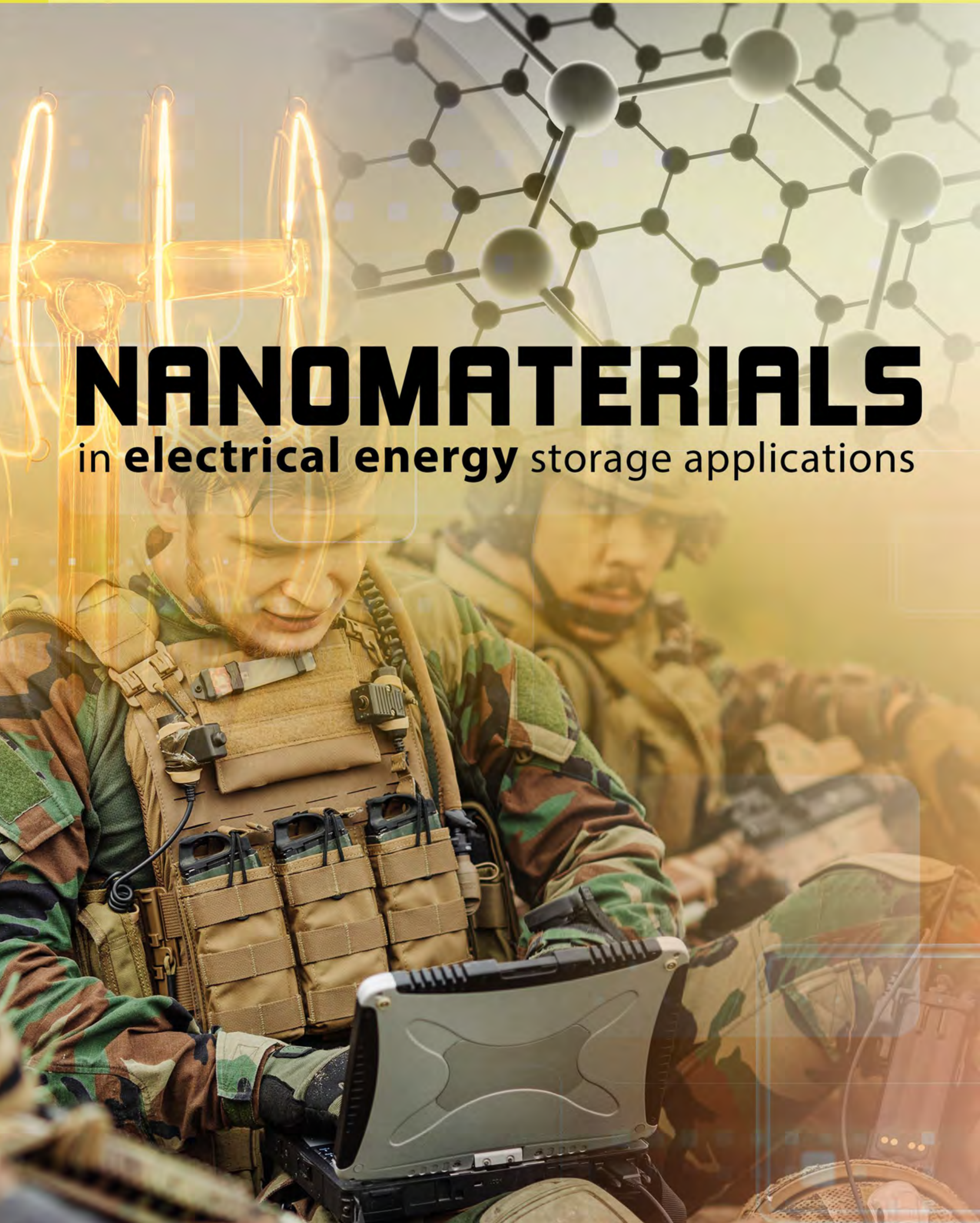
HDIAC's strategy would contribute to BBP 3.0 by implementing a repeatable approach toward Third Offset technology development, eliminating the need for duplication of strategy development efforts.

DoD parties in attendance expressed interest in additional research from the academic sectors, primarily regarding the human effect on the warfighter. Integrating a successful multimodal system capable of determining a subject's threat level in an operational environment could help reduce warfighter stress and negative effects associated with poor performance and decision making. This human-machine collaboration is a direct focus area of the Third Offset Strategy.

HDIAC helped to strengthen the relationship among the academic, industry and government sectors, which should further advance DoD initiatives. Technologies developed by industry and academia drive innovation. By researching and analyzing concepts under development, HDIAC provides information to assist the government in lessening developmental costs and cycle times. BBP 3.0 initiatives promote innovation and competition in research and development in academia and industry in order to better enable and equip the warfighter. The Third Offset Strategy will continue to work in tandem with BBP 3.0 to meet the need for greater agility and responsiveness in U.S. forces. HDIAC is positioned to help with both initiatives to meet future defense objectives.

Better Buying Power Focus Areas

1. **Achieve Affordable Programs**
2. **Control Costs Throughout the Product Lifecycle**
3. Incentivize Productivity and Innovation in Industry and Government
4. **Eliminate Unproductive Processes and Bureaucracy**
5. Promote Effective Competition
6. **Improve Tradecraft in Acquisition of Services**
7. **Improve the Professionalism of the Total Acquisition Workforce**



NANOMATERIALS

in **electrical energy** storage applications

**By: Kathleen Maleski,
Meng-Qiang Zhao, Ph.D. &
Yury Gogotsi, Ph.D.**

Introduction

Two-dimensional nanomaterials, such as graphene and transition metal dichalcogenides, have tremendous potential to broaden the range of materials used by the Department of Defense. In particular, they are very useful in electrical energy storage applications. Due to their unique layered structures and high electronic conductivities, 2D nanomaterials can employ effective and efficient methods of storing energy. [1] Energy storage has erupted as one of the world's greatest challenges, resulting in the stimulation of research to push the limits of materials and technology. From medium (vehicles) to small (personal electronics) dimensions, devices such as batteries and electrochemical capacitors store energy electrochemically. Devices that can perform in extreme environments, provide high energy and power, and can be supplied in configurations that are flexible and conformable have become desirable, as current U.S. DoD initiatives strive to improve upon these characteristics with novel 2D materials. Two-dimensional materials can be fabricated into electrodes, which can be morphed into a variety of shapes and even integrated into structures or garments to create multifunctional materials. The horizon is wide for 2D materials, as they have the potential to be useful in many functional applications, but are currently investigated by how they influence the performance of conventional energy storage devices such as secondary batteries and electrochemical capacitors. [2]

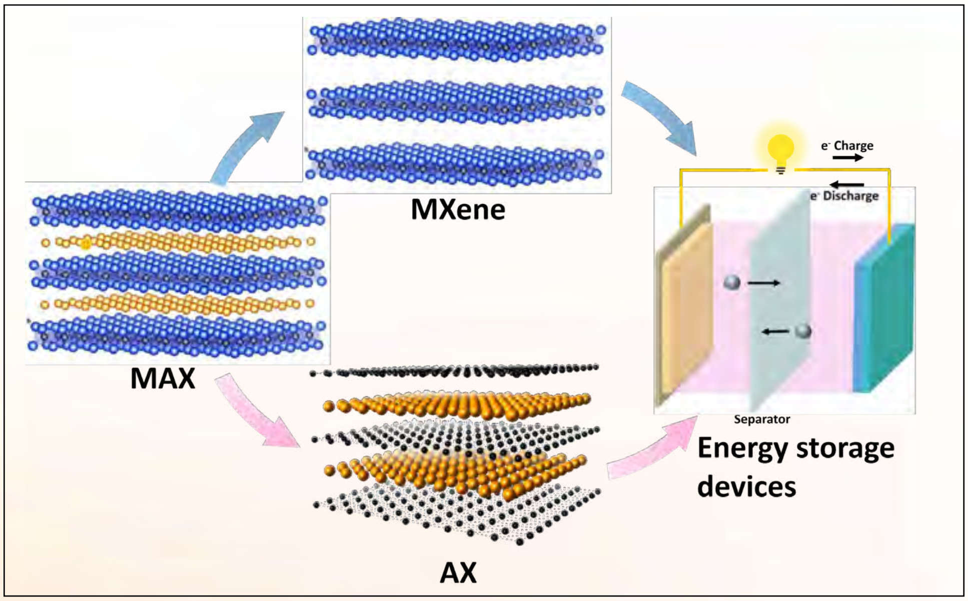


Figure 1. Image shows the production of MX (MXene) and AX materials by selective extraction of 'A' or 'M' element from the precursor MAX phase. Both phases can be used as active materials in energy storage devices, such as batteries and electrochemical capacitors. (Released)

In 2011, material scientists at Drexel University discovered an expansive family of 2D transition metal carbides, carbonitrides and nitrides named MXenes (M – transition metal, X – carbon or nitrogen). [3] The name MXene originated from the structure resembling other 2D materials, such as graphene. Thus, new horizons opened up in the 2D world. This article focuses on energy storage applications of this new family of materials, but synthesis of MXenes, manufacturing of their composites and related structures, as well as a variety of other potential applications will be described.

The MXenes were produced by the removal, or selective extraction, of specific 'A' elements, such as aluminum or gallium, from their MAX precursors (see Figure 1). [3,4] The MAX phases are a family of ternary metal carbides and/or nitrides, listed in Table 1, where they are separated into three classes. They exhibit a formula of Mn+1AXn, where the 'M' element is typically an early transition metal (e.g., Ti, Nb, V, Mo, Ta, etc.), the 'A' element is mostly IIIA and IVA group members (e.g., Al, Si, Ga, etc.), and X is carbon and/or nitrogen. [5]

After the removal of 'A' layers from a MAX phase by etching in an acid, the resulting material has a crystalline 2D MX structure (carbide, nitride or carbonitride), thus MXene. [3,6,7] As a result of wet chemical etching, the surface of MXene is terminated by oxygen or fluorine containing groups,

211 (M_2AX)						312 (M_3AX_2)	413 (M_4AX_3)
Ti_2AlC	Ti_2CdC	Ti_2GaC	Ti_2InC	Ti_2TlC	Sc_2InC	Ti_3AlC_2	Ti_4AlN_3
V_2AlC	V_2GaC	Cr_2GaC	Ti_2AlN	Ti_2GaN	Ti_2InN	V_3AlC_2	V_4AlC_3
V_2GaN	Cr_2GaN	Ti_2GeC	Ti_2SnC	Ti_2PbC	V_2GeC	Ti_3SiC_2	Ti_4GaC_3
Cr_2AlC	Cr_2GeC	V_2PC	V_2AsC	Ti_2SC	Zr_2InC	Ti_3GeC_2	Ti_4SiC_3
Zr_2TlC	Nb_2AlC	Nb_2GaC	Nb_2InC	Mo_2GaC	Zr_2InN	Ti_3SnC_2	Ti_4GeC_3
Zr_2TlN	Zr_2SnC	Zr_2PbC	Nb_2SnC	Nb_2PC	Nb_2AsC	Ta_3AlC_2	Nb_4AlC_3
Zr_2SC	Nb_2SC	Hf_2InC	Hf_2TlC	Ta_2AlC	Ta_2GaC		Ta_4AlC_3
Hf_2SnC	Hf_2PbC	Hf_2SnN	Hf_2SC				

Table 1. Some of the MAX phases reported, organized by MX structure [9]

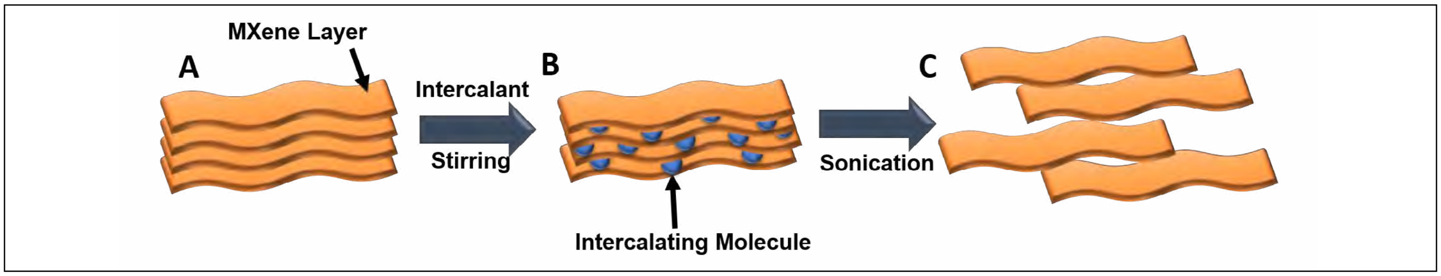


Figure 2. Schematic representing the intercalation and delamination of MXenes. A) Original multi-layer MXene, small spacing between stacked sheets; B) After the addition of an intercalating molecules and stirring, the molecules enter between the MXene sheets; C) After washing and sonication, the MXene sheets become separated and free-standing, forming a colloidal solution. (Released)

therefore, the complete formula is written as $M_{n+1}X_nT_x$, where 'T' stands for surface termination. [6] This surface chemistry dictates many properties of MXenes, in particular making them hydrophilic. If the 'M' layer is removed, AX structures can be produced, but the layers become amorphous/disordered (see Figure 1). [8]

MXenes exhibit a 2D structure with sub-nanometer thick layers, similar to graphene. The major difference between graphene and MXene is compositional: graphene is composed of a network of carbon atoms and MXenes are 2D compounds built of metal and nonmetal ions, like transition metal dichalcogenides or oxides. The majority of MXenes produced to date (about 20) are carbides and are focused on in this article. They come in three different structures (M_2CT_x, $M_3C_2T_x$ and $M_4C_3T_x$). [6] This structural diversity enables MXenes to become materials-by-design, thus facilitating multiple configurations, properties and applications, similar to transition metal dichalcogenides, but with a larger diversity and different properties.

MXenes, such as $Ti_3C_2T_x$, offer high electronic conductivities up to 7000 S/cm, [10] comparable to metals. They are hard, strong, wear resistant, thermally stable in inert environments and have a strong affinity for water (hydrophilic). Because of their high conductivities and layered structures, MXenes have primarily been studied as active materials in energy applications. [6] The MXenes exhibit superior capacity for the reversible intercalation of most metal cations, including Li^+, Na^+, K^+ and multivalent ions, such as Mg^{2+}, and Al^{3+} and a variety of organic molecules. [11,12] This reversible process offers mechanisms for charge storage across various technologies, shedding light on the possible use of MXenes as electrode materials for lithium-ion and alternative energy storage systems. [11] For example, magnesium and aluminum ions were shown to intercalate MXenes from aqueous solutions providing the basis for future Mg- and Al-ion battery applications. [11]

MXene Synthesis, Delamination and Integration with Other Materials

Several synthesis techniques have been used to produce MXenes and give versatility to their manufacturing. Initially, MXenes were produced by using hydrofluoric acid aqueous solution to selectively extract elemental 'A' layers from their corresponding MAX precursors. [3] Later on, it was found that MXenes produced by etching MAX phase in a solution of dilute hydrochloric acid and lithium fluoride exhibited a clay-like behavior due to intercalation of lithium ions during etching. [13] This method is safer than the HF method, and materials produced by the HCl/LiF etching method are both highly conductive and can easily be molded into a variety of shapes and sizes. Within several minutes, flexible MXene films can be rolled to any thickness while retaining high conductivity and arranged to be used as electrodes in energy storage devices, or conform to any shape. This rolling process looks a bit like rolling out cookie dough, with results that are even sweeter from an energy storage standpoint.

> “Through continued optimization and disco
> **and carbonitrides** may find a place as **versa**
> a widespread array of defense applications.”

As noted previously, the layered structure of MXene is advantageous because it allows ions to enter during synthesis. This alone may be sufficient for delaminating MXenes, such as $Ti_3C_2T_x$ clay, and produce colloidal solutions of single- or few-layer flakes. [13] In addition, after synthesis, the MXene layers can be separated by a variety of organic molecules, such as urea, hydrazine, dimethyl sulfoxide and tertiary amines etc., which open up the layers. [12,14] In the case of dimethyl sulfoxide or tertiary amines, these layers can be separated (delaminated) into single-layer flakes with agitation by sonication (see Figure 2). The delaminated MXenes are usually dispersed in water and can be used to prepare supported or freestanding and flexible films/papers via filtration, spray coating, spin coating or other methods allowing for large-scale production. [10,13,15] These flexible MXene papers can serve directly as electrodes without current collectors due to high metallic conductivity, and exhibit improved electrochemical performance compared with those made of multilayer powders, indicating a great potential for using MXenes in flexible and wearable energy storage devices, [16,17] such as combat gear, soldier-borne electronics and applications which require ruggedness, adaptability and reliability.

Similar to other 2D materials such as graphene, MXenes can be used as building blocks to integrate with other materials and produce MXene-based nanocomposites. For example, MXenes were used as nanofillers in a polyvinyl alcohol polymer matrix. The as-fabricated MXene/PVA nanocomposites exhibited much improved mechanical properties relative to pure PVA. [18] Additionally, small polymer chains and carbon nanomaterials (e.g., carbon nanotubes and graphene) were intercalated between MXene layers by a mixing and subsequent filtration method, resulting in MXene-based composite papers with more open structures that facilitated the diffusion of electrolyte ions. [19] The understanding of how multiple nanomaterials are able to work together cohesively allows researchers to develop and engineer hybrid materials with outstanding properties. For example, a Ti3C2Tx MXene film was tested mechanically and was able to support about 4,000 times its own weight. When made as a composite with a polymer, PVA, the film easily supported nearly 15,000 times its own weight. [18]

Electrochemical Energy Storage Applications

Batteries and supercapacitors are two of the most common electrochemical energy storage devices. Batteries, which power our cell phones, computers, cars and more, store charge based on electrochemical reactions occurring within the cell. Electrochemical capacitors, also termed supercapacitors or ultracapacitors, have a different charging mechanism which relies on surface ion adsorption/desorption or redox reaction of the electrode active material (see Figure 3, left). [20] These electrostatic interactions produce quick charging and discharging, making electrochemical capacitors well suited for power applications. Batteries and electrochemical capacitors consist of electrodes, current collectors, a separator and an electrolyte. The two electrodes, a cathode and an anode, are backed by current collectors and divided by a separator. Ionic current flows through the cell when a potential is applied, from electrode to electrode, through the electrolyte, which can be liquid, solid or gel in state. Aqueous, organic or ionic liquid electrolytes are generally used, with the organic ones used in majority of commercial energy storage devices. Each component of the device must be compatible with other components as well as exhibit properties that are associated with the specific target application.

very, the **2D metal carbides, nitrides**
tile and multifunctional materials in
”

Lithium-ion Batteries

With lithium-ion battery technology being one of the most important energy storage technologies used in defense applications, [21] expanding the field to include materials that could improve or replace current ones, providing enhanced performance, has become important for many defense pursuits such as hybrid automobiles, nanoscale electronics and battlefield equipment. Two-dimensional materials, like graphene and MXene, are perfectly suited for applications as the electrode material due to their increased surface area relative to a bulk structure. This allows for larger quantities of ions to be inserted (see Figure 3, right) during charging and removed during discharging, thus increasing the amount of energy stored. Both experimental and theoretical studies on employing MXenes as anode materials for lithium-ion batteries have been conducted due to reversible insertion of Li+ between layers of the material. Using MXene in lithium-ion technology was first tested in 2012 by analyzing Ti2CTx, the lightest MXene, as the active material. It was shown that a capacity of 225 mAh/g and 70 mAh/g was achieved at C/25 and 10 C charging rates, respectively. [22] After promising results, different variations of MXenes were tested and a high capacity of approximately 600 mAh/g was yielded by Nb2CTx MXene, with excellent cycling stability. [14] Another recent study on Ti3C2Tx MXene infiltrated with tin (Sn4+) ions pushed the specific capacity to approximately 800 mAh/g at a current density of 50 mA/g, giving further improvement to MXene anodes. [23] Additionally, the value of approximately 1200 mAh/g was reported very recently for porous Ti3C2Tx-based MXene. [24]

Supercapacitors

While lithium-ion batteries supply sufficient energy for many defense and personal pursuits, the challenges include low power density, yielding several hour charge times. On the contrary, supercapacitors challenge battery technology by allowing for millisecond-second charging times due to the fast surface or redox active electrodes. These charging mechanisms render the importance of active material performance which can provide defense applications, such as fork lifts, wind mills, solar panels, hybrid cars and battlefield equipment, with high power. MXene lends itself to be an outstanding supercapacitor not only because of the high electrical conductivity, but also due to spontaneous chemical intercalation of various cations from the electrolyte in between MXene layers. Delaminating layers of MXene increased performance in supercapacitor applications due to the 2D nature revealed after exfoliation. Reversible capacities of more than 330 F/cm3 were achieved, and more than 10,000 charge-discharge cycles were reached. Attained by Ti3C2Tx paper in

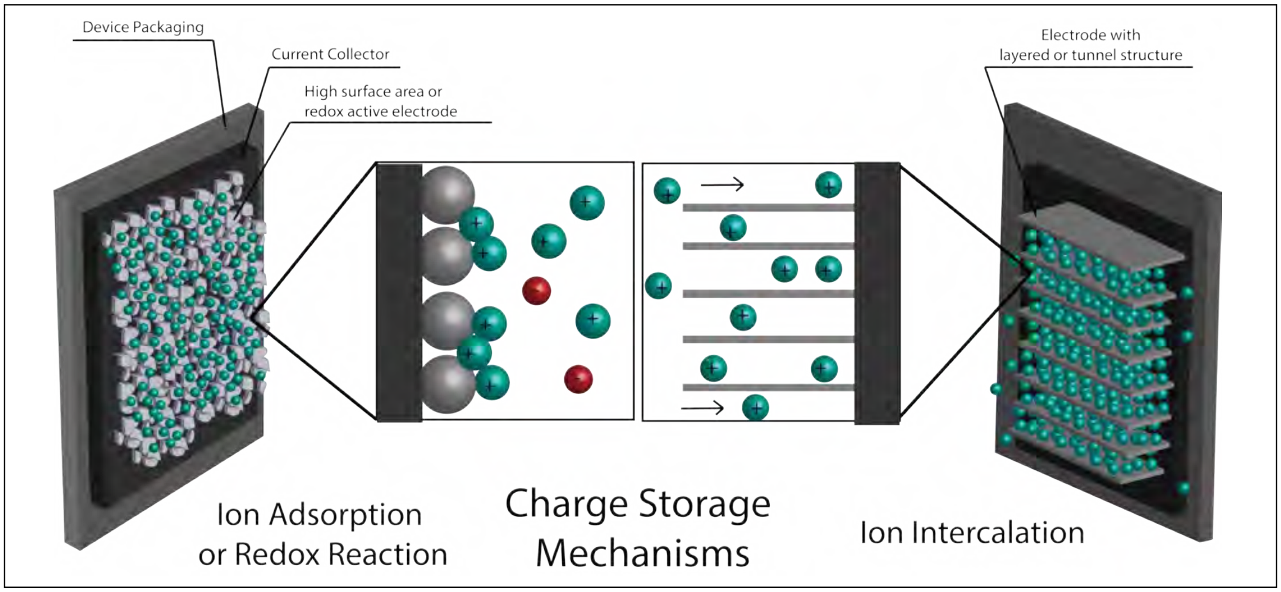


Figure 3. Schematic describing the main differences between two charge storage mechanisms: ion adsorption or psuedocapacitive redox reaction (left) and ion intercalation (right). (Released)

an aqueous electrolyte, these performances exceeded that of the best all-carbon supercapacitors. [12] Additionally, rolled films from Ti3C2Tx clay showed even higher capacities up to 900 F/cm3, along with excellent cyclability and rate performance. [11] It was also found that hybridization of MXenes with other nanomaterials, such as polymers, nanocarbons and metal oxides, led to an improved electrochemical performance compared with pure MXenes. [18,19] MXene with a gel-based electrolyte produced films, which showed impressive capacitive performance. [18] Using electrochemically active polymer, polypyrrole, capacitive performance of the as-fabricated MXene/polymer composites can be pushed further, with a stable volumetric capacitance of approximately 1000 F/cm3 up to 25,000 cycles. [25]

This work provided insight into MXene materials being used as structural energy storage devices such as actuators, sensors and electromagnetic shielding. When MXene is combined with other carbon nanomaterials, such as carbon nanotubes and graphene, performance is also increased due to the opened MXene layered structure, allowing for easy accessibility of ions, thus faster rate performance and high volumetric capacitance. [19]

Hybrid Devices and Alternative-ion Batteries

Current technology offers batteries with high energy densities and capacitors with reliable power densities and a much longer lifetime. Hybrid devices, which encompass a mixture of charging mechanisms, aim to advantageously incorporate the two technologies, increasing the energy and power densities. The research team at the University of Tokyo demonstrated that Ti2CTx MXene can serve as negative electrode for high-power sodium-ion hybrid capacitors, which delivered high capacities at quite high current density (90 and 40 mAh/g at 1.0 and 5.0 A/g). [26] The sodium-ion capacitors also exhibited high power performance, proving the potential of hybrid devices to make the most of both worlds: energy and power. Another MXene, V2CTx, can serve as a positive electrode in sodium-ion capacitors, versus hard carbon negative electrodes. The as-fabricated full cell exhibited high capacity, excellent cycling stability, and achieved an improvement in the voltage window up to 2.5 V. [27] The increase in the voltage window directly relates to improved energy density. Scientists in the University of Waterloo, Canada, used MXenes as sulfur hosts for lithium-sulfur batteries owing to their high underlying metallic conductivity and self-functionalized surfaces. The 70 wt.% S/Ti2CTx cathodes showed excellent cycling performance with specific capacity close to 1200 mAh/g at a five-hour charge/discharge (C/5) and a capacity retention of 80 percent was achieved after 400 cycles at lower currents. [28]

Investigations on using MXenes for other battery applications, such as magnesium-, aluminum- and sodium-ion, are also being carried out to understand how MXenes behave in alternative ion systems.

Future Outlook

The DoD seeks reliable, sustainable, and efficient materials to enable next-generation applications and improve the existing technologies. It is clear these materials possess properties beneficial to energy storage applications; however, MXenes are foreseen to be useful in many functional applications (see Figure 4). Very recently, MXenes were used to fabricate an all solid-state micro-supercapacitor [29], showing the promise of the material toward powering on-chip electronic devices. Mo2CTx MXene [4] as well as Mo2TiC2Tx MXene [30] showed semiconductor-like behavior, while Ti3C2Tx exhibited metallic behavior, suggesting the bandgap of these materials depends on the transition metal present. It was also shown by density-functional theory that the band gap can be tuned by changing the surface termination of MXenes. [31]

Furthermore, delaminated MXene is stable in a colloidal solution [12] enabling production of inks for additive manufacturing, conductive coatings and paints. By spray coating, [15] spin casting [10] or other deposition methods, transparent thin films with optoelectronic properties could be produced, enabling high-quality displays or photovoltaics. As proven by mixing MXene with other materials, such as polymers or carbon nanoparticles, hybridization may be the key to unlocking functional materials which can provide mechanical strength while also providing energy storage or conversion, such as actuation or electromagnetic shielding. Initial biological studies have been conducted yielding Ti3C2Tx membranes, which exhibit ion-selective behavior [32] as well as bactericidal properties. [33] Smart textiles or armor technology could be enhanced by the incorporation

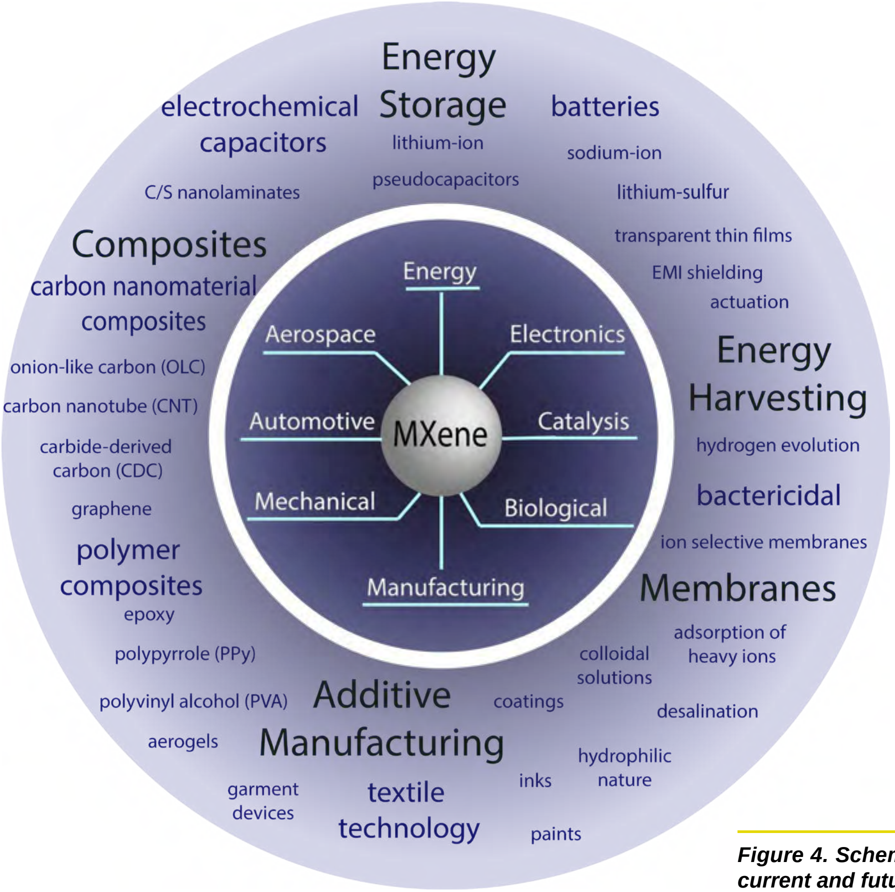


Figure 4. Schematic representing MXene properties and their use in current and future applications. (Released)

of MXene materials through the coating of fibers or manufacturing MXene-loaded fibers. Additionally, vapor phase synthesis of MXenes would open new avenues for electronic applications of MXenes. [34]

In addition to ‘A’ elements, the ‘M’ elements can also be selectively removed from the MAX phases (see Table 1), leading to the formation of ‘AX’ nanolaminates (see Figure 1). For example, applying a positive potential (electrochemical etching) on the Ti2SC MAX phase in aqueous electrolyte leads to the selective removal of Ti, leaving C/S nanolaminates. [8] The uniform distribution of sulfur in carbon frameworks, strong bonding between carbon and sulfur, and the layered structure of C/S nanolaminates afford their great potentials as cathode materials for lithium-sulfur batteries. Li-S batteries can store about four times more energy compared to Li-ion batteries, but the main challenge with lithium-sulfur technology is the reliability and lifetime of the cathode. [35] When testing the as-produced carbon/sulfur nanolaminates as cathode materials for lithium-sulfur batteries, the C/S nanolaminates achieved a high capacity of approximately 900 mAh/g and much better cycling stability compared to graphene/S nanostructures, a similar layered material. Further investigations showed that the electrochemical selective extraction of Ti can also be achieved from a number of other MAX phases, such as Ti3AlC2, Ti3SnC2 and Ti2GeC, creating a new class of ‘AX’ materials. The various ‘A’ and ‘X’ combinations known render the ‘AX’ structures highly attractive for a number of potential applications, such as electrical energy storage and catalysis.

With many configurations yet to be fully investigated, and MXene lending itself to be a material-by-design, numerous opportunities to improve current and create new technologies are available. Through continued optimization and discovery, the 2D metal carbides, nitrides and carbonitrides may find a place as versatile and multifunctional materials in a widespread array of defense applications. ■

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Portable Wind Power

By: Justin R. Chambers & James E. Smith, Ph.D.

Introduction

Deployed U.S. military combatants carry out some of the most grueling and dangerous forward reconnaissance missions. In recent years, these troops have grown to rely heavily on battery-powered portable devices to fulfill operational needs, including operational energy, which is the essential energy required to move and sustain systems for military operations. Mission requirements have seen a significant upturn in operational energy needs with the use of modern tools such as handheld electronics, smartphones and personal computers. These and other portable electric devices play an increasingly important role in the lives of both the military and civilian populations they protect and support.

Given the growing importance of battery life, the ability to charge the battery is critical in maintaining the device's operational effectiveness and the success of the intended missions. Losing power when using these tools in remote locations is not only an inconvenience, but also an absolute safety issue, one that may compromise the mission and the life of the combatant. Further, the weight of extra energy storage can present many challenges, such as limiting the ability to carry additional important equipment, munitions and survival gear. The delivery of additional supplies for extended missions further adds to the complexity of the operation.

Figure 1. The typical load carried by a Marine is 60-100 pounds (Image courtesy of Northern Warfare Training Center, Fort Wainwright/ Released)

Energy Opportunity

Military personnel are dependent on energy storage (i.e., batteries) to increase their operational effectiveness. This dependence presents many risks if the stored energy depletes or charging locations are not available. Forward-stationed troops carry large

Figure 2. Military wind turbine prototype (Image courtesy of WindPax LLC/Released)

amounts of energy storage for extended missions, which can consist of up to 20 percent of the overall carry weight. [1] A typical Marine carries approximately 100 pounds of gear (see Figure 1). [2] With batteries accounting for roughly 20 pounds of that weight, an alternative solution that can displace this extra weight and fulfill energy requirements is essential. Furthermore, any alternative must provide the ability to generate power on-site, extending power capabilities in the event that a mission is extended.

Together, water and energy storage can account for approximately 60 pounds of a soldier's carry weight. This leads to the need for innovative solutions in water purification and energy generation. Alternative energy harvesting technologies, such as solar, have been proposed and tested to supplement future military operations.

Past approaches to power base camps, tactical operations and missions were to carry the anticipated number of spare batteries and use fuel-powered generators or any of the newly developed renewable technologies such as solar cells. While each of these devices has an intended application, they also have cost, size and weight drawbacks. The objective is to increase electrification by providing energy source flexibility; using locally available energy sources; reducing fossil fuel consumption; and expanding the range of the energy use.

Current Approaches

In recent years, development of alternative technologies began to surface to meet the operational energy needs of the military. Ongoing research and development efforts increase the efficiency of current fossil fuel generators using approaches such as waste heat recovery, novel design architecture and alternative fuels. For example, Liquid Piston, Inc. developed a high efficiency rotary engine for energy generation funded by the Defense Advanced Research Projects Agency. [3] It provides an ultra-compact fossil fuel unit that is a fraction of the weight and size. While fossil fuel generators have proven effective, there has been strong push to move toward renewable energy.

Renewable energy has been a concentrated area of interest for its environmental advantages and ability to provide on-site energy generation, thus reducing the transportation liabilities of transporting fossil fuels. The increasing efficiency of solar cells led to a significant spike in the use of solar as an alternative method of energy harvesting in the field. Solar technology, however, will only meet part of the needs of current and future military operations. Therefore, additional supplemental alternatives are being explored. To provide a point of reference, Table 1 shows various on-site energy harvesting approaches for portable application.

Each technology presented here has a place in the modern energy portfolio and best use scenarios. For example, a kinetic energy generator may be worn while the Marines are on the move, generating power from the motion of walking. This may create enough power to charge small batteries, but at this approach requires full time user input.

A thermal generating unit may be used with a man-made fire. This approach can be utilized practically anywhere and is not directly

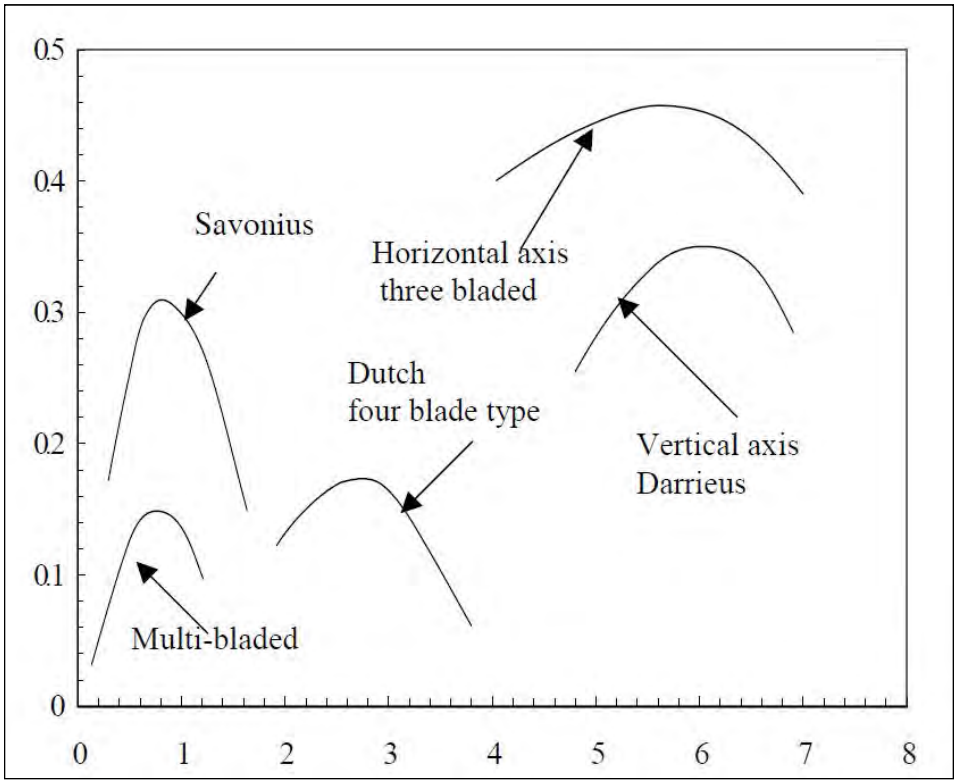

Figure 3. Power coefficients of traditional wind turbine devices. [4] (Released)

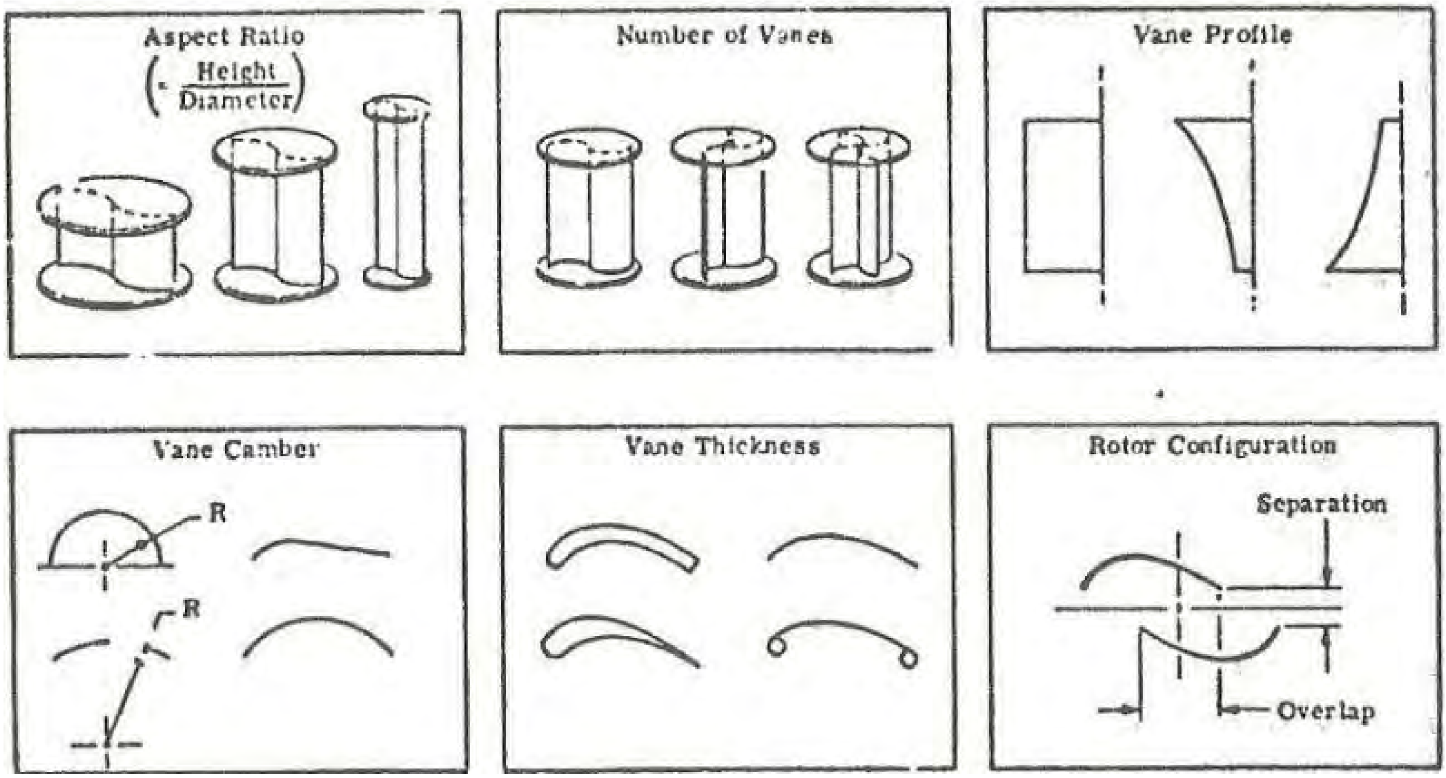

Figure 4. Diagram of Savonius Rotor modifications. (Released)

dependent on weather conditions. For this method, user input is needed to maintain fuel for the fire. This requires partial user input for sourcing fuel (i.e., burnable materials) and maintaining the fire periodically over time.

Solar cells have been the most popular renewable device due to recent developments in performance and cost. Although solar has been shown to work well, it still is limited in field functionality. Solar panels must be positioned in direct sunlight to be effective and require periodic user input to position appropriately. Moreover, solar can only be utilized during the daylight hours in optimal sunlight conditions.

Wind energy can be used in locations with adequate wind such as coastlines, deserts, flatlands, etc. The wind energy can be utilized day or night, given light wind is available, and in many climates and conditions. Once the wind energy device is set up no user intervention is needed to maintain the device.

As these alternative approaches begin to be utilized it must be noted that little development in effective wind turbine technologies has been accomplished. Proposals have been made to implement wind energy into operational energy but little has been seen of a real world solution to effectively supplement the current energy needs, specifically the low energy needs and requirements. Large wind turbines and banks of solar cells are operationally ineffective and vulnerable to attack. Smaller turbines and the same for solar cells that can be tied together have a place in a modern military arsenal.

Arista Power proposed a portable military wind turbine that was rated at 300 watts with a weight of about 15 pounds. [4] Information on this company has since been deleted, leading to the belief that the proposal was never seen to fruition. This may be due to Arista proposing a more common type of wind turbine, but one that has limitations for such applications. The proposed three-blade traditional wind turbine relies on lift to

	Kinetic	Thermal	Solar	Wind
Power:	2.5W	25W	100W	100W
Input:	Motion	Fire	Sun	Wind
Size:	10"Lx2"D	8"L x 5'D	20"x16"x 2"	24"L x 5"D
Weight:	1lb	3lbs	10lbs	10lbs
Cost:	$199.99	$130.00	$750.00	TBD

Table 1. Various on-site energy harvesting approaches for portable application.

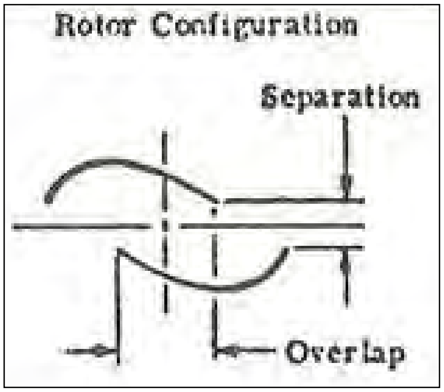

Figure 5. Diagram of Savonius rotor separation and overlap. (Released)

generate power. These devices need to be precisely controlled and primed to operate in the field requiring complex control systems to be effective.

A similar approach has been used by a team of researchers to implement a three-blade wind turbine design into a micro grid, using solar and wind to charge battery storage systems. [5] This project started back in 2009 as Reusing Existing Natural Energy from Wind and Solar, or RENEWS, and the micro grid system weighs roughly 100 pounds. The wind turbine itself is a 300 watt unit weighing approximately 17 pounds. Given that this wind turbine is similar to that of Arista Power, field testing is needed to demonstrate its efficacy.

A New Approach

One technology that can mitigate the energy storage burden is portable wind turbines. A wind turbine system has been developed that is portable, collapsible and provides a rugged, lightweight, power generating device. These devices (see Figure 2) can be easily shipped, transported and carried within an automobile or ruck-sack.

The total wind turbine weight is about 10 pounds, which allows for the displacement of a portion of the required battery storage while reducing the total carry weight. In the event a mission is extended, the battery systems can be recharged rather than relying on the shipment of fully charged batteries. The wind turbines are scalable and can come in a variety of sizes from individual to squad-sized units that can provide the ability to charge battery storage systems. The wind turbines can also provide power for running electronic devices such as laptops, smart phones, LED lighting and other common electronic devices.

These wind turbines can be utilized 24/7 in many areas with light wind as low as three meters per second. Typically areas along the coast, flat lands and desert locations have abundant wind potential provide ideal conditions for the use of wind turbines.

Design

Researchers chose a Savonius Rotor design due its self-starting and self-sustaining capabilities. This is a simple design that also allows it to start and run at low wind speeds, so no monitoring or priming of the device is necessary. In addition to the novelty of it being collapsible, the wind turbine employs advanced features to increase its wind energy capture efficiency.

A modified Savonius Rotor was designed to achieve an improved power coefficient and field performance. Figure 3 shows power coefficients of various common wind turbine designs. It may be noted that the horizontal axis three bladed wind turbine has the highest power coefficient, which is why it is more commonly used and has been attempted to be used in portable applications. Although it presents better performance, it presents limitations for portable use.

Historical test data shows that drag style turbines such as the Savonius Rotor operate with a tip speed ratio below or equal to 1, which will provide a self-starting wind turbine. [6] The tip speed ratio can be defined as:

$$\lambda=\omega R/V, \quad (1)$$

where ω is the rotational velocity of the turbine, R is the radius of the rotor and V is the wind velocity.

The maximum power that the rotor can extract from the wind energy can be defined as:

$$P_{max}=\frac{1}{2}\rho C_p S V^{3}, \quad (2)$$

where ρ represents the density of air, Cp represents the power coefficient, S represents the swept area and V represents the velocity of the wind.

By adjusting the aspect ratio, number of vanes, vane profile, shape factor, vane separation and vane overlap; an improved Cp was achieved. These modifications to a Savonius Rotor are illustrated in Figure 4.

Published test data suggests an aspect ratio of 1.5- 2 for peak turbine performance. [7] The aspect ratio is defined as:

$$AR=Height/Diameter \quad (3)$$

A preferred aspect ratio of 2 was chosen to best meet the collapsibility parameters of the design. Since simplicity is crucial for this design the preferred number of vanes was determined to be three. This also helps to make a smoother running turbine reducing the pulsing rotation of two blade arrangements.

The separation and the overlap are defined in Figure 5 using a two blade Savonius Rotor example.

It has been shown that the best results for power and torque are obtained through an overlap or e/d (e = separation and d = radius) ratio of .24 with no overlap when used in a three-vane arrangement. [7] Figure 6 shows that the e/d ratio is the ratio of the overlap to the diameter of one vane.

Table 2 summarizes the design parameters of the final configuration, which is demonstrated in Figure 6.

Three preferred power standards were set, a typical USB connection 5V @ 1A, standard 12 V port @ 4A and the Ultralife BB-2590 lithium ion battery charging requirements which are 16.4 V @ 3A (49.2 watts) for a 6-hour charging cycle. To achieve these power levels, an analytical

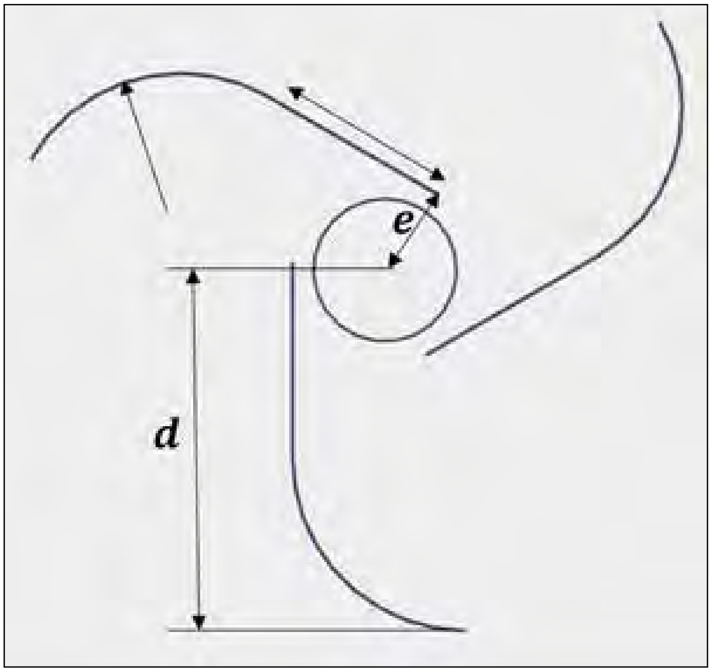

Figure 6. Final design geometry. (Image courtesy of WindPax LLC/ Released)

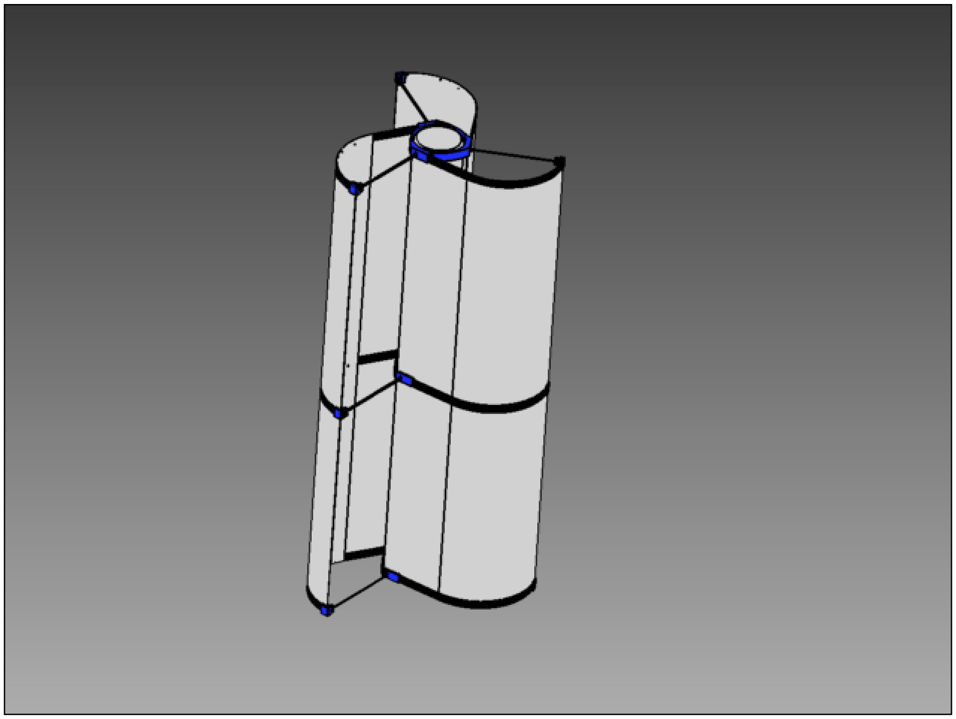

Figure 7. CAD-generated model. (Image courtesy of WindPax LLC/Released)

Aspect Ratio	Number of Veins	e/d	SF
2	3	.24	1

Table 2. Design parameters.

approach was used to size the wind turbines based on the previous design parameters to maximize performance for the intended application and power requirement.

Given the previous power equation for a Savonius Rotor; the S denotes the swept area of the turbine. This area is the total area seen by the incoming wind. The swept area can be defined as:

$$S=hD=h(2R-e), \quad (4)$$

where h is the height of the blade and D is the diameter of the total turbine. The second part considers overlap of the blades where h remains the height of the blade, R denotes the radius of the turbine and e represents the overlap of the blades.

The power production required by the wind turbine was established to be 100 watts at rated wind speeds of 12 meters per second. This power requirement resulted in a wind turbine with a rotor size of 24 inch diameter by 48 inch height when erected. This rotor, as seen in Figure 3, is supported by a 72 inch mounting support that is tethered to the ground. This turbine size will provide adequate power at average wind speeds (6 to 9 meters per second) for charging a variety of devices, some simultaneously.

The turbine was designed using CAD software to allow the prototypes to be constructed using 3D printed parts and commercially available materials and components.

The prototype was constructed using a polycarbonate center shaft, flexible polycarbonate/fabric vanes and 3D printed plastic components. The generator is mounted within the center shaft and connects the rotating turbine with the ground support. The collapsibility of the turbine is achieved by dismantling the vanes from the center shaft hubs, telescoping the center shaft to half its total length and wrapping the flexible vanes around the center for packaging. The developed wind turbine is shown in Figure 8 during initial wind tunnel testing.

Benefits of a Portable Wind Energy Device

The wind turbine system is designed to meet universal power standards, have a modular design architecture and be scalable for energy needs. This unique design provides the ability to combine multiple units, both wind turbines and other power generation devices, to meet the desired power requirements. Wind energy can be complementary to solar and other energy harvesting devices by providing the ability to capture renewable energy on-site in diverse climates such as rain, snow or overcast conditions.

Portable wind turbines are proposed to displace a portion of the stored batteries, and

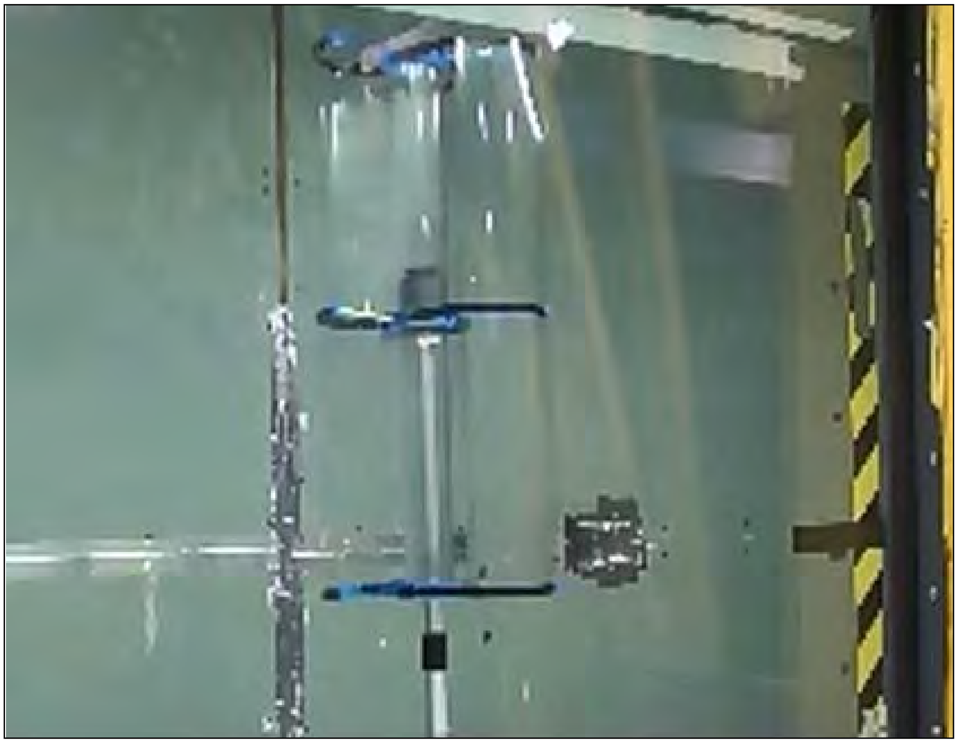

Figure 8. Wind tunnel testing of initial prototype. (Image courtesy of WindPax LLC/Released)

carried with the soldiers (see Figure 9). For example, military operators can store energy for two days and have the ability recharge day or night as needed. This approach helps to reduce the need for logistical supply of fossil energy, environmental liabilities and allows the individual to harvest and regenerate the energy in the field. The important aspect of this approach is the increased survivability and sustainability of the combatant during extended missions with the possibility of providing lifesaving capabilities if stranded.

Conclusion

A portable wind turbine has a significant opportunity to supplement energy storage and provide a renewable energy generation method to recharge battery storage systems. This will bring the tactical units closer to the goal of energy independence, sustainability and survivability in the field. Wind energy diversifies the operational energy portfolio with a renewable on-site method to support and complement other sources of energy. Prototypes for field testing have been built to demonstrate the potential of this technology. Military specification versions are proposed to be developed in collaboration with organizations supporting these initiatives. It is expected that the portable wind energy technology will have a significant impact on future energy independence for both military and civilian populations. ■

Figure 9. WindPax military prototype collapsed for transportation. (Image courtesy of WindPax LLC/ Released)

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Smart Gun Technology

By: Jonathan Hayes

Introduction

From Judge Dredd to James Bond, until recently much of the world believed smart guns or personalized guns were a thing of science fiction. The earliest smart gun research and development, however, occurred almost two decades ago; and one technology researched and developed for use in smart guns has been a part of general industry since the late 1970s.

A smart gun, or personalized gun, is a weapon containing more than standard mechanical parts as operating components used to fire, disable or report information on the weapon. Many smart guns are actually personalized firearms, which only permit authorized users to operate the weapon. Smart guns, or personalized firearms, automatically deactivate under certain circumstances, thus reducing the chance of accidental discharge or purposeful use by unintended persons. [1]

In order to create a useful smart gun, the electronics embedded within the biometrically enabled smart gun must collect a biometric sample and match it to a registered user within a fraction of a second. The electronics used to create a biometric smart gun are significantly more complex than token-based technologies. Personal biometrics could make it nearly impossible to steal and operate a gun equipped with these technologies.

The world of smart guns is growing rapidly. Most smart guns are based in a handful of technology types, which are being implemented in handguns, rifles and semi-automatic styles of guns. The level of progress of the technologies varies widely from basic research to operational, commercially ready products. Solutions vary from an “add-on” to

Image 1. iGun's M-2000. (Image courtesy of Jonathan Mossburg/Released)

existing weapons to those that are factory integrated and cannot operate without their "smart" component.

Benefits/Negatives

Most of the smart technologies being developed for guns could reduce or eliminate accidental or intentional use of lost, misplaced or stolen guns. These weapons would not operate without their properly paired technology or persons. Components, such as radio frequency chips or biometrics fingerprints, would be required to operate the weapon. Smart guns that utilize GPS, cellular or other location-based technologies would stop the weapon from firing and would notify the owner or authorities with information on where and when the weapon was used. Suicide by weapon would also likely decrease, assuming the suicidal person is not an authorized user. Accidental shootings by children or others not intending to fire a live weapon could decrease, assuming they are not enrolled users.

> "A basic weapon is always dangerous, and smart gun technology could **create a level of protection**."

Law enforcement worldwide could benefit from the above-mentioned general use items; however, they face additional issues, including the potential takeaway of a weapon. Weapon takeaways can happen in a number of ways, including a struggle with a perpetrator. If the officer has a smart gun this may prevent the perpetrator from taking action against the officer or innocent bystanders.

The U.S. military could take advantage of smart gun technologies. A basic weapon is always dangerous, and smart gun technology could create a level of protection. Stolen weapons have been an issue throughout military history because they can be used against our own military. Smart gun technologies could render the stolen weapons useless to the enemy. Additionally, smart gun technologies could simplify the command and control currently required when transporting military weapons by simply deactivating smart guns when not in use or being stored. As mentioned above, smart guns with GPS or other available reporting features would allow for the tracking of a lost, stolen, or misplaced weapon and could report on when and where a weapon is fired.

The government understands the costs to create a smart gun is no small feat, as evidenced by the Report to the President Outlining a Strategy to Expedite Deployment of Gun Safety Technology which states, "Firearms manufacturers will need to decide whether to make similar investments here. To achieve the innovations that the President seeks, one or more companies must decide that the benefits of enhanced gun safety technology exceed the costs of researching, developing, and marketing such technology." [2]

This statement does not note the amount of time required to determine any number of factors that must be considered when developing a smart gun. [2]

Development Factors

The Department of Homeland Security Science and Technology Directorate already met with law enforcement agencies and developed the following potential issues and considerations to be included as specifications for smart guns as they are developed: [2]

Reliability (PRIORITY REQUIREMENT)

The largest factor in developing a smart gun is reliability. A firearm must operate the moment it is needed, and with a smart gun, not at any other time or with anyone not authorized. This is a strong situation to create. Home protection weapons may go years without being touched, but are expected to (and usually do) operate properly the moment when needed. All smart guns currently used rely on new technology.

This is an issue because no new technology is perfect: dropped calls, dead batteries, computer malfunction or failure, etc. In most cases, none of these things result in harm or even death, but when a weapon is being used for protection, by the local law enforcement, or a soldier it must. When something is made of multiple components, it is only as reliable as the least reliable piece used in its construction. This must be considered for all forms of smart gun development. The more types of technology developed into a smart gun, the more potential for situational failure.

Durability

Durability and reliability are strongly coupled. Guns, which have been around for centuries, are one of few products that have essentially the same operating function as a century or two ago. While guns can be used indoors, they are more likely used outdoors, exposed to elements, for hunting and in war. Not many technology components are developed for use in these rugged environments, and when developed, they are normally costly.

Permitting multiple users

Depending on whether a weapon is for use by a family, a law enforcement agency or even soldiers, one consideration is the number of authorized users, which will vary depending on the needs of the users. It will also have an affect on the type of technology developed, the computing technology required, the battery and battery life in operation.

Physical characteristics of firearm

Smart gun technology concepts come in many forms; some are “add-ons” while other concepts create a new gun that is only “smart” and never to be used without an authorized user. Add-on technologies operate on or inside existing guns, such as trigger guards or replacing interior firing mechanisms with user-authorized technology.

Ease and predictability of use

Ease and predictability of use involves how natural the operation of the smart gun is to a normal user. Most handguns are simple to operate, though a smart gun must consider more as it is offering more to a user beyond firing a gun. One must control the authorized users, operational component configuration, charging and potentially much more. This could easily contain the most widely varying options in development.

Training

Training links to nearly every aspect mentioned in the list above. Users would have to be trained on the limitations, reliably and durability first. How and who can operate the weapon? What it is that is smart on the smart gun? Lastly, how to use the weapon would all be a part of training.

Maintenance and repair

Current guns have an often-overlooked maintenance schedule that rarely affects the operation of the weapon. This would likely drastically change with smart weapons. Maintaining a charge to battery operated components, preventing circuit corrosion or any number of other items will be dependent on the design of the smart gun.

Adversarial compromise of technology

The potential compromise of technology can be achieved in many ways, some less obvious than others. It could include the leaking of how the technology is built, thus allowing for potential hacking of the circuits used. This could include the removal of the technology and insertion if required of other technology.

External devices

Some smart technologies include the need for paring devices for operation. Other items include the need for a battery charging, or a computer or smart phone application in order to add or remove authorized users.

Power failure

Power failure, or component failure, must be avoided at all costs. Low power consuming components, long lasting batteries, moving functions that can be executed off the device should be considered.

Speed of operation

Any smart gun technology should be seamless and as fast as a weapon without the added technology. This concept will reduce the amount and type of technologies that can be designed into a weapon. [2]

Technologies at Play

The National Institute of Justice Report: A Review of Gun Safety Technologies has a comprehensive list of all major efforts in the smart gun arena up until its publishing in 2013. [1] None of the smart guns and technology researched were developed or led by the federal government, all were by private industry manufacturers. The report identified many projects and technologies, including those currently deemed commercialized and ready to be used, which are summarized below:

Biometrics technologies use unique physiological features to identify a person. In the case of smart gun technologies, a biometric could be used to authorize a user. Biometrics include fingerprints, faces, voices, veins and many other features; however, not all of these biometrics can easily be used to authorize use of a smart weapon.

Fingerprint technologies would require a

Image 2. View of the internal components of the iGun, including the battery and circuit board, enlarged view (Image courtesy of Jonathan Mossberg/Released)

“When a weapon is needed to

user to place a finger on a sensor. The sensor or fingerprint reader would need to be placed strategically on the weapon in order for a user to not have to consciously think, but inherently place their finger on the sensor when handling the weapon for use. In other words, the sensor is needed somewhere on the grip where the finger would normally rest. A fingerprint would have to be scanned and match to a registered user in a fraction of a second. If matched, the weapon is enabled; otherwise it remains in a locked non-operable default state.

Kodiak Industries Intelligun. In 2012, Kodiak Industries developed the Intelligun as a biometrically enabled smart gun. The system implements a fingerprint locking system installed in the handle of a standard 1911 .45 caliber handgun. Through a patented design, Intelligun unlocks the 1911 within a fraction of a second for registered, authorized users. The Intelligun system was designed as an add-on system targeted at sending the firearm to Kodiak or to a Kodiak licensed firearm dealer for installation. [1]

Safe Gun Technologies. In 2013, Safe Gun Technologies developed a prototype fingerprint-based smart gun. The goal was to create a retrofit kit for factory or authorized dealer installation (an add-on). The prototype was developed on a Remington 870 shotgun, which is used by general consumers and law enforcement alike. [1]

Palm print technologies could also authorize a user by implementing a spectroscopic or optical technology based in the slight variances in skin, or perhaps an image based technology that would look at the patterns in the veins of a hand. This technology typically operates in the visible or near infrared spectrum and would compare a registered user’s optical data to that of the person holding the weapon. There are no currently known efforts in palm prints.

Dynamic handgrip recognition is authentication based on the human grasping behavior. DGR is a combination of physical and behavioral characteristics collected and measured over a period of time. This method is different because it is not based on an inherent physical trait like physical biometrics, such as fingerprints. DGR’s hypothesis is that grasping behaviors are unique and could be measured and identified over time. Attributes under consideration are hand size, the hand’s geometric structure and the pressure or strength placed on a grip of a weapon over time. [1]

New Jersey Institute of Technology’s Childsafe Weapons Project. NJIT Professor Donald Sebastian has led the research behind DGR. NJIT research notes that the way in which a person squeezes the firearm while pulling the trigger is a unique and measurable pattern of events. NJIT created a prototype handgun with 32 sensors to measure DGR pressure. DGR testing has been limited to study by NJIT using a small sample size. However, DGR has only been researched on the NJIT prototype, which achieved a high recognition rate based in a small sample size. [1] Independent research on DGR, both on the validity of the recognition method and with a more representadefend life, **it has to work.”**

tive subject sample size, is needed before confirming DGR as a suitable authentication method.[3]

Static handgrip recognition is a potential biometric authentication method based on the human grasping behavior much like dynamic handgrip biometrics. However, instead of using the dynamics of grasping, it exploits the static pressure pattern exerted on the grip of the gun to determine if a person is who they presume to be. This method is based upon a person performing a single action once and its repeatability for a unique, measurable biometric at a single point in time.

Token-based technologies require an item, such as a card, watch or ring, to operate the system. These tokens are all carried or worn on the body; however, other types of tokens such as a microchip could be (theoretically) implanted into an authorized operator. The former would require that a user remember to wear or have the token with them, but in the case of an implant, a user would only need to have the weapon. Watches, rings or cards are all susceptible to theft, and a stolen token would turn an unauthorized user into an authorized user by simply having both the token and the associated weapon. Layering additional security features into a weapon, such as a personal identification code or a biometric fingerprint, could potentially mitigate unintended use.

Radio frequency identification token-based technologies are wireless, non-contact radio frequency based electromagnetic fields that transfer information in support of automatically identifying and/or tracking a token or tags attached to an item. RFID technologies were developed in the late 1970s to track livestock, [4] and now exist in multitudes of general consumer products, such as anti-theft devices in department stores.

Many of these tags do not require a battery to operate and are powered in short ranges by magnetic fields via electromagnetic induction. RFID technologies use readers and tags (tokens) which can either be passive (non-powered) or active (powered) depending on implementation. When used in a weapon, token-based RFID technologies create a communication link between the weapon and the token. Normally, a coded signal is transmitted from the weapon (powered) to the token (generally passive). The code potentials lie within the billions of unique IDs. Once a response is made, the weapon is authorized to be fired. [1]

As previously noted, this technology is not line-of-sight based, enabling the user to wear gloves or the token to be embedded in a sub-dermal implant. The negative of RF technologies is that they are subject to interference dependent on many factors, such as operating frequency and range. However, short range uses, such as for smart weapons, would be less susceptible to interference. A user would want a token-to-weapon system to operate from a few inches away, at most, and within a fraction of a second; something that RFID technologies can easily do.

Armatix Smart System. Armatix developed the iP1 pistol from the ground up as a smart gun. It is not available as a standard mechanical operating gun. The system includes the iP1 and a wrist worn transponder, the iW1. Communication between the two authorizes the weapon to fire. Active RFID is used to establish communication and authorization between the components via near-field communication protocols. Authorization completes if the correct personal identification number is entered into the transponder. The smart system is a commercially available system.[1]

Colt Smart Gun. Colt began developing a prototype 40 caliber pistol in 1997. The system was designed like the Armatix Smart System without the PIN. Development ended in 2000 after contracts with the National Institute of Justice were completed. Gun development stopped due to pressures from the general user community as well as the National Rifle Association. [1]

iGun™ M-2000. The iGun™ M-2000 shotgun is likely the first commercialized smart gun. iGun was developed in 1998 and leveraged a patented ultra-low frequency RFID technology. An operator is required to wear a passive RFID ring, which holds an inert, non-powered chip that, when energized, sends a specific code to the weapon. The signal is sent when a user handles the weapon in a regular gripping method, which depresses a lever in the stock. A signal is generated and if a matching signal is received and matched, a second verification is requested. Only after matching a second time does the firearm enable firing. iGun's intention is to have operation be transparent to any user. The iGun system is a factory integrated weapon and was not intended to be available as an add-on or a modification. [1]

Triggersmart. Ireland-based Triggersmart uses high frequency RFID for authorization between weapon and token. Triggersmart began smart gun research and development in 2010 on a handgun. Triggersmart built three demonstration models on a shotgun, handgun and rifle. Due to legal ownership status changes in Ireland, the system now targets an MP5. Triggersmart is considered a factory add-on as it simply replaces the factory installed lower receiver with the one developed. [1]

Ultrasonic token-based technologies require the operator to wear the token. The token would emit an ultrasonic coded signal that, when received by the weapon, allows the weapon to fire. Ultrasonic frequencies operate in a range that is too high for humans to hear and could be used to determine weapon proximity. When the weapon is too far away or within a specified range, the weapon automatically activates or deactivates.

FN Manufacturing's Secure Weapon System. FN Manufacturing began development of the Secure Weapon System in 2001. The system was based in ultrasonic with a handgrip switch used to activate the system. FN believed in the proximity capabilities of ultrasonic, but the system never made it past a pistol prototype stage. FN later looked to RFID before abandoning its smart gun research.

Future/Now

Gun Guardian does not insert technology in the mechanical components of the gun, and instead secures a firearm by restricting access to the trigger with a manually closed, spring-loaded shield. The shield will only uncover the trigger when one of two items occurs: the correct biometric signature is read via the fingerprint reader or the correct security code is entered into a cipher lock. [5]

Once the biometric signature is verified or correct security code is entered, the shield automatically and instantaneously retracts allowing access to the trigger of the firearm. Gun Guardian is an add-on solution that attaches to the weapon even when unlocked.

Additionally, Gun Guardian has an optional GPS tracker, which allows the firearm to be located in the event of misplacement or theft. The tracker has two activation options: 1) it will only transmit a signal while in the locked position, which ensures soldiers cannot be tracked while on patrol; 2) it gives off a continuous signal which allows the firearm to be located at any time.

Gun Guardian developed and fielded an initial pre-production prototype for operational testing. A greater level of reliability occurs with this style of solution as the core mechanics of the gun are preserved, but a dual level of access is achieved in the case of a failure or need to use one over the other (i.e. very high reliability).

Image 3. RFID chipped ring and iGun internal disabling solenoid pictured. (Image courtesy of Jonathan Mossberg/Released)

The government created a short-term timeline to partner with a greater number of state, county and municipal law enforcement agencies to create specific operating parameters for which they would require to purchase a smart gun. [2]

Without a doubt smart technologies can and will be implemented into weapons, but what form will they take? How long will development take? Can they be reliable in high stress situations? When a weapon is needed to defend life, it has to work. ■

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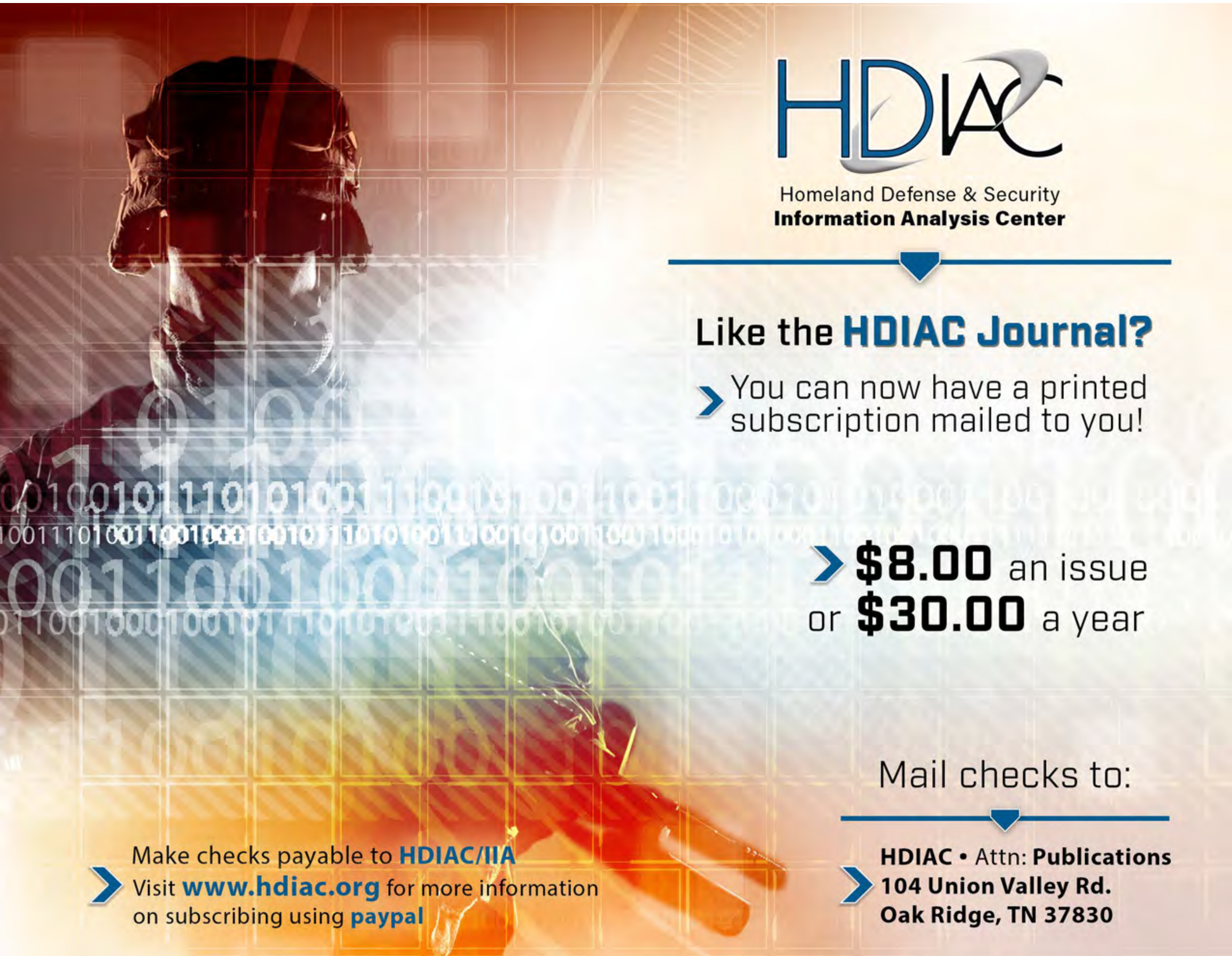

AIRCRAFT DECONTAMINATION:

The Unique Challenges of Decontaminating Sensitive Equipment

By: Brian France, Ph.D.

Aircraft are extremely expensive and sensitive assets, critical for both defense and transportation. Chemical products used on an aircraft must meet strict materials compatibility requirements to ensure they do not degrade, shorten the life expectancy or cause failure of any aircraft component.

Aircraft contaminated with toxic chemicals cannot be decontaminated using traditional decon solutions, which include oxidants such as bleach or hydrogen peroxide. Using these reactive materials would corrode parts; causing the need to identify and replace damaged components to prevent catastrophic failure. Decontaminants that remove the toxic chemicals without harming the aircraft are essential.

In the fall of 2009, the Department of Defense Joint Science and Technology Office and Joint Program Executive Office for Chemical and Biological Defense began developing a surfactant technology for surface chemical and biological agent removal. The goal of this effort was to develop a detergent formulation specifically tailored to remove chemical and biological agents from contaminated surfaces, and had excellent compatibility with all components of an aircraft.

To ensure the product would be successful and widely accepted it would be a dual use item, both for decontamination and as an aerospace equipment-cleaning compound qualified under military and commercial standards.

The advanced detergent product borne from this effort was the first dual use aircraft cleaning and decontaminant technology available, creating a new capability unavailable until now. It was specifically designed to emulsify and lift chemical warfare agents from military painted surfaces.

Its key feature is the stable emulsion that is formed when the water-detergent solution is sprayed over the plane; the emulsion keeps the agents in solution so that they do not redeposit even on a large aircraft surface. The product does not contain a reactive chemistry, as this would not be compatible with the aircraft. It lifts agents from the surface and allows them to be washed off; the runoff can then be neutralized using traditional methods.

To ensure the oily, water-insoluble agents can be removed from the surface of aircraft, the surfactant concentration is much higher than traditional cleaners. This provides the added benefit that when the product is used as a cleaner, it can be diluted to a greater extent than traditional cleaners, like high efficiency products used in today's washing machines. Customers using this product for cleaning realize cost savings because it can be diluted further than traditional cleaners; requires less shipping and storage; reduces ordering frequency; and quicker cleaning reduces labor and cleaning pad costs.

In addition to decontaminating aircraft, the U.S. Army Research Office demonstrated and qualified the product in its auto-decontamination system, a portable demon-

Figure 1: C-130 wash (upper left), C-17 landing gear wash (upper right), SSDX-12 manufacturing (lower left), stimulant agents remain emulsified after one hour (lower right). (Released)

stration device for initial vehicle wash and gross contaminant removal and decontamination. This unit is designed to automate the difficult and dangerous task of an operator washing a vehicle while dealing with the potential splash back of toxic materials while wearing protective Mission-Oriented Protective Posture gear, which can be physically demanding and cause excessive heat stress.

The product is qualified to U.S. Air Force standard MIL-PRF-87937D for a type IV heavy duty water dilutable aircraft cleaner. It has impeccable materials compatibility and does not lead to hydrogen embrittlement, or degrade rubber or wiring. The product is pH neutral, biodegradable and has a long shelf life. It has further been shown to contain zero volatile organic compounds and meets many commercial aircraft specifications including AMS 1626C, British Aerospace AIRBUS AIM09-00-002, Boeing D6-17487 and CSD No.1 Type 1.

Hill Air Force Base in Utah qualified the product as the only approved cleaner that can be discharged to the industrial wastewater treatment facility due to compatibility with their heavy metal recovery process. Hill AFB has also used the product as a facilities cleaner, which has shown to help ensure Occupational Safety and Health Administration expanded standard compliance by preventing the migration of toxic heavy metals from aircraft heavy maintenance facilities to worker break rooms and offices. ■

This patented dual-purpose decontaminant and cleaning product (for both aircraft and facilities) is available under the name SSDX-12™. Additional information can be obtained from TDA Research, Inc. (SSDX-12@tda.com) or their distributor AeroSafe, Inc. (www.aerosafe.com). This effort was funded in part by the U.S. Army Research Office, this information does not necessarily reflect the position or the policy of the government, and no official endorsement should be inferred.

Brian France holds a Ph.D. in analytical chemistry and works to bridge fundamental science and customer needs to develop new commercial products. Dr. France is a Senior Scientist at TDA Research and a Principal Investigator currently leading several R&D efforts. Dr. France has been involved in chemical defense and decontamination R&D for the past decade and is an honorably discharged veteran of the U.S. Army. TDA Research, Inc. is a privately owned small business with significant research and development capabilities. TDA develops technology and manufactures advanced materials, chemical processes, and aerospace and military hardware. TDA has a history of maturing technologies from concept to ton size production.

Liquid Metal

Stretchable, Soft & Shape Reconfigurable Electronics

By: Michael Dickey, Ph.D.

Military communication and electronic equipment needs to be sophisticated and adaptable. Researchers at North Carolina State University are working with the liquid alloys of gallium to develop shape-changing antennas, which could benefit military operations by changing shape on demand to change spectral properties, such as tuning to different frequencies. In addition, these metals can be patterned to form stretchable conductors with extremely deformable mechanical properties. Electronics that are soft and stretchable are being actively researched as a way to put electronics in new places, including clothing and on the body. In addition to forming stretchable conductors, it is also possible to 3D print the metal at room temperature, which for the first time enables co-printing of metals with plastics, elastomers and other temperature sensitive materials.

The phrase ‘liquid metal’ often evokes negative connotations. Mercury, for example, is a liquid metal well known for its toxicity. Mercury served as the inspiration for the T-1000 villain in the classic sci-fi movie, Terminator 2. There are, however, liquid metals with low-toxicity, which have interesting applications based on the element gallium. [1]

The Food and Drug Administration approved gallium for a number of applications, which is consistent with its low toxicity. Recently, droplets of liquid gallium were shown to be an effective medium to deliver cancer drugs. [2] The metal also has a very low vapor pressure, which means it will not evaporate and become airborne. Gallium is technically a solid at room temperature, with a melting point of 30 degrees Celsius. That melting point is low enough that it will readily melt when held in a human hand. Adding other metals, such as indium and tin, lower the melting point below room temperature, which ensures that it stays as a liquid. The resulting liquid has a low viscosity, similar to water.

For the purposes of this research, the most important property of gallium and gallium alloys is the formation of a very thin surface oxide layer, which allows the metal to be patterned into non-spherical shapes even though it is a liquid. [3] The oxide forms spontaneously in air and creates an ex-

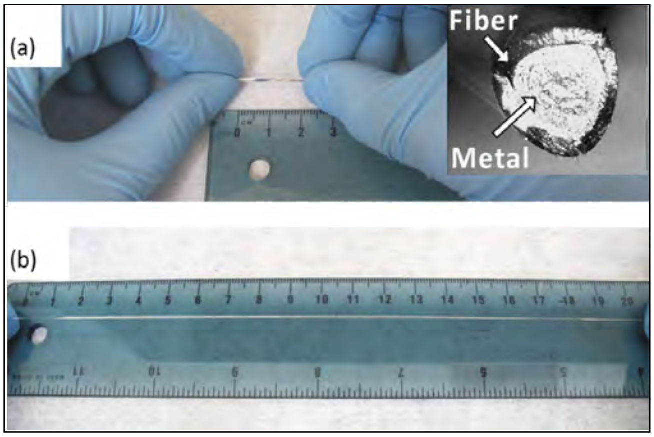

Figure 1. Ultrastretchable wires composed of liquid metal in a hollow elastomeric fiber (adapted with permission from Wiley [4]).

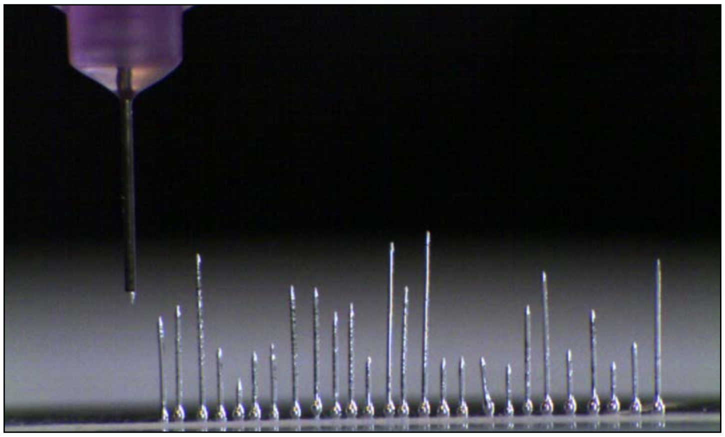

Figure 2. 3D printed liquid metal structures at room temperature. The structures are stabilized by the surface oxide, which forms rapidly at room temperature and ambient conditions. (Image courtesy of Collin Ladd and Dishit Parekh/Released)

tremely thin shell that helps hold the metal into useful shapes, such as wires and antennas.

Liquid metals can be patterned to create soft, stretchable and shape reconfigurable alternatives to conventional applications that utilize solid metals, including electronics, communications and optics. Examples include stretchable wires (see Figure 1), conformal antennas, 3D printed structures and soft electrodes. Liquid metal 'wires' embedded in elastomer overcome the traditional trade-off of composites; that is, usually the addition of solid metals (e.g. powders) to an elastomeric composite makes the elastomer stiffer. In contrast, liquid metal can form conductive composites with elastomers that have metallic conductivity defined by the metal and elastomeric mechanical properties defined primarily by the encasing polymer. Figure 1 shows stretchable core-shell fibers (metal core, elastomeric shell) that maintain electrical conductivity to approximately 800 percent strain. [4] These fibers could be used, for example, to create stretchable antennas or as conductive, soft fibers in electronic textiles.

It is possible to pattern liquid metal into useful shapes such as wires, interconnects and circuits. Unlike solid metals, liquid metal can be injected into capillaries and molded plastic parts. It can also be 3D printed, [5] which allows, for the first time, metals to be co-printed with plastics at room temperature. Although there a number of ways to 3D pattern solid metals, they usually require high temperatures to sinter metal powders using expensive equipment. These high temperatures are not compatible with plastics. As shown in Figure 2, the approach here uses room temperature processing to directly print metal structures, which can be printed in plane or as free standing 3D structures, stabilized by the surface oxide.

Because the metal is a liquid, it is also possible to change the shape of it by inducing it to flow. Although it is possible to pump the metal through capillaries, the use of bulky pumps are inconvenient. In addition, the oxide layer on the liquid metal causes the metal to stick to the walls of capillaries. Thus, the question is, how does one control and reversibly manipulate the shape of liquid metal?

One research group at North Carolina State University recently discovered that electrochemical reactions can be utilized to manipulate the shape of alloys of liquid gallium using only a few volts. [6] The electrochemical reactions deposit a thin oxide on the surface of the metal, which lowers the interfacial tension of the metal. The oxide acts like a surfactant between the metal and the surroundings. Controlling the interfacial tension allows the shape of the metal to be manipulated at small length scales since interfacial forces dominate at small length scales. It is possible to use this phenomenon to induce the metal to fill molds and capillaries using only a few volts. Figure 3 shows some examples of controlling the shape of the metal using modest voltage.

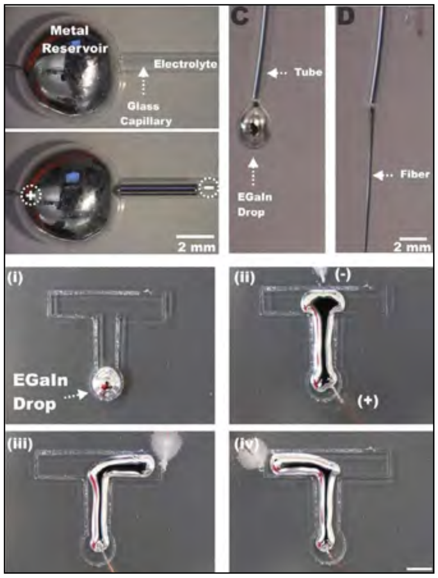

Figure 3. Top: It is possible to control the interfacial tension of the liquid metal using modest voltages, which enables shape reconfigurable metal (with permission from PNAS). Bottom: A photograph of liquid metal manipulated into the shape of a star using voltage. (Photo courtesy of Collin Eaker/Released)

The ability to get the metal to flow can be harnessed to produce shape reconfigurable antennas. [7] Antennas are typically composed of metals and derive their spectral properties from their shape. This new discovery allows for an antenna to change its shape on demand to tune the frequency and other spectral properties of the antenna.

In summary, liquid metal alloys of gallium uniquely combine metallic and fluidic properties. These properties can be harnessed to produce stretchable and soft electronics, as well as shape reconfigurable metals for reconfigurable antennas. ■

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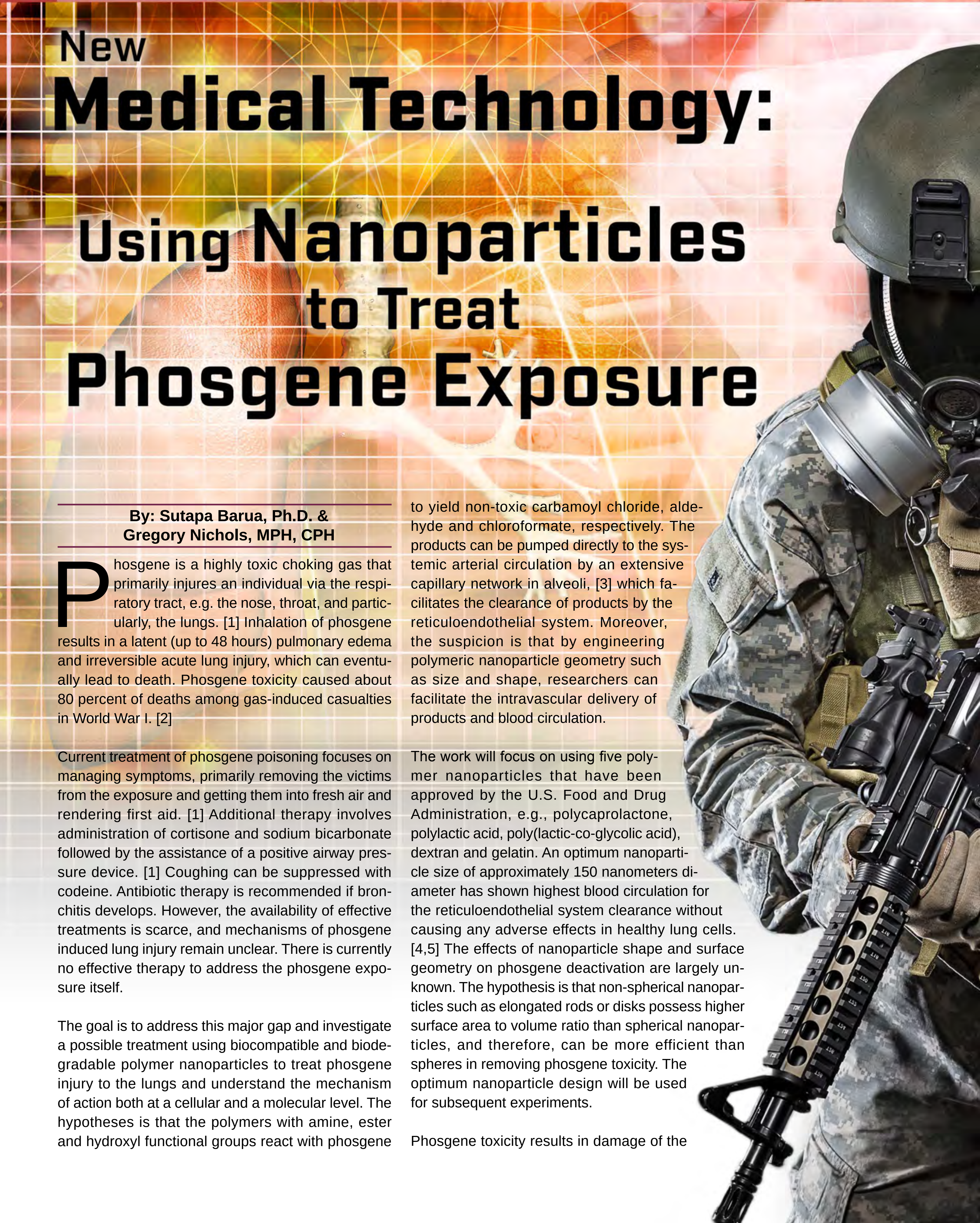

New Medical Technology: Using Nanoparticles to Treat Phosgene Exposure

By: Sutapa Barua, Ph.D. & Gregory Nichols, MPH, CPH

Phosgene is a highly toxic choking gas that primarily injures an individual via the respiratory tract, e.g. the nose, throat, and particularly, the lungs. [1] Inhalation of phosgene results in a latent (up to 48 hours) pulmonary edema and irreversible acute lung injury, which can eventually lead to death. Phosgene toxicity caused about 80 percent of deaths among gas-induced casualties in World War I. [2]

Current treatment of phosgene poisoning focuses on managing symptoms, primarily removing the victims from the exposure and getting them into fresh air and rendering first aid. [1] Additional therapy involves administration of cortisone and sodium bicarbonate followed by the assistance of a positive airway pressure device. [1] Coughing can be suppressed with codeine. Antibiotic therapy is recommended if bronchitis develops. However, the availability of effective treatments is scarce, and mechanisms of phosgene induced lung injury remain unclear. There is currently no effective therapy to address the phosgene exposure itself.

The goal is to address this major gap and investigate a possible treatment using biocompatible and biodegradable polymer nanoparticles to treat phosgene injury to the lungs and understand the mechanism of action both at a cellular and a molecular level. The hypotheses is that the polymers with amine, ester and hydroxyl functional groups react with phosgene to yield non-toxic carbamoyl chloride, aldehyde and chloroformate, respectively. The products can be pumped directly to the systemic arterial circulation by an extensive capillary network in alveoli, [3] which facilitates the clearance of products by the reticuloendothelial system. Moreover, the suspicion is that by engineering polymeric nanoparticle geometry such as size and shape, researchers can facilitate the intravascular delivery of products and blood circulation.

The work will focus on using five polymer nanoparticles that have been approved by the U.S. Food and Drug Administration, e.g., polycaprolactone, polylactic acid, poly(lactic-co-glycolic acid), dextran and gelatin. An optimum nanoparticle size of approximately 150 nanometers diameter has shown highest blood circulation for the reticuloendothelial system clearance without causing any adverse effects in healthy lung cells. [4,5] The effects of nanoparticle shape and surface geometry on phosgene deactivation are largely unknown. The hypothesis is that non-spherical nanoparticles such as elongated rods or disks possess higher surface area to volume ratio than spherical nanoparticles, and therefore, can be more efficient than spheres in removing phosgene toxicity. The optimum nanoparticle design will be used for subsequent experiments.

Phosgene toxicity results in damage of the

terminal alveoli and bronchiole in lungs. [6] Dose dependent nanoparticle and phosgene toxicities will be investigated in epithelial cells in vitro, and through animal studies. A range of nanoparticle doses (0-1000 ng/ml) and phosgene concentrations (0-10 ppm) will be exposed to cells. Toxicities will be measured by fluorescence intensity of live and dead cells using a live/dead assay. It is expected that an optimally designed nanoparticle will remove phosgene from the lungs efficiently, and thereby enhance the mice survival rate.

Phosgene toxicity may induce cell-mediated immunity and humoral immunity derived from bronchial-associated lymphoid tissue and interstitial lymphocyte compartment within the lungs. Little is known about the role of cell signaling pathways in phosgene-induced lung injury. Inflammatory responses may induce the expressions of mitogen activated protein kinase and nuclear factor kappa B as it has been seen for a number of microbial stimuli. [7] Similarly, we hypothesize that MAPK and NF-κB expressions will be induced in response to inflammatory reactions by phosgene, but the protein expressions will be reduced down after the elimination of phosgene by optimally designed biocompatible polymer nanoparticles.

The inflammatory responses by phosgene will be tested using Western blot analysis. Phospho-specific p38 MAPK antibody and NF-κB p65 antibody expressions will be employed to confirm the change of proteins after exposure to phosgene in absence and presence of biodegradable polymer nanoparticles. β-actin will be used as a control. It is anticipated that the protein levels will be enhanced after phosgene exposure, but it will be suppressed to the basal level after eliminating phosgene by polymer nanoparticles. ■

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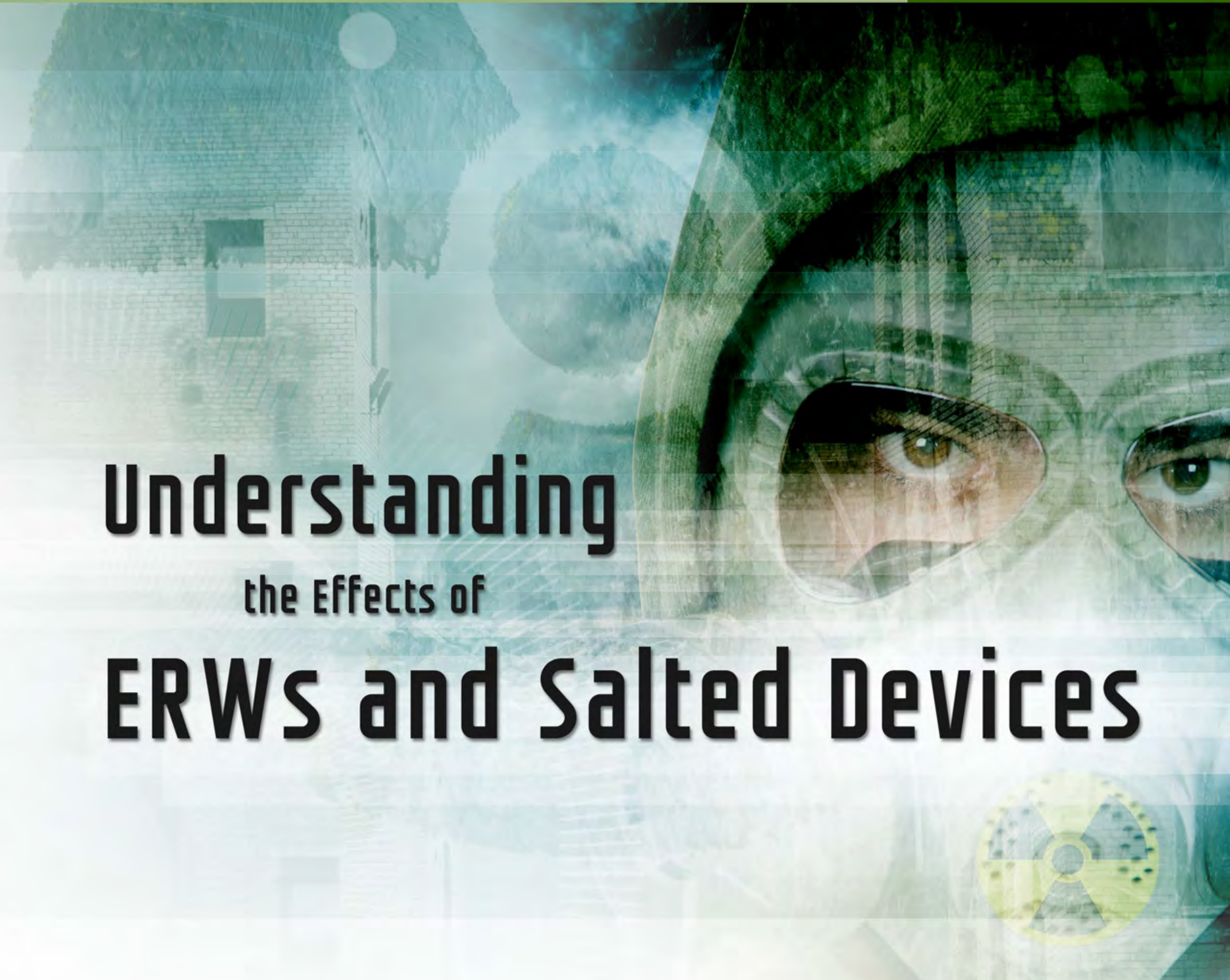

Understanding the Effects of ERWs and Salted Devices

By: Glen Reeves, M.D.

Introduction

In most atomic weapons, neutrons generated during the fission process are intended to trigger further fission events, thus increasing the total energy yield (blast, thermal and prompt radiation) of the device before it disassembles. In thermonuclear bombs, neutrons can be used to trigger fission events in the non-fissile uranium-238 tamper as well.

However, two nuclear weapon types exist where released neutrons are not intended to accelerate the fission chain reaction. One is an enhanced radiation weapon, also known as an ERW or neutron bomb, where fusion neutrons are not confined so as to decrease the ratio of blast and thermal energy released to prompt radiation and also increase the neutron component of prompt radiation. The figures in this article illustrate how the partition of energies released differs between a fission device and an ERW. The range to lethal effect from prompt radiation from an ERW is equivalent to the range to lethal radiation effect of a fission weapon with 10 times the overall yield. A second device is a "salted" weapon, where non-radioactive materials such as cobalt-59 are placed into the weapon so that the neutron flux creates radioactive activation products. The intent is to create radioactive contamination for a longer time over a larger area compared to the activation products and fallout from a non-salted weapon.

History

Samuel Cohen is generally credited as the inventor of the neutron bomb in 1958. [2] The United States was apparently preparing to deploy it to Europe during the Carter administration, but did not do so owing to media and political pressure. USSR President Leonid Brezhnev informed a group of U.S. senators at the Kremlin that they had tested a neutron bomb "years ago," but did not begin production. [3]

France tested its first such weapon in 1980 [4], and informally told Allied officials in 1982 that it intended to go ahead with production, though it is not believed that France did so. [5] China successfully tested an ERW on Sept. 29, 1988, reportedly as a hedge against the Soviets, but did not deploy it. [6] There is speculation that Israel produced and tested a neutron bomb in 1979, but considerable doubt exists that the detected

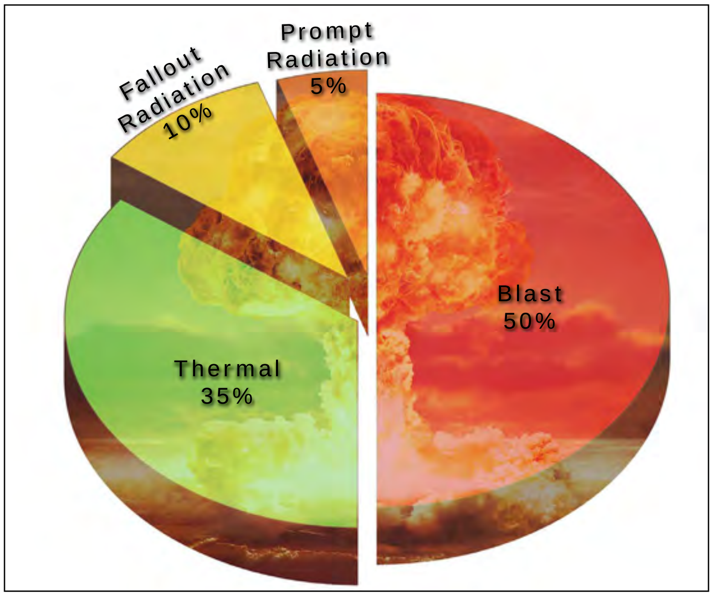

Figure 1. Energy Partitioning of Standard Fission/Fusion Weapon [1]

explosion was a nuclear device. In a speech in Parliament on Nov. 24, 2012 Lord John William Gilbert, the former defence minister for the UK, threatened militants with an enhanced radiation reduced blast warhead, or neutron bomb, to "create cordons sanitaire" along the Pakistan and Afghanistan border; [7] however, the UK has never admitted it has produced or possesses such a device. Gilbert may have conflated neutron bombs with salted weapons.

The initial gamma radiation from activation and fission products from a fission or fission-fusion-fission device is very intense. The half-lives of some of these isotopes are generally within hours or days, [8] and the dose rate falls off rapidly. Other fission products have much longer half-lives, some of several years. However, several isotopes can be irradiated by the neutrons emitted during a fission-fusion weapon detonation that have intermediate half-lives and emit high-energy gammas or beta particles. A salted weapon therefore furnishes an intermediate peak of activity that would render an area unsafe for habitation or human presence for several months or years.

Radiation Biophysics

The biological effects of neutron irradiation differ from those of gamma irradiation. A key concept in comparing the behavior of different radiations upon biological tissues is relative biological effectiveness. The relative biological effectiveness of neutrons, or RBEn, is defined as the ratio of:

RBEn = (Dose from reference radiation to produce a given biological effect)/(Dose from neutron radiation to produce the same effect)

The reference radiation used is generally either 250 kVp x-rays or cobalt-60 gamma rays. RBEn is a function of several variables including:

- Neutron energy
- Type of tissue irradiated
- Tissue thickness and depth in tissue
- Dose rate
- Specific biological effect (e.g., incapacitation versus lethality versus carcinogenesis)

The average energy of neutrons emitted by fission reactions is around 2 MeV; [11] neutrons emitted by a deuterium-tritium fusion reaction have energies of approximately 14.1 MeV. Atmospheric attenuation, while more rapid for neutrons than gamma photons, is slower for higher energy neutrons. Accordingly the neutron/gamma ratio decreases more slowly over distance from ERW energy neutrons. RBEn is at a maximum around 1 MeV, so although higher energy neutrons, while penetrating further through the atmosphere, have relatively less biological effectiveness.

Type of tissue irradiated is important. Materials with high Z (atomic mass), such as lead, best attenuate gamma radiation, while neutron radiation is best attenuated by hydrogen-rich compounds (e.g., paraffin and, in human tissue, fat). Tissues with high lipid concentrations, such as the brain, fat and muscle, and tissues with high water concentration, such as the gastrointestinal epithelium, will therefore be more sensitive to the effects of neutron irradiation. RBEn is higher in the gastrointestinal tract than in skin, cartilage and hematopoietic tissue (in that order). [12, 13] As with any form of radiation, the dose rate decreases with depth in tissue; however, this is more so with neutron than gamma irradiation and the RBEn decreases with depth as it traverses mammalian tissue. [14]

In assessing the medical effects of neutron radiation, the fact that RBEn varies with the endpoint under consideration is very important. It was thought that the RBEn for radiation carcinogenesis was as high as 20-50 or even more [15]; more recent work however has noted, in the Japanese atomic bomb survivors that the neutron RBE is dependent upon the accompanying gamma RBE, particularly at low neutron doses. [16] The Radiation Effects Research Foundation has used a constant RBEn of 10, although this may be larger at low doses. Very high supralethal radiation doses such as 50 Gy, which are capable of causing incapacitation in primates, have an RBEn of less than one. [17] Animal studies using doses around the LD50 (median lethal dose) have yielded RBEn values from 1 to 4, with values decreasing inversely with size. For simplicity the RBEn for human lethality used by the RERF and most Department of Defense and North Atlantic Treaty Organization publications has been assumed to be 1.

Studies of neutron versus photon effects in tissues have shown differences in gene expression related to DNA damage, cell cycle delays, oxidative stress degeneration, regeneration, apoptosis and transcription. [18] Double strand breaks and non-DSB-clustered DNA lesions are the hallmarks of high-linear energy transfer radiations. Neutrons decrease DNA flexibility more than photons, and alter DNA conformation as well. As a result, laboratory studies show that mixed field (neutron and gamma) irradiation increases the mortality, decreases survival time, decreases the latency period in acute radiation sickness or syndrome and delays the time to healing of wound and/or burn injuries in animals with combined radiation and traumatic injury. [19-22] Consequently, the clinical presentations, medical countermeasures employed and outcomes of irradiation with a high neutron component will differ.

Medical Response and Treatment

After any nuclear detonation first responders will go to the areas likely to contain the greatest numbers of casualties capable of survival if given prompt medical care. [23] Their length of stay will be guided by external radiation exposure levels rather than the weapon type employed. Either an ERW or salted weapon will increase the external irradiation from activation products around (or below) the detonation point (ground

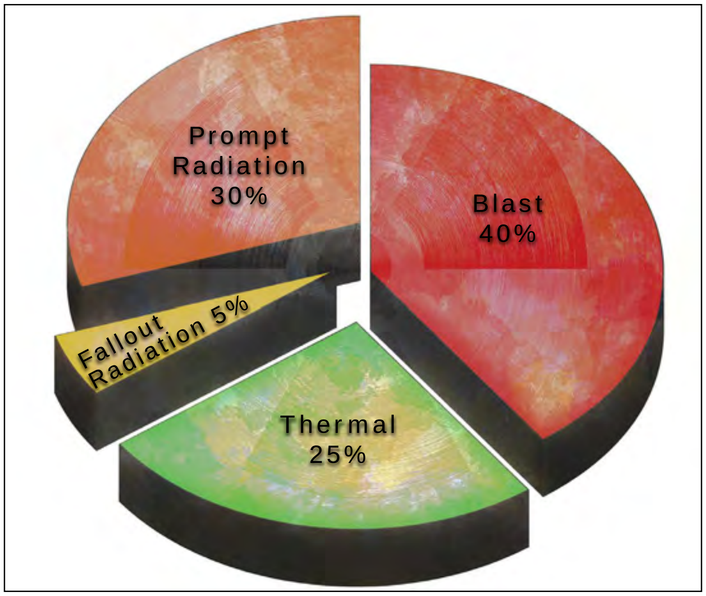

Figure 2. Energy Partitioning of Enhanced Radiation Weapon [1]

zero) and the amount of time medics will have to treat and evacuate survivable patients will be shorter. In addition, while only 15 percent of casualties in Japan had radiation injuries alone (most had combined injury from blast, thermal and prompt radiation), this percentage will likely be higher with salted or ERW weapons, owing to the reduction in blast and thermal effects relative to prompt radiation.

Casualties that spend any length of time in a fallout field are at risk for inhaling radioactive materials, as well as receiving external irradiation. For a salted weapon, it is important to know the isotopes comprising the fallout, as the medical countermeasures used for removing incorporated radioactive materials will vary depending upon the chemical nature of the isotopes.

The presenting symptoms of the prodromal phase of acute radiation syndrome are nausea, vomiting, diarrhea, fatigue, weakness and anorexia. This is followed by a latent phase where symptoms improve, but then the manifest illness phase, when the casualty worsens, sets in and lasts until death or recovery. In mixed field irradiation the latent phase is shorter, and there is more pronounced hypothermia. [25] These symptoms will likely be more pronounced in casualties receiving a large neutron dose.

Very shortly after radiation exposure the lymphocyte count decreases rapidly. Except at the highest doses, there is an initial neutrophil spike, followed by a decline in numbers. Platelets and erythrocytes also decrease soon after the white cell counts drop. Deaths occurring around the second or third week post-exposure are generally due to infection and hemorrhage aggravated by the depleted blood elements.

However, it was noted that mice at the Nevada Test Site, shielded from gamma irradiation by lead hemispheres, died from prominent gastrointestinal signs and symptoms such as vomiting, bloody diarrhea and loss of appetite with relative sparing of the bone marrow. Deaths were earlier, around 4 to 10 days. This observation was verified in laboratory experiments in pigs, [26] and the conclusion drawn was that neutron irradiation aggravated gastrointestinal tract injury with relative sparing of the blood elements. ERW casualties will likely require greater attention to sepsis (which, in neutron-irradiated animals, was noted to be predominantly Gram-negative whereas cobalt-60 irradiated animals had predominantly Gram-positive bacteria [19,22]) and a relative decrease in blood transfusion and transplant requirements. [26]

The hematopoietic syndrome, or hematopoietic subsyndrome of ARS, is a clinical diagnosis assigned to casualties with one or more cytopenias following acute radiation exposure. The World Health Organization convened a panel of experts in 2009 to develop a harmonized approach to the medical management of acute radiation exposure, including HS. [28] A strong recommendation was made for administering granulocyte or granulocyte macrophage colony-stimulating factor in HS, and only a weak recommendation for stem cell transplants, after cytokine treatment has failed. One study ascertained that G-CSF is effective not only after photon irradiation, but also after mixed field irradiation, in accelerating hematopoietic recovery and improving survival. However, a thrombopoietin analogue effective in stimulating recovery of platelets after gamma irradiation

Original material	Activation Product	Half-Life	Energy emitted (MeV)
	Candidate salting agent		
Cobalt-59	Cobalt-60	5.26 y	1.17, 1.33 gammas
Gold-197	Gold-198	2.7 d	0.8, other betas
Tantalum-181	Tantalum-182	115 d	1.12 gamma
Zinc-64	Zinc-65	244 d	1.115 gamma
	Other isotopes hazardous to first responders		
Sodium-23	Sodium-24 (and -22*)	15 h	2.8, 1.4 gammas, 1.4 beta
Chlorine-35	Chlorine-36	301,000y	0.7 beta
Nitrogen-14	Carbon-14	5,730 y	0.156 beta
Iron-58	Iron-59	45.1 d	1.1, 1.3 gammas, 0.45 beta
Aluminum-27	Aluminum-28	2.2 m	1.8 gamma
Manganese-55	Manganese-56	2.6 h	0.85 gamma, several betas
Europium-151	Europium-152	13.5 y	1.1, 1.8 gammas, several betas

Table 1. Significant activation products. Data selected and abbreviated from [8,9]. The asterisk (sodium-22) indicates that if the neutron energy is above 11.5 MeV, sodium-22 can be an activation product by a (n, 2n) reaction. Such a threshold would imply fusion neutron energies, which an ERW could produce. Also, the type and amounts of activation products in an urban environment would depend heavily upon the type of cement and aggregate used in the concrete.*

did not improve survival after mixed-field induced injury. [18]

A basic principle of ARS treatment is prevention and treatment of sepsis with environmental control, selective gut decontamination and use of antibiotic therapy. Because different organisms may induce sepsis in casualties receiving a prominent neutron dose, as from an ERW, it will be necessary to identify the causative organism and start appropriate treatment; other than that, management is not changed.

Control of hemorrhage and restoration of hematopoietic elements with cytokine stimulation, treatment with immunomodulators and transfusions are also similar, with the exception regarding platelet stimulation noted above. Restoration and maintenance of fluid and electrolyte balance, and treatment of shock, will not vary. Supportive treatment in general has been shown to improve survival by a dose-modifying factor (the ratio of median survival doses in dogs given standard therapy versus control animals) of 1.30 in gamma-irradiated animals, but only 1.21 in dogs given neutron radiation. [20] Overall, it appears that for irradiated casualties with the same clinical picture and treatment countermeasures, the prognosis for ERW casualties is less favorable. [31]

Radioprotectors, such as sulfhydryl compounds, protect the animal or human by scavenging damage-causing free radicals or by donating hydrogen atoms to facilitate DNA repair. Thousands of these compounds have been synthesized and have had dose reduction factors, defined as the ratio of the dose of radiation required to cause lethality in the presence of the drug divided by the dose required in its absence, of two or more. [29] Although effective in animals and cancer patients undergoing radiation therapy, and carried but not used by Soviet soldiers and U.S. astronauts, their side effects (nausea, vomiting) and toxicity have so far precluded their routine use by persons expecting to be exposed to radiation. As a rule, they are somewhat less effective against fission neutron than gamma only radiation however. [30]

The long-term risks of carcinogenesis and cataractogenesis are increased in casualties receiving neutron irradiation from an ERW. Inhabitation of an area contaminated by a salted weapon could increase these risks as well, but this is due solely to the environmental behavior and amount of radioactive material deposited, not to different biological effects.

Conclusion

Though the technical sophistication required to construct an ERW or a salted device will most likely preclude their actual employment (in favor of a "standard" fission or thermonuclear weapon), their different effects should at least be understood in principle by emergency responders and other medical care personnel to facilitate responder safety and optimal patient treatment.

For first responders there will be no significant changes in protective equipment, rescue procedures or on-scene emergency treatment. Stay times in contaminated areas will be determined by external exposure dosimetry regardless of weapon type. If the on-scene dosimetry readings are disproportionally higher than expected from the blast damage, the possible detonation of an ERW or salted weapon should be considered.

Specific differences in medical planning and casualty care that can be caused by these weapons include:

- Elevated radioactivity at hypocenter, increasing external radiation risks to both responders and casualties (for both ERW and salted weapons)
- Increased incidence of radiation only injuries with respect to combined injuries (both)
- Shorter latent phase of ARS with ERW
- Wound and burn healing is slower in neutron-irradiated combined injury
- Increased incidence of nausea, vomiting, and other GI signs and symptoms with respect to dose from neutron irradiation
- Sepsis may be caused by different organisms in neutron versus gamma only irradiated casualties (and in combined injury versus radiation injury alone—not discussed earlier)
- Transfusion requirements may be decreased in ERW patients
- Doses of radiation high enough to cause incapacitation might be seen from an ERW
- Neutron irradiation increases risk of late carcinogenesis and cataractogenesis

Although the use of such weapons has been threatened, the likelihood of their use is small. The nations that have developed neutron bombs have, to all external appearances, dismantled or mothballed their arse-

Isotope	Half-Life	Energy emitted (MeV)
Strontium-89	50.6 d	0.9 gamma, 1.5 beta
Strontium-90	28.9 y	0.94 and other betas
Cesium-137	30.2 y	0.66 gamma, 0.19 beta
Iodine-131	8.02 d	0.97 beta, gammas (81% at 0.6)

Table 2. Significant fission products. Source: Data selected and abbreviated from [8]. The CDC and NCI have developed a list of 19 isotopes from atmospheric nuclear weapon testing posing the greatest health hazards [10]; these are the top four in terms of health hazards in the author's estimation.

Isotope	Preferred Prescription	Other Possible Treatments
Cobalt-60	DTPA	EDTA, DMSA, N-acetyl-L-cysteine (NAC)
Gold-198	BAL (British Anti-Lewisite)	Penicillamine
Zinc-65	DTPA; ZnSO4 as diluting agent	EDTA
Sodium-24	Hydration, diuresis, dilution with 0.9% NaCl solution	

Table 3. Decorporation therapy recommendations. Source: Data selected and abbreviated from [23]. Tantalum-182 treatment is not discussed in this reference, presumably because its chemical toxicity is low.

nals (though not forgotten the technology of development).

American scientist Leo Szilard originally proposed salted weapons in 1950, but the U.S. has never tested such a weapon above ground. The British tested a 1 kt bomb incorporating a small amount of cobalt as a radiochemical traced at their testing site in Maralinga Range, Australia, but the experiment was a failure. In 1971 the Soviet Union conducted an underground "taiga" nuclear salvo using three bombs that created enough cobalt-60 to generate half of the gamma dose measurable at the test site 40 years later. No atmospheric testing of such a device has been performed. Nevertheless, while medical emergency response planners should be focused primarily on dealing with the effects of a standard fission nuclear weapon or improvised nuclear device, prudence requires appropriate consideration of the possibility that a neutron bomb or salted nuclear weapon could someday be used. ■

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Dr. Glen Reeves is a consultant on the medical effects of ionizing radiation. He has provided subject matter expertise for the Defense Threat Reduction Agency in counter-terrorism related analysis for radiological dispersal devices, improvised nuclear devices, and other radiological insults to humans. While on active duty in the Air Force he led a program of collaborative research projects with scientists formerly involved in the USSR's nuclear weapons program. This effort produced 20 publications on the effects of radiation on workers and on populations near the Kazakhstan test site. He has authored or co-authored several publications on subjects ranging from the biophysics of enhanced radiation weapons to the medical treatment of radiation injuries.

Calendar of Events

October 2016

10/2/16 - 10/5/16 • **Newport, RI**
AE 2016 International Offshore Wind Partnering Forum

10/3/16 - 10/4/16 • **Charlotte, NC**
CBRN, CIP The Nuclear Decommissioning & Used Fuel Summit & The Nuclear Decommissioning & Used Fuel Strategy Summit

10/4/16 - 10/6/16 • **Rosemont, IL**
CIP SAE 2016 Commercial Vehicle Engineering Congress (COMVEC)

10/5/16 - 10/6/16 • **Bangkok, Thailand**
CIP, HD 2nd Critical Infrastructure Protection & Resilience Asia

10/5/16 - 10/7/16 • **Barcelona, Spain**
AE, HD European Transport Conference

10/6/16 - 10/7/16 • **Dresden, Germany**
CS Smart City-Regional Governance for Sustainability

10/14/16 - 10/16/16 • **Palitinis, Romania**
CS International Scientific Conference SAMRO 2016

10/14/16 - 10/17/16 • **Durres, Albania**
M 8th EFIS-EJI South Eastern European Immunology School

10/14/16 - 10/19/16 • **Savannah, GA**
HD, M International Association of Emergency Managers 64th Annual Conference

10/17/16 - 10/18/16 • **Minneapolis, MN**
AE Biofuels Financial Conference

10/17/16 - 10/19/16 • **Schaumburg, IL**
AE, CIP Fleet Technology Expo

10/18/16 - 10/20/16 • **Westminster, London**
B Biometrics 2016

10/19/16 • **Washington, D.C.**
CBRN, M The Chemistry of Microbiomes: Marine

10/20/16 - 10/21/16 • **Houston, TX**
B International Conference on Biometrics & Biostatistics

10/21/16 - 10/23/16 • **Wuhan, China**
M Viral Infection and Immune Response 2016

10/25/16 - 10/26/16 • **Warwick, RI**
AE, CIP AWEA Offshore WINDPOWER 2016

10/26/16 • **Gaithersburg, MD**
AE, CIP Timing CHallenges in the Smart Grid

10/31/16 - 11/1/16 • **Belgrade, Serbia**
AE 9th Balkan Energy Finance Forum 2016

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Publications

Volume 4; Issue 1
(Publish March 2017)
Abstract deadline:
10/16/16
Article deadline:
11/16/16

Volume 4; Issue 2
(Publish June 2017)
Abstract deadline:
01/16/17
Article deadline:
02/15/17

Volume 4; Issue 3
(Publish Sept. 2017)
Abstract deadline:
04/14/17
Article deadline:
05/16/17