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Modern Topics in Energy and Power Technical Meeting

by Tsvetanka Zheleva, Edward Shaffer, Dennis Bushnell, and Nino Pereira

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14. ABSTRACT
This report summarizes the information exchange at the Modern Topics in Energy and Power Technical Meeting hosted by the Energy and Power Division at the US Army Research Laboratory and held at the Adelphi Laboratory Center, Adelphi, Maryland, 14–16 July 2015. The meeting’s 8 sessions focused on energy conversion technologies, energy and power for directed energy, high-energy-density materials, plasma and nuclear physics, low-energy nuclear reactions, novel compact power sources, quantum vacuum energy, and information-energy parallels, with presentations from subject matter specialists as well as scientists and managers from the Army, academic institutions, national laboratories, and other US Department of Defense and Department of Energy activities. The meeting's intent was in part to provide current perspectives to the Army science and technology community on selected energy and power technology–related topics that have recently attracted attention.

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Executive Summary

This report summarizes the information exchange at the Modern Topics in Energy and Power Technical Meeting hosted by the Energy and Power Division at the US Army Research Laboratory and held at the Adelphi Laboratory Center, Adelphi, Maryland, 14–16 July 2015. The meeting's 8 sessions focused on energy conversion technologies, energy and power for directed energy, high-energy-density materials, plasma and nuclear physics, low-energy nuclear reactions, novel compact power sources, quantum vacuum energy, and information-energy parallels, with presentations from subject matter specialists as well as scientists and managers from the Army, academic institutions, national laboratories, and other US Department of Defense and Department of Energy activities. The meeting's intent was in part to provide current perspectives to the Army science and technology community on selected energy and power technology–related topics that have recently attracted attention.

The meeting was structured to foster exchange of information among participants representing a cross section of different and broadly varied technical focus areas. This posed both challenges and opportunities. The organizers asked the speakers to present a critical overview of their specific topic, which was followed by a discussion of their perspective on the gaps in the technology, the priorities of the ongoing research, and their expectations for the future direction of the field. However, many of the talks were more narrowly focused, mostly on the research in their own organization, with in-depth description of their technology and the applications they expected from them. One talk provided a broad overview of an organization's research portfolio but not in the depth desired for a particular topic. Appendix A provides the meeting agenda, and Appendix B gathers the individual presenter's abstracts. While these reflect the speakers' initial perspectives, the following summary provides highlights captured during presentations over the course of the 3-day meeting. The structure of the workshop did not provide the opportunity for in-depth analysis, discussion, and debate; open questions and significant differences in opinion prevail in some areas. Top-level observations and recommendations capturing the workshop outcomes follow the session summaries.

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1. Introduction

The US Army Research Laboratory (ARL) hosted a 3-day technical meeting entitled "Modern Topics in Energy and Power" (MTEP) during 14–16 July 2015 at the ARL-Adelphi Laboratory Center, Maryland. This meeting provided a forum for the Army energy and power (E&P) science and technology (S&T) community to review the state of the art and the current status of research and development in selected modern topics as well as speculation in concepts with potential relevance to future energy and power technologies. More than 60 subject matter experts (SMEs) and managers from ARL, Navy Research Laboratory, Air Force Research Laboratory, National Air and Space Administration (NASA), Department of Defense (DOD), Defense Intelligence Agency, Defense Threat Reduction Agency, National Renewable Energy Laboratory (NREL), academia, and industry attended some or all of the technical sessions, where topics had been selected by the meeting organizers for their potential relevance to the Army and, for half of these topics, a connection with ongoing research at ARL. This report provides a summary of the MTEP workshop discussions. As such, it captures views and opinions as presented and expressed by the individual speakers. Although a number of the topics presented by the speakers generated considerable follow-on discussion and information exchange after the meeting, this report does not represent ARL or Army endorsement of specific topics discussed, external approaches, or programs.

In its initial phase the MTEP meeting focused on technologies under development with near-term applications, including energy conversion technologies, E&P for directed energy, and high-energy-density materials. The meeting's latter part was envisioned to provide discussion on less-visited topics such as plasma and nuclear physics, low-energy nuclear reactions, novel compact power sources, quantum vacuum energy, and the parallels between information and energy. Although the viability or practicality of some of these areas is uncertain or questionable, a better understanding of the scientific and technical landscape was desired to help inform ideas for potential future E&P research. Following the meeting, participants exchanged information in informal working groups toward furthering discussions on selected areas and exploring the potentials of future research and possible collaborative efforts on more-focused topics such as high-energy-density materials, E&P for directed energy, and others.

The event was hosted and chaired by the E&P Division at ARL's Sensors and Electron Devices Directorate (SEDD). Dr Ed Shaffer, Chief of the E&P Division, as General Chair, chartered the workshop not only to inform ARL of the current status in these areas, but also Army and joint partners through the Army Energy and Power Community of Practice and DOD Energy and Power Community of

Interest. The Honorary Chair was Mr Dennis Bushnell, Chief Scientist from NASA's Langley Research Center, who has extensively investigated a number of the less-well-known topic areas. Technical Chair for the workshop was Dr Tsvetanka Zheleva, Associate Chief for the Energy and Power Division at ARL. The meeting chairs, branch chiefs, and team leads from ARL formed the core organizing committee, nominating speakers for the technical sessions from leading groups from academia and national laboratories working in the areas under discussion. The meeting agenda is shown in Appendix A, the presenters' abstracts in Appendix B, and the attendee list in Appendix C.

1.1 Day One

The first day of the meeting started with a General Session with opening remarks by ARL's Dr Ed Shaffer, who set the agenda for the meeting in the context of the major E&P research topics at ARL in the broad areas of electrochemistry, power components, and power conditioning. In his talk on exotic/advanced energetics, Dennis Bushnell, Chief Scientist at NASA-Langley, presented a precis of the exotic/advanced energetics landscape. He provided brief descriptions of the characteristics and potentials for nanoporous silicon, atomic propellants (hydrogen H, not H_2), strain bond energy release (SBER), pyro-electric fusion, low-energy nuclear reactions (LENRs), isomers, metallic hydrogen, positrons, nuclear thermionic avalanche cells, cold-fast compression, metastable helium, the Slingatron, halophytes, and zero point energy. Mr Bushnell's talk ended with his top-level rank-order suggestion for National Security Applications–LENR, positrons, and SBER. These and others discussed topics, it was suggested, could provide orders to many orders of magnitude greater energy density than chemical fuels as well as revolutionize both defensive and offensive national security, for both platforms and weaponry. The major objectives of the meeting were outlined by Dr Tsvetanka Zheleva (ARL):

- Review current research and state-of-the-art technology of selected topics relevant to energy and power issues in the future.
- Gain collective knowledge and understanding of proposed revolutionary ideas, experiments, models, and concepts.
- Help the Army shape and focus emerging energy and power technologies supporting future capabilities.
- Enable further strategic and critical thinking in the energy and power domain to identify opportunities for mid- and long-term research that addresses DOD needs.

Dr Zheleva named the following 4 focus areas for discussion for each of the E&P topics in the various sessions:

- What is the present status of the S&T?
- Where are the gaps in the understanding of the science or in technology applications?
- What are the research and development priorities for the Army?
- What can be expected from the different technologies in the future?

The first technical session, entitled "Energy Conversion Technologies", was chaired by Dr Paul Barnes (ARL). Dr John Turner from NREL presented "Photoelectrochemical Water Splitting, from Fundamental to Devices," and Professor Lane Martin from Lawrence Berkeley National Laboratory presented "Advanced Thermal-to-Electrical Pyroelectric Energy Conversion". The latter 2 talks gave a comprehensive overview of their own topics but did not compare them with competing technologies for energy conversion.

The next session, "Energy and Power for Directed Energy", was chaired by Dr Mark Dubinskiy (ARL). Dr Gary Wood (ARL), Chief of ARL's Electro-Optics and Photonics Division of SEDD, gave a big-picture overview with priorities, gaps, and future directions for the ARL/DOD laser programs in his "Thoughts on the Future of Laser Directed Energy". He considers directed energy (DE) to be a component of electronic warfare (EW)—part of electronic attack, protection, and support. Furthermore, Dr Wood described the advantages and disadvantages of directed energy warfare (DEW). He described the major requirements of a DE system: power and thermal management, mechanical support, deconfliction, detection (RF) and imaging sensors (infrared and visible), real-time response, and others. After providing an overview of Army high-energy laser programs, starting in the mid-1970s and currently ongoing, Dr Wood gave a deeper analysis of the scalability of solid-state laser (from kilowatts to megawatts of power), the various mechanisms for beam control, and briefly described laser protection programs, including active and passive sensor protection and structural protection. He outlined his view on future directions and overcoming barriers: diode pumping, cryogenic cooling, beam combining, and developing new and improved materials to overcome fiber laser limitations. Dr Wood also addressed long-term challenges such as power scaling for solid-state lasers, diminishing and eliminating the limitations of the line-of-sight requirement, dependence on atmospheric conditions, thermal management, as well as improving the size, weight, power, and cost (SWaP-C) parameters.

In contrast, Dr Dubinskiy's talk, "Fully Crystalline Double Clad Fibers – Next Generation in Laser Power Scaling", was a comprehensive talk focused explicitly on ARL's state-of-the art, next-generation, fully crystalline, double-clad fiber laser program that would enable 1–2 orders of magnitude power scalability of the double-clad lasers compared with that of glass fiber lasers.

The day's last session, "High Energy Density Materials", was chaired by Dr Betsy Rice (ARL). In the first of 3 talks, "Nano High Energy Density Materials", Professor Steve Sun from Purdue University discussed not only new energetic materials for high-energy-density, but also reviewed ways to achieve high-energy densities with new materials and highlighted properties besides energy density that might enable disruptive capabilities. The last 2 talks were classified For Official Use Only and presented only to government employees and government contractors. In her talk "Strain Bond Energy Release from Nano-Diamonds", Dr Jennifer Gottfried (ARL) described the theoretical and experimental progress at ARL toward demonstrating SBER from nanodiamonds. In her talk "Extended Solids", Dr Jennifer Ciezak-Jenkins (ARL) introduced a new class of advanced energetic materials, the so-called extended solids, and reviewed previous work and current research at ARL on storing energy in metastable structures by pressure, resulting in highly strained chemical bonds that are metastable at standard temperature and pressure and can release the energy on command.

1.2 Day Two

The second day of the meeting started with 2 talks on plasma and nuclear physics in a session chaired by Mr Morris Berman (ARL). In the first talk, "Energy and Pulsed Power for National Security Applications: A Naval Perspective", Dr Thomas Mehlhorn, Senior Executive Service (NRL), gave an extensive overview of the current status of the E&P programs at NRL. These range from near-term Naval Energy Initiatives, sailing a "Great Green Fleet" of nuclear and hybrid electric ships and planes running on biofuels, and phasing-in the use of hybrid, electric, and flex fuel vehicles. Long-term energy initiatives include creating jet fuel based on seawater, research on photovoltaics (PVs) of different types, lightweight fuel cell systems for unmanned air vehicles (UAVs), batteries "beyond lithium", and benthic microbial fuel cells (electrodes embedded in marine sediments). Given its importance, NRL now has a national program to develop inertial confinement fusion (ICF) as a potential path to thermonuclear energy. Related topics include long-range wireless recharging with high-power lasers as well as compact, repetitive, efficient, and thermally managed pulsed power for applications of repetitive high-energy electron beams (e.g., for the cleanup of power plant emissions).

In his talk, “Isomers: Energy Storage and Directed Gamma Radiation”, Dr Jeff Carroll (ARL) reviewed the physics of nuclear structure and how this relates to nuclear isomers. These are nuclei with relatively long-lived metastable excited states whose nuclear-scale energy could possibly be liberated with electromagnetic radiation (in contrast with the usual nuclear mechanisms such as neutron and other particle bombardment, and fission). He mentioned not only propitious applications, such as long-lived nuclear batteries that turn on by irradiation and directed energy in the form of highly penetrating gamma radiation, but also emphasized the challenges in nuclear isomer research and the difficulties in realizing practical application.

The next session, “Low Energy Nuclear Reactions (LENR)”, was chaired by Dr Cindy Lundgren (ARL). The nature of the underlying phenomena involved with energy release in these systems remains a subject of open investigation. It is also known by some scientists as the Pons-Fleischmann Heat Effect (PFHE), or as Condensed Matter Nuclear Science (CMNS), over the better-known term Cold Fusion. A number of exploratory efforts are being undertaken in this area in the community, ranging across realms of theory, experimentation, and application. Speakers in this session represented viewpoints from a sampling of these efforts. Key discussions on PFHE energy release involved the nature of the mechanism (neither explained by conventional nuclear reactions nor, believed by some, chemical bond energy) and the viability and value of harnessing this energy for practical applications versus other energy technologies.

The first talk in this session, “LENR – Cold Fusion, CMNS: Present and Future Status”, was presented by Dr Michael McKubre from SRI International. Again, although the underlying phenomena are not well understood, SRI has been performing LENR-related experiments for over 25 years. Dr McKubre provided an overview of SRI’s work on the topic, including a summary of SRI’s efforts to replicate the experiments of others. In his overview, Dr McKubre contrasted measurements that seem to support a nuclear reaction with their problematic aspects, notably a lack of clear, reproducible data in all these measurements. Dr McKubre proposed 2 pathways to reach scientific consensus about the PFHE: the rigorous scientific method or a technology demonstration that produces energy irrespective of a clear understanding of the physical basis.

The second talk, “A Short Discourse on Low Energy Nuclear Reactions (LENR)”, was given by Dr Tapan Patel, a postdoctoral fellow in Dr George Miley’s group at the University of Illinois at Urbana-Champaign (UIUC). Dr Miley is a Professor Emeritus at UIUC who is attempting to commercialize LENR. The talk presented a systematic overview of PFHE research going on at the UIUC (well-known for its PFHE investigations). He outlined their various approaches focusing on deuterium loading in solids with different techniques (electrolytic, gas loading, plasma bombardment, electrodiffusion, and sonic) and discussed future work intended to mitigate the inability to replicate results in earlier experiments, such as preventing the sintering of nanoparticles and higher control point temperatures.

The next session, “Novel Compact Power Sources,” was chaired by Dr Marc Litz (ARL). In the first talk, “The Lockheed Martin (LM) Compact Fusion Reactor Program”, Dr Thomas McGuire presented his program to develop LM’s compact fusion reactor (CFR) concept. He described the novel magnetic cusp configuration that, the researchers believe, allows a stable plasma to be achieved in compact equipment that is consistent with the economic demands on power plants and mobile power sources. He described the status of the current plasma confinement experiments underway at LM as well as the challenges and opportunities for future applications.

The second talk, “GEM*STAR: Accelerator-driven Subcritical System for Improved Safety, Waste Management, and Plutonium Disposition”, by Dr Rolland Johnson from Muons, Inc., described the potential for a new generation of compact nuclear reactors that operate without the need for a critical core, fuel enrichment, or reprocessing. He presented the design of a multipurpose reactor that combines 2 well-developed technologies (namely a high-power proton accelerator similar to that in the Spallation Neutron Source and a long-abandoned concept of a high-temperature molten-salt reactor, both at Oak Ridge National Laboratory). The GEM*STAR reactor contains less than a critical mass of fissile material and almost a million times less radioactivity in fission products than conventional reactors (like those at Three Mile Island, Chernobyl, or Fukushima). The GEM*STAR concept can obtain energy from spent nuclear fuel, natural uranium, thorium, or surplus weapons material.

The keynote talk, aptly titled “Exotic/Advanced Energetics”, presented by Dennis Bushnell, Chief Scientist at NASA’s Langley Research Center, ended the day on a high note, focusing on futuristic ideas. He briefly described various potentially revolutionary ideas for higher power and energy applications. Some of the underlying S&T areas were also discussed elsewhere in the MTEP meeting, such as strain-bond energy release, nuclear isomers, and antimatter fuel. Others areas were posed as suggestions for further discussions on futuristic topics, for example atomic fuels, metallic H_2, amorphous silicon, densified deuterium, nonvalence band thermionics, cold fast compression for thermonuclear fusion, and many other potentially revolutionary ideas.

1.3 Day Three

The third day of the meeting consisted of 2 disparate technical sessions. The first session, "State-of-the Art Applications of the Quantum Vacuum Energy", was organized and chaired by Dr Eric Davis from the Institute for Advanced Studies at Austin, Texas. The first talk, "Empty Space: the Multilayered, Multicolored Superconductor," given by Dr Davis himself, was very informative in outlining the theoretical physics concepts behind quantum vacuum energy (QVE), particularly for the attendees who had little exposure to this area. Dr Davis started with a brief review of the 19th century debate on the empty vacuum versus the aether, followed by a big-picture overview of the quantum fields of nature.

For all these fields, Heisenberg's Uncertainty Principle results in zero-point field fluctuations. On this basis, the vacuum is filled with these different fluctuations. The well-known Casimir effect can be explained in terms of these field fluctuations. He explicitly acknowledged that the vacuum energy is minute in magnitude and of limited application but implicitly assumed that it can be technologically scaled up. Such vacuum fluctuations occur in quantum chromodynamics (QCD), and the exotic "colored" superconducting state of the quantum vacuum in QCD motivated the title of the talk. He argued that the "melting" of the QCD vacuum at ultra-high energies (as in the early universe, or as can be achieved on a tiny scale at the Relativistic Heavy Ion Collider, a nuclear accelerator) can release the energy of the phase transition, which he estimated in a tiny volume after the collision of 2 heavy nuclei as 10^{35} J/m^3. He claimed that for the minute amount of time that the nuclei's constituent quarks behave as free particles, this energy could become available. In the same vein, he speculated that the melting of the Higgs field would release even more energy, although he admitted that this may not be an experimentally reachable goal in the foreseeable future. Dr Davis' talk concluded by mentioning some of the progress in ultrahigh-intensity laser technology, that might lead to exa-watt or even zetta-watt pulses on zepto-second time scales. He conjectured that the resulting so called "sparking of the vacuum" could be a potential mechanism to enable QVE energy release.

Applications of QVE was the topic of the second talk, "Developing Spacecraft Propulsion Methods Using the Quantum Vacuum", presented by Dr G Jordan Maclay, Chief Scientist at Quantum Fields LLC. He emphasized the exquisite precision (to 1 part per billion) achieved in quantum electrodynamics (QED) predictions (e.g., the magnetic moment of the electron and the value of the fine structure constant). He then asserted that zero-point vacuum energy might be extracted in multiple ways, perhaps with static or accelerated surfaces, or by causing interference between different modes in a cavity. To illustrate, he discussed the Casimir force, which results from the exclusion of long-wavelength electromagnetic modes between 2 electrically conducting plates. Such forces are important in microelectro-mechanical system (MEMS) technology and can now be measured accurately as well. He then hypothesized implementing quantum forces for space propulsion as has been proposed by others. In the summary of his talk, and in the subsequent discussions, Dr Maclay admitted that these effects from zero-point fluctuations all involve the longer wavelength components of the vacuum fluctuations and consequently would produce disappointingly small forces.

The third talk in this session, “Matter-Antimatter Propulsion via Parallel Electric and Magnetic Fields”, was presented by Professor Gerald Cleaver from the Center for Astrophysics, Space Physics and Engineering Research and the Department of Physics at Baylor University, Waco, Texas. Professor Cleaver first reviewed the history of the particle/antiparticle pair production, which was conceived in the 1930s and is now part of QED, developed in the 1950s. QED predicts electron-positron pair production from the vacuum when the electric field reaches a critical value (the Schwinger limit, $E_0 \sim 10^{20}$ V/m), which is comparable to the intensity of some current lasers. Professor Cleaver described physical processes that could lower the critical field below the Schwinger limit or, equivalently, enhance particle/antiparticle pair production above the Schwinger limit. These include modifications to the laser pulse shape as well as an external magnetic field. Although Professor Cleaver's presentation primarily dealt with basic physics, he referenced potential applications of matter-antimatter material proposed by others, such as an energy-rich rocket fuel as would be needed for interstellar propulsion. However, the need for a containment magnetic field strength on the order of 50 kT (3 orders of magnitude higher than the maximum of 50 T obtained in the best laboratory magnets) renders such fuel impractical at this point because it cannot be contained even if it could be made in sufficient volume.

The meeting’s final session, on Information-Energy Parallels, was chaired by Dr Vinod Mishra (ARL) and included 2 presentations. The first, “Data Challenges in the Internet of Energy”, was by Professor Anna Scaglione of Arizona State University, who gave an inspiring, scholarly description of electric vehicles, smart thermostats, and smart lighting as a distinct ecosystem that will allow customers to interact with the market of electricity directly while at the same time optimize customer preferences. This will enable improved use of the variable production from renewable energy, from distributed “producers/consumers” and centralized plants alike. In this construct, the distribution grid will require new sensing and control technology as well as power electronics and storage resources. Such developments offer immense opportunities in the near future but also many challenges.

Dr Scaglione noted the differences between the Internet and the energy infrastructure: Unlike the Internet, which is managed in a decentralized way, power systems are large vertically integrated infrastructures that must interact with market forces in their own way. Professor Scaglione noted some of the challenges, including a lack of attraction of industrial control issues compared with other topics, the near absence of data compression techniques sufficiently powerful to deal with the data overflow, and the problem of examining the data to decide on scheduling a large number of transactions. In addition the talk discussed cyber security and privacy issues arising in general with the Internet of Things and with the Internet of Energy in particular.

The last presentation of the meeting, "Secure Energy-Based Critical Infrastructure", was presented by Profesor Wei Yu of Towson University in Baltimore, Maryland. This talk, on the smart grid, was more narrowly focused. Professor Yu described the smart grid as a typical energy-based cyber-physical system that uses modern computing, communication, and control technologies to make the power grid more efficient, reliable, and secure. He emphasized the vulnerability of smart grids operating in hostile environments, as in military tactical microgrid environments, due to the lack of tamper-resistant hardware for sensor, meters, etc. Professor Yu introduced a modeling framework to systematically explore the space of threats in the smart grid and their impacts on both system operations and end users, as well as the development of effective mitigation schemes to defend against these attacks.

2. Observations and Recommendations

Although selected topics were presented to provide a perspective on military-relevant energy and power conversion technologies, this workshop does not represent a comprehensive review of the subject areas. As such, in many cases, the ability to extract relevant gaps, opportunities, and recommendations from the discussions is limited. Given this caveat, a number of summary comments are outlined in the following.

2.1 Energy Conversion Technologies

Observations

- The MTEP session focused on several novel approaches not as well known to the E&P community as more established efforts. The comparative value of emerging energy conversion areas vis-à-vis other technologies for military utility is not widely understood.

Recommendations

- Assemble a team of SMEs to perform an extensive, thorough comparative review on multiple energy conversion technologies (from the conventional to more futuristic) and prepare a peer-review paper and technical report on the topic.
- Such comprehensive review will be extremely useful and currently is missing from the current state-of-the-art literature on the topic.

2.2 Energy and Power for Directed Energy

Observations

- This session turned out to be a programmatic review of existing DE/EW efforts, with limited discussion regarding E&P needs, challenges, and opportunities.
- It was acknowledged that scaling up current output power from 10s to 100s+ of kilowatts is power source limited and thermally constrained for a given platform.

Recommendations

- Continue "technology push"–based E&P component efforts as the Army/DOD defines a comprehensive strategy and focus for DE/EW.
- Continue enabling S&T to reduce DEW SWaP-C; for example the US Defense Advanced Research Projects Agency has defined a goal of 5 kg/kW (1 kg/kW for laser amplifiers).
- Identify and address anticipated/possible barriers to system applications; for example, scalable laser schemes favor solid state diode pumping; cryogenic cooling should be further explored (enhances efficiency); materials to overcome fiber limitations and power efficiency losses (beam combining schemes with large bandwidth possible); hybridized materials, components, subsystems (integration potential of DEW with other structures, systems, weapons has not been explored; use of universal power source for multiple platform applications, etc.).

2.3 High-Energy-Density Materials

Observations

- There is enormous disruptive potential for extended solids, supported by thermochemical evidence.
- The challenge remains to be scale-up to gram batches (limited by high-pressure vessels).

Recommendations

- Continue work to address challenges: deployment of new techniques for large-scale production, characterization of performance properties on small scale, bridging length scales, and develop solid-state quantum mechanical theories.

2.4 Plasma and Nuclear Physics

Observations

- Nuclear isomers, metastable states of nuclei, can store energy for times ranging from microseconds to decades. The isomers can give up their energy spontaneously in radioactive decay; however, the decay can also be stimulated by some external stimulus.
- Nuclear isomers are unique because the external stimulus can be electromagnetic radiation, while all nuclei (including nuclear isomers) can be made to decay by irradiation with the right kind of charged particles or exposure to neutrons.
- Potential applications for nuclear isomers are, for example, gamma ray lasers and radioisotope "reserve batteries", for which nuclear isomers might be uniquely suited.

Recommendations

- Continue research at the discovery level to keep Army scientists cognizant of the latest developments and to participate in relevant team efforts with relevant groups in the United States and elsewhere in the world.
- Explore the gamma ray laser "GRASER" dilemma: the fundamental conflict between need to pump to create inversion while minimizing heating of host medium (to permit Mössbauer recoil-free emission without Doppler broadening).

- Participate in measurements requiring state-of-the-art experimental equipment/facilities with techniques tailored to a particular nuclide of interest.

2.5 Low-Energy Nuclear Reactions

Observations

- Two major gaps inhibit LENR/PFHE efforts: the lack of reproducibility in experiments and the lack of a verifiable theory. Despite these gaps, a number of governmental (United States and others), industry, and academic efforts have proceeded to marginal and inconclusive effect to date.

Recommendations

- The current consensus in the scientific community is that PFHE is not of nuclear origin, hence research along these lines would not be productive.
- To the extent that it is considered necessary to keep track of this field, it makes some sense to evaluate ongoing research at universities or small companies (engage in appropriate "technology watch" efforts).

2.6 Novel Compact Power Sources

Observations

- Numerous scientific and engineering challenges remain in developing practical, nuclear-based compact power sources. Development of the underlying technologies may evolve solutions of more immediate value/application, such as special heat-resisting materials and high-power applications (e.g., producing plasmas/fields for DE).
- Linear accelerator expertise is available to the S&T community in activities such as that offered by Muons, Inc. Such expertise may become useful if the Army decides to modify existing liner nuclear accelerators for nuclear-physics-related research. However, the concept as presented is not currently within the Army's charter.

Recommendations

- The Army should maintain a "technology watch" effort regarding the small nuclear/compact fusion efforts. It would be useful for Army scientists to participate in those pursued by Lockheed and others, not so much for its payoff (which in all likelihood will not be a viable fusion reactor) but primarily for the insight it provides Army scientists into what is and what is not feasible with this type of advanced technology.

- Consider participating with other US government agencies in the proposed project.

2.7 Quantum Vacuum Energy and Matter-Antimatter Topics

Observations

- Although the explanation of the underlying principles given of quantum field theory are scientifically sound, extrapolation toward ideas related to QVE and the ability to access such energy remain speculative.
- No practical applications are anticipated within the foreseeable future because it is still an open question whether there is useful energy to be had.
- There are aspects of pure and applied physics discovery related to quantum fields that remain of interest to the Army/DOD and the broader research community. One example is the analysis by Pereira (International Journal of Theoretical Physics (IJTF), to be published, 2016), questioning the support for QVE implied by Puthoff (IJTF, 2007).
- Matter-antimatter pair production remains out of reach for any practical military application for the foreseeable future. Although the cost was $63 trillion per microgram in 2000, the current cost per microgram has decreased to $200,000. However, to be economically viable as a fuel source, the cost would need to be further reduced by a factor of 10,000 (per "Status of Antimatter", NASA Glenn Research Center, www.nasa.gov/centers /glenn/technology/warp/antistat.html; 2015 July 14). Moreover, regardless of cost, there has been no demonstrated approach to produce antimatter at any practical scale, as needed for its use as a fuel.

Recommendations

Consider tech watch of underlying physics, for example pure physics experiments enabled by peta-watt-class lasers and the associated engineering and materials developments.

2.8 Information-Energy Parallels

Observations

- Since most of the interesting energy and power aspects are treated as peripheral to the core information/cyber-related work, energy-centric discussions in these areas remain a challenge.

Recommendations

- Explore the "holistic" approach to understanding the information-energy parallels; a possible, viable scheme is the Harvard "information philosopher" construct: http://www.informationphilosopher.com/.
- Organize separate workshop on this and related topics.
- Organize seminar series/lecture format inviting leading experts in the field.

3. Conclusions

Overall, the MTEP meeting was an exciting forum for exchange of ideas, including very futuristic ones, related to energy across a very broad range of areas of interest to the E&P community.

Because of the broad range of topics, the variety of approaches received from the presenters and the participants did not provide an optimal opportunity for in-depth discussions on a given topic.

The scientific depth and rigor of information provided was uneven across the areas.

Given the limited scope and time available, for some of the most controversial topics it was difficult to come to a conclusive consensus about the challenges and the gaps and the potential future opportunities.

There is sufficient in-house DOD expertise available to follow up with the information presented at the meeting and the recommendations based on the subsequent discussions, via analysis, exchange of information, follow-on meetings, etc., within selected areas, to include the following:

- Areas for Army/DOD worth further inquiry (but not active programs):
  - underlying phenomena related to LENR
- Areas where Army/DOD should not actively engage (but limited technology watch may be appropriate) at this time:
  - LENR experimentation
  - QVE applications
  - Matter/antimatter physics

Appendix A. Modern Topics in Energy and Power Technical Meeting

This appendix appears in its original form, without editorial change.

Agenda

July 14, 2015

	Welcome and Introductions
7:30	Registration
8:30	Welcome, Overview Energy and Power Topics at ARL Dr. Ed Shaffer - ARL
8:40	National security energy going forward Dennis Bushnell – NASA ST
8:50	Meeting Goals and Objectives Dr. Tsvetanka Zheleva – ARL
	Energy Conversion Technologies, Chair: Dr. Paul Barnes
9:00	Photoelectrochemical water splitting, from fundamentals to devices Dr. John Turner - NREL
10:00	BREAK
10:15	Advanced Thermal-to-Electrical Pyroelectric Energy Conversion Prof. Lane Martin – LBNL
	Energy and Power for Directed Energy, Chair: Dr. Mark Dubinsky
11:15	Thoughts on the Future of Laser Directed Energy Dr. Gary Wood, ARL
12:15	LUNCH
13:00	Fully-crystalline Double-clad Fibers - Next Generation in Laser Power Scaling Dr. Mark Dubinsky, ARL
	High Energy Density Materials, Chair: Dr. Betsy Rice
14:00	Nano-High Energy Density Materials Dr. Steve Son, Purdue University
15:00	Strain Bond Energy Release from Nanodiamonds (FOUO) Dr. Jennifer Gottfried, ARL
16:00	BREAK
16:15	Extended Solids (FOUO) Dr. Jennifer Ciezak-Jenkins, ARL
17:15	ADJOURN

15 July, 2015

	Plasma and Nuclear Physics, Chair: Mr. Morris Berman
8:30	Energy and Pulsed Power for National Security Applications: A Naval Perspective Dr. Thomas Mehlhorn, NRL
9:30	Isomers: Energy Storage and Directed Gamma Radiation Dr. Jeff Carroll, ARL
10:30	BREAK
	Low Energy Nuclear Reactions, Chair: Dr. Cindy Lundgren
10:45	Low Energy Nuclear Reactions (LENR) – Cold Fusion – CMNS; Present and Projected Future Status Dr. Michael McKubre, SRI International
11:45	LUNCH
12:45	A Short Discourse on Low Energy Nuclear Reactions (LENR) Prof. George Miley, Dr. Tapan Patel, Dr. Bert Stunkard, University of Illinoi at Urbana-Champaign
	Novel Compact Power Sources, Chair: Dr. Marc Litz
13:45	The Lockheed Martin Compact Fusion Reactor Program Dr. Thomas McGure, Lockheed Martin Aeronautics Company
14:45	BREAK
15:00	GEM*STAR Accelerator-driven Subcritical System for Improved Safety, Waste management, and Plutonium Disposition Dr. Rolland Johnson, Muons, Inc.
16:00	Exotic Energies Dennis Bushnell, NASA ST
17:00	ADJOURN/ GROUP DINNER (TBD)

16 July, 2015

	State-of-the Art Applications of Quantum Vacuum Energy, Chair: Dr. Eric Davis
8:30	Empty Space: The Multilayered, Multicolored Superconductor Dr. Eric Davis, Institute for Advanced Studies at Austin
9:30	Developing Spacecraft Propulsion Methods Using the Quantum Vacuum Dr. Jordan Maclay, Quantum Fields LLC
10:30	BREAK
10:45	Matter-Antimatter Propulsion via Parallel Electric and Magnetic Fields Prof. Gerald Cleaver, Baylor University
11:45	LUNCH
	Information-Energy Parallels, Chair: Dr. Vinod Mishra
12:45	Data Challenges in the Internet of Energy Prof. Anna Scaglione, Arizona State University
13:45	Secure Energy-Based Cyber-Physical Systems Prof. Wei Yu, Towson University
14:45	BREAK

15:00	Discussion: Chairs: Ed Shaffer, Dennis Bushnell, Tsvetanka Zheleva
17:00	ADJOURN

Appendix B. Presentation Abstracts and Presenters' Biographies

This appendix appears in its original form, without editorial change.

ABSTRACTS AND BIOS

Modern Topics in Energy and Power Technical meeting

14-16 July 2015
US Army Research Laboratory, Adelphi, MD

Disclaimer: The author provided abstracts herein represent solely the individual authors' perspectives. As such, author provided information in this report is offered here "as is", without Army or peer review regarding the scientific or technical validity or merit of the ideas expressed.

Tuesday, 14 July, 9:00

Photoelectrochemical Water Splitting, from Fundamentals to Devices

John A. Turner
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Forty years after the first reported photoelectrochemical (PEC) water splitting experiment, commercial hydrogen production from PEC is still a dream. Literally 100's of millions of dollars and thousands of papers later and still no semiconductor system has been identified that has the potential for economical hydrogen production from PEC water splitting.

Recent technoeconomic analysis studies indicate that a 20% solar-to-hydrogen PEC conversion efficiency is necessary for a commercially viable system. Additional requirements of lifetime (years), and cells costs (<\$400/m^2) make a working device extremely challenging.

To achieve such high efficiencies, semiconductors with superior electronic properties are required as well as highly active catalysts. Clearly then one must decide whether to use an existing PV-based semiconductor or search for a new semiconductor with the necessary electronic properties. The majority of the research has been directed at metal oxides due to their expected low costs, ease of synthesis and stability. Little progress has been made; efficiencies for these oxide systems are abysmally low, primarily due to their poor electronic structure.

The III-V-based solar cells show the highest solar PV efficiency and thus are excellent candidates for a PEC system. In fact, the highest solar-to-hydrogen efficiency to-date for PEC water splitting using visible light is the III-V $GaAs/GaInP_2$ PV/PEC tandem cell, but cell costs are high and lifetime is low.

On the other hand, multi-component transition metal oxides are complex materials, making intuitive guesses difficult and a focused search very challenging.

This presentation will discuss some of the challenges and opportunities facing PEC community in our search for a workable PEC solar water-splitting system that could lead to a commercial device. The discussion will include metal oxides, surface treatments and tandem cells for PEC water splitting.

Dr. John Turner Biography

John A. Turner, Ph. D., is a Research Fellow at the National Renewable Energy Laboratory (NREL). He started his career in electrochemistry at Idaho State University as an undergraduate working on sodium and potassium amalgam batteries. After receiving his B.S. degree in Chemistry he moved to Colorado State University and joined Bob and Janet Osteryoung's group working on pulsed voltammetric techniques. He received his Ph.D. in Electroanalytical Chemistry and then moved to Caltech, joining Fred Anson's group for his postdoctoral work. While at Caltech he worked with Heinz Gerischer on photoelectrochemistry and fell in love with the area. He joined NREL (then the Solar Energy Research Institute) in 1979 to work in Art Nozik's group on hot-carrier processes at semiconductor electrodes. He then began research on photoelectrochemical water splitting for hydrogen production and he current holds the record for the highest solar-to-hydrogen efficiency from a photoelectrochemical-based device. His research topics include semiconductor materials and structures, catalysts for the hydrogen and oxygen reactions, and fundamental processes of charge transfer at semiconductor electrodes. He has twice received the Midwestern Research Institute President's Award for Exceptional Performance in Research. In addition, he has received the Hydrogen Technical Advisory Panel award for Research Excellence, an Idaho State University Outstanding Achievement Award (2006), the Japanese Society of Coordination Chemistry Lectureship Award, and six Outstanding Mentor Awards from the US Department of Energy for his work with undergraduate students. He is the author or co-author of over 160 peer-reviewed publications in the areas of photoelectrochemistry, fuel cells, batteries, general electrochemistry and analytical chemistry. He is a Fellow of the Renewable and Sustainable Energy Institute, a joint institute between NREL and the University of Colorado, Boulder, and a 2012-2014 Sigma Xi Distinguished Lecturer. He is co-Editor of the Journal of Renewable and Sustainable Energy, an AIP journal.

Tuesday, 14 July, 10:15

Advanced Thermal-to-Electrical Pyroelectric Energy Conversion

Lane W. Martin
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The need for improved utilization of energy resources is abundantly clear. In the United States alone, we are unable to utilize between 50-60% of all energy produced (from all sources, renewable or otherwise) due to inefficiencies in energy transport, device operation, etc. The vast majority of this lost energy is dissipated as heat or thermal losses. Harvesting even a small fraction of this energy would dramatically impact what is, along with such topics as water, healthcare, etc., one of the most pressing challenges that faces society today. In this spirit, a number of direct thermal-to-electric energy conversion technologies have been proposed and explored over the years with thermoelectric energy conversion being the most common and widely studied. Thermoelectrics are solid-state devices that transform a thermal gradient into an electrical current. One additional (and complementary) approach to thermal-to-electric energy conversion is so-called *pyroelectric energy conversion* (PEC) in which a solid-state heat engine transforms temporally-varying thermal signatures into electrical current.

PEC is based on the *pyroelectric effect* which is the variation of remnant polarization P of a material as a function of temperature T at constant electric field E $[(\partial P/\partial T)_E]$. Efficient PEC requires operating the material using thermal-electrical cycles to produce sustained pyroelectric generation of electricity; in other words a PEC unit is essentially an electric form of a heat engine. The conversion unit uses a thermodynamic medium whose electric polarization depends upon temperature. Repeated extraction of electrical energy requires a cyclic temperature profile and conversion can be further enhanced by additionally applying an electric field. A wide variety of cycles have been suggested for pyroelectric energy conversion, and classic Carnot and Stirling-like cycle can be conceived, but are practically difficult to achieve. In general, the highest energy conversion occurs for the largest change in P_S with temperature. Conventional thinking places the temperature limits for a thermodynamic cycle where the ferroelectric Curie temperature (T_C^{FE}) is slightly above the maximum temperature T_H and the low temperature limit of the cycle T_L is where P_S is close to its maximum value. In turn, it is possible to envision alternative, practically simple to implement, thermodynamic cycles such as the pyroelectric Ericsson cycle which represents the current state-of-the-art in this community (although additional cycles are also possible, including Drummond-Carnot, Margosian-B, Ericsson-Olsen cycle, etc.).

In this presentation, I will introduce the concept of PEC and provide a foundation for understanding what it takes to create high-performance pyroelectric materials and PEC devices. In particular, we will explore the fundamentals of the field- and temperature-dependent response of ferroelectric materials which are known to exhibit large pyroelectric response. We will examine recent insights into material design algorithms that can allow us to maximize PEC potential in these materials via control of both electrical/dielectric and pyroelectric responses that determine the figure of merit for such applications. Specifically we will discuss how compositional gradients in materials can be used to independently tune material properties thereby enabling the highest figures of merit observed to date. Additionally, we will explore some challenges that have faced the community and have ultimately limited the development of this technology including a lack of basic understanding of materials, a lack of small thermal mass versions of these materials, inadequate characterization methods, and insufficient fabrication methodologies which can now all be addressed and provide a pathway for improved device performance. Finally, we will explore two generations of laboratory-based demonstrated devices where we have already created systems capable of power generation densities of ~30 W/cm^3. We will explore what it takes to optimize PEC cycles via studies of the field-, temperature-, ramp-rate-, and frequency-dependence on the overall efficiency and energy generated. Finally, the potential for applications will be touched upon including niche markets that might be over interest to PEC as compared to other technologies.

Some key references: S. B. Lang, *Physics Today* **58**, 31 (2005); R. B. Olsen, *et al. J. Appl. Phys.* **58**, 4710 (1985); G. Sebald, *et al. Smart Mater. Struct.* **18**, 125006 (2009); C. R. Bowen, *et al. Energy Environ. Sci.* **7**, 3836 (2014).

Professor Lane W. Martin Biography

Professor Lane W. Martin is an Associate Professor of Materials Science and Engineering and a Faculty Scientist in the Materials Science Division at Lawrence Berkeley National Laboratory. Lane received his B. S. in Materials Science and Engineering from Carnegie Mellon University in Dec. 2003 and his M. S. and Ph.D. in Materials Science and Engineering from the University of California, Berkeley in 2006 and 2008, respectively. From 2008 to 2009, Lane served as a Postdoctoral Fellow in the Quantum Materials Program, Materials Science Division, Lawrence Berkeley National Laboratory. From Aug. 2009 to Jun. 2014, Lane was an Assistant Professor in the Department of Materials Science and Engineering at the University of Illinois, Urbana-Champaign. In Jul. 2014, Lane returned to the University of California, Berkeley as an Associate Professor. Lane's research focuses on three main areas: 1) the science and engineering of thermal, electronic, and magnetic properties of materials for applications ranging from waste heat energy conversion to solid-state cooling to electron emission, 2) the design and implementation of multi-functional materials for applications such as logic, memories, and sensing, and 3) the development of oxide materials for solar energy conversion including photovoltaics and photocatalysis. Lane has published >125 papers and his work has been cited over 6,440 times. Lane's work has garnered a number of awards including the American Association for Crystal Growth (AACG) Young Author Award (2015), the Presidential Early Career Award for Scientists and Engineers (2014), the Dean's Award for Research Excellence for the

University of Illinois, Urbana-Champaign (2013), the National Science Foundation CAREER Award (2012), the Army Research Office Young Investigator Program Award (2010), a National Science Foundation IGERT Fellowship in Nanoscale Science and Engineering (2004-2007), the Intel Robert Noyce Fellowship in Microelectronics (2007-2008), the Graduate Excellence in Materials Science Award (2006), and the Materials Research Society's Gold Medal Award for Graduate Students (2006).

Tuesday, 14 July, 11:15

Thoughts on the Future of Laser DEWs

Gary L. Wood
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The attraction of laser directed energy weapons is speed of light engagements, precision targeting, scalable effects, low cost per shot and potentially low logistics overhead. A wide variety of missions have been proposed and in some cases are actively being pursued in the demonstration phase. There are land, sea, air and space missions being planned with supporting research and engineering projects. However, there is little long term (>2025) plans. This presentation will look at the limitations of laser directed energy weapons and what might be done to overcome these limitations that could make for an outline for long term planning.

Dr. Gary L. Wood Biography

Dr. Gary Wood received a Ph.D. in Physics from The Catholic University of America in 1992, and a BS & MS in Physics from Drexel University in '80 & '82, respectively. Dr. Wood has been a US Army civilian employee from 1982 to the present. He worked for CERDEC Night Vision and Electro-Optics Directorate at Fort Belvoir, VA from 1982-1992 and the Army Research Laboratory, ARL, in Adelphi, MD from 1992 until the present. Dr. Wood's research has included basic and applied research in the areas of nonlinear optics, optical materials, lasers and optical processing. Dr. Wood is currently the Chief of the Electro-Optics and Photonics Division within the Sensors and Electronic Devices Directorate. This Division performs research and development of imaging detectors; chem, bio, event and explosive materials detectors; laser sources; laser protection; RF photonics; quantum sciences and devices; biosciences; novel semiconductor materials and devices. Dr. Wood served as the Chair of the Joint Technology Office's high energy solid-state laser technical area working group from 2004-2013. Dr. Wood also serves as the Army technology representative for laser protection (RDECOM CoP lead), ARL Vulnerability Analysis Steering Committee Representative, representative on DOD Sensors Community of Interest committee and Military Sensor and Sources Active Sensing conference committee. Dr. Wood has authored chapters in five textbooks and is the author or coauthor of over 100 publications in refereed journals and conference proceedings. His work includes many patents, Dept. of Army Achievement Awards 1989 and 1998, ARL 10th Anniversary Award for Achievement in Science, Engineering and Analysis in 2002, Dept. of the Army Superior Civilian Service Award for outstanding performance March 2013. Dr. Wood participates in the following professional and honor societies: Optical Society of America, Sigma Xi, Sigma Pi Sigma, DEPS and SPIE.

Tuesday, 14 July, 13:00

Fully Crystalline Double-Clad Fibers – Next Generation in Laser Power Scaling

M. Dubinskiy, N. Ter-Gabrielyan, V. Fromzel
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Fully crystalline channel waveguide lasers are very promising as very efficient and compact sources for many laser applications requiring significant power scaling with nearly diffraction-limited beam quality. In their double-clad implementation fully crystalline channel waveguides, or fully crystalline double-clad fibers (FCDCFs), are simply direct analogs of conventional (glass-based) laser fibers. They have the same ability to provide tight confinement of high numerical aperture (NA) pump light along the entire length of the gain medium (and thus are the most efficient and highly power scalable!) while maintaining propagation of only fundamental laser mode in the low NA doped fiber core. Compared to conventional glass fibers, FCDCFs are best suitable for laser power scaling out of single fiber aperture due to their ~10 times higher thermal conductivity as well as an order of magnitude higher absorption and emission cross sections of common rare-earth dopants in the crystalline core. In addition, at least in case of doped YAG cores, these fibers have an extremely low stimulated Brillouin scattering (SBS) gain coefficient versus that of conventional silica glass. It was shown [1, 2] that due to all of these beneficial features, FCDCF lasers (FCDCFLs) can be scaled to multi-ten kilowatts of power out of single fiber aperture even in the most demanding, nonlinearity-prone, ultra-narrowband, single longitudinal mode laser designs. Unfortunately, fabrication of FCDCFs presents significant technological challenge, and, despite numerous smart fabrication techniques implemented by a number of groups around the globe, very few successes were reported. This paper presents an overview of our research efforts toward real FCDCFLs in comparison with other efforts utilizing either, so called, 'crystal fibers' (which are, in fact, simply relatively thin and not even very long laser rods), or 'crystalline-core glass-clad' fibers (CCGCF). This paper presents a thorough comparative analysis of all of these fiber cases. In particular, we have shown that CCGCFs, though they present a significant technological simplification in fabrication, and a few critical successes in this direction were actually reported recently [3, 4], present a major deviation from the FCDCF concept and do not possess thermal efficiency required for major power scaling. We report our results in fully crystalline channel waveguide lasers based on recent experiments with Er-doped and Yb-doped YAG cores, including a single-mode, eye-safe, Er:YAG channel waveguide laser with diffraction limited output and nearly quantum defect limited efficiency [5].

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Dr. Mark Dubinskiy Biography

Dr. Dubinskiy has over 30 years of experience in advanced laser development as well as laser and nonlinear materials research. He graduated from Kazan State University, Kazan, Russia with MS in EE and a PhD in Physics and Math. He moved to the US in 1994, where he continued working on solid-state laser development in industry, academia and Government - AFRL/WPAFB (1996-1998), and ARL. Dr. Dubinskiy has authored over 210 papers, presentations and book chapters. He has served as a Program Committee Member, Conference Chair and Co-Chair for a great number of international conferences. He has edited a book on ultraviolet lasers and laser spectroscopy. Since 2002 he is a Physicist and Team Leader with the US Army Research Laboratory, where he continues to develop new laser concepts, architectures and advanced laser components for highly efficient high energy solid-state lasers and a variety of advanced solid-state tactical lasers. Mark served as an Associate Editor for Optics Express journal (2006-2011), and is an Editorial Board Member for the International Laser Physics Letters journal. He is also an SPIE Advisory Board member. For his contributions in laser technology development at ARL he has been honored with the 2007 ARL Honorary Award in Science, the 2008 and 2010 U.S. Army Research and Development Achievement Awards. Dr. Dubinskiy is a Fellow of the Optical Society of America, SPIE Fellow and a member of the Directed Energy Professional Society. In 2013 he has also been elected as a Distinguished Member of the ARL Technical Staff - ARL Fellow. Research Interests: Dr. Mark Dubinskiy has a broad range of research interests and technical expertise in conventional, nonlinear and fiber optics, advanced development of lasers and laser sensors in UV, Near-Infrared (IR), Mid-IR, high power solid-state laser and laser systems engineering. His work is focused on fundamental and applied research aimed at enabling mobile Counter-Rocket, Artillery, Mortars (C-RAM) and numerous tactical Army applications for next generation Army systems. This requires development and implementation of novel laser materials and designs advancing laser performance well beyond current technical limits with maximum optical efficiency (quantum defect limited efficiency is a target) and minimum SWAP. His recent research has an emphasis on solid-state lasers with eye-safer wavelengths (for collateral damage reduction) and advanced widely tunable mid-IR laser sources for IRCM and Counter-ISR. Key research lines involve development of new concepts, architectures and advanced critical components for highly efficient and power scalable, nearly diffraction limited, high energy bulk solid-state and fiber lasers. More specifically, he is engaged in development of efficient solid-state SBS phase-conjugate and Raman materials, studies of novel doped single-crystalline and ceramic laser materials, thermally-advanced and composite gain materials for laser power scaling, cryogenically-cooled solid-state lasers, high power Mid-IR lasers, highly scalable eye-safe fiber laser concepts and other topics of great practical importance. Most recently, his work is focused on laser power scaling out of single physical aperture by developing CW diode clad-pumped double-clad Raman fiber lasers and transition from legacy glass laser fibers to fully crystalline double-clad laser fiber architectures. Both approaches have great potential for pushing current single-aperture power scaling limits by at least an order of magnitude.

Tuesday, 14 July, 14:00

High Energy Density Materials, Including Nanoscale Energetic Materials

Steven F. Son
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An aim of energetic materials development is energy density. In this talk I will review what energy density might be possible to achieve with various materials. I will also discuss other material properties that may result in disruptive capabilities, besides energy density. New directions, including nanoscale inclusion or encapsulation in micron scale particles will be discussed and examples given. In addition, I will present recent efforts in areas such as cocrystal energetic materials and other advanced energetic materials.

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Professor Steve Son Biography

Steven F. Son is a Professor in the School of Mechanical Engineering at Purdue University and is affiliated with Purdue's Maurice J. Zucrow Laboratories. He received his Ph.D. from the University of Illinois at Champaign-Urbana in 1994. Prof. Son's research is in the field of combustion with an emphasis on energetic materials combustion, nanoscale energetic materials, microscale engergetics (microenergetics), heterogeneous combustion, reactive materials, combustion synthesis, and explosives safety. His work has included both experimental and theoretical studies. Dr. Son has given invited presentations at national and international scientific meetings and is an author of over one hundred scientific publications. Prof. Son is Associate Editor for AIAA's Journal of Propulsion and Power and Editor in Chief of the JANNAF Journal of Propulsion and Energetics. Before his academic career, beginning in 2006, he was a Technical Staff Member and J. R. Oppenheimber Fellow, Technical Staff Member, and Project Leader at Los Alamos National Laboratory in the High Explosives Sciences Group. Dr. Son has current support as PI or co-PI from ARO, ONR, AFOSR, DTRA, and DOE in the areas of nanoscale energetics in propellants, cocrystal energetic materials, acoustic and microwave insults of explosives, hypergolic gelled propellants, reactive materials, and shock assisted combustion synthesis.

Tuesday, 14 July, 15:00

Evidence for structural bond energy release from nanodiamonds

Jennifer L. Gottfried
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The synthesis of nanodiamond (ND) from molecular explosives was first discovered in 1963 as part of ongoing research into dynamic methods for producing superhard materials in the USSR, and was subsequently re-discovered by multiple scientists over the next 25 years.[1] Recently, NDs have been investigated for numerous applications, including biomedical applications such as drug delivery or biolabelling, quantum applications such as single photon light sources, electrochemical and catalytic applications, and materials applications (e.g., composites).[2] At detonation ND sizes (3-6 nm in diameter), the surface of the ND particle reconstructs into a fullerene-like shell,[3] and is theoretically predicted to have substantial internal stress, effectively compressing the diamond core of the ND to an internal pressure exceeding 50 GPa. In addition to the pressure, the structural bond energy (SBE) in ND is expected to be significantly greater than the chemical energy of cyclotrimethylene trinitramine (RDX).[4] The graphitic shell surrounding the diamond core acts as a protective barrier preventing the unstable diamond surface from reacting.[5] However, simulations of two colliding ND particles have shown that at collision velocities above 5 km/s (per particle), a sudden disruption of the shell and the relaxation of the internal pressure result in destruction of the diamond structure and rapid oxidation.[4] Efforts to thin the graphitic shell and fracture the highly compressed core by applying quasi-static high pressure with a diamond anvil cell did not provide experimental evidence for destruction of the ND shell and the ensuing energy release.[4,6] This suggests that a rapid dynamic loading of the ND, such as that supplied by a pulsed laser, is necessary to disrupt the shell and release the energy. To date, very little research has been published in the open literature demonstrating the energetic applications of ND.[7-9] Here, theoretical and experimental progress at ARL towards demonstrating structural bond energy release (SBER) from ND will be presented.

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Dr. Jennifer Gotfried Bioraphy

Dr. Gottfried received a B.S. in Chemistry (with minors in Physics and Math) from Ohio Northern University in May 2000, a M.S. in Physical Chemistry from the University of Chicago in August 2001, and a Ph.D. in Physical Chemistry from the University of Chicago in August 2005. Dr. Gottfried received numerous fellowships and awards for excellence in academics and research, including the Ohio Northern Recognition Medal (for highest GPA), 2000; Freud Fellowship, 2000; James Franck Fellowship, 2000; National Science Foundation Graduate Fellowship, 2000-2003; and the William Rainey Harper Dissertation Fellowship, 2004-2005. She joined ARL in September 2005 as a postdoctoral fellow and was hired in May 2008. In 2009 Dr. Gottfried was the Gold medal winner for Rookie Employee of the Year – Technical Scientific and Program Support (Excellence in Federal Career Award, Baltimore Federal Executive Board). She was a co-recipient of a 2009 Research and Development Award for “Stand-off Detection of Explosives,” co-investigator on one of the top three FY07 ARL Director’s Research Initiative (DRI) projects (FY07-WMR-04, “Tailored Ultrafast Pulses for Selective Energetic Residue Sampling”), and principal investigator for one of the top four FY09 DRI projects (FY09-WMR-03, “Investigation of Chemical Processes Involving Laser-Generated Nanoenergetic Materials”). Dr. Gottfried has written two book chapters and has 34 peer-reviewed papers, including four invited reviews and three featured cover articles. She has also published 35 ARL technical reports. She has been an invited speaker at three international conferences, presented her work in more than 60 scientific conference presentations, and taught a short course on chemometric analysis at an international conference. Dr. Gottfried's work is focused on laser spectroscopy of energetic materials for laboratory-scale characterization, model validation, and fundamental understanding of reaction mechanisms during explosive initiation.

Tuesday, 14 July, 16:00

Extended Solids as High Energy Density Materials

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U.S. Army Research Laboratory
Aberdeen Proving Ground, MD 21005

Developmental strategies for the formulation of advanced energetic materials (EM) are diverging from arduous, multistep chemical synthesis techniques that, in the past twenty years, have failed to synthesize new EMs with performance properties exceeding that of CL20 and towards innovative disruptive physics-based methods. Such methods are expected to yield atypical materials with the potential to deliver leap-ahead improvements in energy release and power, with concomitant performance augmentation over a wide range DoD applications. These physics-based approaches involve the exploitation of the intrinsic stored structural energy of a material, which is altered under pressure due to changes in the strong intramolecular bonding structure. These modifications under pressure result in metastable structures with highly strained chemical bonds. In some cases these “extended solids”, as this general family of materials is commonly called, are stable at standard operating temperatures and pressures. The formation of extended solids has been experimentally observed in many simple molecular solids, including nitrogen (1–3) and carbon monoxide (4–8) However, carbon monoxide remains one of the only extended solids recovered to ambient conditions for extended periods of time (6), although several others, such as nitrogen, are metastable at pressures significantly lower than those of their synthesis. During this presentation, an introduction to extended solids, previous work and research being conducted at ARL will be discussed.

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Dr. Jennifer Ciezak-Jenkins Biography

Dr. Ciezak-Jenkins earned her Ph.D in Chemistry from Syracuse University in 2004. Her thesis work included research on Inelastic Neutron Scattering of Charge Transfer Complexes. Dr. Jennifer Ciezak-Jenkins began her career at the Army Research Laboratory (ARL) in 2004 as a National Research Council postdoctoral research fellow initially focused on neutron scattering experimentation of materials at ambient conditions and has progressed to working on several other ARL Mission and customer programs. Her current research involves the study of the chemistry and physics of materials subjected to thermomechanical extremes, particularly simple molecular and energetic materials. She experimentally investigates methods related to the quenching of high-energy-density phases formed under thermomechanical extremes. Dr. Ciezak-Jenkins has over 15 co-authored refereed journal articles and has been nominated for an Army RDA award in 2014.

Wednesday, 15 July, 8:30

Energy and Pulsed Power for National Security Applications: A Naval Perspective

Thomas A. Mehlhorn
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The Naval Research Laboratory (NRL), which was established in 1923 to fulfill Thomas Edison's vision of a government research laboratory, is performing research that is stretching the state of the art in alternative energy sources, as well as developing power and energy sources to meet the unique Size, Weight, and Power (SWAP) requirements of DON national security missions. Naval forces need energy to fuel tactical, expeditionary, and shore operations. Today's Navy and Marine Corps, both shore and tactical combined, rely heavily on petroleum fuel - their ships and planes consume ~1.6 million gallons/day of both diesel and jet fuel. Near term Naval Energy Initiatives include increasing the use of alternative fuels; sailing the "Great Green Fleet" of nuclear and hybrid electric ships with ships and planes running on biofuels; and phasing in the use of hybrid, electric, and flex fuel vehicles. Long-term NRL energy S&T to be discussed includes:

- Creating jet fuel from seawater to reduce the fuel logistics supply chain.
- Advances in photovoltaics (PV) including high-efficiency flexible PVs, lattice-matched quantum well PVs, and organic/inorganic hybrid PV materials.
- Inertial Confinement Fusion (ICF) as a potential path to the ultimate shore operation energy source for the Navy and the Nation.
- Benthic microbial fuel cells (electrodes embedded in marine sediments) to provide uninterrupted, sustained power to sensors.
- Practical, lightweight fuel cell systems for unmanned air vehicles (UAVs) to improve battlefield surveillance and communications capabilities.
- Long-range wireless recharging using high-power lasers to power remote platforms including aerial, land-based or submerged vehicles, satellites, and sensors at hazardous locations.

Navy platforms are also challenged with increasing electric power, including the adoption of advanced electric weapons. Next generation weapons systems such as phased-array radars, EM railguns, and directed energy weapons operate on continuous and pulsed high power that cannot be met with current generation energy storage and distribution systems. Pulsed power topics will include:

- Intermediate battery storage systems and batteries "beyond lithium".
- Wide band gap materials for solid-state switches.
- Compact, repetitive, efficient, and thermally managed pulsed power.
- Repetitive high-energy electron beams for the cleanup of powerplant emissions, fuel reformation/production, and inertial fusion energy.

In summary this talk will describe how the Navy's energy strategy balances both near term initiatives and long term S&T, and seeks to incorporate energy and power developments that allow us to more effectively carry out our mission in the future.
Mehlhorn, T. A. (2014). "National Security Research in Plasma Physics and Pulsed Power: Past, Present, and Future." Plasma Science, IEEE Transactions on **42**(5): 1088-1117.

Dr. Thomas Mehlhorn Biography

Thomas Mehlhorn, is the Superintendent of the NRL Plasma Physics Division, and a member of the Department of the Navy (DoN) Senior Executive Service with responsibility for a broad spectrum of research programs in plasma physics, laboratory discharge and space plasmas, intense electron and ion beams and photon sources, atomic physics, pulsed power sources, radiation hydrodynamics, high-power microwaves, laser physics, advanced spectral diagnostics, and nonlinear systems. Dr. Mehlhorn earned his Bachelor of Science, Master of Science and Ph.D in Nuclear Engineering from the University of Michigan in 1974, 1976 and 1978, respectively. He worked at Sandia National Laboratories in Albuquerque, New Mexico as a member of technical staff (1978-1988), department manager (1989-2005), and senior manager (2006-2009). His research interests included intense electron and ion beams generation, focusing and interactions; inertial confinement fusion; high energy density physics; Z-pinch physics; dynamic materials and shock physics; and advanced radiography. Dr. Mehlhorn joined NRL in 2009. He received the University of Michigan Engineering Alumni Society Merit Award in Nuclear Engineering and Radiological Sciences (NERS) in 2004. He is the co-recipient of two NNSA Defense Programs Awards of Excellence (2007 & 2008), a Lockheed Martin NOVA award (2004), two NRL Alan Berman Research Publication Awards (1983, 2011), and was elected to the Tau Beta Pi Engineering Honor Society in 1974. Dr. Mehlhorn is a Fellow of the American Physical Society Division of Plasma Physics (APS DPP) (2011), Fellow of the American Association for the Advancement of Science (AAAS) in Physics (2006), Fellow of the Institute of Electrical and Electronics Engineers (IEEE) (2014), and a member of the American Nuclear Society (ANS), the American Geophysical Union (AGU) and the Directed Energy Professionals Society (DEPS). Dr. Mehlhorn served on the Advisory Board for Plasma and Atomic Physics at GSI, Darmstadt, Germany (2004-2011, Chair 2006). He is a member of the Nuclear Engineering and Radiological Sciences (NERS) Advisory Board at The University of Michigan (1996-1999), (2004-*present*, Chair 2011), as well as the University of Michigan College of Engineering Alumni Society Board of Governors (2009-*present*). Since 2010 Dr. Mehlhorn has served on the DoN Space Experiments Review Board, as well as the University of Missouri Research & Development Advisory Board. He was a Member-at-Large on the APS DPP Executive Committee (11/10 - 10/13) and is a member of the IEEE PSAC Executive Committee (2013-2015). He served on a National Research Council (NRC) Division on Engineering and Physical Sciences (DEPS) panel on the Assessment of Inertial Confinement Fusion Targets (ICF) (2011-2012). He is the author/co-author of over 160 scientific and technical papers.

Wednesday, 15 July, 9:30

Isomers: Energy Storage and Directed Gamma Radiation

Jeff Carroll
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The ability to transform nuclei between long-lived excited states (isomers) and shorter-lived states has been proposed as a means of accessing nuclear-scale energies without fission. This might enable new applications from energy storage and release in nuclear batteries with controllable lifetimes to the projection of directed energy in the form of highly-penetrating gamma radiation. The feasibility of any applications will depend sensitively on the details of nuclear structure and the underlying physical processes, which are the subject of considerable research. This presentation will survey the state-of-the-art, challenges and critical issues in isomer research.

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Dr. Jeff Carroll Biography

Dr. Carroll has more than twenty-five years’ experience in experimental physics related to the fields of nuclear structure, nuclear reactions, and radiation detection. His major focus has been the physical basis underlying metastable nuclear excited states (isomers) and the study of mechanisms by which to control their energy emission for potential applications ranging from isotope batteries with controllable storage times to gamma-ray lasers. He has published more than one hundred articles in peer-reviewed scientific journals, including four in Physical Review Letters and two in Physics Letters B. He has given multiple plenary, invited and contributed presentations around the world and is an internationally-recognized expert in the study of energy release from isomers. Dr. Carroll joined the US Army Research Laboratory in 2011 after a distinguished career in academia and leads the Power and Energy Division’s Alternative Energy Team.

Wednesday, 15 July, 10:45

LENR - Cold Fusion – CMNS: Present and Projected Future Status

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Anomalous heat effects have been reported under many titles including Cold Fusion as well as Low Energy Nuclear Reactions (LENR), the Fleischmann Pons Heat Effect (FPHE), and occur under the general rubric of Condensed Matter Nuclear Science (CMNS). A large number of experiments [1] report the production of heat from metal samples loaded with hydrogen or deuterium in amounts that are consistent with nuclear but not chemical or lattice energy storage effects. The effect is anomalous because there is no agreed to mechanism and products are not (normally) reported in amounts consistent with any known nuclear process. The one potential product of nuclear reaction that has been observed in amounts commensurate and time-correlated with the appearance of excess heat is ^{4}He [2,3].

We have arrived at an interesting time and there are several indications that 2015 will not be "business as usual" in the CMNS field. I have commented often that it would not take much outside interest to convert our field from "resource limited" to "talent limited". I think we are about to see that occur. How we proceed will depend on how we convert this "once in a quarter century" opportunity. Those of us in the field are well aware that data sufficient to motivate significant, serious, scientific and technological interest have existed for a very long time but with few exceptions (one being the US DOD) this has not occurred. What has changed?

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Dr. Michael McKubre Biography

Michael McKubre began his undergraduate studies at George Washington University and completed his B.Sc., M.Sc. and Ph.D. in Chemistry and Physics at Victoria University, Wellington, New Zealand. On completing his Ph.D., Dr. McKubre was granted a two year Postdoctoral Research Fellowship at Southampton University, England. Dr. McKubre joined SRI as an Electrochemist in 1978 and was appointed Manager of the Electrochemistry Program in 1982 and Director of the Energy Research Center in1992. He is an expert in the study of electrochemical kinetics and was one of the original pioneers in the use of ac impedance methods for the evaluation of electrode kinetic processes. In the last decade as Director of the Energy Research Center, Dr. McKubre has applied himself to the discovery and application of potential new energy sources, particularly those associated with the deuterium/palladium system.

Wednesday, 15 July, 12:45

A Short Discourse on Low Energy Nuclear Reactions (LENR)

Tapan Patel[1], George H. Miley[1,2], Kyu-Jung Kim[1], Bert Stunkard[1], Erik Ziehm[1]

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During the past decade, extensive experimental and theoretical work worldwide has been done to study Low Energy Nuclear Reactions (LENR) phenomena and to understand the underlying physics. LENR is also referred to by other terms such as cold fusion and Lattice Assisted Nuclear Reaction (LANR). LENR refers to phenomena that occur when certain metals absorb hydrogen or deuterium and experience anomalous amounts of heat in the presence of an external stimulus such as heat, pressure, magnetic fields, etc. Due to the low energy of reactants, the compound nucleus formed in LENR has little excess energy, thus the resulting breakout products are mainly channeled into stable or near-stable products, avoiding significant radioactivity or nuclear waste problems. Such a power source enables a tremendous advantage in energy density, lifetime, and tolerance to wide differences in environmental conditions (temperature, pressure). Compared to other renewable power units, LENR units offer important technical and economic advantages.

At the International Conference on Cold Fusion (ICCF-17), several companies announced progress on units ranging from kW to MW units. This presentation will provide a comprehensive summary of the LENR field including a historical perspective on some of the original work in the field (Pons-Fleischmann experiment[1]), various leaders and experimental approaches including thin films, gas loading[2, 3], and plasma bombardment[4]. Results from recent gas loading experiments performed by our group will be discussed in-depth to highlight some of the promising results.

Specifically, discussions will be focused on special Pd-Zr-Ni alloy nano-particles placed in a pressure vessel which is then pressurized to 60-100 psi with hydrogen to initiate the reaction. With pressure control, these units are expected to run for several years, before replacement of the nano-particles is required due to build up of transmutation products. Replacement is simply done by substitution of a new cylinder containing fresh particles while the used particles are recycled for use in fresh nano-particles. Our results in terms of thermal energy gain from the pressurized nano-particles, show 15 times the gain of chemical absorption heat[5] and 12 times the gain of heat from traditional hydrogen combustion in the confined reactor volume. Mass spectroscopy work is underway to determine the composition of products in the reactions.

The main obstacle to development of a practical unit is preventing the hot nanoparticles from overheating and sintering together, which limits unit run time[6]. Thus present work is focused on overcoming that problem – one alternative approach is plasma treating micron thin palladium films to create nano and micro deformations on the surface to increase surface area and aid in absorption. This apparatus also has the capabilities for in situ mass spectroscopy and radiation detection along with direct temperature measurements of the reacting foil. The presentation will also discuss a path forward including future experiments and a conceptual design of LENR power units based on gas loading approach.

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Mr Tapan Patel Biography

Mr. Tapan Patel was born in Nairobi, Kenya. He received both his B.S. and M.S. degrees in Mechanical Engineering at the University of Illinois at Urbana-Champaign (UIUC) in 2010 and 2012, respectively. He currently works at the University of Illinois in the Nuclear Plasma & Radiological Engineering (NPRE) department, with a research emphasis on Low Energy Nuclear Reactions (LENR). Specifically, he is involved in the investigation of gas loaded nanoparticles. His work includes analysis of reaction byproducts and heat transfer analysis to determine, characterize and quantify anomalous heat from reactions.

Wednesday, 15 July, 13:45

The Lockheed Martin Compact Fusion Reactor Program

Tom McGuire
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Lockheed Martin Skunkworks is developing a compact fusion reactor concept, CFR. The novel magnetic cusp configuration would allow for stable plasmas in a geometry amenable to economic power plants and power sources. The details of the CFR configuration will be discussed along with a status of the current plasma confinement experiments underway at Lockheed. The presentation will also touch on the potential of a fast development path and challenges to bring such a device to fruition.

http://aviationweek.com/technology/skunk-works-reveals-compact-fusion-reactor-details

Dr. Thomas J McGuire Biography

Dr. McGuire believes that radical energy solutions are needed to develop the world in a responsible way. Ending energy scarcity will transform human society in unprecedented and positive ways, raising living standards across the globe and spurring humanity to spread across the solar system. He earned his B.S. in Aerospace Engineering at Penn State in 1999 and his Ph.D. in Aeronautical and Astronautical Engineering at MIT with a focus in nuclear physics in 2007. Some of his past research includes multi-gridded inertial electrostatic fusion, nuclear thermal rockets for fast Mars colonization, miniaturized star trackers, and air-breathing space propulsion. At the Lockheed Martin Skunkworks based in Palmdale, California, Tom has been a creative force behind projects varying from aerodynamics, electromagnetics, advanced materials, pervasive sensors, energy concepts and space technology as well as stretching the organization's reach with biologically inspired designs. He is the team lead and inventor of Lockheed's compact fusion project, which aims to develop a compact, stable nuclear fusion energy source.

Wednesday, 15 July, 15:00

Gem*Star Accelerator-Drive Subcritical System for Improved Safety, Waste Management, and Plutonium Disposition

Rolland Johnson
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Operation of high-power SRF particle accelerators at two US National Laboratories allows us to consider a less-expensive nuclear reactor that operates without the need for a critical core, fuel enrichment, or reprocessing. A multipurpose reactor design that takes advantage of this new accelerator capability includes an internal spallation neutron target and high-temperature molten-salt fuel with continuous purging of volatile radioactive fission products. The reactor contains less than a critical mass and almost a million times fewer volatile radioactive fission products than conventional reactors like those at Fukushima. We describe GEM*STAR, a reactor that without redesign will burn spent nuclear fuel, natural uranium, thorium, or surplus weapons material. A first application is to burn 34 tonnes of excess weapons grade plutonium as an important step in nuclear disarmament under the 2000 Plutonium Management and Disposition Agreement. The process heat generated by this W-Pu can be used for the Fischer-Tropsch conversion of natural gas and renewable carbon into 42 billion gallons of low-CO2-footprint, drop-in, and synthetic diesel fuel for the DOD at less than $1.50/gallon.

Dr. Rolland Johnson Biography

Rolland Johnson did his undergraduate, graduate, and post-doctoral studies in high energy physics at UC Berkeley and LBL (1961-1974) where he had an extended assignment in Protvino, Russia during the cold war (1972-1973). He enjoyed the next 17 years at Fermilab (1974-1991) where he continued to work on high-energy physics experiments and all of the Fermilab accelerators. After an intermission at CERN to work on the Antiproton Accumulator (1982-84), he worked on the design of the Fermilab pbar complex and led the commissioning and development of the Tevatron Collider. He moved to Maxwell/Brobeck (1991-1993) where he led the installation and commissioning of the LSU CAMD 1.4 GeV synchrotron light source. Then he worked at Jefferson Lab, including a 2 year assignment at the DOE in Germantown until his first retirement. In 2002 he started Muons, Inc. in IL to develop new techniques for muon cooling, neutrino factories, and energy frontier muon colliders. In 2011 he co-founded a new VA company, MuPlus. Both Muons and Muplus are engaged in inventing and developing state of the art accelerators and their components for energy production, discovery science, medicine, homeland defense, and commercial applications. More at www.muonsinc.com <http://www.muonsinc.com> .

Wednesday, 15 July, 16:00

Exotic/Advanced Energetics

Dennis Bushnell, Chief Scientist
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Presentation will review Exotic/"Advanced" Energetics approaches providing in most cases multiples to many orders of magnitude beyond chemical energy density. Brief will include Positron storage and utilization, Atomic fuels [H not H2], Cold Fast Compression, Isomers, SBER, LENR [AKA "Cold Fusion", which it is not], Metallic Hydrogen, Slingatron, Cold Silicon. Almost all of these are capable of providing "Revolutions in Warfare"/ National Security and in some cases would change much world econometrics and geopolitics along the way. LENR also addresses climate.

Dennis M. Bushnell, Chief Scientist Biography

Responsible for Technical Oversight and Advanced Program formulation for a major NASA Research Center with technical emphasis in the areas of Atmospheric Sciences and Structures, Materials, Acoustics, Flight Electronics/Control/Software, Instruments, Aerodynamics, Aerothermodynamics, Hypersonic Airbreathing Propulsion, Computational Sciences and Systems Optimization for Aeronautics, Spacecraft, Exploration and Space Access. 51 years' experience as Research Scientist, Section Head, Branch Head, Associate Division Chief and Chief Scientist. Technical Specialties include Flow Modelling and Control across the Speed Range, Advanced Configuration Aeronautics, Aeronautical Facilities and Hypersonic Airbreathing Propulsion. Author of 252 publications/major presentations and 370 invited lectures/seminars, Member of National Academy of Engineering, Selected as Fellow of ASME, AIAA and the Royal Aeronautical Society, 6 patents, AIAA Sperry and Fluid and Plasma Dynamics Awards , AIAA Dryden Lectureship, Royal Aeronautical Society Lanchester, Swire and Wilber and Orville Wright Lectures, ICAS Guggenheim Lecture, Israel Von Karman Lecture, USAF/NASP Gene Zara Award, NASA Exceptional Scientific Achievement and Outstanding Leadership Medals and Distinguished Research Scientist Award, ST Presidential Rank Award,9 NASA Special Achievement and 11 Group Achievement Awards, University of Connecticut Outstanding Engineering Alumni, Academy of Engineers ,Pi Tau Sigma and Hamilton Awards, Univ. of Va. Engineering Achievement Award , service on numerous National and International Technical Panels and Committees and consultant to National and International organizations. DOD related committee/consulting assignments include USAF Rocket Propulsion Laboratory, BMDC, ONR, Intelligence Community/STIC, AFOSR, NRAC, NRC,WL, LLL, HASC, NUWC, DARPA, AGARD, ARL,IAT, AEDC, JANNAF, NAVSEA, Air Force 2025,AFSOC,Sandia ,SAB, Army War College ,ACOM Joint Futures , SOCOM,TRADOC,SEALS,JFCOM,IDA,NDU,DSB and Army After Next. Reviewer for 40 Journals and Organizations, Editor, Volume 123 of AIAA Progress

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Thursday, 16 July, 8:30

Empty Space: The Multilayered, Multicolored Superconductor

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We present a brief review of the historical debate on the existence of empty vacuum versus aether followed by a brief review of the quantum fields of nature, their structured vacuum and associated phenomenology, and we describe the predicted releasing of energy and matter from the structured vacuum. In quantum field theory, Heisenberg's Uncertainty Principle dictates that the vacuum of space is not empty because it is filled with an aether, a (relativistic Lorentz-invariant) quantum aether, of nonlocal (correlated/entangled) vacuum zero-point field fluctuations (ZPF) that fill up the whole spacetime. The structured vacuum of space is multilayered, consisting of the quantum electrodynamic (QED) vacuum of virtual charged fermions and photons which is subsequently unified with the nuclear weak force vacuum (i.e., electroweak vacuum) of virtual massive $W^{\pm}$ and Z^0 vector bosons; the quantum chromodynamic (QCD) vacuum of virtual quark and gluon interactions that mediate the strong nuclear force; and the Higgs vacuum of virtual massive Higgs bosons which is interrelated with the electroweak vacuum. The QED vacuum behaves like a dielectric and insulator, and nonlinear optical medium. There are many theoretically predicted and experimental approaches (e.g., Casimir effect, Schwinger effect, dynamical Casimir effect, magnetization of the Dirac vacuum, etc.) to deforming the QED ZPF, which can cause the QED vacuum to transduce or release energy, or to release photons and charged fermion particle-antiparticle pairs, etc. QED vacuum energy release is minute in magnitude and of limited application, but it can be technologically scaled up. The QCD-color force of quark-gluon interactions gives the QCD vacuum its unusual multicolored characteristic. Studies show that the QCD vacuum can behave like an exotic superconductor or superfluid when it is deformed by an ultrahigh-strength magnetic field. Theoretical predictions and particle accelerator experiments have demonstrated the "melting" (deconfinement of quarks) of the non-perturbational chromomagnetic vacuum with the accompanying release of 10^{35} J/m^3 of latent heat. And there are further speculations that the quark-Higgs masses could be "melted" to release latent vacuum energy, but this may not be an experimentally reachable goal in the foreseeable future. Progress in ultrahigh-intensity zetta- and exa-watt laser technology R&D programs and their application, in conjunction with high-energy particle accelerators, to probing and deforming the structured vacuum is also reviewed. Theoretical and experimental studies of the structured vacuum demonstrate that the question of extracting useful energy is not a settled matter. Engineering the structured vacuum continues to be an evolving field of theoretical and experimental study in physics.

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M. Fried and B. Müller, NATO ASI Series, Series B: Physics Vol. 255, Plenum Press, New York, pp. 1-28.
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Dr. Eric W. Davis Biography

Dr. Eric W. Davis is a Senior Research Physicist at the Institute for Advanced Studies at Austin (EarthTech Int’l, Inc.) in Austin, TX. His research specializations include breakthrough space power & propulsion physics, beamed energy propulsion, space nuclear power & propulsion, directed energy weapons, future and transformational technology, general relativity theory, quantum field theory, quantum gravity theories, quantum optics/metamaterials/complex light/photonics, and SETI contact/xenoarchaeology. Since 1984, Dr. Davis has worked in academia and industry and has also been a contractor/consultant to the U.S. Air Force, Air Force Research Laboratory (AFRL), Department of Defense (DOD), Department of Energy, and NASA. His professional experience and contributions include: develop megawatt-class laser propulsion physics, systems design, and mission applications for the Air Force laser Lightcraft launch vehicle; design studies on ultrahigh-power laser experiments to explore the structure and properties of the quantum vacuum, and corresponding production of antimatter from the vacuum; conduct theoretical studies on the potential for producing ultrahigh-power coherent light from the vacuum using quantum vacuum generators; design and conduct quantum optics-tomography experiments to produce and measure negative vacuum energy to support studies on general relativistic faster-than-light space propulsion. Dr. Davis is the co-editor/author of the peer-reviewed academic research monograph *Frontiers of Propulsion Science* (American Inst. of Aeronautics and Astronautics Press, 2009, 2nd printing 2012). He also authored/co-authored several AFRL and DOD technical reports, peer-reviewed symposium and technical journal papers, chapters in books, conference papers, and award-winning STAIF-2006 and AIAA Joint Propulsion Conference 2012 papers. He was twice recognized by the American Inst. of Aeronautics and Astronautics for outstanding contributions to national defense and space public policy. He earned an A.A. in Liberal Arts from Phoenix College (1981), a B.Sc. in Physics-Mathematics (1983) and Ph.D. (1991) in Astrophysics from the University of Arizona. Dr. Davis is a Fellow of the British Interplanetary Society, Lifetime Associate Fellow of the American Inst. of Aeronautics and Astronautics, member of the New York Academy of Sciences, member of the Directed Energy Professional Society, lifetime member of SPIE, member of the American Astronomical Society, and a member of the Assoc. For Intelligence Officers. He is a practitioner and advisory board member of the Tau Zero Foundation, a member of the 100-Year Starship Study science advisory board, and a member of the Icarus Interstellar technical advisory board. Dr. Davis has appeared in, or contributed to, many American and BBC television and documentary film projects as well as many online/print news and magazine articles on interstellar flight and breakthrough propulsion physics.

Thursday, 16 July, 9:30

Developing Spacecraft Propulsion Methods Using the Quantum Vacuum

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The lowest energy state of the quantized electromagnetic field is called the quantum vacuum, and is described by QED (Quantum Electrodynamics) as a dynamic state in which virtual photons of all frequencies randomly appear and disappear, producing a near infinite energy density (1). (We will not deal with the other fluctuating fields that are also present, such as virtual electron-positron pairs. Since the photon is massless, the effects associated with it have the longest range and are more amenable to experimental modification.) QED predicts the effects of this pervasive, fluctuating, vacuum electromagnetic field on the magnetic moment of the electron and on the level and lifetime of atomic states, and in radiative corrections correctly to 1 part in a billion. It is possible to modify the ground state vacuum field in a variety of ways, such as with static or accelerated surfaces, or by causing interference between different modes, in order to amplify desired modes and cancel undesired modes, and create forces(2). For example, in the region between two parallel metal plates, boundary conditions require that only the electric field modes propagating perpendicular to the plates for which the transverse electric field vanishes on the plates surface can survive. This vacuum mode modification results in a net attractive quantum force between the plates called the Casimir force, with a verified magnitude of about 1 atm pressure for a separation of 10 nm. This can be interpreted as the pressure due to virtual photons. Casimir forces exist for other geometries, and have been explored using MEMS based technology (3,4,5). If quantum forces could be engineered to provide a net thrust, it would be extremely useful for propulsion (6). Such propulsion devices may need energy to operate or, if we are very fortunate, may operate on energy removed from the vacuum. In the latter case, there must be wake in the vacuum field that has a reduced energy density. In the parallel plate Casimir effect, the vacuum energy density between the plates is negative, meaning it is less than the free field value in empty space, and it would be associated with a negative mass and repelled by a gravitational field (7). However, it does not appear possible to make a conventional object with total mass that is negative. The quantum vacuum can be excited in several ways, producing real photons which carry away momentum, for example with the dynamic Casimir effect, in which a plate is vibrated at a very high frequency, or in the Unruh effect, in which an object is given a very high acceleration(8). It may be possible to utilize these phenomena to produce propellantless propulsion, with energy supplied externally. The vacuum modifications that have been modeled to date, all involve the longer wavelength components, and consequently, produce disappointingly small forces. There are a number of possibilities that have yet to be modeled.

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4. G. J. Maclay, Analysis of Zero-Point Energy and Casimir Forces in Conducting Rectangular Cavities,
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5. G. J. Maclay, "A Design Manual for Micromachines using Casimir Forces: Preliminary Considerations," Proceedings of STAIF-00 (Space Technology and Applications International Forum), edited by M.S. El-Genk, (American Institute of Physics, New York, 2000).
6. Frontiers in Propulsion Science,"ed. M. Millis and E. Davis, AIAA, Weston VA, 2009. The book is a great summary of the state of the art. See Chapter 12, G. J. Maclay, "Thrusting against the Quantum Vacuum."
7. G. Jordan Maclay, "Gedanken experiments with Casimir forces and vacuum energy," *Phys Rev A* 82, 032106, 2010.
8. G. J. Maclay, R. W. Forward, A Gedanken spacecraft that operates using the quantum vacuum (Dynamic Casimir Effect), LANL Arxiv physics/0303108, also *Found. of Phys* **34**, 477, 2004.

Prof Jordan Maclay Biography

Prof.

Prof. Maclay received his Ph.D. in quantum field theory from Yale University in 1972. He held a Post-Doctoral Appointment at Argonne National Laboratory, where he did experiments in particle physics. He worked on the first experiments in proton scattering at Fermi National Laboratory. After working in industry on new product development, he joined the Department of Electrical Engineering and Computer Science at University of Illinois at Chicago, where he taught and did research for almost 20 years. He was the founder and Director of the Microelectronics Laboratory which grew into the Microfabrication Applications Laboratory, a regional center offering MEMS resources to industry. His research was in the area of quantum theory, microfabrication technology, chemical microsensors, and micromachined structures. In 1991, Prof. Maclay received the American Electronics Association award of Science and Technology Advocate of the Year. In 1988 he was Visiting Scientist at the Fraunhofer Institute for Circuits and Systems. When Dr. Maclay retired from the University of Illinois in 1998, he was given Professor Emeritus status. In 1999, he started Quantum Fields LLC with Mary Maclay. Prof. Maclay holds 16 patents, and has over 100 publications.

From January, 2000, for three years, the Breakthrough Propulsion Physics Program at NASA supported Prof. Maclay's research in the properties and use of the quantum vacuum. In 2002, NASA Institute of Advanced Concepts supported Prof Maclay in an investigation into nonlocal communication by means of quantum-entangled states.

One of Dr. Maclay's research efforts at UIC was the application of micromachining methods to investigate quantum vacuum fluctuation effects, such as Casimir forces. Since leaving the University and working at Quantum Fields he has continued to focus on this research area. He has worked on the use of AFM (atomic force microscopy) to measure Casimir forces, and on the modeling of micromachined structures with Casimir forces. He has published, with his collaborators:

1. The first model of a dynamic mechanical system with a Casimir force, which was recently implemented by researchers at Lucent Technology.
2. A model of beams and surfaces bent by Casimir forces in MEMS.
3. The first interpretation of stiction as due in part to Casimir forces.
4. A study of the use of AFM methods to measure repulsive quantum forces, and,
5. QED computations of Casimir forces and energies in conductive rectangular box structures with different dimensions.
6. Recently he has been working on nonlocal communications and entangled states, and published the first complete, short range, model of nonlocal communications.

Thursday, 16 July, 10:45

Matter-Antimatter Propulsion via Parallel Electric and Magnetic Fields

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Particle/anti-particle pair production from the vacuum through intense electric fields has been investigated theoretically for nearly a century [1]. This presentation will review this history and will examine proposals of pair production for intra solar system and interstellar propulsion systems. The quantum mechanical foundation of particle/anti-particle pair production was developed by Fritz Sauter et al. in the 1930's [1] and then placed on a sound quantum electromagnetics (QED) basis by Julian Schwinger in 1951 [2]. Pair production occurs when the electric field strength E_0 is above the critical value at which the fields become non-linear with self-interactions (known as the Schwinger limit). As the energy density of lasers approach the critical strength of $E_0 \sim 10^{16}$ V/cm, the feasibility and functionality of electron-positron pair production has received growing interest. Current laser intensities are approaching within 1 order of magnitude the Schwinger limit.

Physical processes for lowering the critical energy density below the Schwinger limit (and simultaneously enhancing the pair production above the Schwinger limit) through additional quantum mechanical effects have been explored. One under study at the University of Connecticut and the University of Duisburg-Essen is pulsation of inhomogeneous electric fields within a carrier wave [3]. Another is via enhancement of quantum effects by addition of a magnetic field **B** parallel to the electric field **E**. Magnetic field enhancement to quark/anti-quark production through chiral symmetry breaking effects in quantum chromodynamics (QCD) was investigated theoretically by John Preskill at Caltech in the 1980's [4]. Don Page at the University of Alberta showed in 2007 that parallel magnetic fields also enhance electron/positron production via an analogous QED effect [5], with enhancement going predominantly as a linear function of B_0/E_0,
Particle/antiparticle pair production as a highly efficient fuel source for intra solar system and interstellar propulsion was proposed by Devon Crow in 1983 [6]. The

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1 Particle/anti-particle pair production does not (and cannot) take energy from the spacetime vacuum. Rather the energy is drawn from the external electric (and magnetic) fields. This process is very analogous to particle production near the event horizon of a black hole, which reduces the mass of the black hole accordingly. (The primary difference between the two processes is, while both particle and antiparticle are produced from a virtual pair by the electric (and magnetic) fields, only one particle in an initially virtual pair escapes from a black hole (as Hawking radiation) and the antiparticle is captured by the black hole.)

viability of this method of propulsion will be studied, especially from the parallel electric and magnetic field approach.

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[4] J. Preskill, 1987 QCD Lecture Notes,
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[5] S. Pyo Kim and D. Page, Phys. Rev. D78 (2008) 103517.
[6] D. Crowe, JBIS 36 (1983) 507.

Professor Gerald Cleaver Biography

Gerald Cleaver earned his Ph.D. at Caltech in 1993. He is Professor and Graduate Program Director of the Department of Physics at Baylor University in Waco, Texas. Cleaver has graduated nine Ph.D. and M.S. students. He heads the Early Universe Cosmology and String Theory (EUCOS) Division of Baylor's Center for Astrophysics, Space Physics and Engineering Research (CASPER). His EUCOS team conducts systematic computer-based studies of phenomenology of parameter spaces of the string landscape of possible universes. Additionally, Cleaver has been exploring means of evaluating quantum gravity effects on the cosmic microwave background to new levels of precision. He is also researching spacecraft propulsion systems based on in situ matter/anti-matter (MAM) production via quantum field theory effects from parallel electric and magnetic fields. Cleaver has written over 85 peer-reviewed physics journal articles and conference proceedings. He is co-author of an elementary particle physics textbook, referee for eight physics journals, and member of the international advisory board of the Journal of the British Interplanetary Society. He is a member of four IQ and numerous science honor societies. Cleaver and his wife Lisa have three children. Cleaver's interests include flying radio controlled model airplanes, SCUBA, small boat sailing, snow skiing, and Tae Kwon Do.

Thursday, 16 July, 12:45

Data Challenges in the Internet of Energy

Anna Scaglione
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Information and optimization go hand in hand. An ecosystems of Electric Vehicles, Smart Thermostats and Smart Lighting will allow customers to interact with the market of electricity directly, optimizing the customer preferences while better exploiting the variable production from renewable energy, from distributed ``prosumers" and centralized plants alike. In this future, the distribution grid will be the playground for new sensing and control technology as well as power electronics and storage resources that offer immense opportunities but also several challenges. Unlike the internet, which is managed in a decentralized fashion, power systems are large vertically integrated infrastructures and, thus, the interaction between market forces is hampered by the curse of dimensionality. Industrial control data lack the luster of other media and powerful compression techniques that can contain the data deluge are lacking. We will discuss the issue of sifting through big data to decide the schedule and closing the loop on a large number of transactions. If time allows we will touch upon the issue of cyber-security and privacy that arise in general with the Internet of Things and with the Internet of Energy in particular.

Anna Scaglione Biography

Anna Scaglione is a Professor in Electrical and Computer Engineering at Arizona State University. Her expertise is in the broad area of statistical signal processing for communication, electric power systems and networks. She is a Fellow of the IEEE since 2011 and co-recipient of the 2013 IEEE Donald G. Fink Prize Paper Award, 2000 IEEE Signal Processing Transactions Best Paper Award and of the 2013 IEEE Signal Processing Society Young Author Best Paper Award.

Thursday, 16 July, 13:45

Secure Energy-Based Critical Infrastructure

Wei Yu
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The smart grid, as a typical energy-based cyber-physical system, uses modern computing, communication and control technologies to make the power grid more efficient, reliable, and secure. Nonetheless, the smart grid may operate in hostile environments and lacking tamper-resistance hardware for sensor, meters, etc., increases the chance to be compromised by cyber adversaries. In this talk, I will introduce a modeling framework to systematically explore the space of threats in the smart grid and understand their impacts on both system operations and end users, as well as the development of effective mitigation schemes to defend against these attacks.

[1] Y. Liu, P. Ning, and M. K Reiter, "False Data Injection Attacks against State Estimation in Electric Power Grids," ACM Transactions on Information and System Security (TISSEC), 2011.
[2] W. Yu, D. Griffith, L. Ge, S. Bhattarai, and N. Golmie, "An Integrated Detection System against False Data Injection Attacks in the Smart Grid," to appear in the International Journal of Security and Communication Networks (SCN) – John Wiley & Sons, January 2015.
[3] X. Chen, W. Yu, D. Griffith, N. Golmie, and G. Xu, "On Effectiveness of Energy Storage System against Smart Grid Cascading Failure," in *Proc. of ACM International Conference on Reliable & Convergent Systems (RACS)*, October 2014, Baltimore, MD, USA.
[4] W. Wang and Zhuo Lu, "Cyber Security in the Smart Grid: Survey and Challenges,"*Computer Networks*, January 2013.

Professor Wei Yu Biography

Dr. Wei Yu is currently an Associate Professor in the Department of Computer and Information Sciences at Towson University. Before joining Towson University, he worked as a networking software developer for Cisco Systems, Inc. for nine years. He received his Ph.D. degree in Computer Engineering from the Department of Computer Science and Engineering at Texas A&M University in May 2008. His research interests include cyber security, computer networks, and cyber-physical systems. His research is currently supported by federal agencies, including the NSF, NIST, ARL, AFRL, etc. He published over 150 papers, including articles in premier security and networking journals such as *IEEE ToN*, *TDCS*, *TC*, *TPDS*, *TMC*, and *TVT* and conferences such as *IEEE S&P*, *ACM CCS*, *IEEE INFOCOM*, and *ICDCS*. He received University System of Maryland (USM) Regents' Faculty Award for Excellence in Scholarship, Research, or Creative Activity in 2015, the NSF Faculty Early Career Development (CAREER) award in 2014, the 2012 Excellence in

Scholarship Award from Fisher College of Science and Mathematics at Towson University, and the Best Paper Award at the 2013 and 2008 IEEE International Conference on Communications (ICC) – Communication & Information System Security Symposium, respectively.

Appendix C. Attendees List

This appendix appears in its original form, without editorial change.

MODERN TOPICS IN ENERGY AND POWER TECHNICAL MEETING
U.S. Army Research Laboratory
14-16 July 2015

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11	DeChiaro	Louis	Naval Surface Warfare Center	louis.dechiaro@navy.mil	540-653-8040
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18	Hammond	Richard	ARL	Richard.t.hammond10.civ@mail.mil	919-549-4313
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List of Symbols, Abbreviations, and Acronyms

AFRL	US Air Force Research Laboratory
ARL	US Army Research Laboratory
CFR	compact fusion reactor
CMNS	Condensed Matter Nuclear Science
DE	directed energy
DEW	directed energy warfare
DOD	US Department of Defense
DOE	US Department of Energy
DTRA	US Defense Threat Reduction Agency
E&P	energy and power
EW	electronic warfare
ICF	inertial confinement fusion
LENR	low-energy nuclear reaction
LM	Lockheed Martin
MAM	matter-antimatter
MEMS	microelectro-mechanical system
MTEP	Modern Topics in Energy and Power
NASA	National Aeronautics and Space Administration
ND	nanodiamond
NEMS	nanoelectro-mechanical system
NREL	US National Renewable Energy Laboratory
NRL	US Navy Research Laboratory
OSD	Office of the Secretary of Defense
P&E	power and energy
PFHE	Pons-Fleischman Heat Effect

PV	photovoltaic
PW	peta watt
QCD	quantum chromodynamics
QED	quantum electrodynamics
QVE	quantum vacuum energy
RF	radio frequency
S&T	science and technology
SBER	strain bond energy release
SEDD	Sensors and Electron Devices Directorate
SLAC	Stanford Linear Accelerator Center
SNS	spallation neutron source
SWaP-C	size, weight, power, and cost
UAV	unmanned aerial vehicle
UIUC	University of Illinois at Urbana-Champaign

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1 (PDF) INSTITUTE FOR ADVANCED STUDIES AT AUSTIN
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1 (PDF) NAVAL SURFACE WARFARE CENTER
L DECHIARO

1 (PDF) ENERGETICS TECHNOLOGY CENTER
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1 (PDF) QUANTUM FIELDS LLC
J MACLAY

1 (PDF) UNIVERSITY OF CALIFORNIA, BERKELEY
L MARTIN

1 (PDF) LOCKHEED MARTIN AERONAUTICS COMPANY
T MCGUIRE

1 (PDF) SRI INTERNATIONAL
M MCKUBRE

2 (PDF) NRL
T MEHLHORN
J SCHUMER

1 (PDF) THE GEORGE WASHINGTON UNIVERSITY
D NAGEL

1 (PDF) UNIVERSITY OF ILLINOIS
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1 (PDF) ECOPULSE
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J PICKENS

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P ROEGE

1 (PDF) ARIZONA STATE UNIVERSITY
A SCAGLIONE

1 (PDF) PURDUE UNIVERSITY
S SON

1 (PDF)	LOYOLA UNIVERSITY MARYLAND M STAKER
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1 (PDF)	TOWSON UNIVERSITY W YU
23 (PDF)	DIRECTOR US ARMY RESEARCH LAB RDRL CIH S V MISHRA RDRL ROP P REYNOLDS RDRL SED E P BARNES J CARROLL B HANRAHAN M LITZ M WAITS C RONG RDRL SEE L M DUBINSKIY RDRL ROP P R HAMMOND RDRL SED A KING M WOOD E SHAFFER T ZHELEVA RDRL SED C R JOW C LUNDGREN RDRL SEE G WOOD RDRL VT B SADLER RDRL WML B J CIEZAK-JENKINS J GOTTFRIED B RICE RDRL WMP C R BECKER B PLACZANKIS