Description of document:	United States Army Intelligence and Security Command (INSCOM) records concerning Low Energy Nuclear Reactions (LENR) 2008-2010
Requested date:	04-August-2016
Release date:	11-May-2017
Posted date:	15-November-2021
Source of document:	Freedom of Information Act Request Commander, INSCOM ATTN: IAMG-C-FOI 2600 Ernie Pyle St. Fort Meade, MD 20755-5995 Preferred during COVID-19 pandemic: Email: usarmy.meade.902-mi-grp.mbx.inscom-foia-service-center@mail.mil

DEPARTMENT OF THE ARMY
UNITED STATES ARMY INTELLIGENCE AND SECURITY COMMAND
FREEDOM OF INFORMATION/PRIVACY OFFICE
FORT GEORGE G. MEADE, MARYLAND 20755-5995

11 MAY 2017

Freedom of Information/
Privacy Office

This responds to your Freedom of Information Act (FOIA) request of August 4, 2016, requesting a copy of records such as assessments, foreign technology reports and memos concerning Low Energy Nuclear Reaction (LENR) between 2004 to present and supplements our response of August 10, 2016.

We have completed a mandatory declassification review in accordance with Executive Order (EO) 13526. As a result of this review, information has been sanitized as it is currently and properly classified SECRET according to Sections 1.2 (a)(2), 1.4(c) and 1.4(e), and of EO 13526. This information is exempt from the public disclosure provisions of the FOIA pursuant to Title 5 U.S. Code 552 (b)(1). A brief explanation of the applicable sections follows:

Section 1.2(a)(2) of EO 13526, provides that information shall be classified SECRET if its unauthorized disclosure reasonably could be expected to cause serious damage to the national security

Section 1.4(c) of EO 13526, provides that information pertaining to intelligence activities, intelligence sources or methods, and cryptologic information shall be considered for classification protection.

Section 1.4(e) of EO 13526, provides that information pertaining to scientific, technological or economic matters relating to national security which includes defense against transnational terrorism shall be considered for classification protection.

The deleted information is also exempt from automatic declassification in accordance with EO 13526, Section 3.3(b)(1) because its release would clearly and demonstrably be expected to reveal the identity of a confidential human source, a human intelligence source, a relationship with an intelligence or security service of a foreign government or international organization, or a nonhuman intelligence source; or impair the effectiveness of an intelligence method currently in use, available for use, or under development.

Information has been sanitized according to Title 5 U.S.Code 552 (b)(3) the statute invoked is 50 U.S.C. § 3024(i), which allows for the protection of intelligence sources and methods.

In addition, information has been sanitized as the release of the information would result in an unwarranted invasion of the privacy rights of the individuals concerned, this information is exempt from public disclosure provisions of the FOIA pursuant to Title 5 U.S. Code 552 (b)(6).

The withholding of the information described above is a partial denial of your request. This denial is made on behalf of Major General Chrsitopher S. Ballard, the Commanding General U.S. Army Intelligence and Security Command, who is the Initial Denial Authority for Army intelligence investigative and security records under the FOIA. You have the right to appeal this decision to the Secretary of the Army. Your appeal must be postmarked no later than 90 calendar days from the date of this letter. After the 90-day period, the case may be considered closed; however, such closure does not preclude you from filing litigation in the courts. You should state the basis of your disagreement with the response and provide justification for a reconsideration of the denial. An appeal may not serve as a request for additional or new information. An appeal may only address information denied in this response. Your appeal is to be made to this office, for forwarding, as appropriate to the Secretary of the Army, Office of the General Counsel.

The records contained excerpts under the purview of other government agencies. Those excerpts have been referred to those agencies for their review and direct reply to you.

If you have any questions regarding this action, feel free to contact this office at 1-866-548-5651, or email the INSCOM FOIA office at: usarmy.meade.902-mi-grp.mbx.inscom-foia-service-center@mail.mil and refer to case #1164F-16. Please note that you now have the ability to check the status of your request online via the U.S. Army Records Management and Declassification Agency (RMDA) website: https://www.foia.army.mil/FACTS/CaseStatus.aspx. Please refer to FOIA Control Number: FP-16-025573. You may also seek dispute resolution services by contacting the INSCOM FOIA Public Liaison, Mrs. Joanne Benear at 301-677-7856.

Sincerely,

Michael T. Heaton
Director
Freedom of Information/Privacy Office
Investigative Records Repository

National Ground Intelligence Center
NGIC-1851-0324-12

Date of Publication: 2012-01-09

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(U) Purpose

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For more information contact NGIC Production Management at rmngicprm@army.ic.gov COM: (434) 980-7222/DSN: 312-521-7222 SVoIP: 302-235-7557/TS VOIP: 990-5164/990-1141

(U) Key Points

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(U) Source Summary Statement

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(U) Low-Energy Nuclear Reactions

(U) Over 20 years ago, two electrochemists, Martin Fleischmann and Stanley Pons, claimed that they had produced D-D nuclear fusion [b] in one of their electrochemical cells. Their haste to announce that they had achieved room-temperature fusion, along with the difficulty in reproducing their experiments, led to rebuke

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Source marked 25X1-human

within the scientific community and planted a stigma on " cold fusion " and any related research. However, a small community of scientists continued to pursue related research and reported phenomena such as excess heat production, helium and tritium production, and transmutation. These reported effects were triggered by various stimuli, such as electric and magnetic fields and lasers, and some scientists claim the results could be reproducible if certain conditions were met. To date, no one has published a theory widely accepted by the broader scientific community that explains all of the observed phenomena. Many researchers claim that recent LENR experiments have generated excess heat and others have generated nuclear particles (alphas and neutrons),[2] tritium,[3] helium,[4] low-energy gammas, and transmutation.[5] In some instances, excess heat was reported to be 30 to 40 times input energy.[6]

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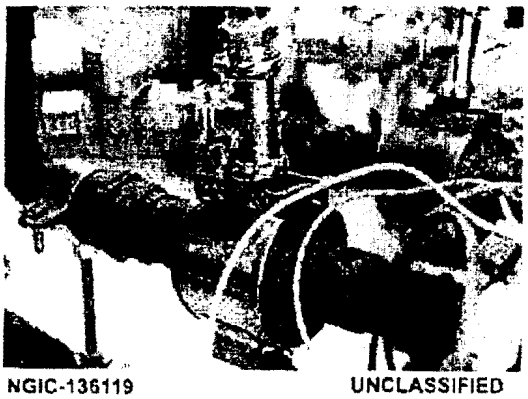
(U) Italian LENR Development

(U) Development of the E-Cat Device

(U) In January 2011, inventor Andrea Rossi, together with Dr. Sergio Focardi, professor *emeritus* of the University of Bologna, announced that they have developed a device that uses LENR to produce excess heat. The name of the device is *E-cat*, meaning energy catalyzer (see two figures below). Later in the year, Rossi claimed that he would make the device available for commercial use by the end of 2011.[9][10] Notably, this device has yet to become commercially available, and Rossi currently states that these devices will be available for commercial purchase in early 2012 (apparently, one can preorder a 1 MW plant from the E-cat website [http://ecat.com] today and take delivery in 3 months) and for home use starting in 2013.[11]



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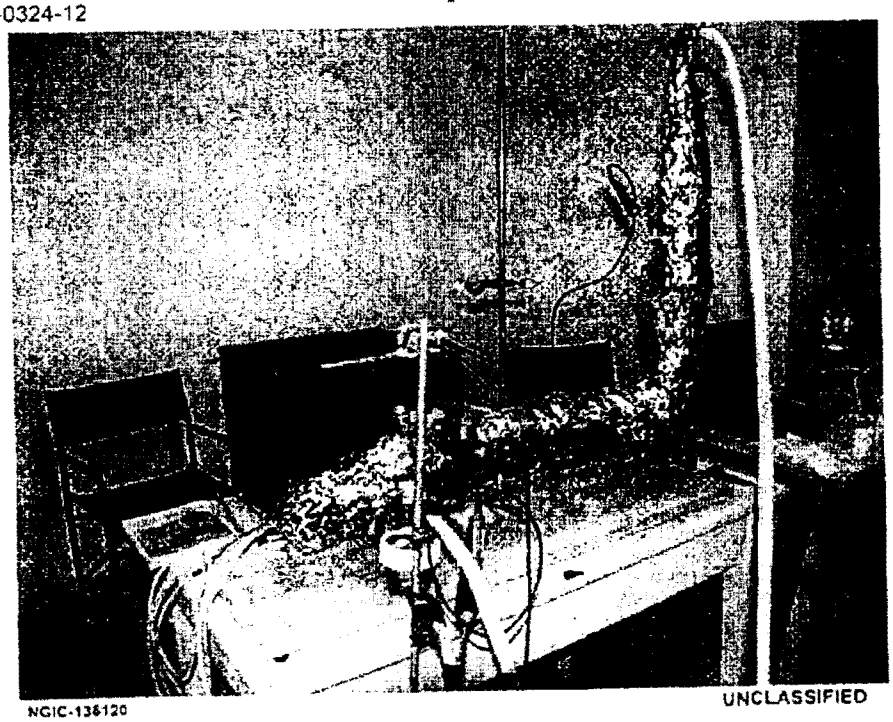
(U) Italian LENR E-cat Device



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(U) Italian LENR E-cat Device (insulated)

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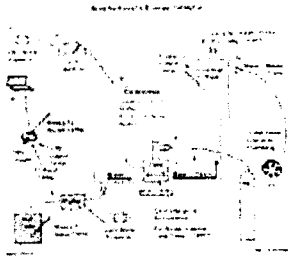


FULL IMAGE

(U) E-cat Testing Schematic Diagram

(U) Reported Operation of the E-Cat Device

(U) Rossi claims that his "black-box" E-cat device works when a hydrogen atom penetrates a nickel atom and transforms it to copper. In one experiment, the reaction between the hydrogen atoms and nickel used 300 watts of input power. In this reaction, the measured output of the device was continual output power of 2.3 to 2.6 kW.[12] Rossi estimated the power output by measuring the amount of steam produced from the water in the device. In a report from the Department of Energy, the claim was a 1.5 kWh output with a 0.4 kWh input using a nickel-copper alloy matrix as a deuterium storage medium.[13]

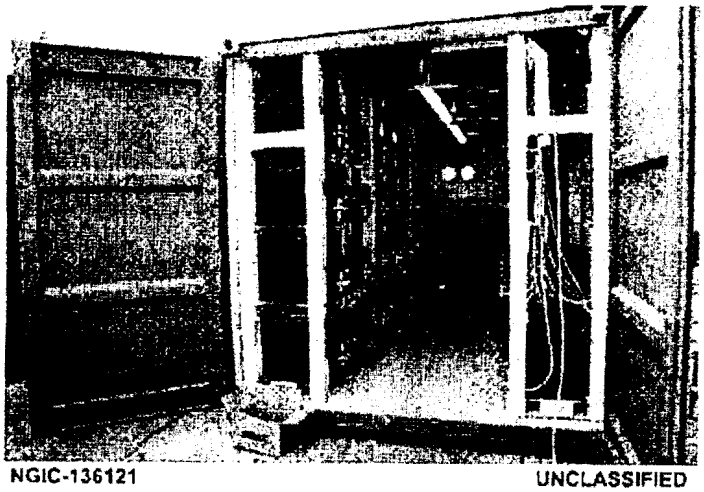
(U) In a March 2010 paper, Rossi claimed that, in a separate experiment, his device produced 21.229% excess heat, equating to 213 times more energy generation than was input to the E-cat.[14] The scientific community continues to question the method Rossi used to take the measurement,[15] including the following:

- (U) The group that tested the device did not perform a condensing calorimetry test on the device, possibly leading to an incorrect measurement.
- (U) The group used an unsuitable device to measure the steam quality, which calls into question the validity of the measurement.
- (U) The group did not check the water output correctly and could have been measuring the wrong output of the device.

(U) Since March 2010, Rossi has reduced the amount of energy that he claims is generated by the E-cat device. In the summer of 2011, Rossi asserted that his device had a six-times output-to-input energy generation. Reporting from November 2011 states that Rossi is now claiming less than six.[16]

(U) Power Generation With E-Cat Devices

(U) A Greek company, Defkalion Green Technologies, was planning to market the E-cat machines, according to a press conference held on 23 June 2011.[17] Rossi planned to deliver a final system in October 2011 to Defkalion. It would have included 330 E-cat machines, which are purportedly capable of delivering 1 MW power (see figure below). However, on 4 August 2011, a press report stated that Rossi and Defkalion terminated their licensing agreement. Rossi stated that this breakup in partnership was a result of financial matters. Instead of Greece, the United States will house the 1 MW plant. This latest report has caused more people within the scientific community to question the validity of Rossi's claims.[18]



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(U) E-cat 1 MW Plant

(U) Validity of Claims in Question

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turn waste into oil, landed Rossi in jail for not disposing of hazardous waste properly.[20] It is not clear if this case also included investment fraud by Rossi. Taken together, these events call into question Rossi's integrity.

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(U) Worldwide, researchers are skeptical of Rossi's claims. However, some scientists from the United States, Sweden, and other countries have attempted to measure radiation and emanations from the E-cat, and two Swedish scientists have obtained samples of some of the materials used in the device. Some have speculated that Rossi copied previously patented technologies, but others believe that he may have developed a new low-energy nuclear reactor.[22] Until detailed measurements and/or exploitation of his device are complete, determining whether Rossi's device performs as stated is impossible.

(U) Conclusions

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- (U) Rossi allowed only limited access to the experiments and allowed no independent verification. Additionally, the testing was poorly conducted.
- (U) Rossi's credentials include questionable business practices and past cases of fraud.
- (U) Rossi continues to delay device shipment without explanation.

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(U) Consideration of Alternative Analyses and Contrary Evidence

(U) This article is about whether the E-cat device works as claimed or does not. There is a LENR community of interest that believes and promotes the claims and concepts in LENR and has a large body of pro-LENR literature available on the Internet.

(U) Although unlikely, it is possible that Rossi actually developed (or made significant progress in developing) a LENR device. Nuclear reactions are known to produce 10 million times more energy output than nonnuclear chemical reactions.[23] The basic process of useable energy is governed by thermodynamics , which limits the output and efficiency of any system that heats a fluid for heat-transfer purposes. We assess with moderate confidence that harnessing energy release from LENR would likely have a low to moderate impact on energy management and production, worldwide, and is unlikely to be scalable in thermodynamic performance to a substantial process.

(U) Intelligence Gaps

- (U) Does the E-cat device perform as claimed?

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- (U) If so, how does it operate?
- (U) Does it involve LENR?

Footnotes

a. (U) Confidence in Assessments. Our assessments and estimates are supported by information that varies in scope, quality, and sourcing. Consequently, we ascribe high, moderate, or low levels of confidence to our assessments as follows: *High confidence* generally indicates that our judgments are based on high-quality information, and/or that the nature of the issue makes it possible to render a solid judgment. A "high confidence" judgment is not a fact or a certainty, however, and such judgments still risk being inaccurate. *Moderate confidence* generally indicates that our judgments are based on information that is credibly sourced and plausible but not of sufficient quality or corroborated sufficiently to warrant a higher level of confidence. *Low confidence* generally indicates that our judgments are based on information that is of questionable credibility and/or plausibility, that may be too fragmented or poorly corroborated to support solid analytic inferences, or that relies on sources that present significant concerns or problems. back

b. (U) D-D nuclear fusion is the reaction when deuterium (a stable isotope of hydrogen) reacts with itself. back

Sources

1. (S//NF) b1

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2. (U) LENR Report | NGIC-1851-0324-12-OS-001 | Author: P.A. Mosier-Boss, S. Szpak, F. E. Gordon, and L. P. G. Forsley | Naturwissenschaften | (U) Triple Tracks in CR-39 as the Result of Pd/D Co-deposition: Evidence of Energetic Neutrons | | Date of Publication: 2008 | | Source Description:(U) LENR report claiming nuclear particles are generated. This report is used for background information only. | back

3. (U) LENR Report | NGIC-1851-0324-12-OS-002 | Author: S. Szpak, P. A. Mosier-Boss, R. D. Boss, J. J. Smith | Fus. Technol. | (U) On the Behavior of the Pd/D System: Evidence for Tritium Production | | Date of Publication: 1998 | | 38-51| Source Description:(U) This report discusses the existence of tritium produced from claimed LENR. This report is used for background information only. | back

4. (U) LENR Brief to Vice Chancellor for Research Seminar Series, University of Missouri | NGIC-1851-0324-12-OS-003 | Author: Michael C. H. McKubre | Energy Research Center | (U) Studies of the Fleischmann-Pons Effect at SRI International | | Date of Publication: 2009-05 | | Source Description:(U) This briefing discusses the production of helium from claimed LENR reaction. This report is used for background information only. | back

5. (U) LENR Report | NGIC-1851-0324-12-OS-004 | Author: Martin Fleishmann, S. Pons, G. Preparata | Il Nuovo Cimento | (U) Possible Theories of Cold Fusion | Volume 107, Edition 1 | Date of Publication: 1993-08 | | Source Description:(U) This report addresses transmutation from experimental cold fusion testing. This report is used for background information only. | back

6. (U) Conference Report | NGIC-1851-0324-12-OS-005 | Author: D. Cravens, Dennis Letts | 14th International Conference on Cold Fusion (ICCF) | (U) The Enabling Criteria of Electrochemical Heat: Beyond Reasonable Doubt | | Date of Publication: 2008-08-10 | | Source Description:(U) This report discusses excess heat produced from claimed LENR. This report is used for background information only. | back

7. (S//NF) b1

b1 | (U) This report discusses the validity and possibility of utilizing LENR devices. This is an NGIC assessment on LENR and is used as background information. | back

8. Referred

9. (U) Not a Peer Reviewed Journal Report | NGIC-1851-0324-12-OS-006 | Author: Giuseppi Levi | Journal of Nuclear Physics | (U) Report on Heat Production During Preliminary Tests on the Rossi "Ni-

H" Reactor | | Date of Publication: 2011-01 | | NA | Date of Access: 2011-01-15 | | Source Description: (U) This report claims to be a peer review journal publication from the Journal of Nuclear Physics. NGIC assesses that the Journal of Nuclear Physics is run by Andrea Rossi and reports on this website are not technically "peer reviewed." | back

10. (U) Internet Site | NGIC-1851-0324-12-OS-007 | Next Big Future | (U) Forcardi and Rossi LENR (Cold Fusion) Demo Today | | Date of Publication: 2011-01-14 | | NA | Source Description:(U) This internet site confirms the existence of the testing on January 15, 2011 performed by Andrea Rossi. | Date of Information: 2011-01-15 | back
11. (U) Internet Site | NGIC-1851-0324-12-OS-008 | E-cat: Cold Fusion Revolution | (U) When will the E-cat be available? | | Date of Publication: 2011 | | NA | Date of Access: 2011-12-08 | | Source Description:(U) This is the marking website for the E-cat device. It states when these devices will be available for purchase. | back
12. (U) Online Publication | NGIC-1851-0324-12-OS-009 | Author: Mats Lewan | Ny Teknik | (U) Ny Teknik Tested the Energy Catalyzer | | Date of Publication: 2011-03-02 | | NA | Date of Access: 2011-12-08 | | Source Description:(U) This is the reporting from Ny Teknik, a Swedish IT and media company. Reportedly Ny Teknik attended the testing of the device by Andrea Rossi. | back
13. Referred
14. (U) Online Publication | NGIC-1851-0324-12-OS-010 | Author: Steven Krivit | New Energy Times | (U) Report #3: Scientific Analysis of Rossi, Focardi and Levi Claims | | Date of Publication: 2011-07-30 | | NA | Date of Access: 2011-12-08 | | Source Description:(U) Steven Krivit is an author of New Energy Times, an online publication and blog. Even though it seems that Mr. Krivit has a bias against Andrea Rossi, NGIC assesses his claims to be accurate with moderate confidence. | back
15. (U) Online Publication | NGIC-1851-0324-12-OS-011 | Author: Steven Krivit | New Energy Times | (U) Rossi's Scientific Failure in Seven Steps | | Date of Publication: 2011-08-07 | | NA | Date of Access: 2011-08-15 | | Source Description:(U) Steven Krivit is an author of New Energy Times, an online publication and blog. Even though it seems that Mr. Krivit has a bias against Andrea Rossi, NGIC assesses his claims to be accurate with moderate confidence. | back
16. (U) Online Blog | NGIC-1851-0324-12-OS-012 | Author: Steven Krivit | New Energy Times | (U) Rossi: Declining Magnitude of Claims | | Date of Publication: 2011-11-27 | | NA | Date of Access: 2011-12-07 | | Source Description:(U) Steven Krivit is an author of New Energy Times, an online publication and blog. Even though it seems that Mr. Krivit has a bias against Andrea Rossi, NGIC assesses his claims to be accurate with moderate confidence. | back
17. (U) Internet Site | NGIC-1851-0324-12-OS-013 | Lenr Canr | (U) Defkalion Green Technologies s.a. press conference | | Date of Publication: 2011-07-23 | | NA | Date of Access: 2011-12-08 | | Source Description:(U) This website lists updates of Rossi's experiments. This reporting was confirmed through additional reporting. | back
18. (U) Online Publication | NGIC-1851-0324-12-OS-014 | E-cat Report | (U) Andrea Rossi Terminates Contract with Defkalion GT | | Date of Publication: 2011-08-07 | | NA | Date of Access: 2011-08-07 | | Source Description:(U) This online report can be verified with other press reports. | back
19. (U) Online Blog | NGIC-1851-0324-12-OS-015 | Author: Steven Krivit | New Energy Times | (U) Rossi: Declines Italian and US Government Testing Offers | | Date of Publication: 2011-11-26 | | NA | Date of Access: 2011-12-07 | | Source Description:(U) Steven Krivit is an author of New Energy Times, an online publication and blog. Even though it seems that Mr. Krivit has a bias against Andrea Rossi, NGIC assesses his claims to be accurate with moderate confidence. | back
20. (U) Online Publication | NGIC-1851-0324-12-OS-016 | ESO Watch | (U) Focardi-Rossi Energy-Catalyzer | | NA | Date of Access: 2011-08-15 | | Source Description:(U) This is an in-depth wikipedia-like report on the history of Rossi's development of a claimed LENR device. | back
21. (U) Internet Site | NGIC-1851-0324-12-OS-017 | Independent eCat News | (U) eCat Cost To Half In One Year | | Date of Publication: 2011-12-06 | | NA | Date of Access: 2011-12-08 | | Source Description:(U) This source lists the price of the E-cat machines. NGIC assesses that this is reliable with moderate confidence. | back

22. (U) Online Publication | NGIC-1851-0324-12-OS-016 | ESO Watch | (U) Focardi-Rossi Energy-Catalyzer | | NA | Date of Access: 2011-08-15 | | Source Description:(U) This is an in-depth wikipedia-like report on the history of Rossi's development of a claimed LENR device. | back

23. (U) Book | NGIC-1851-0324-12-OS-018 | Author: M. Benedict, T. Pigford, H. Levi | McGraw Hill Seriews in Nuclear Engineering | (U) Nuclear Chemical Engineering | | Date of Publication: 1981 | | Source Description:(U) Report is used for background information only. | back

For more information contact NGIC Production Management at rmngicprm@army.ic.gov COM: (434) 980-7222/DSN: 312-521-7222 SVoIP: 302-235-7557/TS VOIP: 990-5164/990-1141

Date of Publication: 2010-07-22

(U) Review of Low-Energy Nuclear Reactions

(U) Purpose

(U) This initiative product assesses recent efforts in low-energy-nuclear-reaction (LENR) research. The purpose of this product is to answer three basic questions:

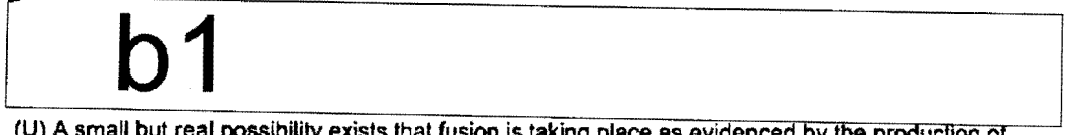
- (U) Is LENR or cold fusion a threat to U.S. national security?
- (U) Will any foreign countries or organizations gain a strategic advantage over the United States in using LENR, or will they have a capability the United States will not have?
- (U) Will LENR/cold fusion contribute in a significant way to the energy-production issues facing the world?

(U) Despite being surrounded by controversy and derided by many physicists, LENR research has nonetheless continued and has recently seen an increase in foreign activity and a revival in the popular media. Although plagued by intermittent and unconfirmed results, charges of "pseudo-science," experimental incompetence, and personality conflicts, LENR research has continued by focusing on refining experiments and on expanding the search for a scientific explanation of the experimental results. The controversy surrounding the legitimacy of claims by researchers to have initiated nuclear reactions with energies significantly below those needed to overcome the nuclear Coulomb barrier continues; nevertheless, some insights into the possibilities of LENR have raised speculation that these processes may not be as "forbidden" as opponents initially claimed.

(U) This product addresses topics within production requirements C513-95-0030 (Electric Gun Technology) and C572-03-0001/2 (DEW Weapons Developments-Foreign), and it supports C590-96-0014.

(U) Key Points

- (U) NGIC finds that the evidence for anomalous heat production in electrolysis cells is credible because of the large number of repeated experiments; however, the source of this anomalous behavior has not been established, and there is no reasonable expectation that this process can result in significant applications as an energy source of any kind. Any serendipitous applications await the correct identification of the physics and chemistry involved. (High Confidence)[a]
- (U) In the United States, LENR is still outside the mainstream of scientific research in that little, if any, is funded through traditional basic-research-funding agencies. In other countries, LENR has met with much less hostility, although it remains at a relatively low-level of activity and acceptance. In spite of these conditions, much progress has been reported over the past decade in both the United States and overseas. (High Confidence)
- (CANE) b1



- (U) A small but real possibility exists that fusion is taking place as evidenced by the production of excess heat and the signature of nuclear "ash." The evidence is illustrative but inconclusive. (High Confidence)
- (U) No accepted theoretical models for the process exist, and absent a theory, experiments tend to be phenomenological in design and purpose. LENR represents a convergence of surface physics, chemistry, nuclear physics, and nanomaterial engineering, and this diversity likely helps explain the lack of a unified theory. (High Confidence)
- (U) Strong evidence indicates that the inability to replicate results on demand may be related to the source of the lattice material (often palladium), and perhaps to trace impurities in the crystal. (Medium Confidence)
- (U) Although the heat or power-producing effects of LENRs are interesting from a scientific perspective, none of the available evidence indicates that these effects can be scaled to either a useable personal or commercial energy source. (High Confidence)

(U) Source Summary Statement

(U) This LENR assessment is based on a review of the open-source scientific literature for technical validity. This assessment is needed before Intelligence Community-collection assets are committed. The majority of the reports on advances in LENR are found in LENR-specific conferences (e.g., the International Conference on Cold Fusion series, of which there have been more than a dozen), web postings, private correspondence, and the popular press. Because LENR has not fully entered the mainstream of scientific funding—and therefore scientific journals—few conventionally peer-reviewed papers on the topic are available. The LENR community attempts to provide some degree of review, but many scientists do not regard that review as adequate. To improve analysis, this article has reduced arguments (both pro and con) to independent scientific issues whenever possible. Many of these issues have been addressed in peer-reviewed scientific literature.

UNCLASSIFIED

(U) Introduction

(U) The study of low-energy nuclear reactions (LENRs) remains at the periphery of experimental physics, in part because of the negative press associated with the original publication of the Pons and Fleischmann results and in part because of the difficulty other research groups have reported in replicating those initial results.

(U) From the original concept of fusion of deuterium nuclei in a palladium lattice at temperatures up to perhaps 1000 Kelvin, the science of cold fusion has evolved to include deuterium fusion in other metals, reactions of protons with nickel, and the transmutation of elements caused by these reactions. The term *cold fusion* has given way to new terms: *low-energy nuclear reactions* and *lattice-enhanced nuclear reactions*, among others. The "low" in LENR refers to the input or initiation energies, not to the output energies.

(U) In early research, the level of heat produced was very low, and the calorimetry needed to show that this heat was excess enthalpy was extremely difficult to perform. This difficulty resulted in data that were often open to question. Showing elemental transmutation is less ambiguous, and given the capabilities of today's instruments (such as the X-ray photoelectron spectrometer), verifying that new elements have appeared after LENRs have been induced is relatively easy. For this reason, LENR researchers have recently emphasized showing that transmutation has occurred to demonstrate more conclusively that reactions not allowed by conventional nuclear physics are taking place.

(U) The normal deuterium fusion reaction requires that two deuterium nuclei be brought together with sufficient energy to overcome their mutual Coulomb repulsion. Most often, this is done by raising their temperature, and the energy needed to do so is at the heart of conventional "hot" fusion. However, this temperature is so high that the reactants cannot be held in a solid container; instead, they must be contained by a magnetic field. This process has proven to be very difficult to accomplish for a time interval sufficient to generate useable energy. In spite of this difficulty, attempts have been under way for the last 50 years, with the expenditure of tens of billions of dollars, and with no real success.

(U) LENR, on the other hand, attempts to replicate the same process by using solid crystalline materials at normal temperatures as the container. The container consists of various metals, most often palladium, with which the deuterium reacts to form a chemical compound. The hypothesis is that the barrier between the deuterium nuclei is somehow reduced in the crystal lattice so that two nuclei can fuse. The process causing the barrier reduction to happen is not well understood, and the possibility continues to be rejected by many scientists. Difficulty in replicating the process on command and the continuing absence of plausible theories describing the process have perpetuated the rejection among scientists. Nonetheless, over the past 20 years many groups have reported observing this process.

(U) How does one begin to mine the experimental data to distinguish fact from fiction? To present as balanced an assessment of the status of LENR as possible, this assessments poses a series of questions and surveys the literature studied to obtain answers. In some cases, researchers active in the field were also contacted. It is not surprising, therefore, that some of the answers may reflect the normal bias in favor expected from proponents and bias against expected from opponents. These questions and their answers may offer some insight into the realities of LENR.

(U) LENR Has Gone Far Beyond Cold Fusion. What Is the Current Consensus Definition of LENR?

(U) No consensus exists on the definition of LENR. The popular term *cold fusion* is still maintained by many in spite of the negative connotations associated with it. *Low-energy nuclear reactions* has been adopted by many to reflect the advance of the research since 1989. Others use terms such as *chemically assisted nuclear reactions* to reflect the belief that the process is initiated by chemical energy while the name *condensed-matter nuclear science* has also come into use, especially by researchers from a solid-state physics background. Nagel[1] of George Washington University (GWU) has coined the term *lattice-enhanced nuclear reactions* to reflect the important role of the crystal lattice while preserving the *LENR* acronym that has become popular. It is quite descriptive of the current understanding of the mechanisms involved.

(U) If there is a point on which a consensus in the field is converging, it is that the nuclear reactions reported are initiated by chemical energy. Those who question the observations claim that the chemical energies that may be involved are many orders of magnitude below the levels typically needed to initiate nuclear reactions—which is true if the comparison is restricted to conventional *plasma* fusion; comparisons to the energies required by conventional plasma fusion may well be inappropriate or even irrelevant. Although the theory underlying the process is sparse, several ideas seem to have some limited support. These will be discussed later in this assessment.

(U) Even more elusive is a full understanding of the environment that triggers the mechanism, the so-called nuclear-active environment. Initially, this environment was thought to exist in the bulk of the palladium cathode used in the Pons-Fleischmann[2] method to produce cold fusion. It is now agreed that the nuclear reactions occur only in the surface region. Recent arguments suggest that this surface layer does not even require palladium for it to be nuclear-active. Nuclear reactions have now been produced in a variety of materials using many methods. The only common feature found in all of these methods, aside from the crystal lattice itself, is the presence of nano-sized particles of material on the active surface. If this observation is correct, four conditions seem to be required to produce the nuclear reactions. First, the particle must have a critical small size; second, it must contain a critical concentration of deuterium or hydrogen; third, it must be constructed of certain atoms; and fourth, it must be exposed to a source of energy. This energy can take the form of a sufficiently high temperature, a significant high flux of hydrogen through the particle, the application of energetic electrons or charged particles, or the application of laser light of the proper frequency. Until the importance of these factors is understood, the effect will continue to be difficult to replicate.

(U) What Has Been Proven (i.e., What Do All Informed Students of the Subject Agree Are True)?

(U) Now we enter the minefield. First, the idea that LENR might represent some "new" physics is generally dismissed with the argument that if some of these "new physics" did indeed exist, its manifestation should not be confined to the singular phenomenon of LENR. Even in the presence of conflicting observations and beliefs, several claims seem to have been replicated in enough laboratories on several continents to warrant general acceptance with varying levels of confidence. They are as follows:

- (U) Electrolysis cells containing deuterium and palladium can, under the proper circumstances, produce some excess energy in the form of heat. Here, "excess" is taken to be the measure of energy leaving the cell less the energy input to initiate and sustain the process.
- (U) The second claim generally accepted as true but not universally replicated is that nuclear reactions do occur, as indicated by the claimed presence of nuclear-reaction products such as helium or neutron emissions. These claims are both difficult to prove and difficult to refute, and the fact is that there is no definitive proof. To explain the lack of reaction products, the theory community has moved toward an explanation that does not involve fusion at all—transmutation.
- (U) A third claim, which seems to be the least accepted, is that nuclear reactions or transmutations are taking place at chemical-energy levels. This claim is at best an oversimplification. Very-low-energy nuclear transmutations, such as neutron activation, are well known and would not be unusual, but whether such transmutations are involved here is unclear.

(U) What Are the Key Experiments, and What Are the Uncertainties in Those Measurements?

(U) Prior to the initiation of the reaction, a solid (crystal lattice) must be loaded with the appropriate concentration of deuterium. This loading can occur in three general ways: electrochemical, in which the lattice is immersed (for example, in a bath of heavy water); thermodynamic, in which the lattice is loaded at

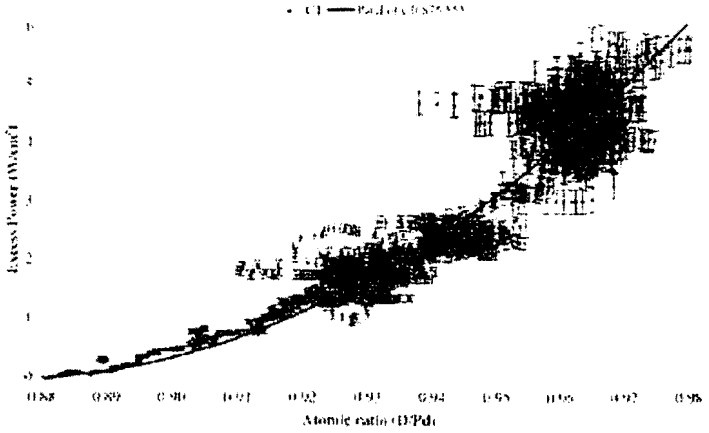
an elevated temperature; or kinetic, using either a plasma or energetic beam of deuterons. By far, the most interest has been in studying the excess heat from a solid, loaded electrochemically, which was the method originally used in the Fleischmann and Pons study. Significant work has also been done looking for the expected nuclear products (often referred to as "nuclear ash") from all lattices except those implanted using energetic beams. Less work has been reported measuring the excess heat from thermodynamic and plasma loadings; the prompt radiation from electrochemical, thermodynamic, and beam loadings; and any measurement of the low-energy particles resulting from any lattice. Essentially no work has been reported studying the prompt radiation (photons) from lattices charged using plasmas or excess heat from lattices charged with particle beams.

(U) Evidence for Excess Heat

(U) Over 100 reports have now been published on the production of excess energy. This is an important point of contrast with "pseudo-science" topics, on which only self-published reports on the Internet—and no peer-reviewed reports—have been published showing positive experimental results.[3] The exact source and mechanism of the excess energy are not agreed upon, but the experiments have been refined to the point that measurement errors are now discounted as the source of the excess energy. What is known about the excess heat production is being accumulated through more precise experimental conditions that have isolated both the electrode material composition and the surface effects of the electrodes as playing a vial role in excess heat production. Observed power gains are generally less (usually much less) than a factor of 10.

(U) Hagelstein, et al,[4] [5] presented a summary paper on new physical effects in metal deuterides for the 2004 Department of Energy (DOE) review. The review touches on a number of other reported effects and is a comprehensive summary of experimental observations.

(U) The relationship between excess heat and the atomic loading factor of deuterium in the palladium matrix has been studied by numerous investigators, and evidence shows that excess heat is a function of loading (i.e., the D/Pd atomic ratio). The effect appears to increase parabolically above a threshold loading of D/Pd ~0.875. At a loading of 0.95 or greater, electrodes exhibited an excess heat three times the measurement uncertainty. For cells with cathode loading between 0.9 and 0.95, half demonstrated measurable excess heat, and half did not. The figure below (from Hagelstein, et al[6] [7]) shows a threshold for excess power generation at an atomic ratio (D/Pd) of about 0.88. At a ratio of 0.93, the excess power is of the order of 1.5 W/cm^3, rising to over 4 W/cm^3 at a ratio of 0.96.



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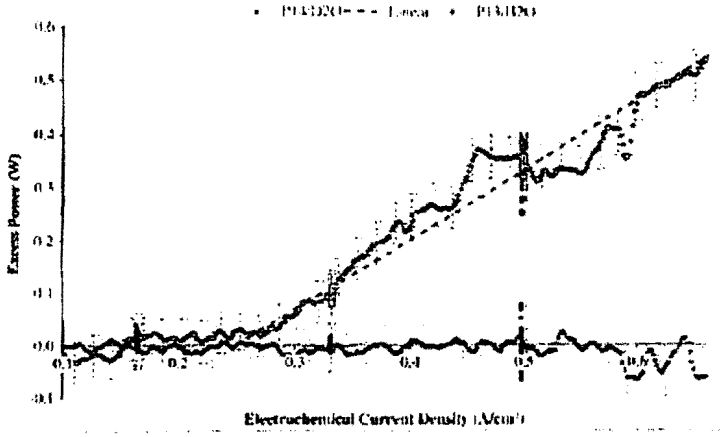
(U) Excess Heat as a Function of Deuterium Loading (Hagelstein)

- (U) A strong sensitivity to operating temperature is also noted. The basic effect is consistent with the expression where $P_{excess} = P_0 e^{-E_a / k_B T}$ where E_a is an equivalent activation energy of about 15Kcal/mol.

(U) Although the realization that the D/Pd loading ratio strongly influenced the generation of excess heat, that alone did not provide an understanding of the effect. In another set of measurements, the excess power generated in the cell was measured against the electrochemical current density (A/cm^3), as shown in the figure below, again taken from the U.S. Department of Energy (DOE) review. In this figure, the two curves are from identical cells operated in series, with the upper curve from the cell with D_2O and the lower curve charged with H_2O. The current density threshold effect is seen clearly at a current density value of about 0.3. Above this value, there appears to be a linear relationship between the excess power and the current density inthe D_2O cell.



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(U) Simultaneous Series Operation of Light and Heavy-Water Cells; Excess Power vs. Current Density.[8] [9]

(U) Evidence for Nuclear Reactions

(U) The correlation of reaction products with excess heat is still is evasive, although it continues to be at the focus of inquiry. Insufficient chemical-reaction products are produced, by orders of magnitude, to account for the excess heat. The search for a correlation has expanded to include products of nuclear reactions—which is an even more difficult search because no known process is available for use as a model. Nonetheless, many attempts have been made to correlate excess heat with the presence of reaction products. Researchers have correlated the presence of ^4He with excess heat, for example, in a variety of environments and with differing results. Studies by Miles and Bush,[10] McKubre,[11] and Gozzi[12] have claimed to observe the presence of ^4He. These studies result in several claims:

- (U) Helium production varies linearly with excess power.
- (U) The amount of helium is consistent with that expected from the D+D reaction (within a factor of 2).
- (U) The helium is partially retained, and the dissolved helium is only slowly released to the gas phase.

(U) Although the search for nuclear products (neutrons, tritons, etc) has not been successful generally, U. S. researchers Mosier-Boss, et al,[13] [14] have reported evidence of the production of energetic neutrons from an LENR device. The researchers also cite other evidence for the nuclear reactions, including X-rays, tritium, and excess heat. In their experiment, an electrode of nickel or gold was placed in a solution of palladium chloride mixed with deuterium oxide. Specifically, their LENR experiment differed from earlier work by using Pd/D co-deposition. An electric current passes through a solution of palladium chloride and lithium chloride and electrolysis simultaneously co-deposits deuterium and palladium, in particles about 60 nm in diameter, in equal amounts, on the cathode's neutral substrate, the gold or nickel. The electric current passed through the solution caused a reaction and a CR-39 plastic track detector recorded "triple tracks," which are claimed to be evidence of high-energy neutrons emitted during the fusion of deuterium nuclei. Specifically, the triple tracks are attributed to the $^{12}C(n,n')3$ reaction. In just moments after co-deposition begins, the cells show evidence of nuclear reactions. The electrode, with its new coating of palladium and deuterium, runs about 3°C warmer than the surrounding solution. The U.S. researchers claim that this is the long-awaited evidence that there are neutrons present in LENR reactions. In a further innovation, they placed the cell in a magnetic field and found that the cathode temperature increased. However, this evidence is not universally accepted.

(U) Kowalski[15] questions whether the triple tracks actually do originate from alpha particles as Mosier-Boss claims. The results of his research indicates that the diameter of the tracks in CR-39 is not consistent with that to be expected from alpha particles, but rather from a particle with more mass.

(U) Other researchers have recently reported the simultaneous production of excess heat and some nuclear process. Mizuno[16] (Japan) cites the simultaneous production of gamma rays and excess heat, while De Ninno[17] (Italy), in a long series of publications by a number of investigators dating back more than a decade, reports the simultaneous presence of excess heat and helium production.

(U) Nuclear emissions consistent with (but not necessarily the result of) D+D fusion have been reported for more than two decades. These emissions include both neutron detection as well as charged-particle emissions. These low-level nuclear emissions typically occur in bursts lasting from seconds to days. The activity seems to be related to current density in the cell. To confuse the issue further, although there have been several observations of excess heat with simultaneous emission of neutrons, X rays or gamma rays, there are also anti-correlation reports between excess heat and neutrons. Several reports also claim to observe weak nuclear emissions which are not associated with D+D fusion. Energetic alpha particles (~15 million electron volts [MeV]) and protons (~14 MeV) have been observed in thin TiD foils. The appearance of these signals under conditions that have led to excess heat generation and apparent low-level D-D fusion may be useful in understanding the processes responsible for these effects.

(U) As far back as 1990, the neutron-detection claims were called into question by experiments done at the Los Alamos National Laboratory (LANL).[18] The LANL experiments concentrated on detecting neutrons from an operating LENR/cold-fusion cell using a high-efficiency well counter and an NE 213 scintillator. The entire experiment took place in a shielded cave approximately 50 feet underground. After approximately 6500 hours of counting time, no evidence of LENR neutron production was seen. Although the experimenters observed all three types of neutron data presented as evidence of LENR/cold fusion up to that time—including large, positive fluctuations in the neutron counting rate; weak peaks near 2.5 MeV in the neutron energy spectrum; and bursts of up to 145 neutrons in 500 microsecond intervals—their conclusion was that the neutron signature assigned to possible LENR/cold fusion processes could be explained by the naturally occurring neutron background (primarily the result of cosmic rays).

(U) Nuclear reactions at the level of chemical energies is nothing new. Neutron-induced nuclear fission, such as that in nuclear-power reactors, takes place using predominately thermal neutrons (neutrons with an average energy of 0.025 eV, well below the chemical-energy level). There are also sources of cold and ultra-cold neutrons (with energies down to 10^{-7}eV), which are used in condensed-matter-physics experiments. The energy levels of these neutrons are so low that effective temperature is used rather than electron volts to define them. Also well known is that very-low-energy neutrons have deBroglie wavelengths of the same size as interatomic bond lengths and can interact with molecules through excitation of molecular vibration modes. Very-low-energy neutrons produced in the electrodes would thermalize (i.e., gain energy from the lattice) and be detectable outside the experiment. Coupled with the fact that neutron signatures have been replicated with no fusion or excess heat severely reduces the credibility for reactions producing neutrons.

(U) Palladium Stock Question

(U) Interestingly, the key experiment may be one not directly related to the LENR process itself. The c omposition and structure of the palladium are speculated to be important to the process, even to the point that the source of the palladium may dictate beforehand whether or not the LENR process will be observed. Experiments in the United States offer "compelling evidence that the anomalous effects in deuterated systems are real. Nevertheless, no one has been able to solve the reproducibility problem. This research area will remain highly controversial until reproducibility can be demonstrated. The lack of reproducibility stems mainly from unknown and uncontrolled variables in the palladium stock. There is a remarkable correlation of excess power with the source of the palladium."[19]

(U) Are There Front-Runners in the Theory? What Are the Most Likely Mechanisms Responsible for the Process? What Is the Status of the Relationship Between Theory and Experiment?

(U) The questions above are all versions of the same one—and unfortunately, regardless of how it is phrased, it has no fully satisfactory answer. Three generic types of theory appear in the LENR literature.

- (U) The first continues to insist that D-D fusion with neutron and He production is taking place.
- (U) The second seeks to explain why neutron or other signatures of D-D or D-T (traditional "hot" fusion reactions) are not seen in many experiments by claiming that transmutation events take place. This claim is based on the Weak interaction (of particle physics), in which there is a collective transfer of energy to a small distribution of electrons. The electrons then penetrate the nuclei, interact with protons, and form neutrons with no momentum—and thus cannot escape to be detected externally.
- (U) The third claims that D-D fusion takes place with no reaction products but with energy deposited directly into lattice as phonons. A related transmutation theory claims that shock waves can be used to initiate a self-densification process, which creates a "neutron soup" that allows for transmutation. The third type admits the conventional hot-fusion nuclear reactions by claiming that a very-low-energy resonance in the cross section exists, which also suppresses radiation signatures. More than anything, these unsubstantiated assertions reflect the urgency with which a theory is being sought.

(U) Although there is no "frontrunner" theory that explains all of the experimental observations, several interesting theories have been put forth.

- (U) Electron-catalyzed fusion (ECF):[20] Dating to at least 1991, ECF works in a similar manner to the better known muon-catalyzed fusion. The central idea is that if an electron is placed in the center of mass of 2 deuterons, the deuterons will be attracted toward one another because of the electron's negative electric charge. The attraction may be able to bring the deuterons close enough to undergo fusion.
- (U) LENR induced by electro-weak interactions:[21] Authors of a 2006 paper on nuclear abundances in metallic hydride electrodes of electrolytic chemical cells propose that collective electron- and proton-surface-plasma modes can give rise to ultra-low momentum neutrons. From this assumption, they calculate the scattering strength as a function of atomic mass number. Interestingly, the authors observe that because the mass number is equivalent to the radius of the optical well, when the neutron wavelength reaches resonance with the radius of the well, a peak appears in the scattering strength, and these peaks seem to correlate with observed nuclear transmutation abundances. This work evolved into LENR induced by electro-weak interactions. The main idea is that, under certain conditions, energy stored in low-energy electrons present on the surface of an electrode can be collectively transferred to create a small number of high-energy electrons. The electrons then penetrate a nucleus and combine with a proton, creating a very-low-energy neutron and thereby causing the transmutation of the nucleus to a (Z-1) species. This process is not a fusion reaction, and therefore it is used to explain why signatures of fusion reactions are not found in experiments, but excess heat is.
- (U) Selective Resonant Tunneling Model:[22] [23] Xing Zhong Li (Department of Physics, Tsinghua University, Beijing, China) developed a model to describe the nuclear reaction cross section at low energies (<100 keV). His model uses a potential that has both a real and imaginary part and compares his model to data from the National Nuclear Data Center (NNDC) at Brookhaven National Laboratory. Li shows that this data contained an error that existed for many years in the form of a false resonance in the cross section near 100 eV. His resonant model indicated that the 100 eV resonance was of the wrong form, and, when checked, the NNDC corrected the data set. Li further

speculates that if an even lower energy resonance were to exist—although he has no indication that one does—it would explain fusion reactions occurring with several hundred nuclear diameters, at low energies, and without strong nuclear radiation.

- (U) Shock-driven densification:[24] [25] The Proton 21 group at the Kiev Electrodynamics Laboratory claim that it has clear evidence, taken from many experiments, of low energy nucleosynthesis. It claims that using an electron beam to compress a small target initiates a self-organizing process of avalanche self-densification that is strong enough to force electrons into the nucleus, leading to the conversion of protons into neutrons and resulting in various nuclear transmutations.
- (U) The Universal Resonance Principle of Synchronization:[26] Gareev and Zhidkova of the Joint Institute of Nuclear Research, Dubna, Russia, have developed a theory they claim enhances very weak or rare reactions (of all kinds). The general idea is that the wave nature of matter allows for weak events to become synchronized, create a resonance condition, and therefore grow in strength to become a rare but observable phenomenon.
- (U) Deeply bound Hydrogen Energy Level: The idea of this theory is that the process proceeds through an interaction with some deeply bound energy level of hydrogen (below the accepted 13.6 eV of the ground state), or alternately that LENR is the result of four neutrons or two deuterons appearing simultaneously at the same point.

(U) Another useful viewpoint considers the cross section for the reactions.[27] The usual picture of fusion interactions operates through penetration of the Coulomb potential (barrier) between the charged particles. The cross section drops exponentially with decreasing energy. Hot-fusion reactions (D-D and D-T) operate at a maximum cross section of ~5 barns (1 barn = 10^{-24} $cm^{2)}$ at ~15 keV. Cold-fusion reactions (at chemical-level energies) would have to take place at ~100 eV or less. In most cases, the cross sections are too small to be measured in the laboratory. An effect called electron screening, which can increase the effective cross section through enhanced Coulomb-barrier penetration, comes into play. Sinha,[28] a researcher at the Indian Institute of Science, has performed a study indicating that the electron screening considerably improves the cross section for fusion in a solid matrix of metal deuterides. An extrapolation of this work would indicate that a standard-physics basis (under special conditions) would account for D-D fusion under those conditions. The key point is that the known interatomic distance for PdH systems is ~2.9 Angstroms, too far apart for fusion. But if coupled with electron screening, a metal matrix that allowed for closer distances may account for low reaction rates of fusion using conventional physics.

(U) The screening effect has also been studied for applications in nuclear astrophysics calculations without the effect of a lattice. The literature indicates that taking into account the screening effect alone does not increase the very-low-energy cross section sufficiently to account for LENR. These results may not be definitive, either because direct independent measurement of the cross sections is still not possible—and thus an unexpected resonance may still exist independently—or because of the lattice environment for LENR experiments. Li[29] [30] claims that his technique can model the cross section at essentially all energies, provided that some calibration data are used. He makes no real predictions but hypothesizes that a resonance in the cross section below 100 eV (on the order of several barns) would explain cold-fusion reactions. Thus, although the possibility of fusion reactions cannot be ruled out, significant nuclear physics-based reasons exist for not accepting the common cold-fusion explanation. This leaves transmutation (as opposed to fusion) as a major potential explanation for the excess heat and other products of LENR experiments.

(U) Numbers of Interest

(U) When two deuterium nuclei fuse, one of three processes can take place:

(U) D+D = ^{3}H + proton + 4.04 MeV

(U) = ^{3}He + neutron + 3.27 MeV

(U) = ^{4}He + + 23.8 MeV

(U) The first two processes (channels) each occur with a probability of about 0.5; the third occurs with a probability of 10^{-6}. For each ^{4}He atom created, about a million protons or neutrons should be created. If the excess heat is attributed to the third of these channels (the one with the largest energy release), we can calculate the number of fusions per second that are needed to produce 1 W of power:

(U) Simple dimensional analysis indicates that the number of fusion events per second necessary to generate 1 W from D-D fusion—yielding 23.8 MeV per fusion event—is about 2.6×10^{11}.

(U) At this point, one of two situations should arise: either protons or neutrons exceeding 10^{16} per second should appear; in their absence, a plausible explanation for their absence should be proposed. In the LENR literature to date, the protons and neutrons have not been observed, and the absence is not addressed other than the argument that somehow the reaction environment suppresses the two most likely channels.

(U) A general expression for the total power in watts generated by any apparatus using nuclear reactions is given by $P = V/2.62 \times 10^{11}$ fusions per second, where = deuteron flux in units of deuterons per cm^2 per second, = macroscopic (geometric) cross section for D+D fusion in units of cm^{-1}, and V= reaction volume in units of cm^3.

(U) If the reacting volume is on the order of 10 cm^3 and the macroscopic cross section is on the order of 10 cm^{-1}, then the power output would be $P = 3.84 \times 10^{-10}$ in watts, requiring a deuteron flux greater than 10^{10} deuterons per cm^2 per second (for 1 W).

(U) Similarly, the anticipated neutron flux from a neutron-producing channel would be ~10^{10} neutrons per cm^2 per second and should be easily detectable. Signatures at these levels have not been reported. To achieve reaction rates on the order of 10^{10} reactions per cm^2 per second (thus explaining the heat production) would require the internuclear spacing be reduced from ~2.9 Angstroms to ~0.5 Angstroms. One speculation is that this reduction may be possible using very controlled electrode material and accounting for electron screening.

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(U) The key recurring issues that plague the acceptance of LENR include the following:

- (U) Some explanation for the nonreproducibility of positive results must be uncovered. It may be related to the inability to properly characterize materials, but that assertion must be validated.
- (U) The absence of theories and physical models explaining the experimental claims continues. Without an acceptable theory on which to base experiments, the field will continue to be populated with measurements that may or may not be relevant to an understanding of the processes.
- (U) Groups who depend on precision calorimetric measurements alone often lack appreciation of the difficulty of making such measurements. Standards must be set for these measurements.
- (U) There is an absence of repeatable correlations between heat generation and evidence of nuclear processes. The possibility of nuclear reactions in the cell volume being triggered by cosmic rays must be eliminated.

(U) A critical type of experiment that has yet to be performed is the measurement of the fusion cross section at very low energies, including in a lattice. All experiments to date concentrate on excess energy production and hype the potential use of LENR as a carbon-free, "green" energy source without much consideration of the nuclear physics involved. Two situations seem logically possible:

- (U) There is a significant cross section for D+D fusion reactions at very low energy because of a resonance not previously observed or somehow otherwise caused by the lattice environment.
- (U) Nuclear transmutation is taking place because of enhanced electro-weak interactions that produce zero-momentum neutrons.

(U) The cross section (measured in barns, 1 barn = 10^{-24} cm^2) for D+D reaction peaks at 0.1 barns at an energy of 3 x 10^3 keV. The lowest actual measurement is ~2 keV, where the value is 10^{-4} barns. NGIC has identified nuclear astrophysics publications that have investigated D+D reactions in metals. These publications show an enhancement of the D+D reaction rates compared to gas-phase experiments. The enhancement is in the form of an increased screening effect that effectively increases the reaction energy. However, this enhancement may not be sufficient to explain the experimental observations related to excess heat fully.

(U) Nuclear transmutation by ultra-low momentum neutrons involves not fusion, but rather neutron absorption. Several facilities worldwide are capable of generating ultra-cold neutrons with energies as low as 10^{-7} eV. Absorption cross sections generally rise as neutron energy decreases according to the "1/v" law, where v is the neutron velocity.

(U) The issue of scaling also remains unresolved. The size of the cells used in all experiments is relatively modest, in large part because of the constraints imposed by calorimetric measurements. To date, only theoretical calculations and hopeful estimates exist for applications. A fully involved U.S. company has sponsored a website and filed for patents claiming that LENR-based systems could be scaled up for use as a CO_2-free power source. A website from the UK presents calculations and claims to show that scaling-up would provide a reasonable power source again useful as CO_2-free. These calculations are based on rather hopeful assumptions, including very significant improvements in the performance of present systems. The data from the scientific literature does not indicate the existence of any resonance, but even if it did, the cross section and therefore the reaction rate is not large enough to be useful. Furthermore, there seems no way to improve the process. In fission or hot fusion, the density of fuel can be increased to increase reaction rates and therefore heat production. There seems to be no way to accomplish a similar effect, however, with the LENR apparatus.

(U) The engineering of the rest of any practical power-producing systems is not usually addressed in the LENR literature. For example, even if one were to accept the most optimistic energy-density values attributed to the process, the result is a thermodynamic process at modest temperatures, far below any practical temperature needed for anything but very low-efficiency conversion. Also yet to be discussed meaningfully is the issue of scaling the required input power to run large electrolytic cells. The power available from a source determines its potential applications. This output power is determined by the energy per reaction and the number of reactions per second that can occur. Neither of these quantities is adequately known for LENR. For practical applications, the issue of scalability will need to be addressed.

(U) Who Are the Active Leaders in the Field, and What Seems to be Their Motivation?

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(U) The Laboratories Reporting Nuclear Transmutations

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(U) Energetics Technologies (ET) Laboratories[32] [33] [34] is located in Israel but is a wholly-owned subsidiary of a U.S. company. Its studies have several interesting features. For instance, ET's electrolysis cells contain ultrasonic transmitters to induce cavitation in the electrolyte at the palladium-electrode surface. The company claims that this arrangement provides some in situ cleaning and activation of the surface, generates dislocations, and assists in loading and excitation of the deuterium-palladium system. In addition, it employs SuperWaves™, a complex superposition of a number of sine waves of decreasing wavelengths, to drive the process. The concept of SuperWaves was developed by the founder, Dardik, who first developed the idea as part of a medical treatment.

(U) ET claims that the use of electrical SuperWave stimulation, in combination with ultrasound stimulation, has produced excess heat of significant amounts in 82% of the cells. ET has attracted collaborators from both the United States and ENEA (Italy), who claim to have used the ET SuperWave electrical stimulation to achieve 73% reproducibility and 60% reproducibility, respectively. The stated reason for this extraordinary enhancement of reproducibility is that the complex SuperWaves enhance the loading of deuterium into the palladium and effectively excites the deuterium-palladium system. The SuperWave interactions intensify the resulting excess heat. The use of SuperWave excitation appears to produce more power gain than has ever been reported before. In one case, ET reported a P_{out}/P_{in} ratio of 30. It also claims to have generated excess power of 34 W and excess heat of 3.5 megajoules (MJ). In addition, ET has reported observing excess power for as long as 40 days and a specific power of 70 W/g of palladium.

(U) Although ET's claimed achievements are generating a lot of publicity, critics claim that the SuperWave stimulation leads to errors in the calorimetry. The measurement of heat input is derived by integrating the complex sine-wave input signal, a process that is prone to numerical errors.

(U) Conclusions

(U) The answers to the questions posed in the purpose section are as follows:

- (U) Is LENR or cold fusion a threat to U.S. national security? **No.** LENR/cold fusion poses no threat to national security at this time. The results in this area are a scientific mystery, but not a threat.

- (U) Will any foreign countries or organizations gain a strategic advantage over the United States in using LENR, or will they have a capability the United States will not have? **No.** The United States has among the best researchers in this field, and it is unlikely that progress would be made without the U.S. experts knowing.
- (U) Will LENR/cold fusion contribute in a significant way to the energy production issues facing the world? **No**, not in its present form. Even given excess heat production, the amounts are so modest as to prevent scaling the heat-production process to useable size.

(U) LENR will not go away—quite the opposite. It continues to grow in scale and credibility. An increasing number of credentialed research groups worldwide are reporting similar results supporting LENR. Absent any unanticipated event, LENR is on the verge of entering the mainstream of science.

(U) The evidence of excess heat related to deuterium loading is overwhelming. Early reliance on calorimetry as the sole basis for claiming LENR activity has been augmented by measurements of "nuclear ash." Further, the early critics' claims that the calorimetry was flawed because of improper calibrations is being addressed, although some doubts still exist—not because adequate precision is not available, but because experimentalists do not appreciate the difficulty of the measurement.

(U) The claim that it is possible to trigger a nuclear reaction with MeV energy yields with essentially chemical energies at the eV level is an oversimplification. Very-low-energy nuclear reactions (fission, neutron absorption, and so forth) are well known. The keys are the mass-energy carried by the incident particle or photon and the binding energy of the target. **NGIC assesses that although LENR cannot be completely ruled out, there is currently no definitive evidence for such reactions.** Each theory proposed lacks signatures that should be present and are not.

(U) Some systematic trends seem to be emerging, among them the relation between excess heat and deuterium loading of the metal matrix.

(U) The nuclear products expected of D+D fusion are not always detected, and the most likely channels for plasma fusion are generally absent in LENR. These phenomena have yet to be explained properly.

(U) Transmutation of elements has been reported, although the data from these experiments are not as robust as data claiming excess heat. This area is experimental and needs to be tracked carefully.

(U) Consideration of Alternative Analyses and Contrary Evidence

(U) Rejection of LENR—and specifically cold fusion—takes two forms: first, general statements made by well-intentioned classical physicists who energetically insist that LENR is not possible and that if one does not want to dismiss the law of the conservation of energy, LENR must be rejected; and second, the inability of experimentalists to replicate results on demand coupled with the continuing absence of a plausible theory to explain LENR. In the early days of LENR, critics claimed that the positive excess heat results were the result of measurement errors (or fraud).

(U) Both of these objections may have merit, but neither together nor individually do they seem to mitigate the positive results reported by an increasing number of reputable research groups around the world. Although early criticism of the LENR results attributed excess heat to experimental errors, the strong experimental data now emerging shows that experimental error is not the source of the positive results.

(U) On the other side of the argument are what may be called the unabashed proponents of LENR and cold fusion. These proponents unequivocally believe that cold fusion is the green energy source of the future and that there is a conspiracy among "establishment" scientists and the energy industry to conceal the success of cold fusion. Their products are usually nothing more than one-sided advertisements.

(U) Two analyses would shed much light on the situation. The first would be a comparative, comprehensive material analysis of the matrix materials that produced both the positive and negative results. The second would be an indepth study of the status of the theories that attempt to explain the phenomenon.

(U) Intelligence Gaps

(U) It is too early to consider any potential key intelligence gaps in the area of LENR. There are several stages in the life of a new science, the first and most important of which is a clear understanding of what is happening. Only with this understanding can attempts be made to exploit the science for potential applications, good or bad. LENR is still struggling with the first stage: understanding.

(U) A number of intelligence collection topics could yield insights into the future of LENR and are likely obtainable from open-source literature:

- (U) The development of a generally accepted theory underpinning LENR.

- (U) Evidence of a very-low energy resonance in the D+D reaction.
- (U) The appearance of results on the detailed characterization of the electrode materials.
- (U) Evidence of scalability in either the operating temperature or the cell volume.
- (U) Identification of a source or sources that appear to produce materials repeatedly successful in replicating positive LENR results.
- (U) Increased interest in co-deposition as a means of loading the cell with deuterium.

Footnotes

a. (U) Confidence in Assessments. Our assessments and estimates are supported by information that varies in scope, quality, and sourcing. Consequently, we ascribe high, moderate, or low levels of confidence to our assessments as follows: *High confidence* generally indicates that our judgments are based on high-quality information, and/or that the nature of the issue makes it possible to render a solid judgment. A "high confidence" judgment is not a fact or a certainty, however, and such judgments still risk being inaccurate. *Moderate confidence* generally indicates that our judgments are based on information that is credibly sourced and plausible but not of sufficient quality or corroborated sufficiently to warrant a higher level of confidence. *Low confidence* generally indicates that our judgments are based on information that is of questionable credibility and/or plausibility, that may be too fragmented or poorly corroborated to support solid analytic inferences, or that relies on sources that present significant concerns or problems. |

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(U) Land Warfare Capstone Threat Assessment, Vol VII: Technologically Feasible Threats

(U) Purpose

(U) This study addresses technologies and sciences that may impact weapon systems in the next 20 to 30 years in support of the Land Warfare Capstone Threat Assessment (LWCTA) Project.

(U) NOTE: Please see the Executive Summary for the most recent updates to the LWCTA. Note that these updates are supplemental in nature; they do not replace the earlier version's information, which may still be valid. However, please check with the NGIC author prior to using the older LWCTA data.

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(U) Key Points

- (U) Sciences and technologies that are being researched today will impact various aspects of the future battlefield in both expected and unexpected ways over the next 20 to 30 years.
- (U) These technologies will impact across the full spectrum of the battlespace.
- (U) Some key examples of these sciences and technologies that may have heavy impact on the future battlespace include the following:
  - (U) Quantum information science (quantum computing).
  - (U) Advanced energy.
  - (U) Photonics.
  - (U) Computational materials.

(U) Background

(U) This volume of the Land Warfare Capstone Threat Assessment addresses technologies that may be technically feasible in the next 30 years and could impact known weapon systems or potentially affect designs of future weapons. The prime reason for this volume is to discuss those technologies and sciences that may impact designs of systems discussed or projected in other LWCTA sections.

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(U) Technologically Feasible Threats to the Future Combat System (System of Systems)

(U) The System of Systems (SOS) that is the Future Combat System (FCS) has been described as an "onion" composed of layers of functionality that are provided by both the network environment and the physical systems comprising the FCS. A technologically feasible threat is required to penetrate and/or negate the protective functions of the "onion." In this view, a comparison can be made between the U.S.

battlefield functions, the battlefield functions an adversary would require to negate the U.S. function, and the technologies that may be involved in that defeat mechanism (see table below).

(U) Battlefield Functions vs. Technologies

U.S. Battlefield Function	Adversary Battlefield Function	Disruptive/Emerging Technologies Categories
Avoid Encounter SA & tactics	**Force an Encounter** Deny U.S. SA & IPB Avoid detection by the U.S. LO	Cyber warfare LO
Avoid Detection Signature management	**Detect U.S. Assets** Foreign netcentric ops Utilize LANs/WANs	C4ISR/RSTA Grid computing Evolutionary computing Quantum sciences
Avoid Acquisition Signature management & electronic countermeasures (CM)	**Acquire U.S. Targets** Foreign ISR/RSTA Commercial networks used for targeting	Electro-optics Electrostatic Nanosensors Optical augmentation Acoustic
Avoid Hit Electronic CM & AP	**Enable Hit** Counter AP munitions APS Jammers Swarming of munitions on U.S. targets	AP CM Advanced electronics Computational materials APS jammers Photonics DEW
Avoid Penetration Lightweight composite armor	**Enable Penetration** Advanced explosives /warhead designs	Propellants High-energy dense materials
Avoid Kill Redundancy	**Enable Kill** Numerical superiority	Robotics Nonlethal tech Nontraditional agents Conventional HE Kinetic-energy weapons Nuclear isomers

AP - armor piercing
APS - active protection system
C4ISR - command, control, communications, computers, intelligence, surveillance, reconnaissance
DEW - directed-energy weapon
HE - high explosive
IPB - intelligence preparation of the battlefield
LAN - local area network
LO - low observable
RSTA - reconnaissance, surveillance, and target acquisition
SA - situation awareness
WAN - wide area network

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(U) Force an Encounter: Deny U.S. Situational Awareness and Intelligence Preparation of the Battlefield by Computer Network Operations

(U) Computer Network Operations

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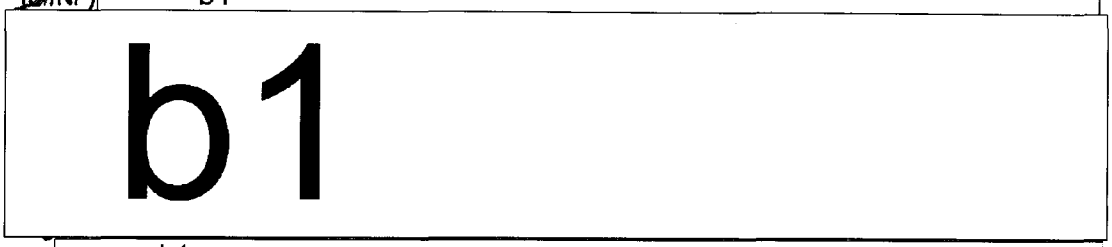

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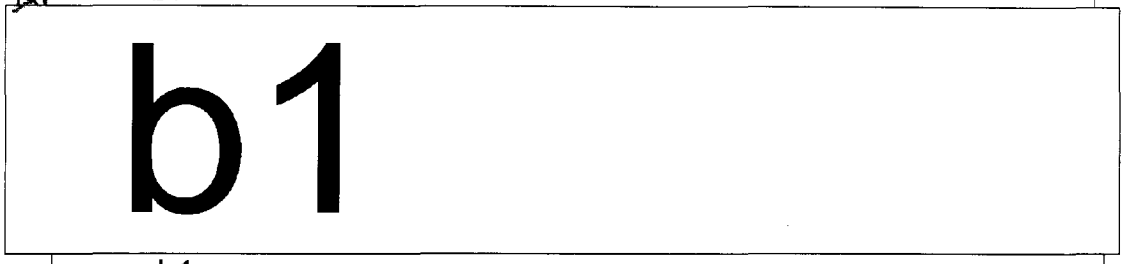

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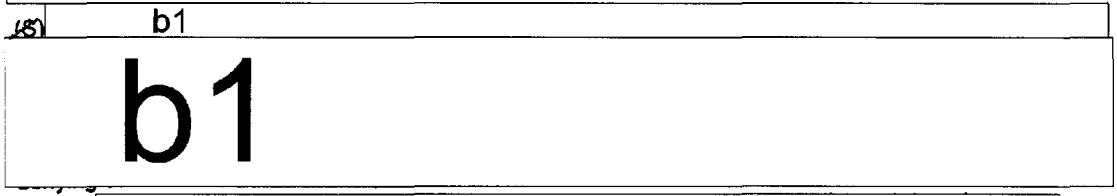

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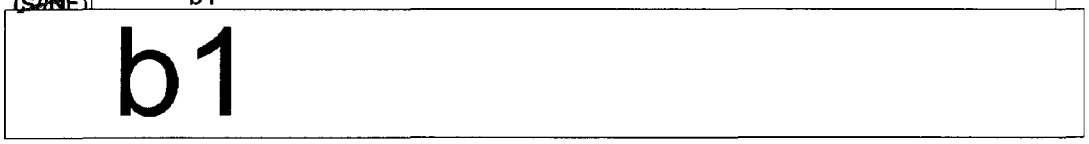

(U) Commercial-off-the-Shelf Software

(U) The Government Accountability Office (GAO) reported that control by the Department of Defense (DoD) over software, particularly that used in weapons platforms, is lacking. Policies intended to mitigate vulnerabilities to information systems focus mostly on operational software security threats, such as external hacking and unauthorized access to information systems, but not on insider threats such as the insertion of malicious code by software developers. The increased reliance on software and a greater number of suppliers results in more opportunities to exploit vulnerabilities in DoD software. Since countries hostile to the U.S. are focusing resources on information-warfare strategies, software security, including the need for protection of software code from malicious activity, is an area of concern for many DoD programs.

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(U) Intelligent-Agent Software

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- (U) Autonomous and collaborative (outside of human control).
- (U) Proactive, adaptive, and deliberate (outside of human knowledge).
- (U) Mobile, reactive, responsive, and self replicating (outside of human response time).

(U) Agents are complex programs intended to accomplish user-defined tasks in asynchronous, distributed, dynamically changing environments. They insulate the user from the details of many computing tasks, thereby increasing the level of abstraction between the user and the task. It is the degree of autonomy that most differentiates agents from other software.

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(U) Force an Encounter: Avoid Detection by the United States

(U) Low-Observable/Counter-LO Materials/Systems

(U//~~FOUO~~) LO technology will continue to reduce the detectability of a variety of platforms and weapons. This technology allows platforms to maneuver stealthily by decreasing their electromagnetic, infrared (IR), and visible signatures. Nanotechnology will play a significant role in developing paints and coatings that will be able to absorb or deflect radar. Plasmas are also being researched as legitimate solutions for LO requirements. The technologies and sciences discussed below could be useful in modifying the signatures of many military targets.

(U) Metamaterial Cloaking Devices

(U) Metamaterials are a new class of electromagnetic materials. Metamaterials owe their properties to subwavelength details of structure rather than to their chemical composition. These materials involve small elements that are arranged into evenly spaced arrays. The arrays may be altered in size, shape, spacing, and composition to create the desired material properties. Metamaterials originally caught the scientific community's attention when negative refractive-index material was demonstrated. Notable concepts to employ metamaterials include superlenses (mirrors that reflect light without shifting its phase) and "invisibility" materials.

(U) "Controlling Electromagnetic Fields" appeared in the 23 June 2006 issue of *Science*. This theoretical article was picked up by news sources around the world, sparked by the idea that invisibility cloaks may be possible. In November of 2006, the same team succeeded by experimentally cloaking a small cylindrical object for the first time. An artificially structured metamaterial was constructed as a cloaking device to hide the cylindrical object over a band of microwave frequencies. This first cloaking attempt was successful by partially decreasing the scatter and shadow from the cylindrical object; thus, the cloak and cylinder resembled empty space.

(U) This research is a step towards developing a cloak that may hide objects from regions in the electromagnetic spectrum; however, there are still many engineering obstacles to overcome before the idea could be militarily incorporated:

- (U) The cloaking effect may be limited to a specific single frequency.
- (U) The internal structure of the metamaterial has to be smaller than the wavelength of radiation. Thus, the nanoengineering process must catch up to the science.

(U) Carbon Nanotubes

(U//FOUO) A carbon nanotube (CNT) is a mesoscopic, macromolecular structure that creates a regularly defined geometric shape from individual carbon molecular bonds. As the name suggests, a nanotube is literally a tube of physical material at the "nano" or "nanometer"scale. Most nanotube diameters range from one-millionth of a millimeter (10,000 to 50,000 times smaller than a human hair) to as much as 3 cm in length. The purity of the molecular bonds provides incredible material properties that can form entirely new molecular structures that are different from those normally encountered by other materials. Nanotubes have a tensile strength 100 times that of steel, a thermal conductivity close to pure diamond (5-times greater than copper), and an electrical conductivity that is capable of currents 100 times greater than metal wire. Nanotubes are recognized as a marvel material with promising characteristics that will have an impact on future technologies and products. The properties of this new form of carbon are extraordinary and may enable revolutionary improvements across a range of electronics, multifunctional materials, energy management, and chemical processes. CNTs improve sensors, electrodes for fuel cells and batteries, armor, LO coatings, hydrogen storage, and many other applications. The focus of current nanotube research is to improve means of CNT synthesis; to fabricate strong and light composite structures, light-emission devices, probes and sensors, and energy and storage devices; and to develop next-generation electronic technologies, such as molecular electronics.

(U) Diamond

(U) Another material development that is creating quite a stir is the ability to manufacture single-crystal diamonds by chemical-vapor deposition (CVD). This method of diamond production has the ability to create not only diamond coatings but also single-crystal diamonds that are on par with gem-quality stones. Diamond has the highest thermal conductivity of any known material and is one of the hardest materials known. Diamond is often used industrially for cutting other nonferrous materials; can aid computers to run extremely fast by using its thermal-management capabilities; can, by extreme cooling, enable high-power lasers to function; and can provide frictionless surfaces for joints or scratch-resistant surfaces. Another area of conjecture is that diamond may eventually replace silicon as the next generation electronics material. This may be enabled by CVD methods of diamond production, which can grow diamonds with perfect crystal structures (extremely low defects), which are highly desired in electronic and photonic applications. Diamond use in weapon systems may also change their signatures, which would affect the abilities of sensors to locate them.

(U) Advanced Power and Energy Technologies

(U) Power and energy technologies are essential for the development of advanced military systems and represent vital dual-use technology. More specifically, energy and power drive most military systems, including weapon systems. Energy-system technologies have the following subsystems:

- (U) Power generation and power conditioning.
- (U) Energy storage.
- (U) Energy conversion.

(U) The functions of energy- and power-system technologies are usually taken for granted because it is assumed that reliable power will always be available. Many weapon-system platforms, because of different energy and power requirements, integrate a host of diverse power and energy technologies, which makes the weapon systems more vulnerable.

(U) Power generation and power conditioning encompass the transformation of biological, chemical, electromagnetic, nuclear, mechanical, and thermal energy into electrical power. The output may be pulsed, burst, or continuous. Military systems require power at levels ranging from milliwatts to gigawatts. These devices include fuel-driven engines, types of generators (tactical, magneto hydrodynamic, and magnetic-flux compression), gas turbines (micro and macro), alternators, fuel cells, and solar cells.

(U) An energy-storage device stores the supplied energy electromagnetically, kinetically, or chemically. These devices include storage batteries, thermal batteries, capacitors, inductors, rotating machines (compulsators or pulsed alternators), homopolar generators, super capacitors, and magneto cumulative generators.

(U) Energy-conversion devices take the power from the storage device and supply it to the load. This is sometimes referred to as a pulse-forming network or pulser. It is composed of various electronic components, such as switches and inductors.

(U) Dramatic improvements in energy and power densities (mainly through the development of advanced materials) will drastically increase the range, speed, and endurance of weapon systems. Power and energy supplied to the load will increase while the size and weight of the overall system will decrease. Perhaps the greatest ongoing trend is the development of integrated hybrid power sources that are reliable, rugged, and packaged into modular components that can be easily replaced on the battlefield. Examples of hybrid power packs are battery-capacitor systems, fuel cell-battery systems, and engine-battery systems.

(U) Low-Energy Nuclear Reactions

(U) In 1989, two scientists working in the United States reported that they had produced cold fusion—a nuclear fusion reaction that is not induced by fission explosions or the use of extremely powerful magnetic fields. When other scientists could not immediately replicate the results, the original work was labeled "bad science" and consigned to the trash bin by the scientific community. A few researchers, however, continued to work the area and a few positive observations have been made. The topic is still controversial—the term "cold fusion" has been replaced by low-energy nuclear reactions (LENR or, less commonly, chemical-assisted nuclear reaction [CANR])—but it has gained enough respectability that, in 2007, the American Chemical Society sponsored a symposium on LENR. If LENR technology comes about, it could be used as an alternate power source for many areas of civil and military use.

(U) Detect U.S. Assets: Foreign C4/RSTA/ISR Sensors and Systems

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(U) Foreign Netcentric Operations: Quantum Key Distribution

(U) Quantum cryptography—or, more specifically, quantum key distribution (QKD)—relies on the Heisenberg Uncertainty Principle of quantum physics for its security. This principle states that complete knowledge of the quantum states of a particle cannot be obtained because the act of measuring these states changes them. Cryptography researchers use this phenomenon to advantage by representing each bit of an encryption key with a single photon. Although the details are complex, any attempt by an eavesdropper to measure the states of the photons and retransmit them to the intended receiver results in either a very high error rate or a very substantial reduction in the data rate, depending on the type of attack attempted. In either case, the receiver would notice the problem and abandon the key immediately. A number of quantum characteristics for single photons could be used to represent the bits of a cryptographic key, but photon polarization usually is the characteristic chosen to illustrate the QKD procedure.

(U) Researchers are exploring the practicality of using the properties of quantum physics to develop a secure method of key exchange. Quantum cryptography can provide a theoretically absolute secure method of key distribution based on current understanding of the physical phenomena involved. At present, QKD has been realized over distances greater than 100 km through both fiber optics and free space. Commercial point-to-point fiber-based systems are expected on the market in the near term. Large-scale, over-the-air electronic key-management systems are not expected until the far term.

(U) Foreign Netcentric Operations

(U//~~FOUO~~) Evolutionary Computing

(U//~~FOUO~~) Evolutionary computing comprises a group of optimization techniques that are inspired by nature. Evolutionary computing applications include pattern recognition, robotics, artificial life, swarm intelligence, mobile agents, modeling, and optimization of neural-network structures and expert systems. Evolutionary hardware is an emerging field that automates and optimizes design and adaptation of structures such as antennas, MEMS, robots, and hardware/software systems. This technology enables self-reconfigurability, adaptability, and learning by programmable devices and has the potential to significantly increase the functionality of deployable systems that need these attributes.

(U) Grid Computing

(U//~~FOUO~~) Grid computing allows resource sharing and problem solving in dynamic groups. Resources can be provided, used, or both. A wide variety of problem-solving techniques may be used, and participants can join or leave with autonomy. Grid computing offers a solution to large data analysis projects by increasing processing speed through parallel processing. The processors, memory, and networks that are needed for grid computing exist, but the software needs development.

(U) Quantum Computers and Quantum Information Science

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(U) Acquire Targets

(U) Electro-optics

(U) Ultraviolet Detection

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(U) Image Intensifiers

(U) Current image intensifiers take ambient light and greatly enhance it. These systems operate in the 400-950 nm region. There are three generations of image intensifiers: Gen I, Gen II, and Gen III. At present, only the United States and Russia produce Gen III systems, while European countries produce Gen II systems, including Supergen, which is an upgraded Gen II system. Gen III systems operate well under low light levels (e.g., a moonless night), but under certain higher light levels, Gen II can perform as well as Gen III. Gen I is the cheapest system and is often used by sportsmen but could be used by insurgents who are unable to acquire the better systems. Over the next decade, manufacturers will develop five different digital image-intensifier candidate technologies: electron-bombarded charged-coupled devices (CCDs) (EBCCDs), electron-multiplied CCDs (EMCCDs), electron-bombarded CMOS[b] (EBCMOS), electron-bombarded active pixel sensors (EBAPS), and microchannel-plate CMOS (MCPCMOS). These digital systems should begin appearing over the next 10 to 20 years.

(U) Thermal-Imaging Systems

(U) Thermal imagers operate in the 3-5μm region (mid-wave infrared) or 8-12m (long-wave infrared). Thermal imagers are more costly than image intensifiers, but they can detect heat from objects and can be useful in locating personnel hiding in foliage or determining if a vehicle has been recently used. Thermal imagers may be either cooled or uncooled. The cooled thermal imagers have better resolution but are more expensive. InSb and HgCdTe are usually used as detectors for these systems. Uncooled systems are cheaper and are often called microbolometers. Over the next 20 years, thermal imagers are expected to become cheaper, lighter, and mulitspectral (i.e., be capable of operating in two or more regions).

(U) Short-Wave Infrared

(U) The short-wave infrared (SWIR) region (1-3 μm) has typically been used for earth sciences, astronomy, and industrial/laboratory applications. SWIR detectors are now being considered for military applications. SWIR systems may be able to detect the Nd:YAG laser (1.06 m) and the Erbium eye-safe laser (1.54 μm) commonly used for rangefinding and target designation. It may also have applications in detecting camouflage. The SWIR detector presents a scene to the viewer more like an imager intensifier than a thermal imager. A SWIR detector is typically made from InGaAs.

(U) Nanosensors

(U) A sensor system based on self-assembling MEMS sensor networks has been envisioned for many years. This network would contain devices that measure temperature, motion, and light intensity, and it would sport a miniature antenna and a radio with a range of 10 to 50 meters. Other devices inside that range would pick up the signal from the first and add readings of its own before passing the package along to a third device. The data eventually moves to a base station from where the info can be routed to a personal computer or to a wireless network.

(U) This represents only one offering of this type of technology, but the concept and architecture are fairly representative of what can be achieved using MEMS-based sensor networks in the field. These systems would be distributed over a fairly limited area of interest. One application might have the sensors scattered over the grounds surrounding a high-value building or the perimeter of a base. Another application would be to scatter the sensors by aircraft or UAV over an area of interest to detect vehicle or personnel movements.

(U) Electrostatic-Sensor Technology

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(U) Optical Augmentation

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(U) Counter-LO Acoustic Detection

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(U) The digital processing of information from acoustic sensors may permit automatic target recognition for some types of targets. Helicopters have distinctive acoustic signatures caused by the harmonic resonance produced by rotating main and tail rotors. Similarly, jet-engine compressor modulations may be identifiable.

(U) The hardware that is likely to be associated with air-defense, acoustic-detection systems is well developed. Little, if any, improvement is needed. Signal processing and the requisite computer algorithms are major areas that require improvement. Computer and algorithm development for many civilian and military applications are proceeding rapidly. A great deal of technology transfer is involved. This work will enhance the future capabilities of acoustic-detection systems.

(U) Enable Hit

(U) Advanced Electronics

(U) The requirements for increasing speed of operation for digital circuits and increasing frequency of operation for analog circuits have resulted in traditional electronic materials, such as of silicon (Si) and gallium-arsenide (GaAs), approaching the limits of their performance. In order to meet the requirements of systems that are now under development, new semiconductor materials are under investigation. These materials have been under R&D for many years. Now, it appears that a number of these materials are on the verge of being commercially viable.

(U) It is important not to become obsessed with the absolute performance of a technology or material. There are real-world considerations that must be kept in mind when selecting a materials technology to be used in producing microelectronic circuits:

- (U) In the real world, cost is as important as performance.
- (U) The material with the lowest total cost that meets the performance specifications is the one that will be employed.
- (U) If a material has unique performance characteristics, which are required to meet the design specifications, then it will be used if the market will support the required price.
- (U) Silicon is still the backbone of the microelectronics industry and will remain so for the foreseeable future.
- (U) The table below provides approximate costs for various wafers that are currently commercially available. Microelectronic-circuit producers want to have as large of a throughput as possible. Larger wafers permit the manufacture of more microcircuits simultaneously. Clearly, silicon is far ahead of other electronic materials in terms of both wafer size and wafer cost.

(U) Wafer Cost

Material	Wafer Size (mm)	Price (USD)
Silicon	300	200.00
GaAs	150	700.00
SiC	50	4000.00
GaN	50	10,000.00
GaN on SiC	50	10,000.00
GaN on Diamond	50	7000.00
Diamond	5	UNK

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(U) Silicon

(U) Silicon is still the backbone of the microelectronics industry and will be for the foreseeable future. Over the years, there have been many claims that silicon was to be replaced by the latest and greatest new material. While it is true that silicon often has inferior performance characteristics when compared to compound semiconductors, if silicon is capable of meeting the specifications required to solve the problem at hand it would not matter. Issues of manufacturing cost are much more important than absolute performance levels, as long as the problem specifications are met. One big advantage of silicon is that a 300-mm wafer only costs $200.

(U) When bulk silicon does not meet the performance requirements for the given problem, it is possible to extend its capabilities:

- (U) Silicon-on-insulator (SOI).
- (U) Silicon-germanium (SiGe).

(U) Gallium Arsenide

(U) The electronic properties of gallium arsenide (GaAs) make it an excellent material for high-performance electronics applications. GaAs was the first compound semiconductor material to see widespread use in the production of microelectronic circuits. GaAs is capable of operating at higher voltage gradients than silicon. Due to its high electron mobility, GaAs is able to function in the microwave region of the radiofrequency spectrum. Since GaAs is a direct band-gap material, it also efficiently generates light.

(U) GaAs integrated circuits (ICs) have found commercial application in handsets for cellular telephones and in receivers for direct satellite broadcast. GaAs high electron-mobility transistors are capable of very low noise performance. This is useful for receivers at microwave frequencies where most noise is generated internally by the transistors used to make the receiver. GaAs power transistors also find application in the power amplifiers used in handsets for cellular telephones. GaAs-based ICs are a dual-use technology and are used by the military in electronic systems.

(U) One reason that GaAs has not been used more on the battlefield is its cost and difficulty in component production. If advances in GaAs lithography and material production are successful over the next decade, GaAs will likely proliferate much more throughout the battlefield.

(U) Silicon-Carbide

(U) The physical and electronic properties of silicon-carbide (SiC) make it an excellent material for high-temperature, high-power, high-frequency radiation-resistant applications. SiC is a wide band-gap material, which allows SiC to operate at high temperatures and withstand a voltage gradient much larger than Si or GaAs devices. SiC is a much better thermal conductor than either Si or GaAs. In fact, SiC has a thermal conductivity three times better than Si and nine times better than GaAs. This permits the construction of high-voltage, high-power diodes; power transistors; and power thyristors. SiC also has a high saturated electron velocity that is twice that of Si. This enables SiC devices to operate at high frequencies.

(U) Components are available for sale on the commercial market. At present, these components are mostly diodes intended for power applications. Applications include DC to 3-phase power converters (e.g., electric cars, hybrid cars), power supplies, power-factor control, and motor control. However, these types of components are dual use and would find application in military systems.

(U) SiC-based transistors can handle higher frequencies and higher power levels than GaAs-based power transistors. These properties make them useful for power amplifiers for radiofrequency applications. The ability to operate at higher frequencies is important, as this expands the frequency range available for communications use. This makes it possible to accommodate more users as well as to increase the bandwidth of the communications channel.

(U) Gallium-Nitride

(U) The physical and electronic properties of gallium-nitride (GaN) make it an excellent material for high-temperature, high-power, high-frequency, radiation-resistant applications. In fact, GaN transistors have been tested at temperatures as high as 300° C. GaN devices can withstand a voltage gradient much larger than silicon or GaAs devices. This permits the construction of high-voltage, high-power electronic components. GaN has the same thermal conductivity as Si and has a thermal conductivity three times better than GaAs. GaN has a high saturated-electron velocity that is twice that of silicon. This property enables GaN devices to operate at higher frequencies than either silicon or GaAs. Interestingly, GaN actually has better high-frequency performance than its physical parameters (such as saturated electron velocity) would initially lead one to expect. It turns out that for AlGaN/GaN heterojunctions, a two-dimensional electron gas (2DEG) is created, and this improves electron mobility considerably.

(U) One important application for GaN transistors is in power amplifiers. High-frequency, high-power transistor amplifiers would find application in radar, radio transmitters, and in cellular-telephone towers. GaN power transistors that can produce 174 W at 6 GHz and 81.3 W at 9.5 GHz already exist. Test results have also indicated that GaN transistors are much more linear than power transistors now currently in use. When a component, such as a power transistor, possesses a nonlinear response, then spurious components will appear in the output signal. These spurious signals arise from the mixing (interaction) of the desired signals, which are applied to the input of the amplifier. These internally generated spurious signals often are the limiting factor in system performance.

(U) Diamond Electronics

(U) The physical and electronic properties of diamond make it an excellent material for high-temperature, high-power, high-frequency, radiation-resistant applications. Based on theoretical calculations, it is predicted that diamond transistors will be capable of operating at temperatures as high as 1000° C. Schottky diodes have been constructed using diamond material and have been tested at temperatures as high as 600° C. Transistors constructed from diamond material can withstand a voltage gradient much larger than Si or even GaN devices. This permits the construction of high-voltage, high-power electronic components. Diamond has a very high thermal conductivity. In fact, diamond has a thermal conductivity 16 times higher than SI and has a thermal conductivity 5 times better than SiC. Diamond has a high saturated-electron velocity that is twice that of GaAs and GaN. This property enables diamond-based transistors to operate at higher frequencies than either GaAs or GaN.

(U) One increasingly difficult problem of microelectronics is how to get rid of the waste heat generated by ICs or power transistors. In the case of digital ICs, such as microprocessors, the thermal problems are a result of having a few hundred million transistors located on a single die and switching at gigahertz clock speeds. Power amplifiers for radiofrequency and microwave applications are required to produce several hundred watts of output power. Since electronic amplifiers are not 100% efficient, there is a lot of thermal energy that must be dissipated if the power transistor is to be kept from being destroyed due to extreme temperature.

(U) There are two ways that diamond could be employed to help solve the current heat-dissipation problems. Microelectronic components could be constructed using diamond wafers. The high thermal conductivity of diamond would assist in carrying the excess heat away from the die and to the external heat sinks that are used to dissipate the heat to the environment. Another technique would be to grow an active layer of another semiconductor material such as GaN or Si on a diamond substrate. The diamond substrate would serve to mechanically support the semiconductor devices and act as a heat spreader to better transmit the waste heat to a heat sink.

(U) Diamond-based microelectronics would have application in military electronics. If microprocessor, digital-signal processing, and analog-to-digital converter ICs could be constructed using diamond transistors, then the heat dissipation problems associated with these high-performance components would be much more manageable. Power transistors based on diamond materials would have superior heat-dissipation capabilities and would be useful in power-switching applications and in the construction of high-power amplifiers for use in radio and radar transmitters.

(U) Polymer Transistors

(U) To solve any given engineering problem, the most desirable solution is the one that meets the specifications with the minimum cost. The performance of plastic ICs is not going to match that of ICs based on monocrystalline silicon. For applications envisioned for plastic ICs, either low-resolution lithography (feature size ~ 5 μm) or printing methods will be used to pattern the circuit elements on the substrate.

(U) Polymer-based transistors have many desirable characteristics:

- (U) Low cost (disposable electronics).
- (U) Lightweight.
- (U) Flexible.
- (U) Inexpensive equipment needed for manufacturing:
  - (U) Contact printing.
  - (U) Inkjet printing.

(U) State-of-the-art microelectronics is a topic of high interest, worldwide. For obvious reasons, developments in high-performance microelectronics are followed closely by both industry and the military. However, it is easy to forget that in many instances low-performance microelectronic components are more than adequate to meet system requirements. In developing a system, cost is as important as performance. It does no good to design a system with impressive performance characteristics if it is too costly to manufacture and deploy. Plastic-based ICs are intended for applications where large numbers of inexpensive low-performance ICs are able to meet system requirements. One goal is to make radiofrequency identification (RFID) tags so inexpensive that it would be economically justifiable to place them on something as inexpensive as a bag of potato chips.

(U) In applications where low-cost, flexible circuitry is needed and there is no requirement for high-speed operation, plastic ICs could be militarily important components. One major application for plastic-based ICs is RFID tags for consumer products. However, RFID tags will also be useful to the military. These ICs could find application in tracking supplies destined for soldiers in the field. Since the operation of these ICs is based on radio waves instead of optical scanning, direct access to the IC is not required. It would be possible to locate the proper shipping container simply by passing a receiver within range of the IC. It would also be possible to embed other information such as the contents of the package, expiration dates, and technical specifications on the enclosed items. All of this information would be accessible without opening the package or shipping container.

(U) Other applications of plastic ICs will take advantage of the flexible substrates. There are numerous applications where it would be useful to incorporate electronic circuitry onto the case of the system. The flexibility of the substrates would make it possible to incorporate electronic circuitry on the contours of the case of an electronics system or on the surface of a vehicle. For example, plastic IC-based electronics could be integrated into the wing or body of a UAV. This could easily lead to a savings in weight and an increase in platform capability. In a similar vein, flexible circuits would be useful in wearable electronic systems. The flexible aspects of the plastic ICs would find application in the wearable electronics that are a part of soldier systems.

(U) Polymer-based microelectronics is a technology that is low performance compared to the other technologies discussed here. The applications addressed by this technology are those that can be done with incredibly cheap electronic circuits. Some envisioned applications will require circuits costing less than 1 cent. In a manner of speaking, this technology is an attempt to make electronics as cheap as ordinary notebook paper.

(U) Photonics

(U//~~FOUO~~) Photonics is the development of light-based capabilities where light is used in devices in a manner analogous to how electrons are used in electronics. It is a branch of optics that seeks to emulate electronics to transfer information from point to point at the speed of light. This can be done by dealing with the granular nature of electromagnetic (EM) waves in lasers, fiber optics, optical sources, and targeting systems—anywhere the distinction between a trajectory and production of groups of individual photons can be made. New manufacturing techniques have opened up a wealth of new materials, size and dimension capabilities, and new interfaces and devices to allow new ways of transmitting and manipulating light and information. Smaller, lightweight devices that use little power and are not subject to RF/directed-energy/electromagnetic interference may be possible. Communications and processing in the optical domain increases current bandwidth limits tremendously; initiatives for generic optical domain of mathematical functions are currently targeting 200 GHz speeds.

(U) Computational Materials

(U) The simulation of processes and material properties at the scale of individual atoms provides researchers with a powerful tool with which to ascertain the fundamental understanding and model-processing techniques necessary to develop new materials and devices. Atomic-scale simulation allows the study of the material structure and properties during the dynamic formation, strain, and breaking of atom-atom bonds within large collections of atoms. The simulation method probes dynamic atom motion at high temporal (~ femtosecond) and spatial (~ ångström) resolutions, which is a much finer level of detail than that currently afforded in experiments.

(U) These atomistic simulation tools, in conjunction with careful experiments, can be used to develop precisely engineered materials and advanced electronic devices with optimized and tailored performance specifications. Areas in which this research would be useful include epitaxial assembly processes, heat transfer, atomic-scale wear and lubrication, fracture and deformation dynamics, laser interaction with matter, and the structure and properties of new materials. Furthermore, these simulations can be used to help understand empirical phenomena and experimental results from the nanoscale to the macroscale.

(U) The resulting materials, processes, and devices that evolve from these simulations will probably impact many military applications by introducing new structural, electronic, and magnetic materials. Possible applications of these new or modified materials include increasing the lifespan of highly stressed aircraft components; further reducing corrosion in susceptible machinery components; and improving the computational speed, security, and robustness of targeting, communications, and tracking systems with new sensors and magneto-electronic devices. Additionally, as the ability to identify optimum processing conditions and components will evolve the ability to custom design materials with very targeted properties. When this revolutionizes worldwide materials research, many military systems will be impacted. Therefore, advances in the fundamental tools used to fabricate emerging devices will dramatically change the technical landscape for future combat systems.

(U) The wide availability of high-performance computing (HPC) combined with the promise of materials and devices effectively engineered at the atomic scale will drive more participation and production in this area of simulation. The relatively low cost of atomistic simulation also allows countries with small research investments to participate in the worldwide R&D process.

(U) The possibility of tailor-made materials and devices will also continue to attract resources from countries and industries that stand to benefit from this functionality. Many of the codes used in today's computational materials R&D are based on European work. Worldwide, many researchers are now working collaboratively to actively exchange and update new code developments. The research productivity observed to date within the field of atomistic simulation will very likely grow based on the trends observed in open literature.

(U) Worldwide, the area of computational science is maturing from a somewhat haphazard implementation of modest-sized codes designed to operate at one scale to the development of complex codes developed by large teams to explore and predict properties across a large span of time and length scales. The lack of a systematic evaluation process has made the effective implementation of the peer-review process difficult to enforce since standards for code verification and validation do not exist. This has resulted in a wide variation in the quality of published research and has kept the field from effectively constructing models with high-value predictive capability.

(U) Although care must be taken in evaluating current research results, computational science is likely to overcome these current difficulties and mature into a more reliable field that will consistently produce effective results. High-quality and reliable results will become a reality as resources mature and are effectively combined in leading countries. The following are some of the key components necessary for continued efficacy and growth of atomistic-simulation research:

- (U) The existence of and easy access to powerful computing resources.
- (U) Sufficient and stable funding support for research.

(U) Directed-Energy Weapons

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(U) Commercially available handheld lasers have achieved enough power to pose a threat as well. An example of this is Wicked Lasers, a company based in Shanghai, China, that specializes in portable lasers. Some of Wicked's lasers are physically indistinguishable from legal class IIa laser pointers. The main difference is that Wicked's lasers produce 50 to 350 mW of power and are classified as class IIIb lasers. These portable lasers are easily purchased online for an affordable price, thus creating an ideal harassment tool, if in the wrong hands. Such lasers are probably behind many of the lasing incidents that targeted aircraft.

(U) APS Jammers

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(U) The most important consideration in APS jammer design is the placement of the jammer. The designer has three distinct options:

- (U) Stand in: portable jammer is placed near target/radar.
- (U) Self protection: place jammer on the munition.
- (U) Standoff: place jammer on the launcher or launch platform.

(U) The following table outlines the tradeoffs between these three options.

(U) Jammer Placement Tradeoffs

Consideration	Self Protect	Standoff	Stand In
Size, weight, and power	Most constrained, reduces munition payload/range.	Platform dependent, somewhat constrained for portable systems. Insignificant factor for most vehicles.	Portable system, somewhat constrained.
Jammer complexity	Simplified antenna pointing. Range parity.	Antenna must track target. Range disadvantage requires higher EIRP or more complex waveforms.	Range advantage reduces power, antenna gain, and/or waveform complexity.
Cost	Expendable item. Most constrained cost.	Reusable system. Most expensive.	Reusable system, less complex, moderate cost.
Logistics	Many more items, long shelf life, requires reliable battery/power to reduce maintenance requirements	One system per launcher/platform. Routine maintenance required.	Limited number of systems. Rugged design for portable employment.
Employment	Fire and forget.	Requires line of sight to target. Operator tracks target during munition flight.	Requires pre-emplacement. Limited to ambush TTP.
Technology availability	Low power, solid state monolithic microwave integrated circuits (MMIC). Barrage or swept waveform.	Moderate power traveling wave tube (TWT). Digital radio freq memory waveform generation	Low power, solid state, or TWT. DRFM or barrage waveforms.

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(U//~~FOUO~~) Analysis of jammer placement options against typical foreign APS radars indicates that all three placement options are technically feasible. Stand-in jamming would be effective; however, its limited tactical flexibility makes use with rocket-propelled grenades its most likely application. Self-protection jamming is feasible, with the most likely application on antitank guided missiles (ATGM). Decreasing the cost of RF power devices, due to commercial application in the millimeter-wave (MMW) band, will facilitate expendable self-protection jammers. Standoff jamming is feasible for both RPG and high-explosive antitank (HEAT) launchers; however, due to the relatively long ATGM launch ranges, standoff jamming is not possible with those systems. Wide variation in the radar cross sections (RCS) of existing munitions suggests that considerable progress can be made in RCS reduction without the application of advanced stealth technology. These reductions would significantly reduce the cost and complexity of APS jammers. High absorption rates in the V-band offer the APS radar significant protection against standoff jamming but will tend to benefit the jammers for close-in self protection and stand-in jamming.

(U) Micro-Electromechanical Systems

(U//~~FOUO~~) MEMS are micrometer-scale machines that can replace much larger systems or enable new capabilities. Examples include inertial-navigation systems on a chip, micropower turbines for micro-UAVs, lab on a chip, smart sensors for persistent ubiquitous sensor networks, and autonomous robotic systems for surveillance and weapons delivery. The replacement of macroscopic systems by MEMS in larger weapon systems will leave room for more fuel, thus increasing range or endurance, leaving room for additional onboard capacity, and/or allowing the system to be reduced in size. Finally, current and future fabrication techniques will increase the risk that MEMS will be widely available and affordable for any country that wants them.

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(U) Nanoparticles

(U) Several uses of nanomaterials are based on nanoparticulates. Some of these are structural fillers such as nano-clay particles for composite materials or nano-metallic particles used for the seed growth of carbon nanotubes. However, one area of particular military interest has been the use of nanoparticles for energetic material applications. Due to its increased surface area, nanoparticles allow oxidation to take place much more readily and actively. Aluminum burns with several times the energy of organic energetic materials, but if mixed with organics, it does not ignite quickly enough to participate in the initial phase of the reaction where the shockwave is generated. In theory, nanoparticles of aluminum could chemically react with sufficient speed, but many obstacles, mostly related to the oxide coating that naturally forms on aluminum pieces of any size, remain to be overcome. The chance for success may be small, but the payoff could be large.

(U) Composite explosives, which are composed of a powerful but sensitive explosive compound mixed with nanoparticles of an insensitive explosive, might be less sensitive than the powerful compound but may yield nearly the same power.

(U) Experimental studies of composite propellants have shown that replacing some of the standard aluminum powders with nanopowders can result in increased burn rates and lower exponents (a measure of the susceptibility of burning rate to changes in chamber pressure). Both are desirable properties.

(U) Enable Penetration

(U) Propellants

(U) Improvements in propellants for artillery rockets will result in increased range, payload, and/or acceleration. Improvements will come from the increased use of energetic binders and oxidizers. Some improvements may also be attained by modifying the grain design of propellants. The introduction of nanoparticulate aluminum may also result in improved performance.

(U) High Energy-Density Materials

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(U) Enable Kill

(U) Nonlethal Technologies

(U) Nonlethal technologies are explicitly designed and employed to incapacitate personnel and/or material while minimizing fatalities and undesired damage to the surrounding environment. These technologies cover a wide spectrum of applications that have an assortment of different effects. Most common areas include nonlethal munitions for security force (kinetic impact, flash/bang, tear-gas/riot-control agents); electroshocking devices (Tasers, stun guns); acoustics (sirens, loudspeakers, directional hailing devices); and dazzlers (strobe lights, high-candlepower flashlights, low-power laser dazzlers).

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(U) Advanced Nonlethal Payload Delivery Systems

(U) Advanced nonlethal delivery systems are under development. For close-range security-force usage, vortex weapons are being investigated in Russia, Germany, France, Sweden, the United Kingdom, and the United States. The basic design of these devices is a shock tube that can generate a pulse by the explosive combustion of a fuel (acetylene and air or other flammable gas), and the pulse forms a vortex ring due to the specially designed shape of the interior of the shock tube. A tear agent can be infused into the vortex ring and remain contained in the ring, much like a smoke ring, until the ring is carried to the target where it discharges the payload upon impact.

(U) Extended range, non-line-of-sight (NLOS), nonlethal payload-delivery systems such as mortars and airbursting rockets are the next generation of long-standoff, nonlethal payload-delivery systems for security and military forces. Any country that has smoke-filled mortar rounds and would like to add tear-agent mortars to their inventory can do so. Many countries already have these rounds at their disposal. Airbursting rocket systems would also be ideal for this purpose, due to their inherent ability to carry a larger amount of the payload and to shower the target with the nonlethal agent with reduced risk of permanent injury from the shell fragments. Counterarmor and counterpersonnel artillery or missiles that carry metal subprojectiles can instead be modified to carry rubber or foam nonlethal counterpersonnel submunitions in order to augment a country's capability in large-scale riot-control operations.

(U) Advanced Nonlethal Chemical Antipersonnel Agents

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(U) Antimaterial Chemical and Biological Agents

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(U) Combustion modifiers and fuel viscosifiers are agents that could be used to specifically attack vehicle engines. Combustion modifiers work by changing the combustion temperature of the burning fuel, either to lower it, which causes the vehicle to stall, or to increase it to the level that the engine pistons could melt or deform, leading to cracking of the engine block. Fuel viscosifiers generally thicken the fuel to the point that it will not flow as expected through the engine. This could clog the fuel injectors and stall the engine. Many of these chemicals are commercially available and marketed as "antiknock" agents (modifiers) or fuel/oil-spill cleanup aids (viscosifiers). These would most likely be used as sabotage agents and be applied to vehicles by clandestine means. The possibility exists that these agents could be aerosolized and ingested into running engines if dispersed by the air intake of the vehicle.

(U) Super acids and super caustics are classes of chemicals that can be used to corrode or degrade any number of materials. Paint, plastics, glass, metals, rubber, wood, and obviously organic biological systems can be targeted by these types of chemicals. The advantage of these agents is that they are commercially available, cheap, and do not have to cause catastrophic damage to an entire system to be effective. For example, partial degradation or yellowing of an optical surface would render the optical device useless. Dissolving the plastic/rubber covering of electrical wiring would expose the wires and possibly short out the system. Sticky foams have been investigated for antipersonnel applications as well as potential as a vehicular countermobility agent. These agents are fast-setting polymers that glue the target in a sticky mass. Slippery substances are of interest as area-denial agents. When applied to a surface, they form a film that has the traction of wet ice. Russia, China, and other countries have openly discussed these types of technologies as being of interest for future nonlethal applications.

(U) Robotics

(U) Robotics includes robots and autonomous systems that operate independently and/or cooperatively with other systems. Future versions of these systems may also be remotely reprogrammable or independently adaptive. Microrobotic systems could be designed to infiltrate friendly facilities, vehicles, or persons for surveillance purposes or to disable friendly equipment by infiltrating and attacking key components. Autonomous systems extend the reach and capability of forces while reducing the risk to personnel. Progress in autonomous robotic systems, including self maintenance, task performance, stealth, position and navigation sensing, communications, cooperative operations with other systems, and energy scavenging will make these technologies an increasing threat over the next 20 years.

(U) Over the next 20 years, robotics and autonomous ground systems will be smaller and smarter and will operate in cooperative groups. The major technological factors in the advancement of robotic systems are intelligent computational systems and smaller, lighter electronics for use in the development of sensor packages and onboard processors.

(U) Autonomous Weapons Systems

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(U) Denial and Deception

(C//NF) An outstanding technology in the denial and deception (D&D) category is the use of robotics as decoys. The usual application of robotics that comes to mind is in the UAV or other sensor platforms. However, robotics also enables an adversary to create high-fidelity, self-propelled decoys that could saturate a RSTA network with false information.

(U) Robotic Systems

(U) A robot is a complex engineering system composed of mechanical, communications, and computational systems. It requires not only expertise in component technologies and subsystems but also a broad understanding of the integration process involved in the combination of components and subsystems into an operational robotic system. The Defense Advanced Research Projects Agency definition of autonomy in terms of a robotic vehicle implies that the vehicle can be assigned a complex task or mission and will then execute it, possibly acquiring information from other sources as it goes but without further guidance on what to do.

(U) There are four classes of ground robotic systems:

- (U) Teleoperated ground systems represent systems that have been developed and fielded for mineclearing/explosive-ordnance disposal and reconnaissance/surveillance and are controlled by an operator.
- (U) Semiautonomous ground systems represent systems that have been developed and fielded for mineclearing/explosive-ordnance disposal and reconnaissance/surveillance and are partially preprogrammed and updated by an operator.
- (U) Platform-centric autonomous systems maneuver through their dynamic environment and perform their mission with minimal human control and minimal connectivity requirements.
- (U) Network-centric autonomous systems that cooperate with other manned or unmanned systems while executing their mission.

(U) Robotics-Enabling Technology

(U) Enabling technology areas that are important to the development of the different classes of autonomous ground systems are listed below:

- (U) **Fundamental operational autonomous behaviors.** These are computational behaviors and software-based subsystems that are interdependent and provide the system with some level of intelligence:[c] perception, navigation, planning, mission and vehicle management functions, and learning/adaptation.
- (U) **Human-robot interaction (HRI).** HRI has emerged as a topic of research on the different ways in which humans can interact with robots. As autonomy increases, the roles between humans and robots can range from supervisory to peer to mechanic; each requires different interactions with humans to facilitate a better understanding of the decisions made by the robotic system. HRI is an interdisciplinary effort that addresses social informatics, human factors, and cognitive and usability concepts as they can be applied to the development of robotic systems.
- (U) **Power/energy.** The development of power management and energy sources that will allow the robotic system to operate for long periods to facilitate mission requirements.
- (U) **Health maintenance.** These are technologies that will target, prevent, or mitigate failures of the robot's sensors or electronics.

(U) Robotic systems are slowly being integrated into commercial and military operations. A completely robotic military vehicle lies far into the future. The use of robotic systems in a military environment has been limited due to the technical challenges that machine perception and intelligent control systems encounter in a complex and changing outdoor environment. A more likely scenario will be the integration of intelligent control systems into the next version of military vehicle so that the operator will have a clearer picture of the environment in which to operate or that the vehicle will be teleoperated or semiautonomous.

(U) Chemical - Nontraditional Agents

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(U) Conventional High Explosives (C-H-N-O)

(U) The next generation of explosives will be based on organic chemistry and will not have significantly more power than current formulations. Incremental improvements may lead to measurable increases in shaped-charge penetration and rocket-motor capabilities, but most advances in technology will be achieved with the object of reducing production costs, increasing stability, decreasing sensitivity, or altering detectability (taggants can be added to increase detectability). Devices set to look for nitrogen compounds cannot detect nitrogen-free explosives (e.g., TATP).

(U) Kinetic-Energy Weapons

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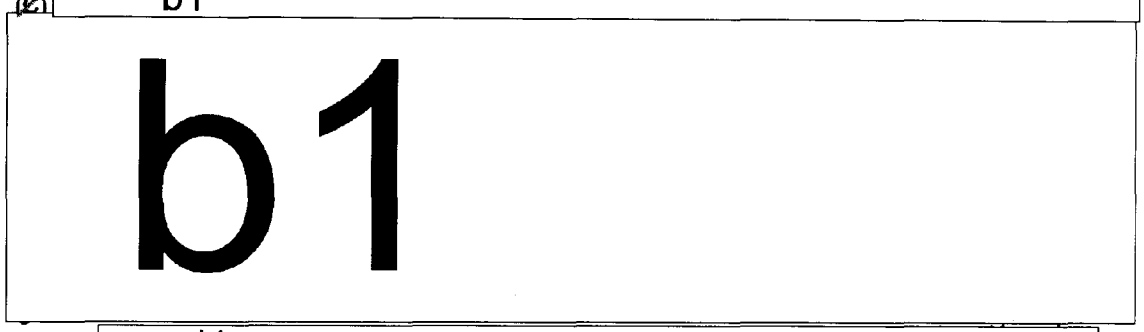

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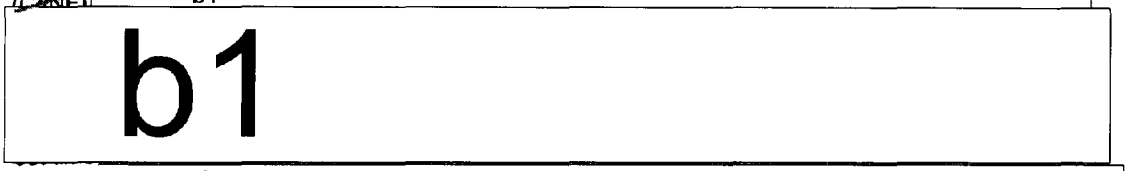

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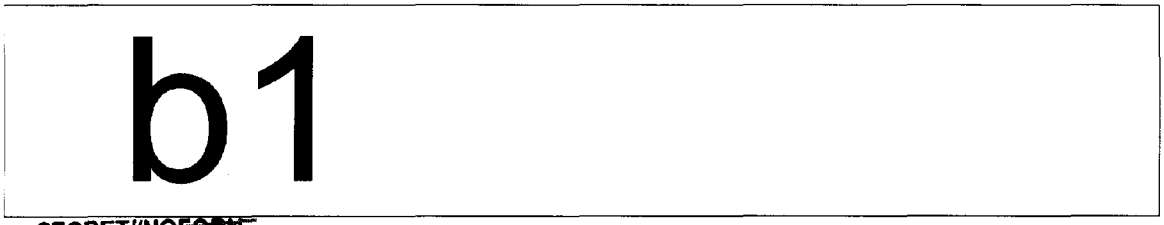
(U) EDKEW Research Programs



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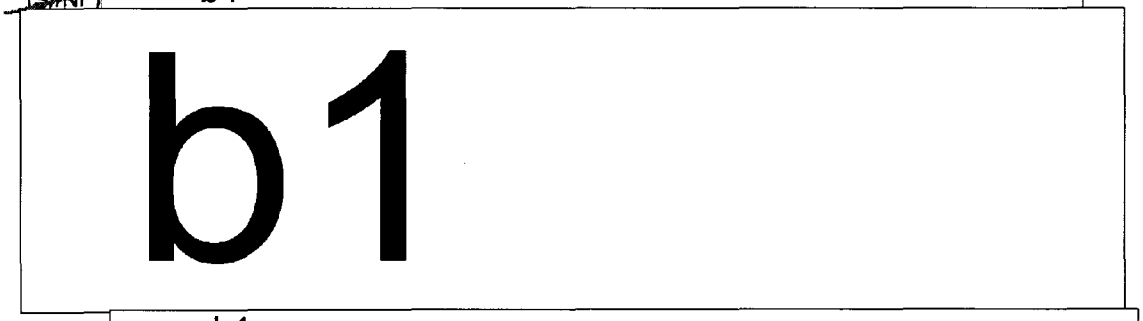

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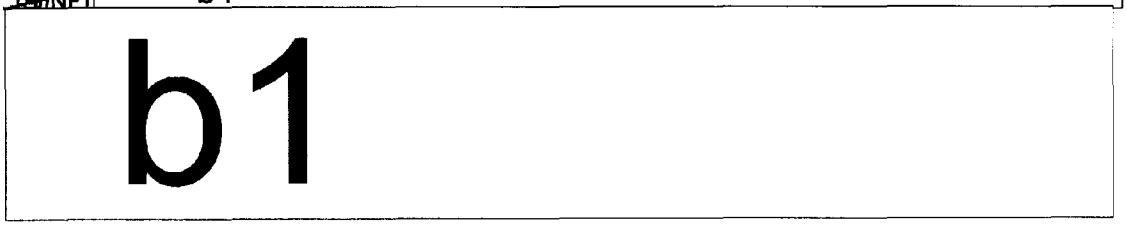

(U) Structural Bond Energy Release

(U) The concept that large quantities of energy can be released when a crystal with highly strained bonds relaxes to a structure with lower bond strains was proposed in the United States in the 1930s but was never fully investigated. In the 1960s and 1970s, a few Soviet scientists researched the field. No structural-bond energy-release (SBER) explosive has yet been developed, but when reactions yield greater energy than predicted by classical physical chemistry, SBER is sometimes suggested as the reason.

(U) Nuclear Isomers

(U) Atomic nuclei can exist in strained states. The energy released when these nuclei revert to their ground states is in some cases only a few orders of magnitude below that of nuclear fission and according to most interpretations of the Nuclear Test Ban Treaty, isomer reactions are not subject to its provisions. The problem is that isomers that release large quantities of energy with extreme rapidity are difficult to produce, can be highly radioactive, and may require intervention to assure that decay takes place in the required rapid manner. Energy is released in the form of gamma rays. Many nuclear isomers have been synthesized (one, Tantalum$_{180m}$ is found in nature), but none have yet been found to be suitable. Few scientists consider research in this area to be promising.

(U) Conclusions

(U) Many areas of research in the world may impact future weapon systems in unimagined ways. Today's sciences and technologies that have not been thought of in connection with weapon systems or counters can be suddenly found on the battlefield if an opponent decides that it could create a tactical advantage.

Footnotes

a. (S//REL TO USA, ACGU b1

b. (U) Complementary charge-coupled devices. |

c. (U) Intelligence means that the robot can pursue its goals and execute its tasks such that they optimize some given performance measurements. Intelligent agents operate flexibly and rationally in a variety of environmental circumstances, given the information they have and their perceptual and effectual capabilities. |

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