HDIAC Journal
The Journal of the Homeland Defense and Security Information Analysis Center

Volume 3 Issue 4 Winter 2017

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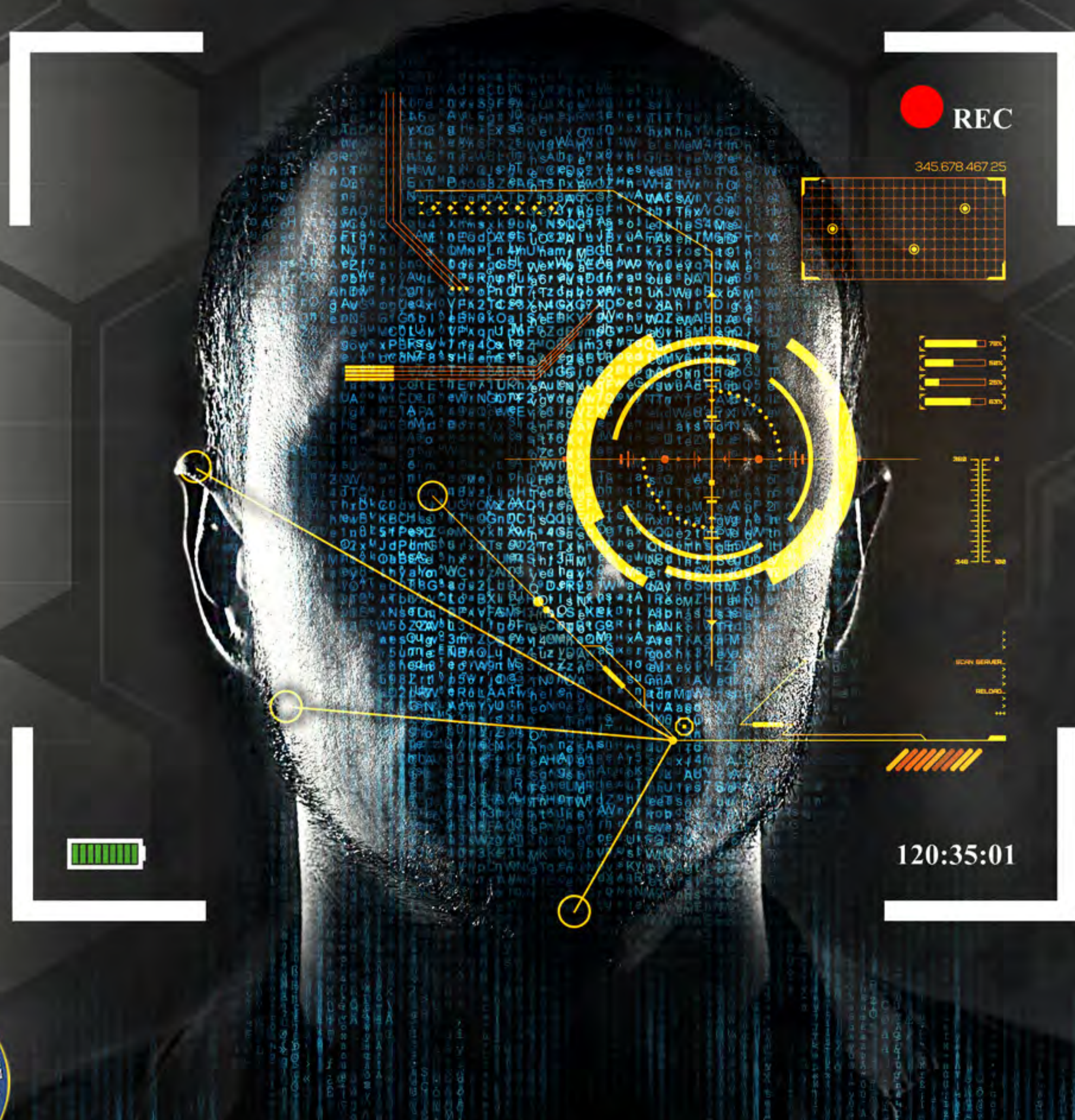

HDIAC JOURNAL
The Journal of the Homeland Defense and Security Information Analysis Center

Volume 3 • Issue 4 • Winter 2017

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About this Publication:

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DoDIACs
Department of Defense Information Analysis Centers

AE **Alternative Energy**
B **Biometrics**
CBRN **CBRN Defense**
CS **Cultural Studies**
CIP **Critical Infrastructure Protection**
HDS **Homeland Defense & Security**
M **Medical**
WMD **Weapons of Mass Destruction**

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Message from the Director:

Better Buying Power 3.0

Stuart Stough
HDIAC Director

Each year the Homeland Defense and Security Information Analysis Center partners with academic, industry and government organizations to research, develop and produce two state of the art reports. These SOARs highlight emerging trends in HDIAC's focus areas and posture future needs and requirements to ensure the Department of Defense is best prepared for technological developments.

The SOARs also help meet the Better Buying Power 3.0 objective of achieving dominant capabilities through technical excellence and innovation. Specifically, leveraging the knowledge gained and connections developed will assist the government in working toward incentivizing productivity and innovation.

One of HDIAC's SOARs looks at uses of nanotechnology for military surface applications. The report sought to identify and understand how the Department of Defense can utilize nanotechnology, the manipulation of matter on an atomic scale to create new materials, to improve the functionality of surfaces, particularly those with military and defense relevance. The report's authors researched emerging technology of great interest to the DoD and identified applications near commercialization, while also identifying products available within the past three years.

Better Buying Power 3.0 acknowledges the "DoD's military products are developed and fielded on time scales that are much longer than some commercial development timelines, particularly those associated with electronics, information technology, and related technologies." By researching and reporting on innovations as they approach readiness, HDIAC is able to incentivize productivity by identifying nanotechnology products that could be of use to the DoD in the immediate or near term.

These SOARs also help incentivize innovation by, "emphasiz[ing] technology insertion and refresh in program planning." [1] The pace of research and development in nanotechnology is rapid; the SOAR assists the DoD in determining where the focus should be. Whereas BBP 3.0 acknowledges IT and sensor technology refresh times of 18 months and 2-4 years, respectively, nanotechnology developments occur on a daily to weekly basis.

The overall goal of the nanotechnology report is to give the DoD a list of products and technologies to focus on or consider utilizing. The report streamlines the research agenda so the military is not focused on basic or applied research that will not have near term applications or commercial relevance. The products discussed in the report are soon to be released and have possible relevance and application for military initiatives.

Information presented in this SOAR provides two key advantages to ensuring DoD mission readiness and strengthening acquisition strategy. First, by gathering data on products that are commercially available or near-commercialization, HDIAC provides a procurement list of sorts and conducts a comparison analysis of relevant and commercially viable technologies that DoD has readily available and can use to streamline its purchasing strategy for new nanotechnology-related products. Next, research information presented in the SOAR that is not currently viable for commercial development, as it is still more than two years away from practical application, can be used by DoD to address gaps in research strategy needed to drive particular applications of basic and applied nanotechnology research into commercialization faster.

Future HDIAC SOARs will continue to connect ongoing technological advancements with government needs and requirements, thereby meeting the BBP objectives.

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1. Under Secretary of Defense. (2015, April 9). Implementation Directive for Better Buying Power 3.0 - Achieving Dominant Capabilities Through Techncal Excellence and Innovation. Retrieved from http://www.acq.osd.mil/fo/docs/betterBuyingPower3.0(9Apr15).pdf (accessed January 10, 2017).

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**

Using Old Technologie Individual Warfighter

By: Gregory Nichols, MPH, CPH

Introduction

The individual warfighter now carries more than 100 pounds during combat operations, with a significant amount of that weight attributed to electronic gear and energy needed to power it. [1] In a 2011 memo issued to all U.S. Forces in Afghanistan, General David Petraeus stated, “Energy is the lifeblood of our warfighting capabilities.” [2] Power generation is such an important part of the contemporary warfighter experience that it is key in several initiatives, including Reliance 21, in which energy and power technology is represented as one of 17 communities of research emphasized as part of a larger effort to improve the strategic development of DoD’s science and technology planning.

For land-based warriors, power is required for multiple systems, and reliability is important, especially during missions where maintenance is not possible. [3] Unfortunately, power requirements for sensors, compact communications equipment and light sources have not shrunk as fast as device size and weight. [4] In order to tackle this challenge, alternative forms of energy are proving to be reasonable solutions.

Three existing technologies that warrant reinvestigation are 1) thermo-electrochemical cells, 2) betavoltaic batteries and 3) electromagnetic generators. The processes behind thermo-electrochemical cells, betavoltaic batteries and electromagnetic generators have been known since the late 19th and early 20th centuries, but recent advances in science and technology make them more relevant and practical for uses in military environments.

Devices for Alternative Power Sources

Thermo-electrochemical Cells

Thermo-electrochemical cells, also known as thermogalvanic cells or thermocells, produce electrical power by utilizing electrochemical oxidation-reduction potentials in a temperature-dependent environment to convert thermal energy to electrical energy. [5,6] They have virtually unlimited applications given their simple design, durability and flexibility in form-factor.

The design of a thermocell is relatively simple (See Figure 1). Electrodes at either end are held at different temperatures. Typically, platinum is used as an electrode material due to its high catalytic activity. [6] Thermocells are filled with a redox electro-

s in New Ways to Power the

lyte, which can be an aqueous solution, a non-aqueous solution or a solid-state membrane. [7] Ferri/ferrocyanide is commonly used in order to get high exchange current densities. [6] The movement of electrons between the temperature gradient of the electrodes creates a voltage potential. As long as the temperature difference persists, a steady state is maintained. [7]

Using flexible materials, such as multi-walled carbon nanotubes, in the electrodes can allow the cells to be molded into any shape, which eliminates extra equipment needed to transfer the waste heat to the thermocell. [7] Carbon nanotubes have exceptional electronic, mechanical and chemical properties, which make them ideal for use in many electrochemical applications, particularly due to fast kinetics and a large, accessible internal surface area. [5] Recent research utilizing thermocells with MWCNT electrodes and the traditional ferri/ferrocyanide electrolyte demonstrated an efficiency three times higher than conventional thermocell devices with platinum electrodes. [5] In addition, thermocells using MWCNT electrodes have a relative power conversion efficiency that is 50 percent higher than platinum-based electrode thermocells. [6]

Aside from exploring new electrode materials, the use of ionic liquids, such as ethylammonium nitrate, as electrolytes has been investigated as a replacement for ferri/ferrocyanide. Thermocells based on ionic liquids can be highly flexible and would allow placement directly onto human skin, taking greater advantage of waste heat produced by the human body to further enhance the temperature gradient needed to maintain electrical activity from the thermocell. [8]

Betavoltaic Batteries

Betavoltaic batteries, sometimes referred to as betavoltaic cells or just betavoltaics, are a type of nuclear battery that convert the kinetic energy from radioactive decay of a beta-emitting radioisotope into electrical energy through the use of a semiconductor or junction device. [9] The key component in a betavoltaic power source is a beta-emitting material. [10] Beta radiation is essentially a high-energy electron released from an unstable nucleus. Betavoltaic batteries are durable power sources, which can be designed at small sizes because their energy density is 100 to 10,000 times higher than standard chemical batteries where miniaturization is limited by their low energy density. [9,11] Apart from their smaller sizes, betavoltaics can last anywhere from 15 to 100 years and have anti-jamming capabilities, [4,9] making them extremely useful for applications in military equipment and sensor networks that must operate in remote environments such as arctic and mountainous regions. [9,12,13,14] Because of their long lifetime, high energy density and ruggedness, betavoltaics are an excellent option for applications where photovoltaics are not viable power. [9]

The key benefit of a betavoltaic battery is that no re-charging is needed. The battery will continue to operate until the isotope reaches a volume where the radioactive decay becomes impractical to produce enough electrons to power a device or is depleted completely. Although betavoltaics never need to be charged, they will gradually continue to lose power over time as the radioisotope decays. The lifetime power output and time to failure is directly dependent on the half-life of the radioisotope being used, making the radioisotope the most important component of a betavoltaic battery.

Apart from the half-life, another key consideration is what effect(s) any radiation damage may have on the semiconductor devices. [10] Isotopes with long half-lives are more desirable then isotopes with shorter ones, and isotopes with a single crystal material have been typically preferred to minimize the loss of current. [10] In order to increase power output, radioisotopes with

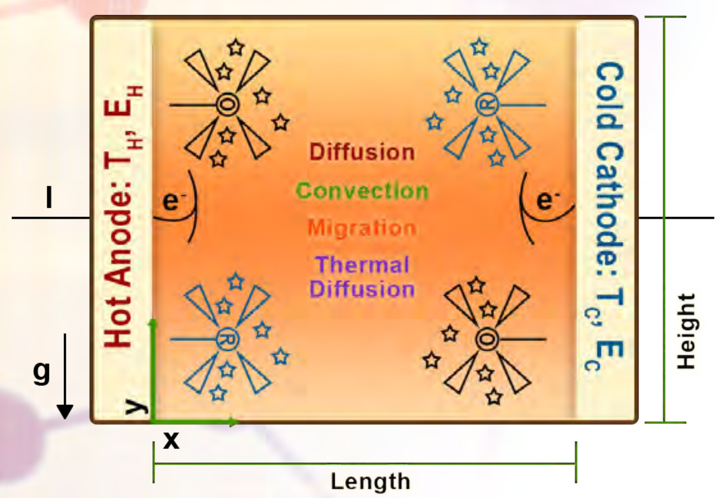

Figure 1: Schematic representation of thermocell. [7] (Released)

high specific power should be used, [9] and they should have a maximum beta particle energy. [10] A list of beta-emitting isotopes that have been explored for battery use is available in Table 1.

Tritium and Krypton-85 are among the most commonly used beta sources because they are widely available. [10] In fact, tritium is used commercially in night-vision gear. [4] Promethium is another betavoltaic material that was once considered for commercial use particularly in medical devices and military applications. [10] Betacel Model 400, using Pm-147 fueled betavoltaic batteries, was tested for pacemakers by U.S. and German companies. [10] Although Pm-147 was very promising, it was overshadowed by the lithium battery, developed around same time. Lithium batteries only last about 7 years, compared with the 10 years or more of betavoltaics, but since lithium batteries are non-nuclear, they were more preferred for commercial civilian use. [10]

β-Emitter	Half Life	Average Energy (keV)	Maximum Energy (keV)	Average Specific Power (mWg^{-1})
‡H-3	12.32 y	5.69	18.59	324.914
‡Ru-106	1.02 y	10.03	39.4	196.948
‡Ni-63	100.2 y	17.42	66.94	5.796
‡S-35	87.37 d	48.76	167.33	12339.148
Pm-147	2.62 y	61.93	224.6	340.367
‡P-33	25.35 d	76.43	248.5	70701.623
Ca-45	162.61 d	76.86	255.8	8129.21
Cs-137	30.08 y	187.1	1175.63	96.241
‡Sr-90	28.79 y	195.8	546	160.238
Y-90	64 h	933.6	2280.1	3.011E+06
T1-204	3.783 y	244.05	763.76	669.977
Kr-85	10.76 y	250.7	687.4	581.465
Os-194	6 y	16	96.6	29.123
Ir-194	19.28 h	800	2233.8	3.97E+06
Sm-151	90 y	19.63	76.6	3.061
Tm-171	1.92 y	24.77	96.4	159.876
Eu-155	4.753 y	47	252.7	135.209
Th-234	24.1 d	47.9	273	6566.085
‡C-14	5700 y	49.47	156.475	1.313
Hg-203	46.594	57.87	492.1	4731.189
Ru-103	39.247	63.8	763.4	12213.974
‡Si-32	153 y	69.55	227.2	30.116
‡P-32	14.27 d	695.03	1710.66	11.78E+05
Ce-144	284.91 d	82.1	318.7	1548.169
Pr-144	17.28 m	1208	2997.5	5.408E+08
Sb-125	2.76 y	86.7	766.7	533.025
W-188	69.78 d	99	349	5836.159
Re-188	17.004 h	763	2120.4	4.43E+06
Zr-95	64.032 d	117	1123.6	14885.746
Nb-95	34.991 d	43.43	925.6	10111.622
Fe-59	44.495 d	118	1565.2	34792.309
Hf-181	42.39 d	121	1029.8	12196.924
W-185	75.1 d	126.9	432.5	7063.894
Ce-141	32.508 d	145.3	580.7	24525.828
Tb-160	72.3 d	210	1835.1	14042.472
‡Ar-39	269 y	218.8	565	44.22
‡Ar-42	32.9 y	233	599	357.507
K-42	12.36 h	1430.5	3525.45	5.118E+07
Tm-170	128.6 d	317	968	11215.49
Sn-123	129.2 d	523.1	1403.6	25470.351
Sr-89	50.563 d	587.1	1500.9	100977.803
Y-91	58.51 d	603	1544.3	87654.311
‡ : Pure beta emitters, no x-rays or gamma-rays are emitted				

Table 1: Radioisotopes for betavoltaic batteries. (Addapted from [9] / Released)

Converting the energy from the radioactive decay into electricity is another very important part of betavoltaic, making the semiconducting material just as important as the beta-emitter. The use of silicon combined with radioisotopes has been well-studied since silicon is widely used in integrated circuits and in microelectromechanical systems, is easy to manufacture and has a relatively low cost compared with other semiconductors. [9] Betavoltaics with silicon diodes irradiated with Ni-63 layer show high efficiency. [15] In addition, non-crystalline betavoltaic structures using hydrogenated amorphous silicon have been used. [9] Hydrogenated amorphous silicon has a band gap of 3.3 eV making it an effective candidate for use in betavoltaics. [9]

Electromagnetic Generators

One method for reducing the need for large batteries as power sources has been to convert kinetic energy from motion and vibration into electricity to power wireless sensors and ultra-low power microelectronics devices. [16,17] Harvesting kinetic energy requires a transduction mechanism to convert the energy from movement into electrical energy, [18] and electromagnetic transduction is an effective method for energy scavenging applications. [19,17] A simple design used to produce electromagnetic induction includes the use of permanent magnets, a coil and a resonating cantilever beam, [18] although several variations exist (See Table 2).

Electromagnetic generators employ electromagnetic induction from relative motion between a magnetic flux gradient and a conductor. [18] As the cantilever moves between the magnets, an electromagnetic field evolves leading to the generation of an electrical current. These systems have been used in a range of technologies, including remote sensors, wearable devices and mobile electronics. [20] While generating electricity through electromagnetic transduction can be a practical and effective means of powering electronic devices, more research is needed especially regarding applications in harsh environments due to inconclusive evidence of the reliability of the device's

Electromagnetic Generators

Reference	P (μW)	F (Hz)	A ($m\ s^{-2}$)	Mass (g)	Volume	Material
Shearwood [81, 84]	0.3	4400	382	0.0023	5.4mm^3	GaAs
Sheffield University (UK)						Polyimide
Amarithajah [92]	400[a]	94	-	0.5	-	Discrete Components
MIT (US)						
El-hami [24]	530	322	-	-	0.24cm^3	Steel
Southampton University (UK)						
Mizuno 2003 [85}	0.4 nW	700	12.4	-	2.1 cm^3[a]	Silicon
Warwick University (UK)						
Glynne-Jones [91]	180	322	2.7	-	0.84cm^3	Steel
Southampton University (UK)						
Perpetuum [96]	4000	100	0.4	50	30cm^3	Steel
UK company						
Kulah [86]	2.5[a]	11400	-	-	4mm^3	Silicon/parylene
Michigan University (US)	4 nW	25			2cm^3	Silicon/styrene
Huang [87]	0.16	100	'Finger Tap'	-	-	Copper
Tsing Hua University (Taiwan)						
Pérez-Rodríguez [88] Barcelona University (Spain)	1.44	400	-	-	250mm^3	Polyimide
Beeby [90]	0.5	9500	1.92	0.028	-	Silicon
Southampton University (UK)						
Li [93]	10	64	16.16[a]	-	1cm^3	Copper/brass
Hong Kong University (China)						
Ching [94]	830	110	95.5[a]	-	1 cm^3	Copper/brass
Hong Kong University (China)						
Scherrer [89]	7000	35	-	-	9 cm^3	LTCC/beryllium/copper
Boise State University (US)						
[a]Simulated results						

moving parts compared with more stationary methods of generating power.

Conclusion

The use of betavoltaics, thermocells and electromagnetic generators were initially not feasible since the power demands of devices and systems grew at an exponential rate and the power capacity of these technologies were too small to handle a growth in demand. Ironically, as power demands increase, it may become more practical to explore utilizing these technologies as a means to power small devices and sensors individually rather than continuing to develop methods of powering entire systems. Although these technologies are over 100 years old, a resurgence in their interest for meeting energy demands of high-power networks may prove effective for military applications in rugged and harsh environments. ■

Table 2: Summary of electromagnetic generators. (Adapted from [18] / Released)

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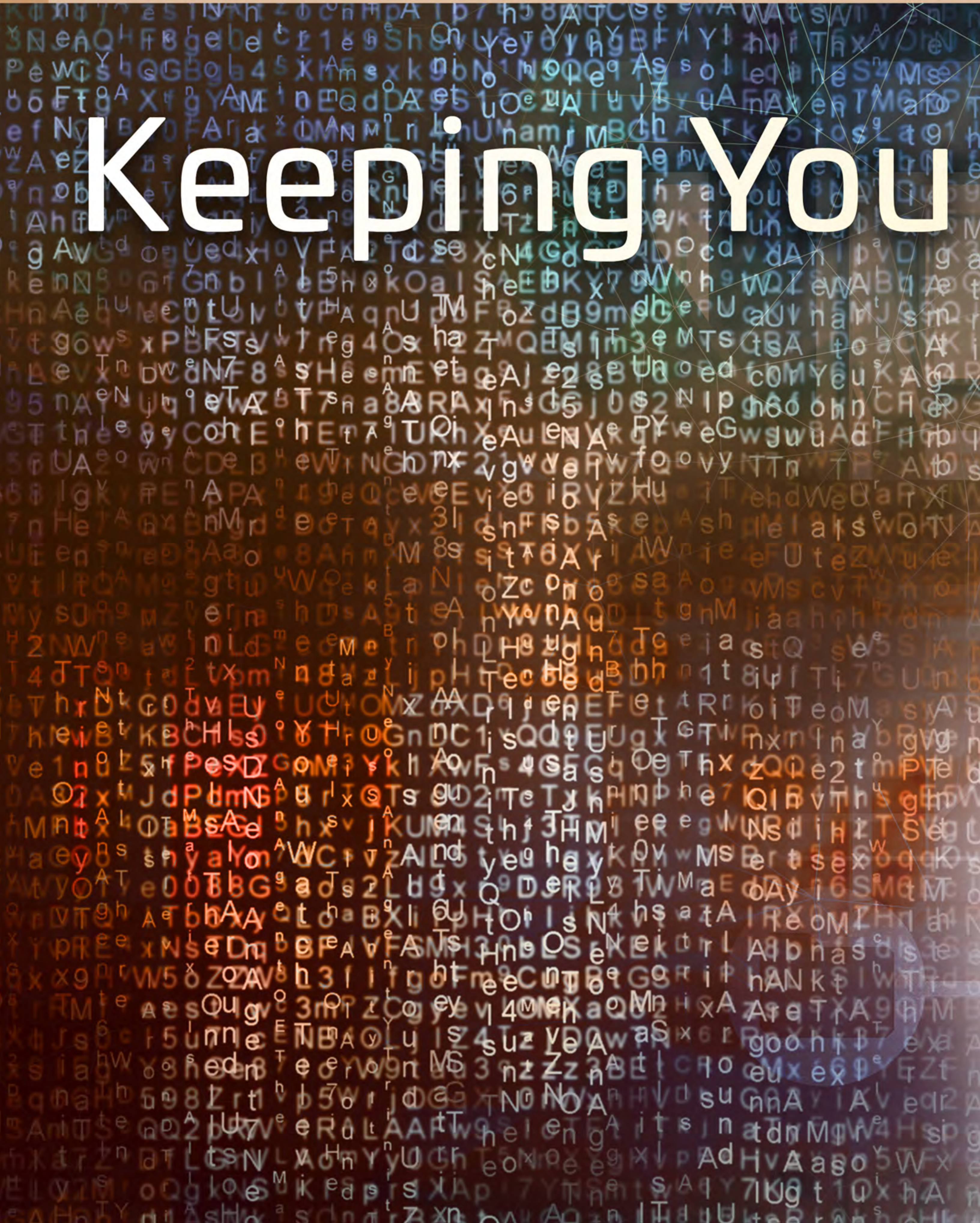

SAFE

<<Security Automation for Facilities and Events>>

Via Video Analytics

By: B. Scott Swann & Zenovy Wowczuk, Ph.D.

Introduction

Protecting critical infrastructure in today's threat-rich environment requires a portfolio of sophisticated solutions. Threats of all types jeopardize the nation's security and continually evolve in complexity. In 2010, as the Arab Spring spread across the Middle East, monitoring social media quickly emerged as a new opportunity to identify such dangers, because social media often serves as a platform for people to express discontent. Terrorist groups are known to use social media to recruit and organize, or facilitate a range of other criminal activities that threaten global safety. Whether terror-related, a political uprising or an organized protest that could lead to civil disorder or criminal violence, monitoring social media is a valuable tool for law enforcement and intelligence agencies to protect society. While it is imperative that civil liberties be protected and that policy implementation guides be allowed to mature along with the technology, the use and application of social media monitoring is anticipated to grow.

Social media, of course, represents only a fraction of the overall threat information that is posed to critical infrastructure and event management. Digital evidence, criminal violations, signals intelligence and overseas encounters in theater with foreign fighters all represent critical datasets for protecting the United States. Historically, as threats evolve, the United States implements stopgap solutions to ensure security and safety is preserved. Over time, this approach results in a portfolio of fragmented solutions that must be sustained and often are not interoperable or efficient.

When putting emergency safeguards in place results in new stove-piped systems or applications, these emergency systems inevitably grow in complexity. Both cost to the overall security ecosphere and efficiency can be impacted. In a landscape where agencies are immersed in daunting collections of threat information, inefficient enterprise solutions increase liability. Too often, when tragedies occur, law enforcement investigations reveal that vital information, had it been known to exist, may have prevented an attack or mass casualty.

Since the September 11th terrorist attacks, one of the biggest concerns within the intelligence community has been information sharing. No agency wants to be liable for sitting idle on a critical piece of data that could have prevented a catastrophe. Security automation for facilities and events is a comprehensive concept that reduces these risks. SAFE reduces overall costs for sharing and exploiting information, enables disparate data to persist in the same environment and, most importantly, allows for near real-time alerts when danger warnings are detected. SAFE supports an enterprise approach to storing data and applying tools and analytics to reduce threats.

A SAFE Impact on Military Operations

Exploiting actionable intelligence from information posted on social media sites (such as Twitter, Instagram and Facebook) is a progressively powerful line of defense for protecting critical infrastructure, facilities and events.

In May 2015, Pentagon spokesman Col. Steve Warren confirmed an increased force protection at military bases across the globe. Warren stressed that this was not due to a specific threat but "a general increase in the threat environment." [1] He later stated that this protective measure was in large part ordered in response to activity observed on social media. [2] Unfortunately, the threats posted to social media were identified too late during the recent terrorist attacks in Paris, France and Orlando, Florida.

The New York Times reported,

> The gunman who committed the massacre at a popular gay nightclub in Orlando used multiple Facebook accounts to write posts and make searches about the Islamic State. "Now taste the Islamic state vengeance," he declared, denouncing "the filthy ways of the west." He even searched for references to the massacre while he was carrying it out …
>
> And on Sunday morning, after opening fire at the Pulse nightclub and while a three-hour standoff with police was underway, "Mateen [the suspected gunman] apparently searched for 'Pulse Orlando' and 'Shooting.'" [3]

Post-investigation techniques are no longer sufficient for managing the intelligence provided by social media. It is imperative that intelligence capabilities advance toward more preventive measures that can predict potential attacks and analyze trends of the data that is available within social media. Such advancements will protect critical infrastructure, soldiers and American citizens. Of particular interest is gathering and exploiting the facial data found in photos or videos – data that is potentially associated with profiles or posts of threatening information.

Building upon social media exploitation, the SAFE concept can be implemented to deliver a Real-Time Surveillance and Exploitation Center for military operations. The RT-SEC is a virtual environment, such as a cloud infrastructure, that serves as the central analytical platform for processing threat information that may contain faces. The RT-SEC considers specific data sources available to the Department of Defense that may contain faces. It also considers an aggregate of all the analytical services in corresponding legacy systems that provide protective intelligence to the military.

By implementing the RT-SEC, surveillance, as an example, can be enhanced to search against large datasets and provide near real-time actionable intelligence. The RT-SEC uses perimeter and mobile video cameras to alert DoD security personnel when suspicious individuals or activity is detected. By merging video, biometrics, identity intelligence and behavioral/pattern-of-life information, warfighters will be automatically notified of suspicious behavior or malign actors operating near DoD facilities. These warfighters will not need to rely exclusively on a match against the Biometric-Enabled Watchlist. The RT-SEC can operate in both communications-austere and communications-rich environments, depending on the operational need. Further, the RT-SEC demonstrates scalability and can integrate camera and source inputs from multiple DoD facilities now and in the future.

How does RT-SEC work?

The RT-SEC ingests large quantities of photos and videos from a variety of intelligence sources, building a dynamic, searchable face database to support advanced analytics, site exploitation, and military action. The RT-SEC can manage multiple watchlists that can be defined with scalable sensitivity for thresholding and alert notification. The RT-SEC alerts can be routed to a warfighter's mobile device for immediate action, or automatically integrated into intelligence products for the Intelligence Command Center for adjudication. Existing DoD and intelligence command systems that provide identity intelligence do not aggregate across such a diverse collection. These collections, as previously described, evolved as the threats to the United States have grown exponentially. The RT-SEC offers the DoD a dynamic architecture that can keep pace with the comprehensive threat to the warfighter. It will model an infrastructure to expedite the dissemination of identity intelligence. The RT-SEC will also overcome the challenges that currently exist from stove-piped systems or capabilities requiring extensive human involvement to connect the faces encountered in the war on terrorism.

The RT-SEC leverages several proven technologies and best practices into an integrated capability. The infrastructure will control a suite of world-leading biometric technologies and host these tools within a cloud or similar virtualized environment. While each of these technologies independently proved to provide substantial investigative capabilities, this concept extends beyond any traditional implementations. The fully integrated suite of tools, combined with new business

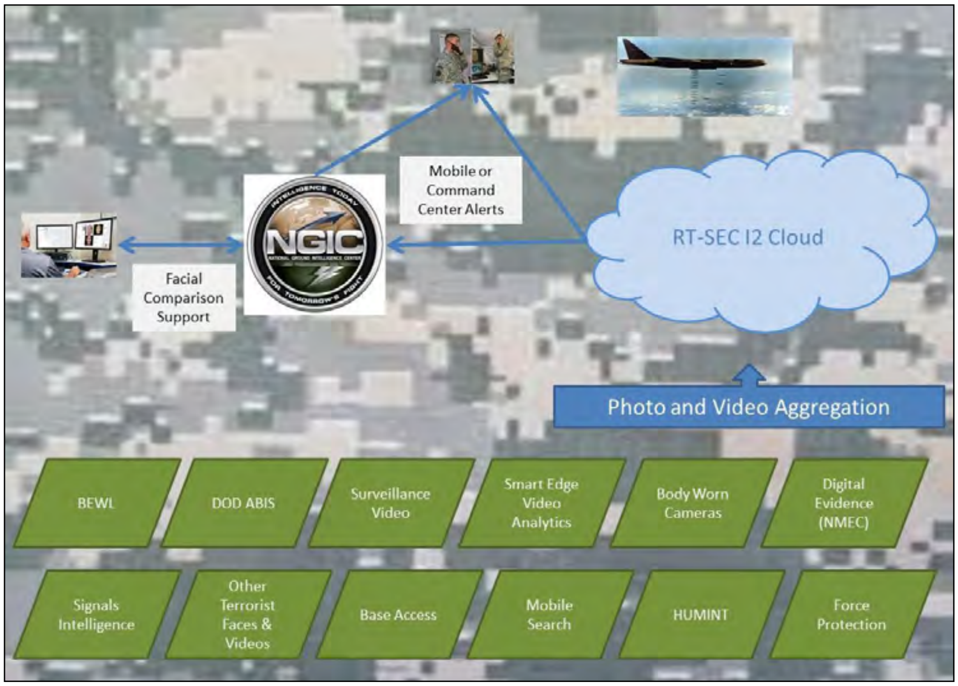

Figure 1: Illustration of the anticipated data sources that could be demonstrated in the RT-SEC proof of concept. (Released)

rules specific to the DoD, will exploit disparate data sources of faces and videos with unprecedented speed and accuracy. Additional technologies that augment the RT-SEC capability can be evaluated for subsequent integration to continually improve upon the critical infrastructure protection. This identity intelligence capability can be achieved rapidly based upon the current state of these technologies, and it has the potential to directly assist in protecting the United States against the threat of terrorists and other enemies.

The RT-SEC will support and demonstrate a range of alert options. The end goal is to get alerts to the warfighter down-range at unparalleled speeds. Equally as important, the data that before would remain dormant or take extensive time to exploit can be made available to the forces in near real-time. These identity intelligence alerts or products will enable real-time decisions in special operations worldwide. The alert infrastructure will support command and control when adjudication or strategic operations are required (See Figure 1).

Figure 1 illustrates the anticipated data sources that could be demonstrated in the RT-SEC proof of concept. The overall concept could be demonstrated without operational data to prove the theory of SAFE. Whether the data is operationally relevant, or simulated, the information from these sources will be transmitted in large volumes to the RT-SEC Identity Intelligence Cloud or virtual environment. The video analytics and face recognition will occur in near real-time to generate the alert infrastructure. Data sources anticipated to be a part of the RT-SEC include, but are not limited to: the BEWL, representative data from Automated Biometric Identification System enrollments, surveillance video, information from the smart edge video analytics technology solution to support low-bandwidth constraints, body-worn cameras, representative data from the National Media Exploitation Center and Signals Intelligence, terrorist face archives from other sources, base access enrollments, mobile searches (such as smart phones or Handheld Interagency Identity Detection Equipment devices and human intelligence source data), and force protection generated information. Today, these DoD data sources have no way to co-mingle in a single environment to support near real-time alerts to the warfighter; but through RT-SEC this is made possible.

The RT-SEC Identity Intelligence Cloud concept is based on facial recognition from images and photos, but could easily extend to other technologies. For example, the solution could demonstrate the ability to detect movement in selectable areas, loitering, crowding, and occupancy counts. For vehicles, the solution could validate the ability to detect movement in a selected area; detect a vehicle crossing a line or tailgating; detect stopped vehicles; and perform speed analysis and license plate recognition. There are many promising advancements with video analytics, and the RT-SEC and SAFE concepts provide a framework to deliver these services to the warfighter. With the integration of more advanced analytics, the RT-SEC could demonstrate the ability to provide alerts on suspicious objects, protect assets, detect lights, and identify potential weapons. Collectively, the capabilities described with the RT-SEC concept are based on proven technologies. While facial recognition technology has not reached the maturity of fingerprints and DNA, it has been operationally proven to provide superior investigative proficiency. The RT-SEC pushes the technology to a new level. It provides an extensive safeguard for protecting military bases or other sensitive sites, demonstrating the ability to support a wide range of events that could pose threats to critical infrastructure.

SAFE Use Cases

Facilities and events are under constant pressure to increase their security posture. Methods for monitoring social media are rapidly progressing. Industry leaders not only deploy data aggregation and analytic techniques, but they use advanced linguistic interpretation to ensure threat information is fully interpreted and searchable in its native language. Likewise, this country has a comprehensive national screening solution comprised of the large-scale biometric systems at FBI, DHS and DoD. Each of these systems of record plays a critical role in keeping threats from entering the country, protecting the warfighter, or preventing crime.

The data used to support this mission, however, has broader applicability. For example, the biometric data of people who may be building improvised explosive devices should be shared with the correct personnel to help prevent their entry into critical infrastructure or to major events. Also, troves of threat information have been collected from signals intelligence and from digital evidence. Robust systems exist to collect and store this information, but exploitation must cut across multi-intelligence stakeholders. The DoD proof of concept for RT-SEC provides a detailed example of how SAFE streamlines security safeguards and permits an infrastructure to support the ever-evolving threats to our society. With the SAFE concept, it becomes possible to understand that a person's photo that was derived from digital media collected from the Osama bin Laden raid could send an instant alert to the National Ground Intelligence Center if that person tried to gain access to a military base or a Department of Energy facility.

In another use case, think about a detainee that was released from Guantanamo Bay and was subsequently linked by the Terrorist Device and Analytic Center to a latent fingerprint in an improvised explosive device that killed dozens of U.S. military troops. The goal is to ensure that the photo obtained from the detainee is available to support real-time surveillance at critical infrastructures worldwide, military bases, embassies and major events so it can be made actionable anywhere. While SAFE serves as a concept, the building blocks exist today to merge much of the existing face and video data and provide near real-time alert capabilities from live streaming surveillance video that searches across SIGINT, digital evidence, social media, and a range of other critical information. These technologies have been implemented independently with great success and continue to be adopted within the U.S. government as well as commercially.

While sophisticated techniques improve our ability to monitor social media, there are still short-falls with the technology. Beyond stopping an imminent incident, the most critical capability to support the investigation is to identify people involved with planning or intending to execute the attack. Video and image data exist within social media, but it is currently not being leveraged. This information is often rich with identifying data that is otherwise unknown. Manual searching through this data is a daunting challenge, but video analytics and face-recognition automated technology offer a potential solution core to the SAFE concept. Facial recognition technology has the power to search millions of records within seconds, as demonstrated through large-scale biometric systems worldwide.[4], [5] The country of India, for example, has a national database that exceeds one billion records. SAFE can leverage this technology and exploit data in ways never before possible.

SAFE Summary

The SAFE concept fuses data that comes from social media and other threat information that comes from exploitation software (biometric modalities and items-of-interest images) with enhanced video surveillance data at a specific location to provide real-time actionable intelligence and vulnerability assessments. The enhanced video surveillance algorithms can be integrated into any existing facility that has a surveillance hardware infrastructure. With the software, users can rapidly customize alert features based on priority security needs of the facility and known local threat trends. The facial recognition feature cross-correlates between video data and social media pictures and video. The platform will be able to provide 1) predictive threat modeling based on historical data collected, and 2) real-time vulnerability assessments as threats are detected. ■

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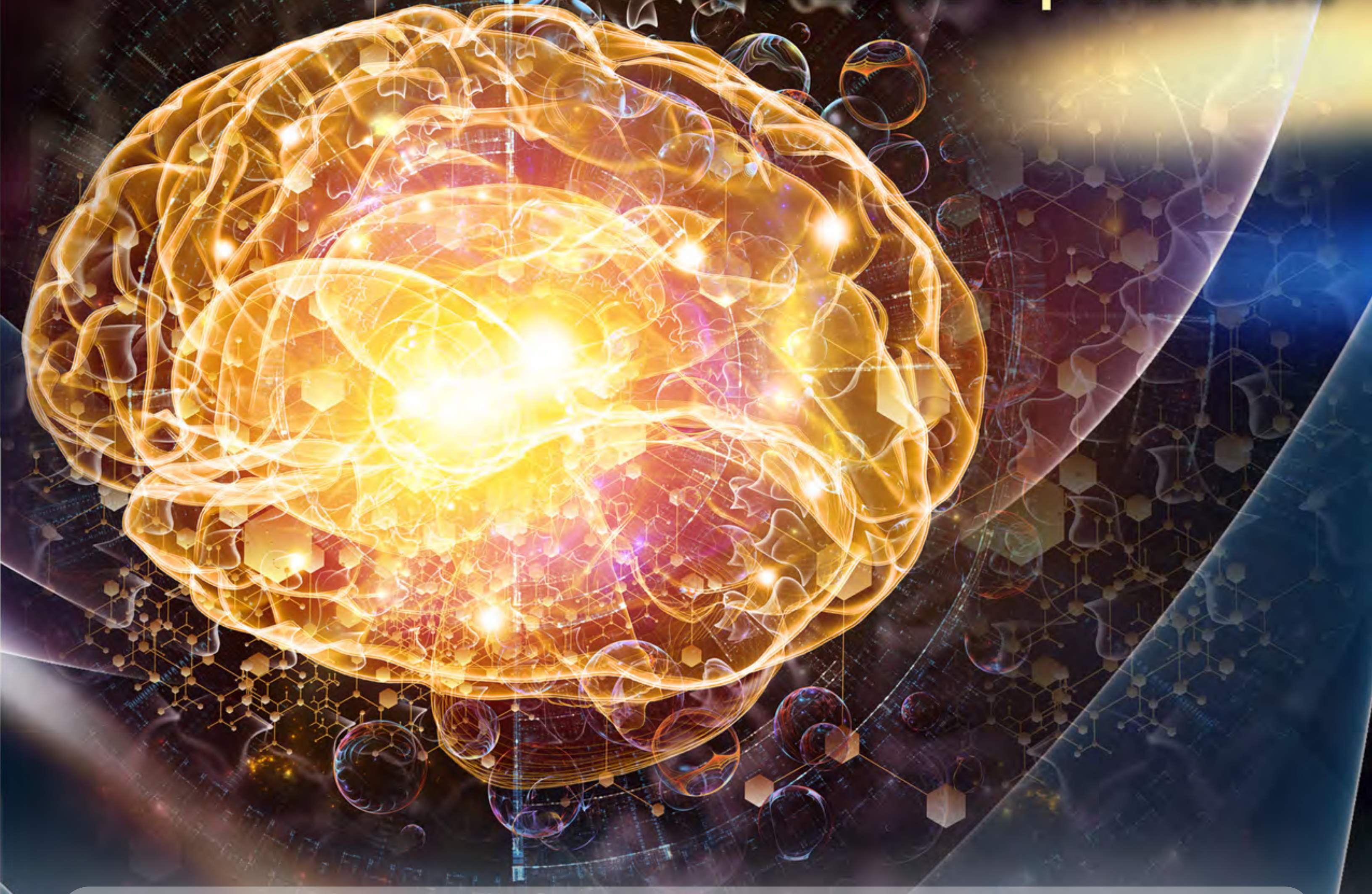
Battlescape Brain: Engaging Neuroscience in Defense Operations



By: James Giordano, Ph.D.

Neuroscience and Technology in Defense Contexts

Recent convocation of participatory parties in the Biological and Toxins Weapons Convention has prompted a renewed focus upon which, how and to what extent currently available and/or new biotechnologies and techniques could be developed, weaponized and utilized. In this light, it becomes important to re-consider current progress and near future research and development of neuroscience and neurotechnology (i.e., neuroS/T), and the potential to employ neuroscientific tools and products in various domains of national security and defense.

At present, neuroS/T is being used in military contexts:

- For diagnostics and treatments of medical conditions;
- To create human-machine networks for optimizing particular types and dimensions of operational performance of military and intelligence personnel
- To develop non-lethal and lethal weapons

(for overviews of use in each and all of these ways, see [1]).

In the main, it is the latter two types of application that foster the most concerns. For example, as depicted in Table I, a variety of pharmacological agents (e.g., stimulants, including amphetamine derivatives; eugeroics, such as modafinil; and nootropics, such as the racetams) and brain-machine interfaces (such as EEG-based neurofeedback, transcranial magnetic and electrical stimulation, and brain-computer interfaces) can be employed to modulate activity within identified neurological networks operative in cognitive and motor processes and functions to facilitate and/or optimize key performance elements instrumental to the training and capabilities of warfighters and intelligence operators. [2,3,4,5]

As well, neuroS/T can be weaponized to target neurological substrates and mechanisms that affect physiology, cognition, emotions and behaviors. As shown in Table II, such “neuroweapons” include drugs to degrade physiologic and cognitive functions, and/or to alter emotional states to affect the desire or capacity for aggression and combat; organic toxins that can induce neuromuscular paralysis and death; microbial agents (e.g., bacteria and viruses, inclusive of “bio-hacked”, genetically-modified organisms) that can incur various levels of morbidity – or mortality, and a number of technologies that can be used to alter sensory, perceptual, cognitive and motoric functions. [6,7,8,9,3]

Table I: NeuroS/T Approaches to Training and Performance Optimization

Pharmacologic Agents		
Stimulants	-Amphetamines (e.g. - dextroamphetamine)	Facilitated attention, focus, and arousal; decreased fatigue; improved memory.
	-Substituted phenylethylamines (e.g. - methylphenidate)	
Eugeroics	e.g. - modafinil; armodafinil	Increased wakefulness; decreased fatigue; facilitated reasoning.
Racetams	e.g. - piracetam, oxiracetam, aniracetam	Putative general ‘nootropic’ effects; increased focus.
Neurotechnologic Methods		
EEG-based Neurofeedback	Increased vigilance; directed attentiveness; improved concentration	
Transcranial Neuromodulation	**(e.g.- TMS; tES)**: Improved vigilance; increased focus; improved cognitive reaction time.	
EEG-based Brain-Computer Interfacing (BCI)	Facilitated signal-noise/object recognition and discrimination	
Abbreviations		
TMS	Transcranial magnetic stimulation	
tES	Transcranial electrical stimulation (e.g. - direct, alternating and/or pulsed current stimulation)	

For further detail see: [4, 2, 3, 5]

Current Conventions, Defining “Neuroweapons” and the Dilemma of Control

Obviously, research, production, and stockpiling of defined neuro-microbiologicals, and select chemicals and toxins are constrained and/or proscribed by the extant BTWC and Chemical Weapons Convention. However, other neurobiological substances (e.g., pharmaceutical formulations of neurotropic drugs, organic neurotoxins and bio-regulators) and neurotechnologies (e.g., neuromodulatory devices) developed and utilized as medical products might not, and these are readily and commercially available. [7,9]

As noted in a 2008 report of the National Research Council of the National Academies of Sciences entitled Emerging Cognitive Neuroscience and Related Technologies, products intended for the health market can be, and often are studied and developed for possible employment in military applications (e.g., to optimize or degrade aspects of human performance [10,11]). In the United States, any such activity in federally funded programs would be subject to oversight in accordance with dual-use research of concerns policies (of 2012 and 2014), reflecting the general tenor of the BTWC and CWC to date. [12]

But while such oversight and regulation constrains dual-use neuroS/T research in participatory states, it may provide opportunities for non-participatory countries and/or non-state actors to make in-roads in such enterprises to achieve a new balance of power. [13] Indeed, neuroS/T is an international endeavor, and a number of nations are engaged in dedicated programs of neuroS/T research with defense applications that may exert global strategic influence. [14] Moreover, neuroS/T research and development need not be illicit; exemptions for health and routine experimental use may foster a grey zone within which investigations for viability and employment as weapons may be undertaken.

The dedication of private and/or governmentally-supported industrial efforts to neuroS/T research and development could also enable and (at least be argued to) justify postures and protocols of diminished transparency, as commercial interests can be shielded as means to protect proprietary interests and intellectual property. Under such veils, dual-use agendas can be fostered and developed. An additional concern is that neurobiological and neurochemical substances and certain neurotechnologies can be obtained and/or developed (i.e., “bio-hacked”) with relative ease by individual non-state actors who may be supported by state-endorsed venture capital, and who may operate without regard for regulations defined by the current BTWC, thereby creating further opportunistic windows for influence.

If we define a weapon as, “a means of contending against another...to injure, defeat, or destroy,” [15] the question is not if, but to what extent the brain sciences could – and likely will - be engaged in such pursuits. Given such possibilities and probability for use, military applications of neuroS/T should not be overlooked or disregarded. Neuroweapons should not be considered for their mass destructive effect(s), but rather, should be acknowledged for their capability for amplified disruption that is executable on a variety of levels, from the individual to the political. This is particularly true of hybrid and asymmetrical engagement scenarios, in which the desired outcome is an increasing “ripple effect” resulting from a relatively small initial insult.

Furthermore, the ability to utilize neuroS/T to gain influence on the global stage is not limited to warfighting applications. The growing prominence of non-Western nations in neuroS/T research and production may afford greater leverage, if not purchase, to effect “strategic latency” (i.e., the potential to evoke significant shifts in the balance of power) by manipulating health care and biotechnology sales markets to affect socio-economics, and international relations. That neuroS/T can, and likely will be engaged for dual-use serves to fortify the strategic latency impact. [16]

Over the past decade, several academic papers and books, and international governmental reports have focused upon the military and dual- use potential of neuroS/T. [17,7,18,19] Initial studies, like the 2008

urotechnology

National Research Council report [10] and the 2014 report of the Temporary Working Group of the Organization for the Prohibition of Chemical Weapons, [20] illustrated military interest in, and potential utility of neuroS/T, but were equivocal about realizing capabilities, and/or the threat of such neuroS/T development and use by hostile groups. However, with progress in the field, the subsequent 2014 National Academies' report Emerging and Readily Available Technologies and National Security: A Framework for Addressing Ethical, Legal and Societal Issues [21] clearly and definitively elucidated the viability and prospects of neuroS/T in international military and security scenarios. Indeed, given the pace, scope and investment(s) in the brain sciences, and the means that neuroS/T affords to "affect minds and hearts", current capabilities – and limitations – can rightly be seen as prompts to overcoming existing challenges, and increasing future opportunities. [22,23,6]

The Need for Deep Surveillance

In light of this, I opine that there is a need for increased surveillance of international neuroS/T research and development efforts and agendas. This will require more nuanced insights to the ways that current and near-term developments in neuroS/T could be exploited in security and defense operations, and the direct and manifest effects that such use might evoke. The scientific literature can be useful to assess current trajectories of neuroS/T research developments and advancement. Profiling recent and current literature for trend analysis in neuroS/T research and development is certainly important both to gauge progress, and to gain insights to what types of current tools and techniques could be usurped into use as weapons. But pulsing the literature is not sufficient, as information dissemination may be restricted in proprietary or otherwise classified projects, and/or publication may not be an option (or necessary contingency) for those personnel who have been recruited and are employed (by states or non-state organizations) to conduct research on a strictly financial quid-pro-quo basis.

Thus, surveillance should focus upon (1) university and industrial programs and projects in neuroS/T research, development, test and evaluation that have direct, dual-use and/or viable security and/or intelligence applications; (2) the extent and direction(s) of governmental and private investment in and support of neuroS/T research and development; (3) efforts toward recruitment of researchers and scholars with specific types of knowledge and skills; (4) product and device commercialization, (5) current and near-future term military postures, and (6) current, near- and intermediate-term market space occupation and leveraging potential. While requiring more finely grained investigation and more extensive intelligence, this level and type of surveillance is of high value for empirical, analytic modeling and gaming approaches to plot realistic contexts and trajectories of neuroS/T development and use, generate outcomes' speculation, and formulate contingency planning. [24] And, as Sonia Ben Ouagrham-Gormley (2015) recently noted, [25] appreciation for tacit knowledge of the personnel involved in international neuroS/T research and production will be crucial.

But here a caveat is warranted: the 2008 National Academies Report cautioned that surveillance-based identification of efforts to produce weaponizable neuroS/T could lead to a spiraling reaction of testing and production of countering (and/or more effective) agents. [10] These reactions will likely not be limited to incapacitating agents and devices, but will also be focused upon those techniques and technologies capable of optimizing human performance. The 2014 National Academies Report readily acknowledged the realistic possibility of escalating neuroS/T research and development (within an integrative multidisciplinary paradigm), its potential to affect international security, and the ethical, legal and social issues, questions and problems arising in and from attempts to monitor and effectively regulate both use and escalation. [21]

Indeed, as the changing perspectives of the 2008 and 2014 National Academies' reports demonstrate, the use of neuroS/T in military and insurgency settings is no longer viewed as a proverbial "Chicken Little" (i.e., "sky is falling") scenario of exaggerative claims and fears. [10,21] NeuroS/T has become ever more capable, and it's interest to, and role in military and insurgency settings is now evident and increasing. [8]

Table 2: Weaponizable NeuroS/T

Pharmacologic Agents	
Tranquilizing agents	e.g. - Benzodiazepines; barbiturates; neuroleptics; etc.
Mood altering agents	e.g. - Monoamine agonists and re-uptake blockers
Affiliative agents	e.g. - Methylenedioxymethamphetamine-MDMA; oxytocin
Dissociative agents	e.g. - Ketamine; phencyclidine
Psychedelics/ Hallucinogens	e.g. - Lysergic acid diethylamide; tryptamine derivatives; psilocybin
Cholinergic agents	e.g. - Pilocarpine; physostigmine; (RS)-propan-2-yl-methylphosphonofluoridate [sarin]
Microbial Agents	
Viruses	e.g.- Togaviridae: Equine encephalitis; Flaviviridae: flavivirus
Bacteria	e.g.- Bacillis anthracis: anthrax; Clostridium botulinum: botulism; cyanobacteria; Gambierdiscus toxicus: cinguatoxin
Organic Toxins	
Bungarotoxins	Krait snake toxin
Conotoxins	Cone snail toxins
Dendrotoxins	Mamba toxin
Maculotoxin	Blue-ringed octopus symbiotic bacteriotoxin
Naja toxins	Cobra toxins
Saxitoxin	Shellfish toxin
Tetrodotoxin	Pufferfish toxin
Neurotechnologies	
Neurosensory immobilizing devices	High output sensory stimulators (to evoke disorientation/discomfort)
Transcranial neuromodulating devices	Neural network stimulators for use in in-close operations against individual actors/targets
Nano-neuroparticulates	High CNS aggregation lead/carbon-silicate nanofibers (CNS network disrupters)
	Neurovascular hemorrhagic agents (for in-close and population targeted use)

****For further detail see: [3,7]***

The recent convening of the State Parties of the BTWC fortified that a clearer view of the ways that neuroS/T is — and can be — employed within these scenarios is important to effectively depict risks and threats. The BTWC should continue to work to revise definitions of what constitutes a bioweapon, what is weaponizable and establish grounding criteria upon which dedicated efforts to more accurately assess and analyze neuroS/T research and development can be structured.

Toward What Response?

Still, there is question as to what extent international research efforts in neuroS/T should – and realistically can – be regulated. Projective and prescriptive ethical ideals can be developed, and these can be useful in formulating guidelines and policies that are sensitive and responsive to real-world scenarios of biotechnological research and its translation. [26] But the flexibility of these approaches also means that they are not conclusive, and the relative fluidity (or diversion) of neuroS/T between healthcare and dual-use or military applications demands due diligence to evaluate any such uses within the often blurred contexts (and "fuzzy" distinctions) of public health, political and military ethics, and the reach and rigor of international treaties and law. So while it is clear that the "sky is not falling," it remains to be seen if and how we may be best prepared for – and respond to - the possibilities that the building clouds of neuroS/T capability portend for the future. ■

Acknowledgements

This work was supported in part, by funding from the Lawrence Livermore National Laboratory.

Disclaimer

The views expressed in this essay do not necessarily reflect those of DARPA, the Joint Staff-Pentagon, the United States Department of Defense, Lawrence Livermore National Laboratory, or the United States Department of Energy.

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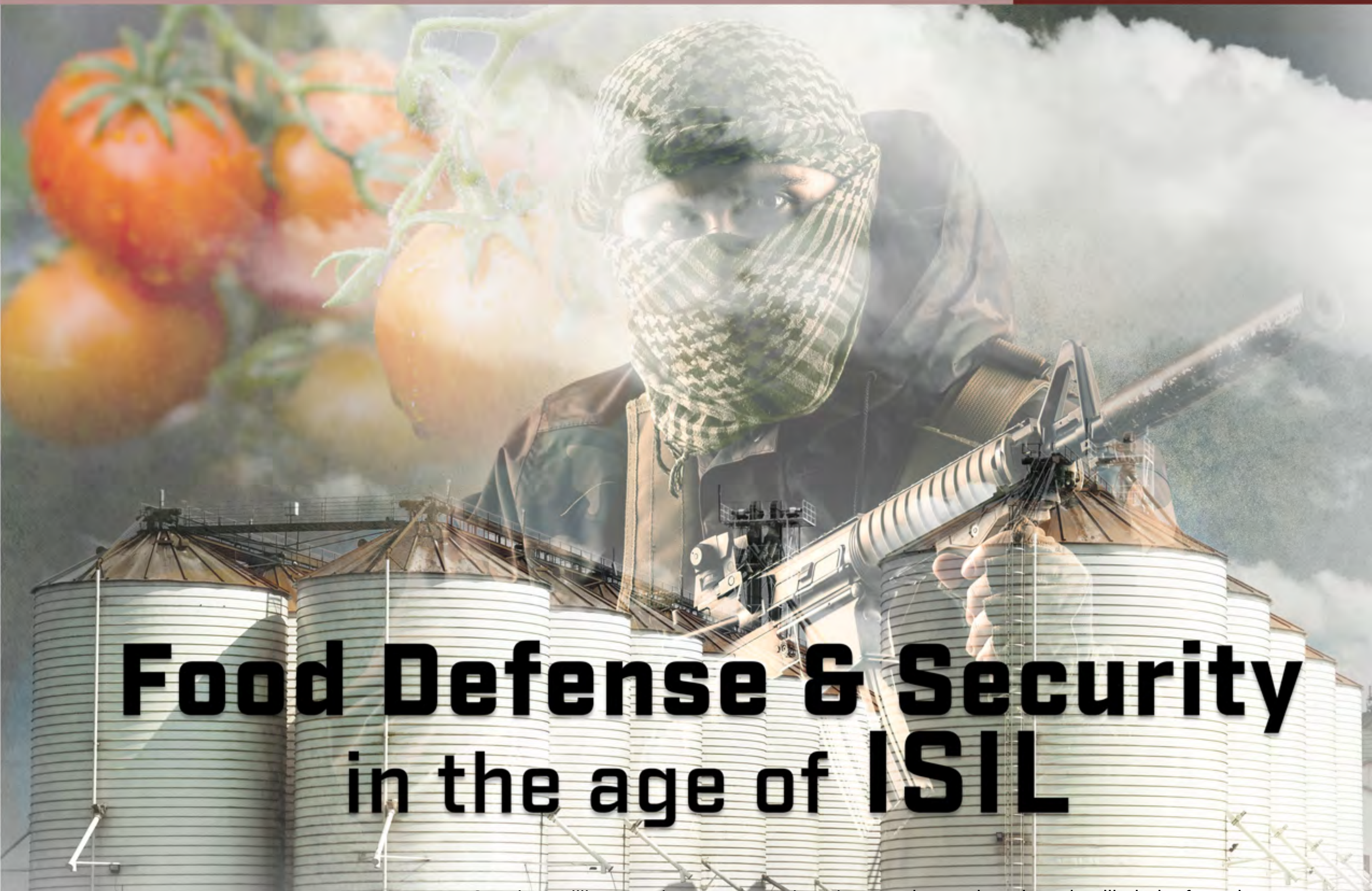

Food Defense & Security in the age of ISIL

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Introduction

The food and agriculture sector is one of the United States' 16 critical infrastructures, [1] supplying a safe, economical and abundant food supply to the consumer, as well as the warfighter. As a general rule, foods sourced in the United States or produced under conditions which meet U.S. pre-harvest and harvest regulatory standards pose little to no risks, beyond those already addressed and mitigated by food sector–specific screening tests and standard operating procedures for food handling and processing.

The United States has not known widespread hunger since the Great Depression (1929-1939), when, at its height, between 13 and 15 million people were unemployed. [2] Currently, the United States Department of Agriculture's Food and Nutrition Service administers large-scale and comprehensive programs designed to prevent and mitigate hunger in the U.S. population. While these programs provide mechanisms for food support in time of need, they also could unintentionally enable vulnerability. The current generation of Americans is not accustomed to storing food for emergencies or finding alternate food sources should the food supply be disrupted on a large-scale or for an extended time. Complicating this, the food supplies on-hand in major U.S. cities are generally understood to be sufficient for only three days, although this does not take into account regionally warehoused supplies, which move quickly through normal distribution channels.

The southern United States is subject to seasonal hurricanes, ice storms and other large-scale weather events, so it is not uncommon to see emergency supplies moved into big-box stores in anticipation of major weather events. Depending on public concern, consumers may empty the shelves of staples such as bread, milk, baby formula, water and toilet paper during an intense flurry of short-term stockpiling. As weather emergencies worsen, transportation companies pull tractor-trailer trucks off the road to avoid damage as conditions deteriorate, disrupting the efficient system of food distribution.

This disruption is usually short-term if transportation systems remain intact and can be rapidly restored after a severe weather event. Private sector distribution resumes, providing consumers with necessary food supplies. In disasters like Hurricanes Katrina and Rita (2005), however, recovery of adequate food supplies was delayed because transportation infrastructure was seriously damaged.

The possibility of significant localized or regionalized shortages looms. At such times, cooperation among federal and state governments – along with the private sector, utilities, and non-government organizations – is vital for timely restoration of food and potable water supplies.

Intentional Contamination

Food and water supplies require protection from intentional adulteration caused by insider threats (such as disgruntled employees) or by organized terrorist groups such as the Islamic State of Iraq and the Levant, whose sympathizers or members could infiltrate companies in the food and agriculture sector.

Contamination of a single ingredient, such as wheat or eggs, could spread contamination into a wide variety of products, thereby magnifying the event's scale. Loss of faith in the integrity of domestic food or water supplies would alarm the public and might cause civil unrest until an alternative safe supply can be identified, mobilized, delivered and accepted.

A secondary—but not insignificant—element in any intentional food or water contamination event would be the effect on "brand quality" or "brand confidence." Food corporations work to create a brand that symbolizes quality and trust. When something damages or destroys that image, the economic effects on the company can be devastating.

Imagine a scenario where a staple like milk or bottled water is intentionally contaminated, which happened in China in 2008, when unscrupulous dairies used powdered melamine to disguise watered-down milk and infant formula. [2] This kind of economic devastation should be recognized in the "big-picture" context of the safe and secure food supply that is part of national security.

If the national food defense strategy fails to recognize farming as essential infrastructure, the immediate effect on the milk- and dairy-products market would be swift, perhaps even existential, because the company "brand" associated with such an attack could be put out of business.

In China, public trust was irrevocably shattered as consumers and the press considered the possibility that the milk supply as a whole—rather than just milk produced by one corporation—was contaminated and as they recognized the reality that no effective federal oversight existed. [3] In the U.S., the short- to medium-term effects would be that large quantities of milk and dairy products would be recalled and destroyed out of an abundance of caution. In a sufficiently large-scale event, overall supply would suffer. The cost of other foods would increase as companies compete for milk or milk products such as cheese, butter, and whey.

Groups such as ISIL understand very well the potential psychological impact of contaminating food and water. In 2015, 45 ISIL members died in Mosul, Iraq, when unknown persons appear to have intentionally contaminated their Iftar meal, the ceremonial end of the religious fast each evening during Ramadan. [4,5,6] To date, no publicly available information has revealed the exact nature of the event, although given the rapidity of the deaths it is likely that a rapid-acting toxic substance was involved rather than a foodborne pathogen.

ISIL leadership experienced firsthand how such an event instills fear and terror, possibly priming them to use poison to eliminate those considered enemies. Whether ISIL has the capability to deliver a major blow to U.S. food and water supplies is a discussion best reserved for other forums, but there is clear and openly available evidence indicating that ISIL recognizes the importance of critical infrastructures to the U.S. and would like to damage them significantly.

Defending the U.S. Food Supply

How should the United States address the full spectrum of potential threats to the food and water supply, whether of natural or terrorist origin? How does the U.S. defend the food supply?

Food defense is not just a "whole of government" issue, but rather a national problem, especially since the majority of players in this sector function outside of government. In other words, government assets and policies are important for protecting food and water, but the private sector and academia are also important and therefore must also be part of the solution.

In response to these needs, faculty in the Auburn University colleges of Agriculture, Engineering, and Veterinary Medicine have established a Food Defense Working Group [7] to leverage resources and address the full spectrum of needs. Working group members take a holistic approach, [8] from long experience recognizing the food and agriculture sector's complexity. The group understands threats may come in many forms and from many directions and are convinced that practical, economically sound preparedness plans and solutions must be developed so that farms, ranches and companies in the food and agriculture sector remain profitable and viable. Their survival is fundamental to assuring that a safe, economical, robust and abundant food and water supply continues to remain available. The food and ag sector industry voice therefore must not be lost, since industry knows the intricacies of its daily operations far better than government.

In simple terms, food defense and food safety are two sides of the same coin, connected in that the lack of one element makes the other element more susceptible to intentional threats. Current U.S. Food and Drug Administration regulations call for companies to create and maintain food defense plans, [9] "Each covered facility is required to prepare and implement a food defense plan. This written plan must identify vulnerabilities and actionable process steps, mitigation strategies, and procedures for food defense monitoring, corrective actions and verification."

Warfighters must be guaranteed a food supply at least as safe and reliable as that expected by the consumer. The Department of Defense has developed shelf-stable MREs (Meals Ready-to-Eat), which are supplied to warfighters for consumption of relatively short duration in situations where alternate and safe options of fresh food are unavailable. Difficulties have arisen and potential vulnerabilities have emerged when warfighters consume fresh or processed foods supplied by certified DoD vendors, which are frequently sourced, prepared and served by local contractual employees. Although the food is subject to the same inspection standards as in the United States, the presence of non-U.S. personnel in the food handling areas and the potential for intentional contamination cannot be discounted.

Robust strategies are therefore necessary to prevent food and water contamination by adversaries and must evolve as threats evolve. Here too, food corporations and experts outside of the Department of Defense can provide expertise and alternative views for developing strategies to deal with potential threats.

The Spectrum of Threats to the Food Supply

Threats to the food supply can take many forms, the majority of which do not originate with terrorists or adversarial state actors. By far the biggest concern for food corporations is the adulteration that can result from the actions of a disgruntled employee working within the production and processing cycles. Since the food supply is the result of a highly complex system of systems, each with its own set of vulnerabilities, food defense must be comprehensive, starting with all the inputs (ingredients) and following through to the actual food product outputs, which are then transported to wholesalers, retailers and ultimately the consumer, whether civilian or military.

Common to all elements of the system is the human element, because if compromised by someone seeking revenge or economically motivated to do harm, the systems of protection can be circumvented and thereby compromised. A recent example, in June 2016, of a disgruntled employee occurred at the St. Cloud, Minnesota-based GNP Co., which was forced to recall 27 tons of chicken, under its Gold'n Plump and Just Bared Brands, when it was discovered that an employee had intentionally put sand and black soil in the company's products. [10]

Remotely launched cyber-attacks are increasingly emergent as a persistent problem directed at food corporations. Industrial control systems used in food processing can be made to alter processes (e.g. cooking temperature) thereby compromising food safety, or else proprietary operation relational information can be extracted.

Proprietary information theft has also become a huge problem for the food industry. In many cases these remote attacks are not the result of amateurs hacking into systems, but instead originate from adversarial foreign states, such as China and Russia, who seek to gain an unfair economic advantage for their food production and processing industries, without requiring investment in infrastructure or process development. Modern cyber-based food control systems must be sufficiently robust to achieve real-time detection of hacking and malware intrusion attempts. The systems must also assure that the resulting food product meets all requirements associated with regulatory food safety and nutrition compliance, including traceability (lot and processing date) – often even to point of origin – and consistent with all specification requirements as set by the food processing company or its customers.

Food and Water Threat Agents

Food and water defense must consider a panoply of threat agents that could cause a loss of confidence in the food supply; these could actually cause the food supply to become unsafe should they be deployed in an actual event.

Planning by government agencies is often directed toward and concentrated on "high consequence, low probability" events such as the impact of botulinum toxin if introduced into the milk supply. However, the food industry is appropriately more concerned about "low consequence, high probability" events, which though localized still can have a profound effect on liability (e.g., contributing to the likelihood of personal injury lawsuits, as well as consumer perception of the brand quality and corporate image, both of which affect product marketability.

Food and water defense should consider the human element as the most important risk factor day-in and day-out. Insider threats, whether the result of disgruntled employees or actual adversaries or sympathizers of adversaries, are most likely not going to be sophisticated. Insiders are enabled by motivation, ID badge/card-key access and workshift-based opportunities, as well as their knowledge of specific vulnerabilities in their local food production processes and system controls or related to the water utility.

Disrupting the capability and opportunities available to an adversary (sophisticated or not) to intentionally contaminate food products and water seems an obvious first goal for a defense plan, but often may not be considered as a priority in the midst of day-to-day business operational requirements. This must quickly change since actions of a single employee are capable, given the right circumstances, to quickly bring a company to the brink of financial disaster.

Chemical Agents

Common chemical agents are likely to be used by unsophisticated adversaries, where as highly concentrated odorless, tasteless and colorless chemical agents are more likely to be available to and utilized by agents of rogue states. Potential chemical agents include industrial chemicals, lubricants and cleaning agents, as well as those on the Environmental Protection Agency's "List of Extremely Hazardous Substances and Their Threshold Planning Quantities." [11] Any of these could cause death should they be introduced into the food supply, but due to qualities of pH, taste, etc., most of them are unlikely to be effective.

Industrial chemicals have caused population-level problems in the past. Of particular concern are those which are highly persistent, such as brominated flame retardants, [12] organophosphates, dioxin and PCBs, [13] all of which have been associated with food and animal feed contamination events.

From the perspective of concentrating on high probability events associated with ready access and availability, the food industry should be most focused on preventing accidental or intentional contamination of food products by industrial chemicals, lubricants and cleaning agents that are already present in food production and processing facilities.

Biological Agents

Biological agents are likely to be beyond the capability of most unsophisticated adversaries. The Biological Weapons Convention is a legally binding treaty that outlaws biological arms. It was signed by 165 nations and has been in effect since 1975. Any time the presence of biological weapons is confirmed and proven intentional, the involvement of sophisticated and well-financed adversaries such as ISIL, or other rogue nation states is implied. If a nation state, the intentional use of biological weapons is addressed by the BWC treaty and is considered an act of war. Of prime concern in the investigation of a foodborne outbreak is the ability to discern what is unintentional contamination, versus that which is not.

The Centers of Disease Control and Prevention has described more than 250 different agents of foodborne disease, including algae, bacteria, molds and fungi, viruses, parasites and their related toxins. Naturally-occurring foodborne diseases caused by bacteria include botulism, brucellosis, infections caused by Campylobacter, Clostridium perfringens and *Escherichia coli*, Listeriosis, salmonellosis, shigellosis and vibriosis. [14,15] Each could be introduced in the food supply inadvertently through contamination or intentionally as criminal acts of terror or biological warfare.

As CDC stipulates, "When two or more peo-

The Spectrum of Food & Water Threat Agents Summary

Chemical Agents

- **Industrial chemicals**
  - Brominated flame retardants
- **Organophosphates**
  - Dioxin
  - PCBs
- **Lubricants**
- **Cleaning agents**
- **Chemicals on the on the Environmental Protection Agency's "List of Extremely Hazardous Substances and Their Threshold Planning Quantities"**

Biological Agents

- **Examples of Foodborne Disease Agents**
  - Algae
  - Bacteria
  - Molds and fungi
  - Viruses
  - Parasites and their related toxins.
- **Foodborne Diseases Caused by bacteria**
  - Botulism
  - Brucellos
  - Infections Caused by Campylobacter
  - Clostridium Perfringens & Escherichia coli (E. coli)
  - Listeriosis
  - Salmonellosis
  - Shigellosis & vibriosis

Toxins

- **Bacteria**
- **Fungi & Algae**
  - Aflatoxins on crops (B1, B2, G1, G2)
  - Aflatoxins in milk (M1 and M2)
- **Plants**
- **Seafood Related**
  - Cyanobacteria
  - Tetrodotoxin
- **Eukaryotic animals**
  - Shellfish
  - Reptiles
- **Industrial chemicals**
- **Pharmaceutical**
- **Food-preservation chemicals**
- **Processes**
  - Grilling
  - Fermentation

***Continued on page 22**

ple get the same illness from the same contaminated food or drink, the event is called a foodborne disease outbreak." [16] In 2015, the CDC monitored 17-40 potential food poisoning or related clusters each week, and investigated more than 195 multistate foodborne outbreak clusters, which led to the identification of confirmed or suspected vehicles of transmission and subsequent recalls of chicken, pork, sprouts, cheese, ice cream, nut butter, cucumbers and raw frozen tuna food products. [16]

As of 2016, multistate foodborne outbreaks in the U.S. due to naturally occurring bacterial contaminants have included alfalfa sprouts (Salmonella Reading and Salmonella Abony), [17] flour (*E.coli* 0121 and 026), [18] frozen vegetables (Listeria monocytogenes), [19] raw milk (Listeria monocytogenes), [20] pistachios (Salmonella montevideo), [21] alfalfa sprouts (*E. coli* O157; Salmonella muenchen and Kentucky), [22,23] shake and meal products (Salmonella virchow) [24] and packaged salads (Listeria monocytogenes). [25]

A Closer Look at Select Bacterial Toxins

Depending on the specific food item and the time, temperature, pressure, acidity, salinity and amount of water used during processing, most bacteria are killed during cooking and processing, including select agents such as Clostridium botulinum and Bacillus anthracis and their associated toxins.

Some particularly hardy thermoduric and psychrophilic bacteria are able to survive processing and may subsequently replicate in foods. Time-temperature-pressure charts constitute essential food science technical knowledge and are the basis for food industry based "Good Manufacturing Practices," including "use by" dates and holding temperature requirements (refrigeration/freezing) for foods such as milk, uncooked meat and eggs. Shelf-stable ultra-pasteurized milk and packaged meals are sterile as produced; however, they do not remain so once opened. Shelf-stable items must be promptly used, refrigerated or frozen to retard bacterial growth and preserve product wholesomeness, similar to any conventional product.

A good example is Staphylococcal enterotoxin B, or SEB, which is among the most common form of food-poisoning due to post-market bacterial contamination. SEB causes numerous cases of household and institutional food poisoning, usually attributable to unsafe household food handling practices (leaving foods out on the counter at room temperature) by the food preparer or other household consumer. All of the examples above illustrate how a bacterially contaminated food product can be widely dispersed across the country or even the world, causing a disease outbreak over a large geographical distance or population.

In some cases, naturally occurring events may be difficult to discern from those caused intentionally, since the latter may be purposely masked, may be locally targeted rather than widespread and may not involve unusual pathogens, thus mimicking naturally-occurring foodborne disease events. Future efforts for monitoring and protecting the modern food supply will necessitate development of faster methods for detection and identification of bacterial pathogens.

Toxins

Toxins capable of causing disease originate from many sources, including bacteria, fungi, algae, plants, eukaryotic animals such as shellfish and reptiles, as well as industrial chemicals, pharmaceuticals, food-preservation chemicals and processes such as grilling and fermentation. The use of toxins to cause foodborne disease strongly implies criminal intent. There is general agreement among experts that use of certain purified and concentrated toxins connotes a level of sophistication not generally associated with lone terrorists or ordinary criminals, rather than with disgruntled employees. Rather, such events instead suggest well-funded adversaries who are unusually knowledgeable and well-equipped. If the involvement of a nation state in such an event is proven, it may be considered an act of war.

Among the toxins produced by fungi and algae the most important are the aflatoxins (B1, B2, G1, G2), produced by Aspergillus fungi). The United Nations Food and Agricultural Organization estimates that globally, 25 percent of crops are affected by mycotoxins, among which aflatoxins are the most problematic.

Aflatoxins occur on a wide variety of crops (corn, tree nuts and peanuts, cottonseed, figs and spices) in the field prior to harvest, and extensive post-harvest contamination may occur if conditions of storage are not sufficiently dry. Aflatoxin M1 and M2 are toxic metabolites found in milk and dairy products of cows which ate grain that had aflatoxin contamination. Because aflatoxins are hepatotoxic and carcinogenic to humans and animals, the FDA has established "action level" thresholds of 5 ppb for M1 and M2 in milk and 20 ppb for aflatoxins in other human foods and animal feeds. Detection of a violative level of aflatoxin requires removal of the affected commodity lot from commerce. [26]

Seafood-related toxins are produced by various species of marine and freshwater algae and cyanobacteria (blue green algae), which are then concentrated by filter-feeding shellfish, including clams and oysters. Human exposure is primarily controlled by state health department regulatory closure of affected shellfish beds, with enforcement by state and federal fishery authorities. Tetrodotoxin [27] is a highly bioactive neurotoxin produced by marine bacteria in the Vibrionaceae family, which concentrates in the liver and gonads of certain species of Puffer Fish ("fugu" sushi), Globe Fish and Toadfish (order Tetraodontiformes), as well as some amphibian, octopus and shellfish species. These species are not commercially fished in U.S. waters or legally imported, and therefore are not of prime concern to the U.S. food industry, but do occasionally appear as smuggled goods, and therefore could theoretically enter the food supply in limited quantities.

Radiological Material

Although highly unlikely, radioactive materials, particularly those more commonly available or associated with other industrial processes (such as radiation sources for diagnostic imaging and X-ray inspection of pipeline welds) could be used to contaminate animal feeds or food stuffs. Delivery of those materials associated with other industrial processes would be exceedingly difficult and likely detectable. Such actions would require that a motivated criminal or radicalized individual with some level of technical knowledge gain access to a food processing plant in order to contaminate milk, meat, eggs, produce, or access to animal feeds on-farm or at a feed mill during commercial processing. Less problematic materials on the other hand could be delivered by less sophisticated adversaries. One example:

> Gas lantern mantles contain thorium to produce incandescence when lantern fuel is burned on the mantle. Although only thorium is initially present on the mantle, the thorium daughters build up, some over a period of weeks and some over a period of years, and significant quantities of these daughters are present when the mantle is used. Some of these daughters are released when the lantern fuel is burned on the mantle. [28]

If potential threats to the food and water supplies were to emerge through U.S. or allied intelligence efforts, and deemed plausible, appropriate federal and state authorities working with industry experts could recommend or even require that radiation monitors be installed where foodstuffs enter and exit the processing plant, or water is sent to the consumer. Incidents involving radioactive materials are addressed according to the requirements of the Nuclear/Radiological Incident Annex of the U.S. National Response Framework. Multi-agency experts on the NRF Advisory Team for Environment, Food and Health would be convened to assess the incident and make response and mitigation recommendations based on the specific event.

> The Advisory Team includes representatives from EPA, the Department of Agriculture, the Food and Drug Administration (USDA), the Food and Drug Administration (FDA), the Centers for Disease Control (CDC) and Prevention, and other federal agencies. The advisory team develops coordinated advice and recommendations on environmental, food, health, and animal health matters for the Incident Command/Unified Command (IC/IU, DHS, the Joint Federal Office (JFO) Unified Coordination Group, the coordinating agency, and/or State, tribal, and local governments, as appropriate. [29]

Physical Hazards

There is a higher probability for the use of physical hazards to intentionally adulterate food, because this is attainable by all ranges of adversaries, including those with marginal capabilities. Physical hazards primarily bring to bear economic effects (costs of recall, etc.) rather than serious public health risks. Physical hazards have been intentionally introduced during food processing, but also unintentionally, usually as a result of equipment or process failures, carelessness or by accident. Potential contaminants include metal, plastic, paper, insects, rocks and dirt to name but a few. Because of the ubiquitous nature of insects, rocks and soil at the source farms, their introduction is generally avoided through rigorous process engineering, intensive maintenance schedules for equipment, and employee training. Most food industry processes also include highly sensitive metal detectors at the end of the production lines, which immediately identify any metallic contamination and remove the affected items.

Thus, actual ingestion of such materials is quite rare, but does on occasion occur, and may cause physical damage (mouth cuts, damage to teeth, esophageal or intestinal abrasion or other injury). If swallowed, medical monitoring and appropriate intervention may be required. These materials are most frequently used by disgruntled employees – who have both opportunity and access – to halt production and cause a costly business disruption. A recent example of intentional contamination involved a disgruntled employee who added dirt and sand to poultry products. [10] The financial impact of such events may be significant; large quantities of affected food have to be recalled, damage to the corporate brand is possible, and liability exposure may be significant if members of the public experience actual physical injury or illness from these exposures.

Antibiotic and Pharmaceutical Residues

The availability and use of antibiotics and other pharmaceuticals in animal production over the last century has – along with the many benefits to animal health and food safety – also created the potential for animal-source foods – meat, milk, eggs, fish and shellfish – to contain significant residues of these substances.

Beginning in the 1980s, the public health and food safety regulatory agencies of the United States, European Union countries and other developed nations have engaged in active discussion and consensus-building with regard to the use of antimicrobials in food animal production and aquaculture. In 2012, the U.S. Food and Drug Administration published Guidance for Industry #209, which established the principle of "judicious use" of antimicrobials, and called for limiting the uses of medically important antibiotics in food-producing animals to only those that are necessary to assure the health of the animals.

The Spectrum of Food & Water Threat Agents Summary

*Continued from page 20

Radiological Material

- **Radiation sources for diagnostic imaging and x-ray inspection of pipeline welds**
- **Thorium**

Physical Hazards

- **Metal**
- **Plastic**
- **Paper**
- **Insects**
- **Rocks**
- **Dirt**

Antibiotic and Pharmaceutical Residues

- **Presence in animal-source foods**
  - Meat
  - Milk
  - Eggs
  - Fish
  - Shellfish

Allergens

- **Anaphylaxis**
  - milk
  - eggs
  - fish
  - shellfish
  - wheat
  - soy
  - peanuts
  - tree nuts

Heavy Metals

- **arsenic**
- **beryllium**
- **lead**
- **cadmium**
- **hexavalent chromium**
- **copper**
- **cobalt**
- **iron,**
- **mercury**

Beginning in January 2017, any herd-level medication delivered in feed or water must be under the direction of a licensed veterinarian, and requires a new type of prescription, the Veterinary Feed Directive. The USDA Food Safety Inspection Service and the FDA work together closely to establish safe thresholds for antibiotic residues and meat, milk and dairy products, eggs and seafood; both agencies also operate extensive food safety surveillance and laboratory testing programs. The USDA's Food Animal Residue Avoidance and Depletion program provides real-time technical information to the U.S. food animal production veterinarians responsible for issuing VFDs and overseeing the judicious use veterinary pharmaceuticals in food animals.

The FARAD website [30] maintains the list of drugs which are not legal for use in U.S. food–producing animals due to their known potential for harmful effects to consumers, as well as web-based on-line access to professional decision-making tools to assist food animal production veterinarians in making appropriate post-treatment withdrawal intervals for meat, milk and eggs. These consumer protection measures also serve to protect and limit the liability exposure of U.S. farmers, veterinarians, and food industry corporations.

Although both accidental and intentional introduction of antibiotics in the food supply has occurred in the past, the development of rigorous domestic detection programs, regulatory oversight, and inventory accountability programs is lessening the possibility of widespread contamination of the food supply by antibiotics. That said, increasing amounts of the U.S. food supply originate in foreign countries which do not have the same standards of accountability. This has on multiple occasions resulted in seizure and destruction of substantial amounts of imported food, deemed unfit for human consumption either because of the presence of drugs not legal for use in the U.S. or because of the presence of drug residues above the allowable thresholds.

Allergens

Food allergies occur commonly in the U. S. where 4-6 percent of children are affected. [31] Ninety percent of serious allergic reactions (anaphylaxis) are due to milk, eggs, fish, shellfish, wheat, soy, peanuts and tree nuts. Prevention of food allergy incidents involves measures instituted during processing to prevent cross contamination, proper food labelling and education of the public. [32]

Hearings have been conducted to help the FDA determine how manufacturers use advisory labeling for food allergens. The Food Safety Modernization Act [33] provides guidelines for the prevention of intentional adulteration of the food supply which includes the introduction of allergens into food. The rule requires risk reduction strategies for processes in registered food facilities. The intentional introduction of food allergens is not considered a major overall risk to the consuming public. Scenarios can be foreseen whereby an intentional introduction of food allergens could be utilized locally by adversaries wishing to do harm to an individual or otherwise damage the reputation of a restaurant or other food retailer.

Heavy Metals

Heavy metals – which include arsenic, beryllium, lead, cadmium, hexavalent chromium, copper, cobalt, iron, and mercury [34] – are not a major concern for the food processing industry. Human exposure is usually the result of community environmental health hazards associated with permitted industrial process discharges into waterways upstream of municipal water intakes, mining leachate which has contaminated groundwater (superficial aquifers) as well as surface water, or exposure to other hazardous waste in the environment. If ingested, these metals can be absorbed and become persistent toxins when the body concentrates and stores them. Infants and children are particularly susceptible to ingestion of heavy metals due to their highly active metabolism during normal periods of rapid growth. Depending on the dose and duration of such exposures, they may suffer long-term medical sequellae or even death. An important exception to the above statements is lead. The CDC estimates that at least 4 million U.S. households,

> …have children living in them that are being exposed to high levels of lead. There are approximately half a million U.S. children ages 1-5 with blood lead levels above 5 micrograms per deciliter (µg/dL), the reference level at which CDC recommends public health actions be initiated. [35]

Childhood exposure to sources of lead in the U.S. environment has been steadily de-

> "If the United States food and water supplies **are to remain safe,** expenditure of effort will have to increase **in the coming months and years.**"

creasing since the 1980s, thanks to federally-funded public health initiatives for blood lead surveillance testing of young children and programs for remediation of environmental sources in and around the home. As the CDC indicates, "No safe blood lead level in children has been identified. Lead exposure can affect nearly every system in the body. Because lead exposure often occurs with no obvious symptoms, it frequently goes unrecognized." [35]

Municipal drinking water systems, such as those recently affected in Flint, Michigan may be a significant source of childhood exposure to lead, mainly due to deteriorating and poorly maintained legacy water distribution systems, which contain lead solder joints and even on occasion lead pipes. [36,37] Water from these contaminated municipal systems could theoretically contaminate foodstuffs which might use the water as part of the food process. The food processing industry is aware of the potential threat of lead contamination and proactively monitors lead levels in supply water.

Many other municipal systems across the United States are similarly aged as the Flint, Michigan municipal water system, therefore similar problems of potable water contamination are highly likely in the future, and an abundance of caution is justified. There is an ongoing discussion among food corporations as to whether heavy metal monitoring of water supplies should be increased in frequency.

Future Terrorism in Context

A recent article by the STRATFOR Intelligence Group [38] reflecting on the 15th anniversary of the 9-11 attack is helpful to frame the context for forecasting probabilities of future attacks by terrorists on the food supply. As was stated earlier, the most pressing problem for the food and agricultural industries are insider threats, which most frequently are due to disgruntled employees wishing to cause economic harm on their employer. Next most likely to occur are criminal incidents, where there is an economic motive. This leaves the last category of concern – the actual attack by terrorists or adversarial nation states on the food supply. An article published by STRATFOR on Sept. 8, 2016, [39] reminds that, "Sophisticated Tradecraft is Not Dead…Before the 9/11 attacks, al Qaeda had amassed an impressive array of terrorist planners, trainers and training camps." To be sure, in the wake of 9/11, the United States and its allies were relentless in tracking down, killing and capturing many of the individuals responsible for the planning and execution of the attack, including Osama bin Laden.

> This does not mean, however, that sophisticated tradecraft is dead, or that groups and individuals cannot develop and use it in future attacks. The poor preparation and delivery exhibited by most jihadists today cannot be allowed to lull security forces into complacency, only to be caught off guard by advanced operatives tomorrow. Amateur jihadists frequently stumble into FBI sting operations, but professional terrorists are not as easy to snare. More important, tradecraft was neither the only nor the primary reason that 9/11 attackers were so successful… The critical component of the 9/11 attack was the perpetrator's conceptualization and planning…Mohammed (Khalid Sheikh Mohammed – the 9/11 attack planner) adopted an outside-the-box strategy. He decided to use an improvised weapons system that was part of the United States' infrastructure - air transportation – to attack the nation itself. [39]

He was successfully able to do this because he had a deep and detailed understanding on how this critical infrastructure worked.

If a major attack were to successfully occur on the food, agriculture or water infrastructures, it will likely be found that the adversaries responsible have that same detailed knowledge of the organization and operational functionality of the things being targeted, as did those responsible for 9/11. The most efficient way for this knowledge to be gained by the adversary is to place people inside the systems to do reconnaissance and elucidate the exploitable weaknesses. Assume that those adversarial pathfinders are already here.

As stated earlier, the human element is always the most important factor in defeating a strident and thinking adversary. Amateurs are frequently easy to catch, but a well-funded, technically proficient adversary or group of adversaries will not be. If the United States food and water supplies are to remain safe, expenditure of effort will have to increase in the coming months and years. Food and water have from the beginning always been highly effective weapons of war. Government alone or government and the military will not be adequate to the task to be faced, for our adversaries understand well how both work. In the future, the food, agriculture and water industries will have to work as equal partners with government and the military.

In reality, the expertise on food, agriculture and water does not reside in Washington, but rather in the industries and the people that actually put food on the table and water in the taps. A significant requirement for assuring the continuation of a safe, abundant uninterrupted food supply is to better share warning intelligence with the people in the infrastructure that actually need it. Accompanying this requirement is the need for government to seek out expertise in the industry and – most importantly – listen to what they have to say. ■

The Auburn University Food Systems Institute Food Defense Working Group collaborates with the food industry, state and federal regulatory and law enforcement agencies such as the Federal Bureau of Investigation, the Department of Homeland Security, the Department of Health and Human Services (Centers for Disease Control and Prevention and the Food and Drug Administration), and the U.S. Department of Agriculture's Food Safety Inspection Service to develop methods and strategies to prevent and detect potential food-related terrorist events.

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 • Polybrominated diphenyl ethers (PBDEs) – Used in the manufacture of plastics, textiles, electronic castings, circuitry
 • Hexabromocyclododecanes (HBCDDs) – Used as a component of thermal insulation in the building industry
 • Tetrabromobisphenol A (TBBPA) and other phenols – Used in the manufacture of printed circuit boards, thermoplastics (mainly in TVs)
 • Polybrominated biphenyls (PBBs) – Used in the manufacture or consumer appliances, textiles, plastic foams
 • Other brominated flame retardants.
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Analog
Proc

Reducing the Battery Cost of Battlefield Situational Awareness

By: Brandon Rumberg, Ph.D.

The massive growth in the number of sensing devices worn by soldiers and placed in the battlefield creates new opportunities, such as soldier biosensing and better situational awareness. But these sensors must all acquire and communicate data over long periods of time, which creates new challenges for system designers—from larger batteries that soldiers must carry in order to power all of these sensors, to a glut of sensor data that overloads network bandwidth and analyst resources.

This trend to collect more and more data puts a strain on the digital systems that collect and analyze the sensor information. Nevertheless, designers of battlefield sensing systems invariably gravitate to these digital processing architectures, including microcontrollers and digital signal processors, because the last three decades have seen significant digital processing improvements, and because small and programmable analog architectures have not been available until now.

Recent innovations in analog signal processing [1] make it possible to analyze or screen the data in the sensor's analog domain so only the desired information passes to the rest of the signal chain—a technique that affords a 10x overall power reduction in many sensor systems (including acoustic, vibration and bio-sensing applications), while also reducing the size and cost of these systems.

Data Reduction and Analytics at the Sensor **"Edge"**

Power consumption is a key challenge facing battlefield-deployed sensor systems, and the other big challenge is to deal with the large amount of data generated by innumerous sensor nodes in the battlefield or on the soldiers. To reduce network bandwidth requirements, some of these analytics are pushed from the cloud to the "edge" of the network on the sensor nodes; however, the ability to perform these analytics at the sensor edge is limited by the cost of supplying sufficient battery power into the battlefield.

Today, edge devices are typically "dumb" by necessity, because designers cannot afford to compromise the battery life of the device with significant processing. Consequently, these edge devices generate a deluge of irrelevant data that are not filtered until reaching the gateway or the cloud. With low-power analog processing, the system can afford the power cost to reduce the sensor data to only the data that are desired for the application.

Early identification of key data will provide cost and efficiency advantages at all layers of the signal chain by enabling each layer to only process and send the relevant data, and will provide performance advantages in back-end data analytics by allowing developers to redirect their focus away from finding relevant data and on to building upon relevant data.

Analog Signal Processing— **Efficient, Programmable** and Small

Efficiencies in both power and data reduction can be understood by exploring embedded sensor architectures and understanding how analog processing can provide significant benefits. In the traditional embedded sensor architecture shown in Figure 1(a), data processing starts with digitizing — via the analog-to-digital converter — all of the analog data from the sensor. This raw digital data may then be transmitted for offline analysis, but it is generally desirable to minimize transmission by first reducing the raw data to relevant information using the digital processor, and then act on this information by, for example, notifying the soldier or transmitting the data upstream for further action.

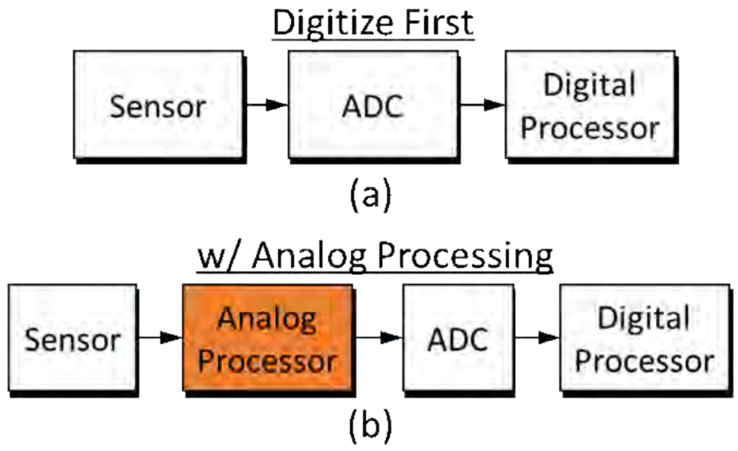

Figure 1: Sensor processing architectures. (a) Traditional approach where all processing is digital. (b) New paradigm where an analog processor "screens" the data so that system resources are not wasted on irrelevant data. (Released)

This process can be extremely inefficient, since all of the data, whether valuable or not, are first digitized by the ADC — which often dominates the power consumption of optimized systems — and then processed by the digital processor — which may alternatively dominate the power consumption. This inefficiency is quite dramatic in higher-bandwidth sensor systems. For example, in acoustic systems, the ADC power is significant due to the speed and resolution requirements, and it is also important to analyze *all* of the sensor data, even though most of the data are not critical for the application.

To improve efficiency, an analog signal processor may be inserted between the sensor and ADC, as shown in Figure 1(b). By programming the ASP with sophisticated signal processing and detection algorithms, tasks that are typically digital can be performed earlier in the sensor signal chain (prior to digitization), thereby reducing the system's throughput requirements and power consumption; consequently, the size and cost of the signal chain componentry and battery are also reduced. To reap these benefits, this paradigm requires low-power, programmable analog processors, which are enabled by recent innovations in low-power analog processing circuits, [2] nonvolatile analog memory [3] and programmable analog architectures. [1] The efficient signal-chain architecture shown in Figure 1 (b) can be achieved with the addition of an analog processor integrated circuit. [1] This innovative architecture provides significant benefits to sensor systems in the battlefield. These benefits are discussed further below, as well as applicability of the technology in acoustic, bio-sensing, and vibration systems.

As discussed above, the power consumption of battlefield systems with higher-bandwidth sensors is typically dominated by the ADC and the digital processor. The most effective way to address this power consumption is to reduce the activity of the ADC and digital processor. This is accomplished today by either duty cycling those components — which risks the loss of important data — or by adding an "always-on" low-power DSP that wakes up the digital processor based upon the signal

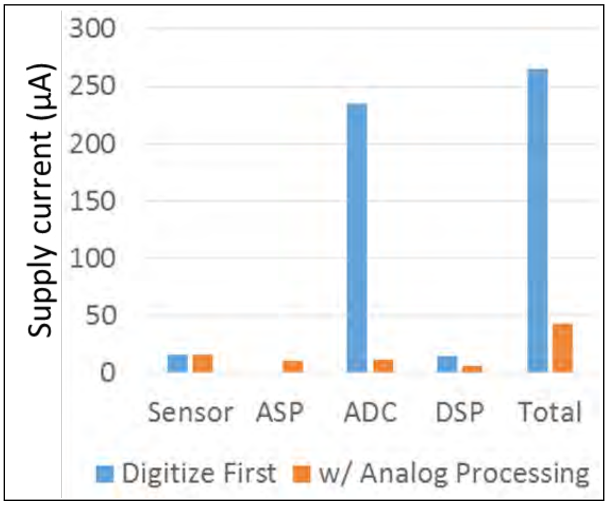

Figure 2: Power breakdown of the architectures shown in Figure 1 for a "wake-on-voice" application. (Released)

content — which still incurs the power consumption of an always-on ADC. Since ADC power consumption does not scale nearly as aggressively with the technology node as does the power consumption of digital logic, [4] the ADC will dominate even more of the system's power consumption in the future. The alternative approach in this article is to reduce the quantity of data that are digitized by performing data analysis in the analog domain. Fewer data are digitized, thereby better balancing the power budget across the signal chain. Figure 2 compares the always-on power breakdown of the two approaches in an acoustic "wake-on-voice" application. By frontloading some of the DSP tasks into the ASP, the ADC power — and thereby the system power — has been significantly reduced.

Analog processing has been shown to be more efficient than digital processing in low-to-moderate precision applications, [5] such as embedded sensors and perceptual processing algorithms (e.g. acoustic processing, where the instantaneous dynamic range of speech is only 30-35dB [6]). In these types of applications, complex signal processing algorithms use nonlinear operations for scale-invariant feature extraction [7] and to represent statistical models. [8] Analog circuits can provide small and efficient realizations of these nonlinear operations, because the nonlinear operations can be built from the large-signal characteristics of a small number of circuit elements, [9] whereas digital implementations require inefficient lookup tables or iterative methods to realize the same operations. As a result, analog processing can provide efficient analytics at the edge, which benefits battlefield operations by significantly reducing the power supply demands.

While analog processing is not a new paradigm, one of its key challenges has been to field small form factor analog processing architectures. With recent innovations in programmable, non-linear analog architectures, sensor system designers now have the ability to build programmable analog processing blocks with a much smaller programming overhead as compared to currently available analog and digital architectures. This enables an IC implementation of current application architectures in a much smaller footprint that, in some scenarios, can efficiently fit inside the sensor transducer. This small size is achieved in mature, and less expensive, CMOS process technologies. Additionally, since the ASP's data reduction reduces the processing and memory requirements of the system, it is possible to significantly reduce or totally eliminate some of the downstream blocks and ICs, thereby reducing total system size and cost further. In the end, analog signal processing may enable small, disposable sensors for use in the battlefield.

Analog algorithm development has been accelerated by the Reconfigurable Analog/Mixed-Signal Processor architecture, which received the best paper award at the International Symposium on Quality Electronics Design. [1] This architecture (See Figure 3) combines a large-scale programmable analog processor IC with analog application software. The architecture is fully programmable, and even allows reprogramming in a deployed environment, such as on the battlefield. The 5mm x 5mm architecture is an array of blocks, so it is also scalable for small form-factor applications — e.g., an acoustic event detection architecture may be as small as 0.5mm x 0.5mm. The RAMP architecture (See Figure 4) is a field-programmable analog array — similar to a digital FPGA — and consists of an array of circuits that can be reconfigured via a switch fabric. In contrast to other FPAAs (e.g. [10] and [11]), the RAMP has been designed for sensor processing: it is arranged in a stage-based processing flow that proceeds from sensor interfacing, to feature extraction, to pattern recognition, to mixed-signal and digital circuits — and it is self-contained and can be reprogrammed over a simple serial interface. It provides analog re-programmability with a focus on low-power analog signal processing. For example, the Computational Analog Blocks include circuits for feature extraction and pattern recognition. A development environment helps with high-level creation of more complex algorithms.

Military Applications

Analog processing is quite beneficial to high-bandwidth sensor applications for the battlefield where it is important to analyze all of the data. In these high-bandwidth systems, it is much more efficient to use analog processing to analyze the data prior to the digitization phase, and thereby avoid digitizing all of the data and wasting power. With a power reduction of up to 10x in sensing and communications circuitry, the total power requirement of the system can be greatly reduced. This reduction in power enables the use of smaller, lighter batteries, and possibly enables operational use of energy-harvesting technologies (e.g. solar) which are not adequate to power today's sensing and communications systems. The RAMP ASP technology can be configured/programmed for a number of different sensor paradigms and application tasks, all at much lower power levels than seen in today's implementations.

Acoustics

Acoustic, or audio, applications can benefit greatly from ASP technology. Analog processing can extract audio features — e.g. voice, short-term SNR in a frequency band, or long-term audio features like background noise statistics — to aid later digital processing. To do this, it is important that all of the sensed data are analyzed so that critical data are not overlooked. This staged approach saves power by keeping later stages in sleep mode until needed. The RAMP architecture enables the ability to perform audio signal processing in the analog domain, thereby analyzing the audio and determining "voice" or "non-voice" triggers at a power level about 10x lower than current solutions. This power reduction is realized by leveraging low-power analog circuitry and by keeping the ADC and DSP circuity in sleep mode until a trigger is detected. Additionally, the ASP can offload DSP tasks such as noise suppression and gain normalization to obtain additional power savings.

Voice activity detection is a good exam-

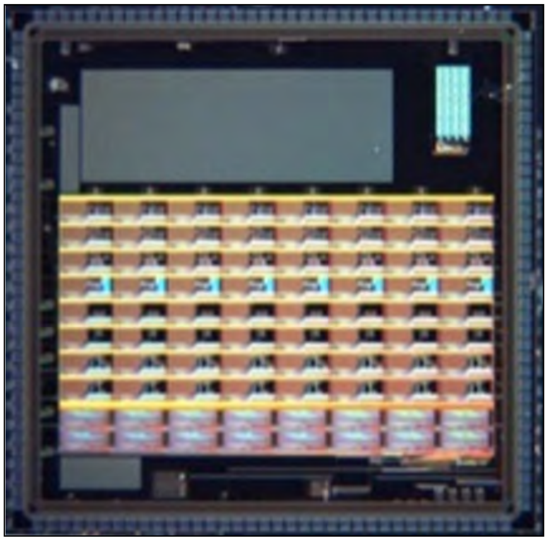

Figure 3: Reconfigurable Analog/Mixed-Signal Processor IC. (Released)

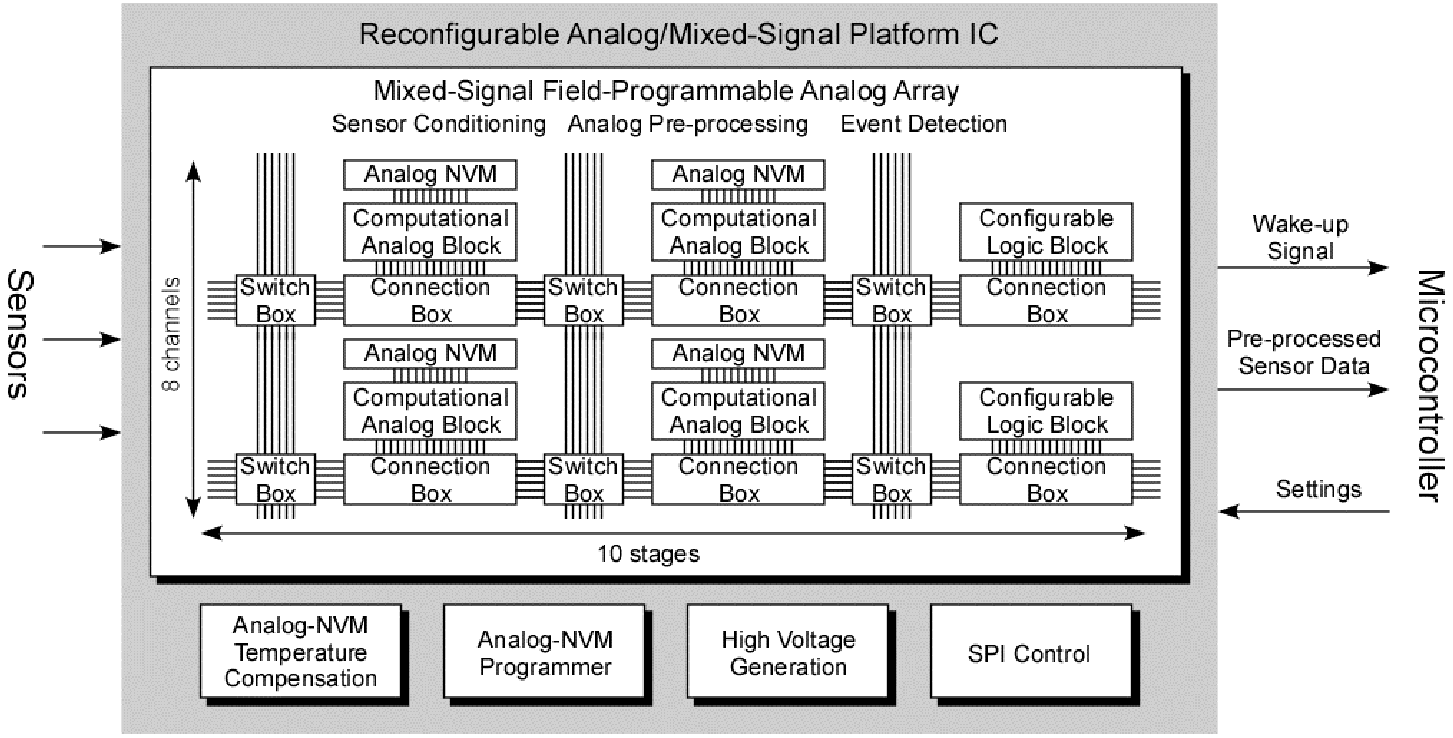

Figure 4: Architecture of RAMP analog signal processor IC. A mixed-signal field-programmable analog array provides efficient signal-processing capabilities. (Released)

ple of system power reduction using analog processing. In voice-control systems, the first step is to determine whether a voice is heard. Since upwards of 90 percent of the audio that is detected by the microphone is not voice, the "digitize first" approach wastes significant power by digitizing and processing all of the audio (duty cycling is not an option) in search of voice to trigger the next stage of voice control. In contrast, the VAD algorithm can be placed in an analog processor, which generates a "wake-on-voice" signal to trigger the ADC and DSP to wake up and analyze the voice for keyword or voice-command processing. This approach provides a 10x reduction in power as compared to today's leading competitive solutions—from 300µA supply current for a complete microphone/ADC/digital VAD solution to 30µA for a microphone/analog VAD solution. Figure 2 shows this power breakdown. Voice triggering could be a key complement to the battlefield soldier, and allow mechanical systems to remain off until voice is detected or a specific keyword is triggered.

In addition to voice, the RAMP solution can be programmed for **acoustic surveillance systems** to analyze acoustic sensor data for non-voice signatures as well. This could include key battlefield surveillance items such as classification and identification capabilities for continuous sources (vehicles, aircraft, etc.) and impulsive sources (gun fire, artillery impacts, etc.). An early ASP demonstrated an analog algorithm for acoustic vehicle surveillance [12] that can be used at remote battlefield outposts. The algorithm detects vehicle activity and classifies the type of vehicle. That prototype system was demonstrated to have 90% accuracy at a power consumption that will increase the monitoring system lifetime from 4 months (for current digital implementations) to 9 years on a pair of AA batteries.

Bio-Sensing

Soldier health and status are key indicators in demand on the battlefield, and the RAMP architecture can provide insight into these parameters, albeit at a much lower power cost than other solutions. With the architecture, one can monitor the average heart rate and other metrics as is typically done with current digital-based solutions; however, it would be much more efficient to focus on the "out of normal" measurements. For instance, the RAMP could be programmed to look for a particular heart rate or a heart arrhythmia, indicative of a specific situational analysis. Once detected, a "trigger" could be sent and a specific measure could be taken. The RAMP has been used to demonstrate an out-of-range heart-rate system that draws just 7µA of supply current [1]. The key to this scenario is remaining "always-on" and looking for the "out of normal" signature at very low power, which is best accomplished with an analog processor solution.

Vibration Monitoring

Vibration monitoring provides a good example of how analog processing at the edge sensor device can significantly reduce data. In mechanical systems or equipment deployed on the battlefield, machinery wear or maintenance downtime (which occurs regularly but is unpredictable) has detrimental impacts. In these systems, monitoring the vibration characteristics offers a glimpse into early troubles and allows preventative maintenance. One challenge in vibration monitoring is how to handle the large quantities of vibration data that are generated by the vibration sensors that are distributed throughout a mechanical structure or machine. Vibration data are captured at a moderately high frequency (up to tens of kilohertz), and thus generate a significant amount of data for an embedded sensing device. This abundance of data requires more powerful processors and greater power consumption.

Vibration monitoring devices digitize all of the data and then perform an FFT on the data. Peaks in the FFT spectra indicate the vibrational modes of the monitored structure, and the health of the structure can then be inferred from the relationship between the

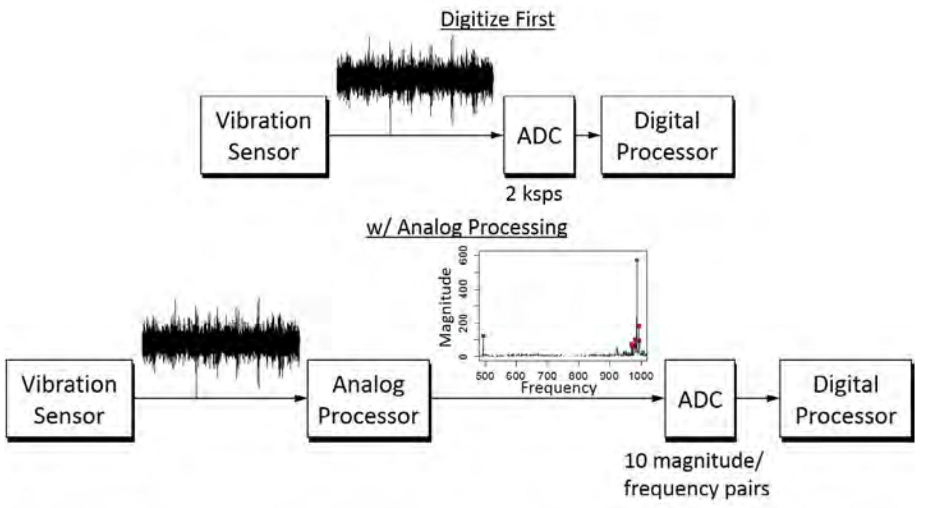

Figure 5: Application of analog pre-processing to vibration monitoring. The analog processor extracts the vibration modes and thus reduces the data that must be digitized by 100x. (Released)

vibrational modes. Essentially, the desired vibration information is contained within a relatively small number of data points (i.e. the modes), so by extracting this information earlier in the signal chain—prior to digitizing the signal—the necessary resources for an embedded vibration monitoring device can be significantly reduced. Extracting these modes with analog processing provides a 100x reduction in the data that must be digitized and handled by the processor — from 2048 data points for an FFT frame to 10 pairs of frequency and magnitude datum. This process is illustrated in Figure 5. While data reduction is a key benefit to vibration monitoring applications, analog processing will provide additional benefits to the power, size, and cost of the entire solution.

In addition to the continuous reduction of vibration data described above, analog processing can also provide vibration event detection similar to acoustic event detection like voice or vehicle detection. In battlefield surveillance systems employing seismic (vibrational) measurements, vehicles and footsteps are recognized by their seismic signatures. An ASP can be programmed to trigger on these signatures, which significantly reduces the power requirements of unattended ground sensors.

Conclusion

The military and Department of Defense agencies have a significant need to improve energy efficiency in the field, especially with the massive growth of sensors and of data capture / analysis. While digital processing has been used in most settings because it is flexible, easy to program, robust to noise, and also benefits from technology scaling, analog processing is able to operate in real-time and perform many computations inherently that require significant overhead and power consumption in the digital domain. Additionally, the requirement to digitize the ever growing amount of analog-based sensor data makes digital processing an even less efficient option. The alternative to digital processing is programmable analog circuity, which has been in existence for many years, but recent innovations make it more efficient, flexible, and easy to use, which will accelerate the development of sensor systems using analog processing. Essentially, any application requiring low-power sensors and higher data bandwidths will benefit from an ASP solution for reduced system power consumption and reduced data requirements, which in turn has the potential to reduce the cost of the system and simplify the design of the end product. ■

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MRSA and the Critical Need to Develop a First-Line Treatment

By: Charles Rice, Ph.D.

In 2007, the Department of Veterans Affairs implemented its National MRSA Prevention Initiative program to reverse skyrocketing health care costs and poor patient outcomes caused by the deadly bacteria *methicillin-resistant Staphylococcus aureus*, more commonly known as MRSA. Because of its resistance to common antibiotics, such as methicillin and related β-lactam compounds, the Centers for Disease Control and Prevention considers MRSA a serious threat to public health.

In 2011, MRSA infected 80,500 people, with nearly 1 in 7 (11,300) cases resulting in death. [1] MRSA is a major infective agent in the lung, at surgical sites and in the bloodstream. Hospital acquired MRSA infections increase health care costs [2] due to specialized laboratory testing needed to confirm the presence of drug resistant MRSA bacteria.

Because MRSA infections can occur in medical care facilities, the VA enacted stringent measures within NMPI to curtail disease transmission with specialized hygiene, sanitation and decontamination practices.

The VA has 153 medical centers with around 600,000 patient admissions each year. [3] The median length of stay is three days. [3] During a three-year period from 2007 to 2010, 13.6 percent of the 1.7 million patients screened for MRSA upon admission tested positive, whereas only 6.3 percent of patients tested positive for MRSA upon admission to a non-VA facility. [3] This demonstrates the increased the risk for acquiring a MRSA infection in a VA facility compared with a non-VA facility.

In addition, the highest risk lies within intensive care units. [3] Studies show that VA patients have a higher readmission rate if they have had MRSA infections. [4] One of the NMPI's goals is to lower the rate of MRSA infection (this is an unspecified number because any reduction is better than no reduction), thereby lowering transmission rates within the health care setting. The outcome of these efforts manifests as a reduction in the rate of MRSA infection within VA patients admitted to the hospital. [5]

The rate of MRSA hospital-acquired infection within VA facilities was about 1.5 cases per 1000 patient-days in 2006, [3] which means there were approximately 2,700 MRSA infections during 1.8 million patient days in a VA health care setting in 2006. Compared to other infections, MRSA triples the per-patient hospital expenses (~$90,000/patient for MRSA hospital-acquired infections versus ~$30,000 for non-MRSA hospital-acquired infections). [3]

MRSA also impacts patients after they leave the hospital. Side-effects and morbidity from MRSA and its treatment double post-discharge costs (~$36,000 for MRSA hospital-acquired infections versus $18,000 for non-MRSA hospital-acquired infections). [6] Using these estimates, the 2,700 hospital-acquired MRSA cases in 2006 increased health care costs by $210 million. In a thorough analysis of MRSA prevention and costs between 2007 and 2010, NMPI lowered hospital-acquired infections of MRSA within intensive care units by 70 percent (from 783 to 241) and cut non-ICU MRSA hospital-acquired infections in half. [6]

During the three-year analysis period, the program resulted in 2000 fewer MRSA hospital-acquired infections and lowered health care costs by $75 million. [6] These efforts are laudable and demonstrate the impact of improving patient care practices and hospital procedures to lower MRSA infection rates. Another option to reduce MRSA infection rates is with improved antibiotics.

In 2011, the U.S. healthcare system prescribed 118 million courses of β-lactam antibiotics. [7] In their current form, however, these drugs do not stop MRSA infections. The inability to immediately identify and treat infections from MRSA leads to morbidity, mortality and increased health care costs. [2,8] Delays in delivering effective anti-MRSA drugs can be overcome by screening– a daunting task that the VA has successfully employed, yet is burdensome on the U.S. healthcare system that deals with hundreds of millions of bacterial infection cases each year. [7]

The University of Oklahoma's work is directed towards an alternative: improving first-line antibiotics to simultaneously kill both MRSA and the non-drug-resistant staph infection bacteria.

The vast majority of patients presenting with symptoms of bacterial infection are treated with inexpensive broad-spectrum β-lactam antibiotics. [7] Patient outcomes are positive, unless β-lactam resistant bacteria, such as MRSA, are present. Surviving MRSA colonies invade host tissue to release toxins that cause tissue injury, leading to significant patient morbidity. In cases where the initial symptoms are attributed to MRSA, β-lactams are avoided in favor of more effective antibiotics given without delay. [9]

Most MRSA infections, however, are not diagnosed immediately. Instead, after initial infection symptoms arise, patients suffer while numerous first and second-line antibiotics are prescribed to no avail. [10] Upon the initial presentation of staph infection symptoms, a critical need exists for a first-line antibiotic to treat both MRSA and susceptible staph bacteria without the need diagnose MRSA and use more expensive antibiotics. [11] This requires a therapy that can block the function of penicillin binding protein 2a (PBP2a) and PBP4, the leading causes of β-lactam antibiotic resistance in MRSA infections. [12,13]

It may be possible to achieve this outcome with a discovery made at OU. [14] Low cost β-lactam antibiotics that kill non-resistant staph infection bacteria also prevent the growth of MRSA if administered with a readily available and inexpensive polymer: branched poly(ethylenimine), or BPEI. The goal is to develop β-lactam + BPEI combinations as a potential first-line antibiotic. This route to reduce morbidity, mortality and health care costs has the ability to restore anti-MRSA potency to obsolete FDA approved antibiotics, thereby improving the MRSA infection control aspects of NMPI in a cost-effective manner.

If MRSA is diagnosed or suspected, several antibiotics can be used (vancomycin, linezolid, daptomycin). To date, no MRSA strain is currently resistant to more than one of them. [15,16] People die from MRSA infections because MRSA was not initially suspected, and thus ineffective first-line antibiotics, usually β-lactams, are given. MRSA relies on PBP2a and PBP4 to survive in the presence of β-lactam antibiotics. [12,13]

Only after morbidity from MRSA toxins are more effective antibiotics given and these life-saving medications become drugs of last resort. Unfortunately, in many cases, the effective drug is given too late to prevent mortality. [2,15] Life threatening situations can be avoided with timely treatment. [17] New antibiotics, such as oxadiazoles, [18] tedizolid [19] and teixobactin, [20] will be new drugs of last resort.

But, according to OU, these drugs are not likely to be first-line antibiotics due to their cost. Thus, they will reduce mortality rates but may not reduce morbidity. Likewise, they will not reduce healthcare costs incurred from long periods of hospitalization, sometimes in the intensive care unit, while giving drugs of last resort. [21-25] These new drugs of last resort are expensive, often require intravenous delivery and their use is often delayed until specialized laboratory testing confirms the presence of drug resistant bacteria. [2,10] As an alternative, the different approach brought forth by researchers at OU may be able to kill MRSA before its toxins cause widespread damage to tissue and endanger the patient's life.

The approach utilizes a cationic polymer that disables resistance with MRSA, making it susceptible to low-cost penicillin-type β-lactam antibiotics. As scientific research moves forward, the goal for this technology is to lower health care costs, reduce tragic morbidity and save

lives. As depicted in Figure 1, the bacterial cell wall is composed of peptidoglycan and wall teichoic acid. Susceptible *S. aureus* is killed by cellular lysis caused by two factors working together: 1) β-lactams that disable penicillin binding proteins that perform essential cell-wall crosslinking chemistry (See Figure 1B, 1G); and 2) activity of enzymes that degrade existing cell wall peptidoglycan. Methicillin, a β-lactam antibiotic, occupies the active site of penicillin binding proteins to prevent the enzyme's cell wall synthesis function. MRSA uses a variant of PBP (PBP2a) that is not affected by β-lactams (See Figure 1C) and therefore peptidoglycan biosynthesis continues, allowing MRSA to persist under antibiotic attack. This mechanism of antibiotic resistance is not perfect; there is an important flaw that can be exploited to stop MRSA. The essence of resistance, the PBP2a enzyme, does not operate single-handedly. PBP2a functionality requires wall teichoic acid, or WTA, to keep the enzyme in its proper location and teichoic acid the target for BPEI attack.

Restoring the efficacy of β-lactam antibiotics against MRSA occurs with many different compounds with many different targets. [26-30] A common theme is weakening the cell envelope framework by interrupting the cytoplasmic expression and membrane translocation of essential proteins, enzymes and precursors required for the assembly of peptidoglycan, lipoteichoic acid and WTA.

OU's work describes an approach that significantly departs from the status quo by deactivating mature WTA in situ through electrostatic interactions with branched polyethylenimine. [14] An example of the current state of the art is preventing the biosynthesis of anionic wall teichoic acid polymers, thereby disrupting PBP2a, restoring potency to β-lactam antibiotics and stopping the growth of MRSA. [31] Laboratory studies demonstrate this paradigm with genetic mutants that lack WTA molecules. WTA-deficient strains of MRSA are re-sensitized to amoxicillin, ampicillin, methicillin, nafcillin and ceftizoxime. [31] Thus, WTA is a potential drug target. [32]

Unfortunately, developing WTA inhibitors has been slow and the compounds have failed in pre-clinical trials. For instance, tunicamycin and ticoclopidine re-sensitize MRSA to β-lactams such as methicillin, oxacillin and cefotaxime. [31,33] These compounds, however, are unlikely to advance past pre-clinical trials. [34] Inhibition of a WTA regulatory protein with Targocil® also re-sensitizes MRSA strains to traditional β-lactams, [35-38] but this and related compounds have also failed in pre-clinical trials. [39]

OU's methodology allows the biosynthesis of WTA to continue and uses cationic polymers, such as branched polyethylenimine, that bind to WTA and disable its function in a direct manner. [40] The overall premise is that a new antibiotic could arise from a combination of BPEI and β-lactam antibiotics (See Figure 1G). A combination treatment of BPEI and traditional and β-lactam antibiotics is possible because these compounds are readily available, low cost and exhibit synergy against MRSA.

Targeting WTA restores β-lactam antibiotic efficacy against MRSA; BPEI potentiation of β-lactams occurs with MRSA; BPEI binds to bacterial cells in regions where WTA is located; and the anionic WTA backbone interacts with cationic BPEI. Formulations of an antibiotic with a compound that blocks the resistance pathway are a viable therapeutic strategy. For example, β-lactam antibiotics can be deactivated by bacteria that possess β-lactamases, a growing cause of resistance. [41] Clavulanic acid is a β-lactamase inhibitor that restores β-lactam efficacy. [41,42] The amoxicillin formulation is marketed as Augmentin and is now available in generic form. The success of β-lactam + β-lactamase inhibitor is an example that a combination therapy can be clinically and commercially viable.

In the long term, OU envisions combining Augmentin® with BPEI to create a formidable antibiotic. As oxacillin is resistant to β-lactamase, [43] however, a BPEI + oxacillin combination would be complementary to an BPEI + Augmentin® combination.

The expected research contribution is the ability to provide strong evidence of the importance of BPEI + β-lactam formulations, which enables opportunities to develop new first-line antibiotics. The significance of this contribution is a reinvigoration of obsolete ineffective antibiotics. Likewise, improved first-line antibiotics will have concrete benefits of more effective treatments of infections that are drug susceptible, resistant or both that will limit tissue damage.

Achieving treatment success in a timely fashion will decrease morbidity and mortality. The patient will not have to endure multiple treatments with an array of antibiotics to clear the infection, thereby improving quality of life. [2] Shorter hospital stays and fewer surgeries to treat damaged tissue will reduce the cost of medical care. [2] If the infection is treated quickly, expensive medical diagnostic tests to confirm the presence and strain causing bacteremia will not be needed. [2]

The next stage of research involves further laboratory testing of the new antibiotic formulation to determine if this new approach is feasible for use to treat humans. While hurdles exist, the low molecular weight BPEI polymers provide guarded optimism because the polymer is very water soluble. The strong hydrophilic nature allows for IV and oral dosing, reduces protein binding effects, limits lipophilicity and reduces cytotoxicity from membrane permeation. [44]

Data collection is underway to evaluate in vitro inhibition of MRSA growth in the presence of serum and the ability to kill different MRSA strains. Likewise, OU has been able to validate the BPEI drug binding target (WTA), its mechanism of action and mode of action.

Shortly, OU will be evaluating cytotoxicity against skin, liver and kidney cells. OU has also established a valid bioanalytical technique, high-performance liquid chromatography, to demonstrate low protein binding, in vivo measurement of free BPEI concentration in murine blood, and an in vivo estimation of BPEI half-life in murine blood. Other critical questions in drug discovery will be examined in future work: in vivo ADME (adsorption, distribution, metabolism, excretion) and in vivo evaluation of liver toxicity, kidney toxicity and maximum tolerable dose.

Thus, while these efforts will take time, research developments at the OU are beginning the crack the armor of MRSA bacteria and bring effective treatments within sight. ■

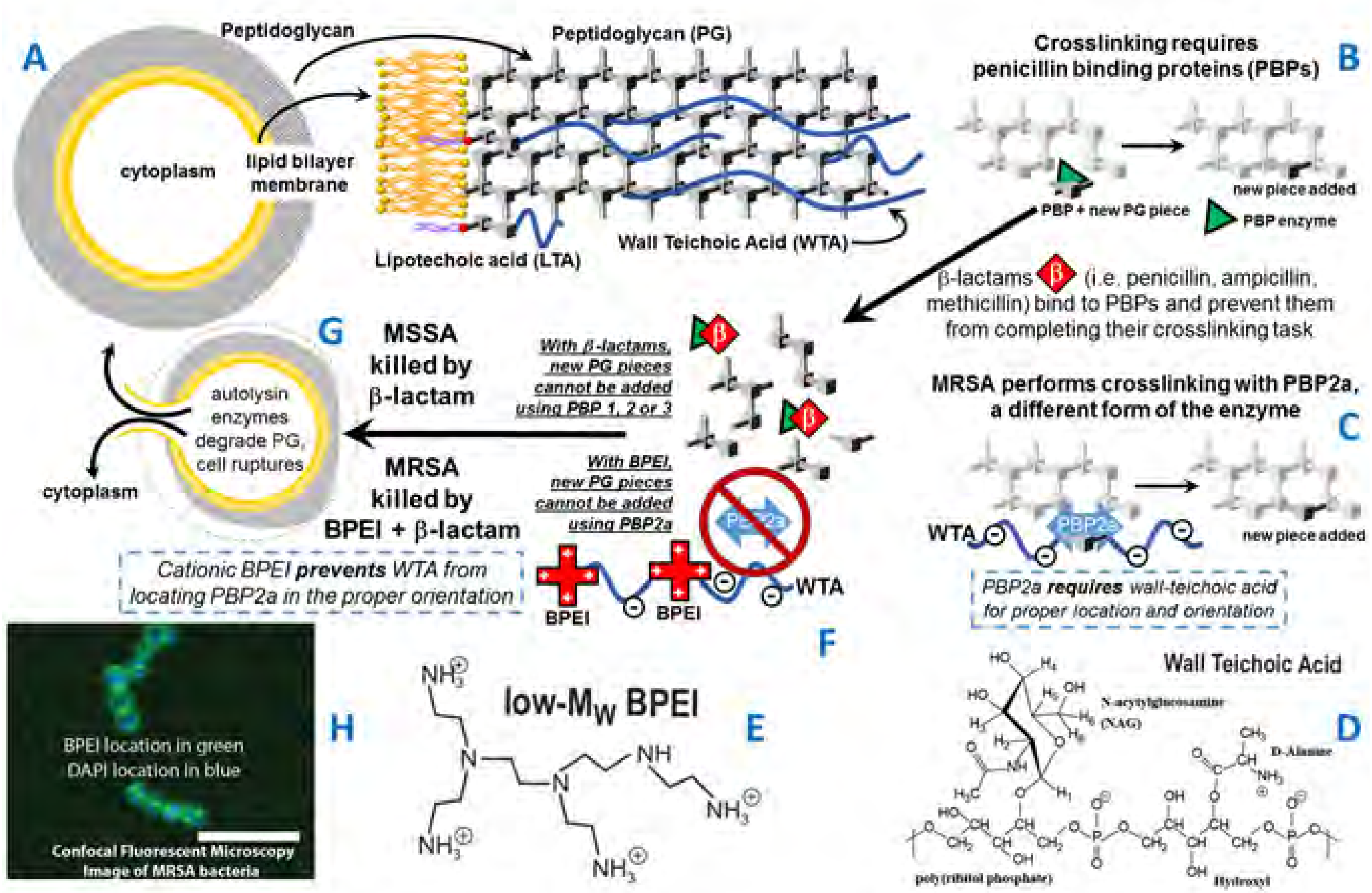

Figure 1. The cell envelope of MRSA** (A) **is composed of a membrane, peptidoglycan, and teichoic acids. PBP enzymes perform crosslinking** (B)**. Most PBPs are disabled by β-lactams yet MRSA also uses PBP2a** (C) **for crosslinking. WTA** (D) **is required to locate PBP2a. Cationic polymers, such as low-MW BPEI** (E)**, can bind to WTA** (F) **which prevents peptidoglycan crosslinking. The end result is a thinning of the peptidoglycan leading to cell death** (G)**. BPEI with a fluorescent molecule provides a probe to identify the location of BPEI. Optical section of BPEI bound to MRSA** (H)**, imaged by LSCM, stained with BPEI-AlexaFluor 488 (green) and DAPI (blue). The merged image shows BPEI binding to the cell wall and DAPI in the cytoplasm (scale bar = 5 μm).

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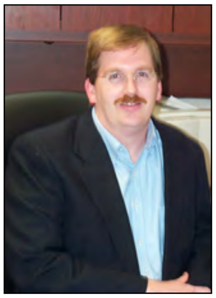

Dr. Charles Rice is an associate professor at the University of Oklahoma. He began his academic training at Illinois State University where he completed his undergaduate and Masters work. At Purdue, Dr. Rice used nuclear magnetic resonance to study the photodecomposition of trichloroethylene on titanium dioxide, in addition to research with hyperpolarized xenon as a means to enhance weak NMR signals. In 2002, Dr. Rice went to University of Oklahoma where he joined the Department of Chemistry and Biochemistry and is an associate professor. The research group uses NMR spectroscopy to answer questions relevant to vertical advancement in chemistry and biochemistry. Their research led to the discovery that branched poly(ethylenimine) restores β-lactam antibiotic activity against *methicillin-resistant Staphylococcus aureus*, **also known as MRSA.**

Restful Sleep For Optimum Performance and Reduction of Post-Traumatic Stress Disorder

Lee Gerdes

The truth about restful sleep and performance is non-intuitive. In fact, many performance oriented athletes, scientists and the military still consider high performance directly related to stimulation – not relaxation enhanced, effective restful sleep. [1,2,3] Top performing athletes serving their fans and warriors serving their country are oriented to achieve objectives. The brain is a highly complex system – probably the most complex system known in the universe – and artificially clamping it or stimulating it toward some kind of "norm" refutes the current science of allostasis, or consistency through change - versus the previously held understanding of homeostasis, which dictates a set-point target for everyone in every condition. Achieving restful sleep requires a self-directed brain adjustment of its own rhythms and on its own terms. Sleep is one of the most important factors for optimum performance and well-being. Restful sleep is the basis for optimum performance – both cognitively and physically. The Harvard Business Review neatly summarizes findings that optimum performance directly connects to attaining restful sleep. [4]

The impact of less sleep greatly lengthens reaction time, impedes judgment and interferes with problem solving. The importance of sleep is not going unnoticed. The NFL now encourages players to track sleep in order to help optimize their performance. [3] Quickness, strength, endurance, flexibility, play recall and cognitive performance on the field are all part of what is behind the NFL's effort.

Fortune Magazine recently reported on how tracking sleep and diet helped Michael Phelps in Rio. [5] No performance was more pronounced than that of Michael Phelps and the U.S. Men's Olympic Swimming Team, who made sleep a core focus in their successful training endeavors. Fatigue Science reports sleep is associated with significantly increased reaction times, reduced injury rates, improved overall health, longer careers, better accuracy, faster sprint times and fewer mental errors. [6] These same results could prove crucial to the superior performance and longevity of our warfighters. A completely non-invasive process for promoting restful, deep sleep can be accomplished through high-resolution, relational, resonance-based, electroencephalic mirroring technology, or HIRREM. [7]

Research funded by the Department of Defense using HIRREM neurotechnology to evaluate and relax the brain for special operations warriors indicates the need for relaxation, not stimulation. [8] HIRREM has been associated with reduced symptoms in a pilot study of people with insomnia. [9] A relaxed brain is able to achieve dynamic flexibility in brain activity patterns and demonstrates increased reaction speed and improved hand-grip strength, as well as reported recovery from years of traumatic stress symptoms. These findings were recently presented at the Medical, Biomedical & Biodefense: Support to the Warfighter Symposium. Most importantly, perhaps, is the fact that the relaxed brain supported more efficient and satisfying restful sleep. [10]

Under contract with the U.S. Army Research Office, Brain State Technologies successfully produced a wearable headband device for sleep and performance support. [11] Development included collaboration with researchers at Wake Forest School of Medicine, sleep medicine consultants from Harvard Medical School and the University of Virginia School of Medicine. Brain State Technologies' continued development of this device resulted in the production of the BRAINtellect® 2 (B-2), which has the potential to allow warfighters to relax and balance their brain while in the field to manage stress and facilitate relaxation for improved sleep and optimal performance.

Studies have also shown a causal link between individuals with sleep disorders and the later development of Post-Traumatic Stress Disorder. [12] Researchers began by reviewing data from a study of military service members deployed to Iraq after 9/11. In that study, published in 2013 in the journal Sleep, a group from the Veteran's Administration and others found the risk for PTSD conferred by insomnia symptoms was almost as strong as … combat exposure. [13,14]

Sleep support may have the additional benefit of not only contributing to optimal performance, but prevention of later disorders that may render warfighters unable to return to combat operations. With the availability of a portable headband device to self-manage brain rhythms, such as the BRAINtellect 2, presents a cost efficient and likely effective device for most warriors to facilitate their own restful sleep and optimum performance. Those delving into the science of neurotechnology and the incredible complexity of the brain will appreciate this practical approach of supporting the brain to optimize itself. ■

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Lee Gerdes is founder and CEO of Brain State Technologies®. He is the creator of Brainwave Optimization® and wearable headband technology, BRAINtellect® 2. Lee is the author of Limitless You: The Infinite Possibilities of a Balanced Brain. His work emanates from a combination of his interests in how the brain works and how it affects mind, body and spirit – and his own personal trauma, an assault that occurred in 1992. Lee has dedicated his life to understanding neuroplasticity (the ability of the brain to change itself) and how it can be applied to improve peoples' lives. Lee's work has been featured in countless magazines, newspapers, and television and radio interviews. Lee's education includes Doane College in Crete, Nebraska; Columbia University in New York; John F. Kennedy University in Orinda, California and Wartburg Seminary in Dubuque, Iowa.

Nuclear Weapons Effects Predictions for Ground Shock & Target Response

By: Eugene Sevin, Ph.D.

Strategic Nuclear Forces are the backbone of U.S. nuclear deterrence strategy and undoubtedly will remain so over the long term. However, there is an ongoing national security need to enhance nuclear test monitoring capabilities.

Nuclear treaty verification and hard target defeat are crucial application areas of nuclear weapons effects. Both technical areas heavily rely on computational geophysical modeling and simulation. From a treaty verification perspective, effort is underway to generate synthetic seismograms by coupling shock propagation in geologic media from source region to long-range teleseismic regions. The long-range purpose is to study the influence of near-source region geology on explosive source detection and ground shock propagation.

Improvements in ground shock modeling are also important to the hard and deeply buried target application. A special consideration for HDBT is the coupling of energy from the weapon to the ground. Coupling efficiency is the fraction of the total weapon yield converted to kinetic energy of downward-moving solid or non-vaporized ground material. The amount of energy coupled to the ground is strongly dependent on the weapon's actual height of burst or depth of burst, as well as on nuclear design details (i.e., yield-to-mass ratio, fission fractions, etc.). Geologic properties also play a role.

Many important HDBTs are beyond the reach of explosive penetrating weapons and are at only risk of destruction with nuclear weapons. [1]

Current experience and empirical predictions indicate that earth-penetrator weapons cannot reach to depths required for total containment of the effects of a nuclear explosion; however, shallow penetration (up to about 3 meters) captures most of the advantage associated with the coupling of ground shock. As the survivability risk to the penetrator increases with increasing penetration depth, a better understanding of energy coupling is important for improved HDBT protective designs and vulnerability assessments.

Another important modeling consideration for HDBT is failure prediction. Current methods rely mostly on continuum finite element models, and thus are intrinsically incapable of predicting structural failure. Rather, damage to and collapse of underground structures is based on heuristic reasoning (e.g., tension strains and velocity vectors in the vicinity of free surfaces) at late times in the simulation. Newer finite element models techniques, such as the mesh-free X-FEM method that represent internal (or external) boundaries (e.g., holes, inclusions or cracks) without requiring the mesh to conform to these boundaries, appear to be a promising approach to improving damage and failure prediction for HDBTs.

Several years ago, the Defense Threat Reduction Agency undertook a multi-year Advanced Concept Technology Demonstration program on hard target kill to validate numerical simulation tools for vulnerability assessment of HDBTs, which led to unexpected results. Rather than validating the efficacy of existing simulation tools, the program highlighted the shortcomings of these tools, as well as the complexity of modeling geologic materials and the particular difficulty of characterizing large-scale faulted media.

In January 2010, DTRA sponsored a workshop on ground shock in faulted media to identify and evaluate various approaches for advanced modeling of low-strength interfaces representative of faults and other discontinuities in hard rock masses, and the effects of these discontinuities on interpretation of seismic measurements for targeting and treaty verification applications. Large rock masses are an important consideration to HDBTs, as they strongly influence the propagation of shock waves emanating from explosions, causing directional channeling of energy and giving rise to asymmetric flows. Understanding these effects, and being able to model them with confidence is important to interpreting seismic signals from explosions, and to assessing the vulnerability of HDBTs to attacks.

The findings and recommendations of the workshop covered four areas: dealing with uncertainties; improving modeling tools; simulation verification; and validation experiments. These findings focused on both targeting and treaty verification applications, although priorities are not necessarily the same for each. Of paramount concern was the need to deal with uncertainties in a more quantified manner than previously performed. This will require extensive sensitivity studies over a range of geologic conditions, which in turn requires probabilistic site models that do not currently exist and improvements to the computational tools that make such studies practical.

With these considerations in mind, the workshop report recommended that the highest priority undertaking is to quantify the influence of near-source region geologic conditions on ground shock propagation in faulted media as it effects both targeting and treaty verification applications. [2]

For targeting applications, the need is to determine geologic conditions that are dominant for weapons effects predictions (ground shock and target response) and can be sufficiently well defined for typical denied hard target sites. For the treaty verification community, the comparable need is to quantify the conditions under which near-explosion source region geology influences seismic signal detection and discrimination at all ranges of interest.

From a target vulnerability assessment perspective, improved rock failure predictions require implementing mesh-independent technology in simulation codes to model fractures and joints. It also is important to introduce automated data management from model generation through post-processing to make large-scale simulations practical for both targeting and treaty verification applications. Over the longer term, there is a need to formulate and adopt an Uncertainty Quantification formalism, as the Department of Energy laboratories have done, to characterize uncertainties in an operationally meaningful way. ■

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Dr. Eugene Sevin is an independent consultant on nuclear and conventional weapons effects, hardened facility design and computational structural mechanics. He has been on the faculties of the Illinois Institute of Technology and the Technion, Israel Institute of Technology. Dr. Sevin is a consultant to the Defense Threat Reduction Agency as a member of the TASC A&AS team under subcontract to TASC, on matters related to hardened targets, blast mitigation, high performance computing in structural mechanics and preservation of DTRA's nuclear test database. He also is a consultant to the Institute for Defense Analysis. He was principal author of DTRA's two-volume report on Improved Ground Shock Vulnerability Number, and was co-chair of the steering committee for DTRA's Ground Shock in Faulted Media Workshop held in January 2010.

Calendar of Events

February 2017

02/15/17 - 02/17/17 • **Tokyo, Japan**
HDS, M Nano Tech Japan 2017

02/26/17 - 03/03/17 • **Ventura, CA**
HDS, M Gordon Conference: Nanomaterials for Applications in Energy Technology

02/27/17 - 03/01/17 • **Washington, DC**
AE 2017 ARPA-E Energy Innovation Summit

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03/14/17 - 03/16/17 • **Indianapolis, IN**
AE, CIP Green Truck Summit

03/15/17 - 03/16/17 • **Rome, Italy**
HDS SMi's 10th annual Border Security

03/20/17 - 03/23/17 • **San Diego, CA**
M, CIP 10th International Conference on Managing Fatigue in Transportation

April 2017

04/10/17 - 04/12/17 • **Minneapolis, MN**
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04/25/17 - 04/28/17 • **Tampa, FL**
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AE Solar Summit 2017

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(Publish Dec. 2017)
Abstract deadline: 7/14/17
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