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Advanced Systems and Concepts Office

FINAL REPORT

2007 001

High Energy Science & Technology Assessment

June 29, 2007

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June 29, 2007

Prepared for:

Defense Threat Reduction Agency
Advanced Systems and Concepts Office

Contract No: DTRA01-03-D-0017
Task Order 18
Technical Instruction 18-06-11

Prepared by:

Rich Sutton, George Ullrich

SPONSOR: Defense Threat Reduction Agency
Dr. James Tegnelia
Director

Advanced Systems and Concepts Office
Dr. Michael Wheeler
Director

BACKGROUND: The Defense Threat Reduction Agency (DTRA) was founded in 1998 to integrate and focus the capabilities of the Department of Defense (DoD) that address the weapons of mass destruction threat. To assist the Agency in its primary mission, the Advanced Systems and Concepts Office (ASCO) develops and maintains an evolving analytical vision of necessary and sufficient capabilities to protect United States and Allied forces and citizens from WMD attack. ASCO is also charged by DoD, and by the U.S. Government generally, to identify gaps in these capabilities and initiate programs to fill them. It also provides support to the Threat Reduction Advisory Committee (TRAC), and its Panels, with timely, high quality research.

ASCO ANALYTICAL SUPPORT: Science Applications International Corporation has provided analytical support to DTRA since the latter's inception through a series of projects on chemical, biological, and nuclear weapons issues. This work was performed for DTRA under contract DTRA01-03-D-0017, Task Order 18.

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REPORT: The publication of this document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of the sponsoring agency.

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1.0 Executive Summary

The potential energy that can be tapped from the nucleus (> 10^6 eV/atom) is vastly greater than the energy available from the electronic states of an atom (< 1 eV/atom). The conversion of mass into energy, via fission and fusion reactions, is the basis for the only existing "high-energy" weapons, but further refinements in the design of these weapons, to make them more relevant to the post-Cold War security environment, are certainly possible. Another possible way to extract energy from the nucleus is to exploit the energy stored in metastable isomeric states. Also, despite the negative publicity about "Cold Fusion," the nuclear community continues to watch research in the area of low energy nuclear reactions with guarded optimism for possible future commercial and military applications. Anti-matter annihilation reactions involve the complete conversion of mass to energy with energy densities three orders of magnitude higher than nuclear fission and fusion. The prospect of compactly storing positrons in the form of charge-neutral positronium holds promise for viable military applications of anti-matter.

The Defense Threat Reduction Agency (DTRA) is chartered to monitor new potentially militarily useful sources of energy and to maintain cognizance of others' work in these fields as a hedge against technology surprise.

DTRA tasked SAIC under Contract DTRA01-03-D-0017, Technical Instruction 18-06-11, to conduct a Workshop on a wide range of energy-related technologies that are not chemical in nature, but have credible scientific basis and preliminary experimental results.

The format for the Workshop included a Panel of invited Subject Matter Experts (collectively referred to as the Expert Panel) well versed in the candidate technologies with a broad experience base in past DoD/DTRA advanced technology programs. This Panel was charged with providing individual critiques regarding the status and potential of four primary high energy technology research areas. The Expert Panel consisted of the Honorable Harold Smith, former DoD/ATSD(NCB) and currently a Distinguished Visiting Scholar and Professor at UC, Berkeley; Dr. Jack Davis, ST Executive, Plasma Physics Division, NRL; Dr. Gerald Yonas, Director, Advanced Concepts Office, Sandia National Laboratory; and Dr. Fred Wikner, former OSD Director of Net Assessment and presently consultant to Applied Research Associates Inc.

To avoid a myriad of disparate perspectives on each of the topic areas, a key expert was assigned to coordinate the presentations in each topic area and to serve as the Chairman of the topic area Panel. The four topic areas and the respective Panel Chairs were:

Low Energy Nuclear Reactions (LENR), Dr. David Nagel, GWU

Anti-Matter Annihilation, (b)(6)

Nuclear Isomers, Dr. Jim Silk, IDA

Advanced Nuclear Fission and Fusion Concepts, Dr. Don Linger, DTRA

An additional topic that was discussed but which did not have a Panel was, **Exotic/Extreme Physics.**

Each of the panels presented impressive results showing good progress in experimental design and execution and in first-principal demonstration of energy extraction, containment and control. Unfortunately, none of the energy sources studied are yet sufficiently advanced to be considered for development in the next five to seven years.

The Expert Panel noted the embryonic stage of development of most of the high energy technologies, and commented that DTRA, as a combat support organization, should stay abreast of the work but not necessarily serve as the primary sponsor for these technology areas.

The recommended course at this stage of development is for DTRA to provide some sponsorship, but more importantly, provide leadership in the form of working toward an interagency working agreement to assure its interests are protected and to speed the needed research by preventing overlap or duplication and identifying, with the other agencies, the most fruitful directions for new research.

2.0 Introduction

The High Energy S&T Workshop was a follow-on to the Novel Energetics Workshop but with the focus on energetic materials and phenomena whose energy is derived from the nucleus or subatomic processes. The Workshop objectives were to explore the following five potential areas of high-energy research:

- **Nuclear isomers**
- **Low energy nuclear reactions (LENR)**
- **Anti-matter annihilation**
- **Advanced nuclear fission and fusion concepts**
- **Exotic/extreme physics**

Only the first three topics are discussed in detail this report, because they were the primary focus of the Workshop and could be treated at the unclassified level.

The Workshop was structured to include a Panel of Experts, well versed in the topical areas and familiar with DTRA's missions and research portfolio. The Panel of Experts consisted of:

> **The Honorable Harold Smith**, former DoD/ATSD(NCB) and currently a Distinguished Visiting Scholar and Professor at UC, Berkeley
>
> **Dr. Jack Davis**, ST Executive, Plasma Physics Division, NRL
>
> **Dr. Gerald Yonas**, Director, Advanced Concepts Office, Sandia National Laboratory
>
> **Dr. Fred Wikner**, former OSD Director of Net Assessment and presently consultant to Applied Research Associates Inc.

The panel of Experts was instructed to screen and critique candidate high-energy S&T topics and provide recommendations regarding their maturity and relevance for DTRA.

The three topics of Nuclear Isomers, LENR, and Anti-Matter Annihilation were presented as Panel Discussions, starting with an overview by the Panel Chairman; followed by a detailed presentation by each panelist, and finally a discussion period with the Panel of Experts and the Workshop participants.

The following questions were posed for the discussion period:

- Should the high energy S&T topics be included as part of a balanced investment portfolio in "Disruptive Energetics?"
  - Do we understand the underlying physics sufficiently well to proceed with confidence?
  - Do the potential pay-offs outweigh the risks?

- What should be the focus of the investment?
    - Well-defined, refereed, repeatable experiments?
    - Proof-of-concept tests?
    - Theoretical investigations?
    - Other?
- What are the potential applications?
    - Could these topics underwrite game-changing improvements in warfighting?
- What are the potential risks?
    - How many orders of magnitude of the specific energy density is likely to be lost to system-level packaging?
    - What criticisms should we anticipate from scientists, from the DoD bureaucracy, from Congress, …?
    - Will these topics bump up against nuclear arms control agreements?

3.0 Workshop Overview

The High Energy S&T workshop was held in the DTRA Headquarters Auditorium at Ft. Belvoir, VA. The first day was dedicated to unclassified work while the second day was maintained at the Secret CNWDI level to facilitate in-depth discussions on several of the topics.

3.1 First-Day Agenda

The agenda for the first day is shown in Figure 1. Each of the three Panel Chairs provided a summation of their topical area followed by detailed briefings by each of the Panel members. Dr. Bob Park was invited to speak at lunchtime, where he provided a perspective for evaluating new and evolving scientific and technical concepts against risky assumptions and faulty premises.

Agenda – 12 Dec 2006
(Unclassified Session)

0830	Admin & Introductory Remarks	ASCO Staff, SAIC Staff
0900	OSD Perspective	Spiro Lekoudis, DDR&E
0930	NNSA Perspective	Dave Crandall, NNSA
1000	Break	
1015	**Panel 1 – Nuclear Isomers**	**Jim Silk, IDA (Panel Chair)**
	James Carroll, Youngstown State	
	(b)(6)	
	Ehsan Khan, SIER Program Rep	
1215	Lunch	
	Luncheon Talk: "A Skeptic's Viewpoint"	***Bob Park, UMD***
1300	**Panel 2 – LENR**	**David Nagel, GWU (Panel Chair)**
	Mitchell Swartz, JET Energy Inc.	
	Michael Melich, NPGS	
	Lewis Larsen, Lattice Energy LLC	NET: Allan Widom spoke as well
1500	Break	
1515	**Panel 3 – Anti-matter**	**Ken Edwards, AFRL/MN (Panel Chair)**
	Allen Mills, University of California, Riverside	
	Gerry Smith, Positronics Research LLC	
	Paul Csonka, University of Oregon	
1715	Adjourn	

Figure 1. The Energy Workshop Agenda – Day 1

3.2 Second-Day Agenda

The second day included a perspective from the intelligence community, a review of an OSD-sponsored Net Assessment of Novel Energetics, and a discussion on the potential for 4th Generation Nuclear Weapons. Most of the presentations were classified. At the end of the day, the Expert Panel reported their individual observations and a "Hotwash" briefing was presented to the senior leadership of the DTRA. Figure 2 shows the agenda of the second day.

Agenda – 13 Dec 2006

(Session Classified)

0830	Intelligence Perspective	(b)(6)
0930	OSD Net Assessment (Blue Team)	
1015	Break	
1030	Exotic Energy and Power Concepts	Charles Rhodes, U of IL
1130	Lunch	
1230	**Panel 4 – 4th Generation Nuclear Weapons**	**Don Linger, DTRA** Ed Turano, LLNL
1400	Break/Expert Panel Deliberations	
1430	Expert Panel Findings and Recommendations	
1530	Adjourn	
1600	Hotwash (Government Only)	
1700	Finis	

Figure 2. The Energy Workshop Agenda – Day 2

4.0 Perspectives from Government Officials

4.1 Dr. Mike Wheeler, DTRA Director of ASCO welcomed all to the Workshop and provided additional context for the meeting. He spoke about the 2003 Summer Defense Science Summer Study on Future Strategic Systems, chaired by Johnny Foster. Three main themes emerged:

a. Whether we maintain legacy nuclear weapons and/or develop new weapons (emerging technology). This debate regarding the composition of the stockpile is still ongoing.
b. How to prevent strategic surprise from taking place by challenging the strategic community and policy community to look ahead at emerging technologies that could have military implications.
c. What options can be given to the President to hold targets at risk without breaking the nuclear threshold – this effectively being a "holy grail" for the policy community.

He proceeded to explain how High Energy technologies fit within the DTRA research portfolio. DTRA has become the one place to concentrate all the nuclear weapons activities within the DoD. The Director of DTRA is also now dual-hatted as the Director of STRATCOM's Center for Combating WMD worldwide. DTRA has also just adopted a Campaign Structure whose topics are cross-cutting. He expressed his belief that High Energy technologies will contribute to several of these Campaigns.

4.2 Dr. Spiro Lekoudis, DDR&E, **Director for Weapons Systems,** referenced a comprehensive review of all DoD energetics research that was conducted the previous summer in response to Defense Planning Guidance and to support the POM and the Budget Estimate Submission (BES) process. He noted the gap between chemical energetics and nuclear energetics and how 50 years of research has only extended the chemical energy density by perhaps a factor of two. He acknowledged that some of the topics under consideration in this Workshop have the potential of narrowing that gap but he was circumspect about the prospect of additional funding to do so. While he recognized that the energetics community may be in distress, he placed some of the blame on the acquisition pipeline and the lack of awareness of the art of the possible. He lauded DTRA's initiative in conducting this Workshop and commented that he depends on such forums to gather the necessary information to make informed decisions. He cited the need for lighter, smaller, and more effective weapons as the primary motivator for advanced energetics, particularly in the context of difficult-to-defeat targets such as hardened bunkers and underground tunnels. He also expressed some frustration that DARPA R&D is not suited for long-term research even if the projects are "DARPA-hard." DARPA's mandate for prompt (3-year) transition to the warfighter limits their involvement in such pursuits as novel energetics.

4.3 Dr. Chris Deeney, National Nuclear Security Administration (NNSA) spoke for **Dr. Crandall** who was unavailable for the morning session. He expressed strong support for DTRA's program in trying to better understand nuclear weapon output and felt that more effort is needed here. As far as NNSA programs are concerned, the focus has been on the Reliable Replacement Warhead (RRW) and Complex 2030, which will provide the infrastructure to support our future nuclear stockpile. However, in today's environment anything nuclear is a tough sell and even the RRW is getting push-back from Congress.

He discussed the NNSA concerns about technology surprise in developing scientific fields related to high energy, high energy density, and high energy release rates. In this regard, he expressed concern about the decline in nuclear curricula at our universities and the dearth of U.S. students interested in pursuing the nuclear career field. This is not the case in Japan, Europe, and other parts of the world, where the leadership values nuclear power and recognizes the dual-use nature of the technology as a pathway to proliferation. He briefly described the NNSA Academic Alliance program, which seeks to reverse some of these unfavorable trends and demographics and train the next generation of scientists and managers for the nuclear enterprise.

In response to a question regarding NNSA-sponsored laser research, he commented that lasers and particle accelerators are fertile fields of research to meet future requirements. For example, he cited an important need for proton radiography.

In regard to other potential nuclear sources of energy, he felt that existing treaties and arms control protocols would get in the way, unless it is clear that there is zero yield from either fission or fusion processes. He noted that nuclear spin isomers might be exempt from current legal strictures, but the loophole will not likely last if such concepts are actively pursued.

5.0 Summary of Survey Presentations

5.1 Nuclear Isomers Panel

Dr. Jim Silk , Institute for Defense Analysis (IDA), chaired the panel on Nuclear Isomers. An experimental nuclear physicist by training, he has been with IDA for 17 years, serving as the Deputy Director of the Science and Technology Division for the last four. He led the OSD-sponsored review of Nuclear Isomer Triggering in 2002, and served as a member of the Low Energy Nuclear Reaction Verification Red-Team.

Dr. Silk acknowledged the attractiveness of nuclear isomers given that their specific energy density is within a factor of a 100 of that of nuclear weapons. However, in his opinion, nuclear isomer research is still immature, energy break-even is improbable, and fuel production is likely to be harder than was the case for nuclear weapons. He discussed the experimental results and the reasons for difficulties in demonstrating energy gain and appropriate levels for triggering radiation release. These are related to the theoretical intractability of nuclear transitions and the crossover between natural low energy transitions and high energy depletion state thresholds. He summarized the current state of controversy regarding the Hf^{178m2} isomer by stating that he has not seen any evidence of observable triggering. His recommended path forward is shown in the panel below:

Path Forward

- How to resolve the controversy?
  - Design a new (null) experiment?
  - Red team the data analyses? White team?
  - Let it play out?
- Beyond this, where should the research program go?
  - Nuclear structure studies - K-mixing mechanisms
  - Search for natural 2-γ decays
  - Other isomers
  - Other triggering mechanisms
  - Diversify

Dr. Carroll, Youngstown State University, reviewed the basics of nuclear isomers and their induced depletion (he prefers this term in lieu of "triggering"). He presented a table of 32 storage isotopes having lifetimes measured in seconds to years, highlighting those that store the most energy for the longest time as potentially useful for DTRA applications. Dr. Carroll summarized the current work being performed as following one of two approaches: 1) performing nuclear spectroscopy to characterize the energy levels and transitions or 2) direct measurement of depletion of metastable states with gamma ray, neutron or heavy ion irradiation followed by detection of decay rates of discrete energies. He reviewed nuclear spectroscopy and depletion data for several interesting isomers. The panel below shows some of the more promising candidates having depletion paths or induced decay modes:

REPORTED DEPLETION

- **^{178m2}Hf – depletion paths identified (> 300 keV)**
- **^{242m}Am – depletion paths available**
- **^{108m}Ag – depletion path in literature (partial data)**

SPECTROSCOPY

- **^{180m}Ta – photons, confirmed and connected to nuclear spectroscopy**
- **^{178m2}Hf – photons near 10 keV – not confirmed or substantiated by spectroscopy**
- **^{177m}Lu – neutrons, not confirmed**
- **^{68m}Cu – photons (Coulomb excitation), not confirmed**

- **THREE POSSIBLE CASES OF MEASURED DEPLETION**
- **THREE ADDITIONAL ISOMERS WITH DEPLETION PATHS**

The panel that follows is Dr.Carroll's summary of his views regarding the issues slowing progress:

IMPEDIMENTS TO PROGRESS

- **TIME – experiments are typically difficult to perform and analyze**
- **MATERIAL – isomeric material needed in sufficient quantity for tests – purity typically insufficient for spectroscopic measurements as targets (isomer beams may solve this problem)**
- **MANPOWER – support needed to expand research dedicated to depletion tests and related spectroscopy**
- **PERCEPTION – latest depletion-related research considered solid, but nuclear physics community wary of extraordinary claims (as it should be).**

Dr. Ehsan Khan, Department of Energy, Science Division, and former Program Manager for DARPA's Stimulated Isomer Energy Release (SIER) Program presented his perspective on the attractiveness of Nuclear Isomer Release Energy. Based on his experience with the Hafnium Isomer Production Panel (HIPP) he believes there are various feasible methods to increase production rates. He also believes that one of the drawbacks of past triggering experiments has been that the detection of low levels of triggered radiation is difficult in the presence of triggering radiation, other reactions, as well as electro-magnetic interference. Detecting the triggered radiation in such a complex background will need very careful experimental design.

Dr. Schumer, NRL, presented his perspective on why nuclear isomers/isotopes are intriguing energy-storage media. The question, which he believes remains unanswered, is whether nuclear isomers/isotopes can serve as a source of energy-on-demand? Dr. Schumer reviewed recent and proposed work at NRL, ARL and NSWC. He emphasized the need for a broader scope of research, including triggering using particles as well as gamma rays and showed some promising results under high current/ fluence, short duration pulsed particle beams, allowing measurement of product decay without the presence of the primary beam contributing noise.

His guidance on future isomer/isotope research is shown in the panel below:

Nuclear isomers/isotopes are intriguing energy-storage media, but the question remains: can they be *energy-release* media?

- Basic research is required before applications can be envisioned
- Efforts should be multi-faceted and multi-institutional
- Focus should expand beyond "Unobtainium" (i.e. $^{178m2}Hf$)
  - including pure spin-isomers (not K-hindered)
  - including electron-capture and internal conversion isotopes
- Experimental evidence should be:
  - tempered with theoretical expectations
  - "open" vetting by experts, including both peers and un-invested community ("open" is TBD by concerned agency)
- After confirmation, system study is still required to deem ready for real life (is efficiency good enough?)
- All of this is required before beginning Manhattan-style effort to produce material

5.2 Low Energy Nuclear Reaction (LENR) Panel

Dr. David Nagel, George Washington University, chaired the Low Energy Nuclear Reaction (LENR) Panel. He is a Research Professor in the School of Engineering and Applied Science of George Washington University. Dr. Nagel is a recognized authority on low energy nuclear reactions in condensed matter. He commented on the present state of LENR research, noting some of the more important problems impacting LENR research today:

PROBLEMS

- **Potential Importance for Energy, Materials and Weapons**
- **Polarization of Scientists**
- **Diverse Mistakes**
- **Technical Complexity**
- **Flows of Money and Information Disrupted Early & Remain Poor**

On the other hand, Dr. Nagel pointed to many recent positive developments that indicate substantial progress in understanding and demonstrating LENR. He also mentioned the need for a theoretical basis to underpin experimental work.

PROGRESS

- **Continuous Activity & International Conferences**
- **Better Instrumentation, Calibration and Controls**
- **Some Systematics Found & Verified for Heat Generation Experiments**
- **Nuclear Ash Measured & Correlated with Heat Production**
- **More Attention to Materials**
- **New Experiments Performed**
- **Some Inter-lab Reproducibility**

Dr. Mitchell Swartz, JET Energy, INC presented a brief summary of the results of excess heat experiments in electric-field loaded deuterated metals:

EXCESS HEAT IN
ELECTRIC-FIELD LOADED DEUTERATED METALS
Research and Development

BRIEF SUMMARY OF RESULTS:

SIGNIFICANT EXCESS HEAT OBSERVED IN PALLADIUM HEAVY WATER (PdD) SYSTEM, PALLADIUM HEAVY WATER (PdD) CODEPOSITIONAL SYSTEM, SOME NICKEL LIGHT and HEAVY/LIGHT WATER SYSTEMS

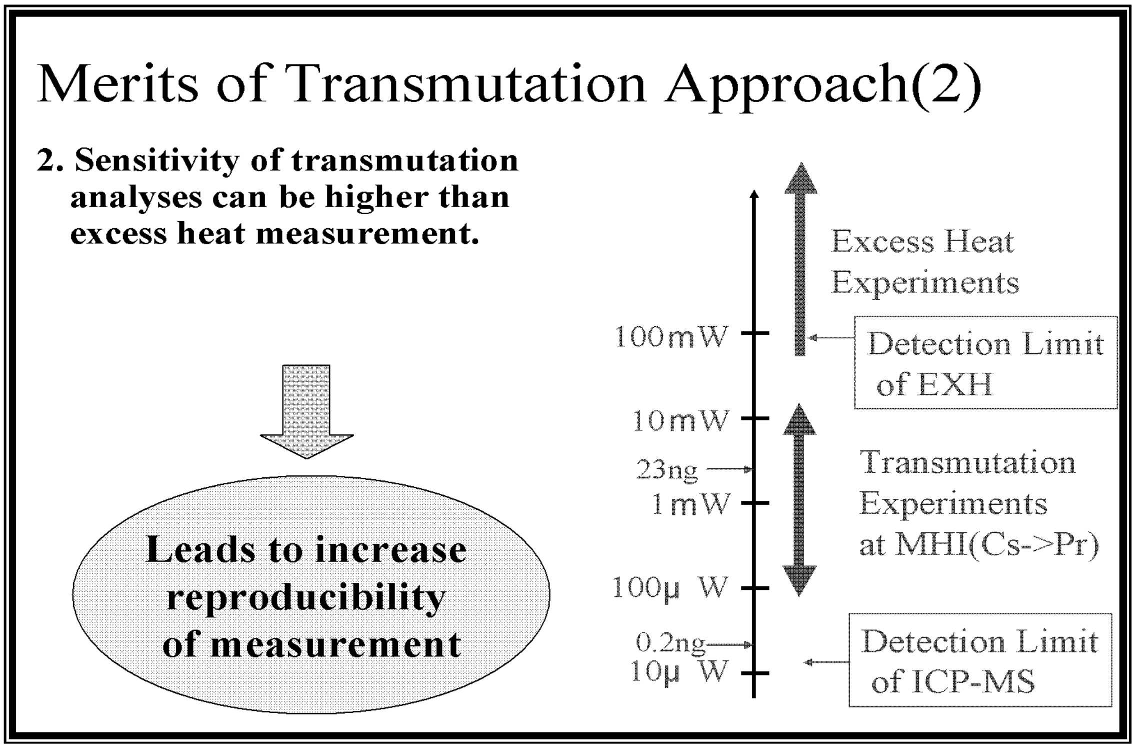
EXCESS HEAT NOT OBSERVED IN IRON, ALUMINUM, OR DAMAGED PALLADIUM NICKEL SYSTEMS

© JET Energy, Inc. **DTRA ASCO Workshop on High Energy Science and Technology** Dec. 12, 2006

He explained his methods for controlling measurement error and system noise by using dual calorimeter measurements that allowed precise differential measurement and integration of power. He was thus able to compare measurements of several different instruments to allow judgment of consistency in his reported results.

The diffusion and electrophoresis equations show the advantages of low conductivity electrolytes and relatively high voltages for loading D into the electrodes with co-deposition of electrode material. Dr. Swartz obtained energy and power gains over the D charging (loading) input power and discussed the importance of determining optimized operating points. Impressively, he showed a video demonstrating enough power to spin the propeller of a model airplane.

Professor Michael Melich, W.E. Meyer Institute for Systems Engineering, Naval Postgraduate School, talked about transmutation as the signal for detecting LENR using experiments conducted in a Deuterium cell with an electrolytic Pd diffusion barrier. Quantifying the transmutation products as an experimental approach potentially affords greater sensitivity and reproducibility than excess heat, since the new elements are not present initially and can be detectable in very small concentrations:



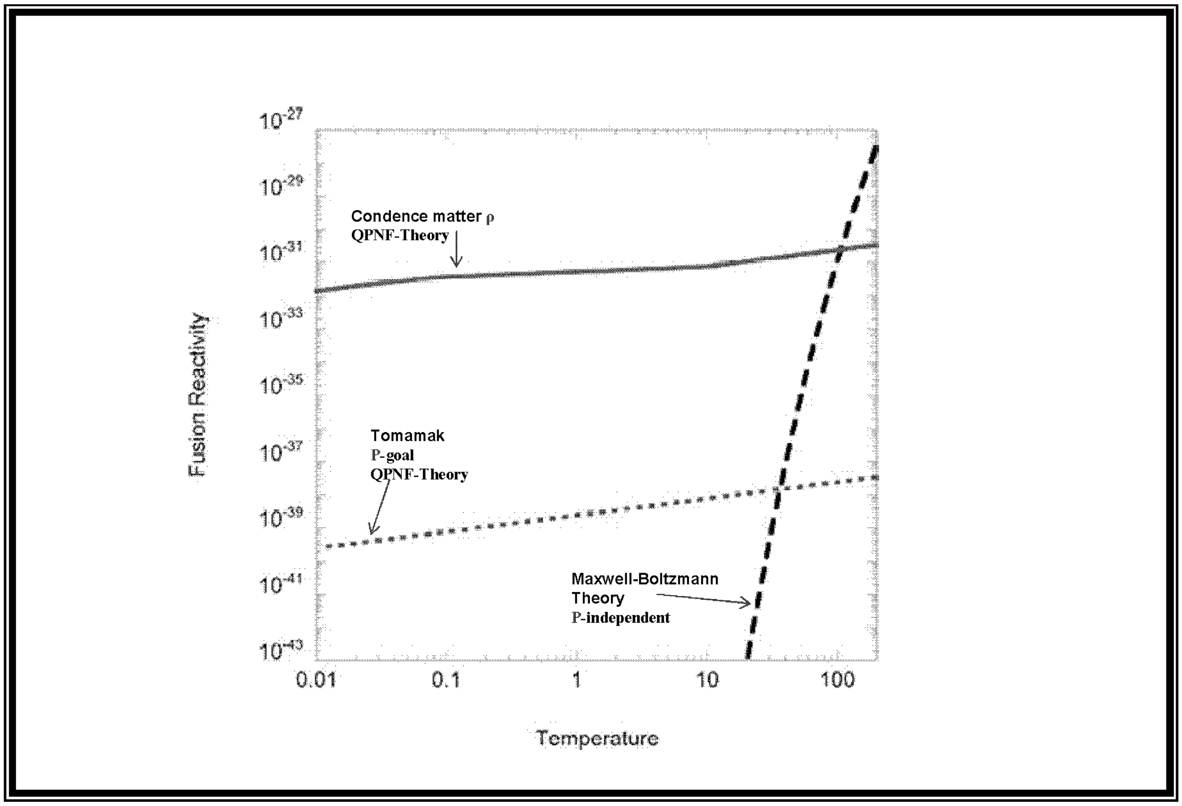
Recent trials confirmed that following standard electrolysis experiments, the diffusion barrier contained elements not present before the runs. In principle, the results of a single run can then be analyzed by other labs to determine the degree of consistency in detection of small concentrations of transmuted elements.

Lewis G. Larsen, President and CEO, Founder and Prof. Allan Widom Consultant and Member of Lattice Energy LLC and Northeastern University, Dept. of Physics presented proprietary material on the Widom-Larsen theory for metal hydride surface catalysis of LENR. A convincing thesis was advanced to describe many of the known features of LENR without invoking any new physics. The theory is premised on the weak force (beta decay) of the Standard Model.

NET: Kim did not present on the 12th or 13th, though he was in the audience. He provided slides to DTRA after the meeting.

Yeong E. Kim, Purdue Nuclear and Many-Body Theory Group, Department of Physics, Purdue University described a theory based on Quantum effect broadening of the distribution (via the Gamow factor). For n(E) that is Maxwell-Boltzmann (MB), Fermi-Dirac (FD), or Bose-Einstein (BE) distribution, modified by the quantum broadening of the momentum-energy dispersion relation, $\delta\gamma$(E-εp), due to particle interactions.

The Quantum Nuclear Plasma Fusion theory provides a mechanism for enhanced net reaction rates at lower temperatures as illustrated for Deuterium-Deuterium:



5.3 Anti-Matter Annihilation Panel

Mr. Ken Edwards, AFRL/MN, chaired the Anti-Matter Panel. He is Director of the Revolutionary Technologies Integrated Product Team, chartered to plan and develop revolutionary paradigm-shifting munitions for the Air Force of 2025. He is currently focused on Positron Energy Conversion for explosive and propulsive applications and has overseen work in this area for several years. This has been a joint program conducted in partnership with DARPA.

Mr. Edwards listed the primary advantage of stored positrons to be their very high specific energy densities without creating any radioactive nuclear debris or long-term radiation following an annihilation reaction. Regarding storage mechanisms, he showed some schemes for efficiently moderating and storing positrons in the form of positronium (Ps) (a pseudo-atom consisting of a positron and an electron) using Penning traps. He noted that positronium can be stabilized using crossed magnetic and electric fields. Quantum chemistry calculations suggest potential lifetimes of up to a year or longer.

Dr. Gerry Smith, Professor Emeritus (Physics), Penn State, and Positronics Research, LLC reported on the "Physics and Experiments with Long Life Positronium" and described the theoretical basis for extended half-life of Ps in the crossed fields of a Penning trap. It was postulated that radiation-damaged Silica Aerogel (SA) might be paramagnetic and with controlled pore size, crossed fields (based on remnant magnetic fields and an imposed (modest) electric field) would allow storage of positronium for significant times at useful densities.

Dr. Smith summarized the work he felt would need to be accomplished to demonstrate this concept for anti-matter storage:

Program Goals & Challenges (Near-Term)

Demonstrate improvements for higher density and longer-term Ps storage

- Intense, larger volume (10x) e^- irradiation of SA (>20 MGy)
- Test ultra light SA (> 100 nm cavity) and magnetized SA
- e^+ beam injection into Penning trap (20 mCi source)
- e^+ accumulation, cooling and lifetime (10^6, 3 meV, > 20 sec)
- e^+ extraction into silica aerogel (5 μsec)
- OWPs number enhancement (10 SA vol. x 30 field/temp = 300x @ 400G, 0.5K)
- OWPs density enhancements (30 field/temp/10 SA vol. = 3x @ 400G, 0.5 K)
- OWPs lifetime enhancement (TE; 100 nm, 1.2 ms = 100x; 1000 nm, 0.36 sec = 36,500x)

Dr. Allen P. Mills, Jr., Physics Dept., University of California, Riverside, CA proposed the need for apparatus to provide larger numbers of Ps atoms in order to study aspects of stimulated annihilation and their Compton wavelength. Dr. Mills described his program for a series of increasingly intense positron sources and showed calculation of their efficiency in producing Ps. A $^{12}C(d,n)^{13}N$ reaction provides positrons when the nitrogen decays, which are then slowed and cooled in a Penning trap. His program may lead to development a 50 W source of positrons. The sources currently under way are in the milliwatt range.

Dr. Mills scientific objectives are to measure g for Ps, (needs 10^8 Ps); to observe stimulated annihilation, (needs 10^{11} Ps); to make an annihilation gamma ray laser and measure the Compton wavelength, and to ignite fusion (perhaps 10^{19} Ps). Larger sources and more refined positron moderating and cooling techniques will be required for Dr. Mills' more advanced planned sources.

Stages to 50 W antimatter source

Year	Model	d^+ Energy	Current	slow e^+/s	
2008	HFPS-1	1.5 MeV	1 mA	no mod.	
2008	HFPS-2	1.5 MeV	1 mA	10^9	
2009	HFPS-3	5 MeV	1 mA	10^{10}	1.6 mW
2010	HFPS-4	5 MeV	10 mA	10^{11}	16 mW
2011	HFPS-5	30 MeV	10 mA	$3x10^{12}$	0.5 W
201X	HFPS-X	30 MeV	1 A	$3x10^{14}$	50W

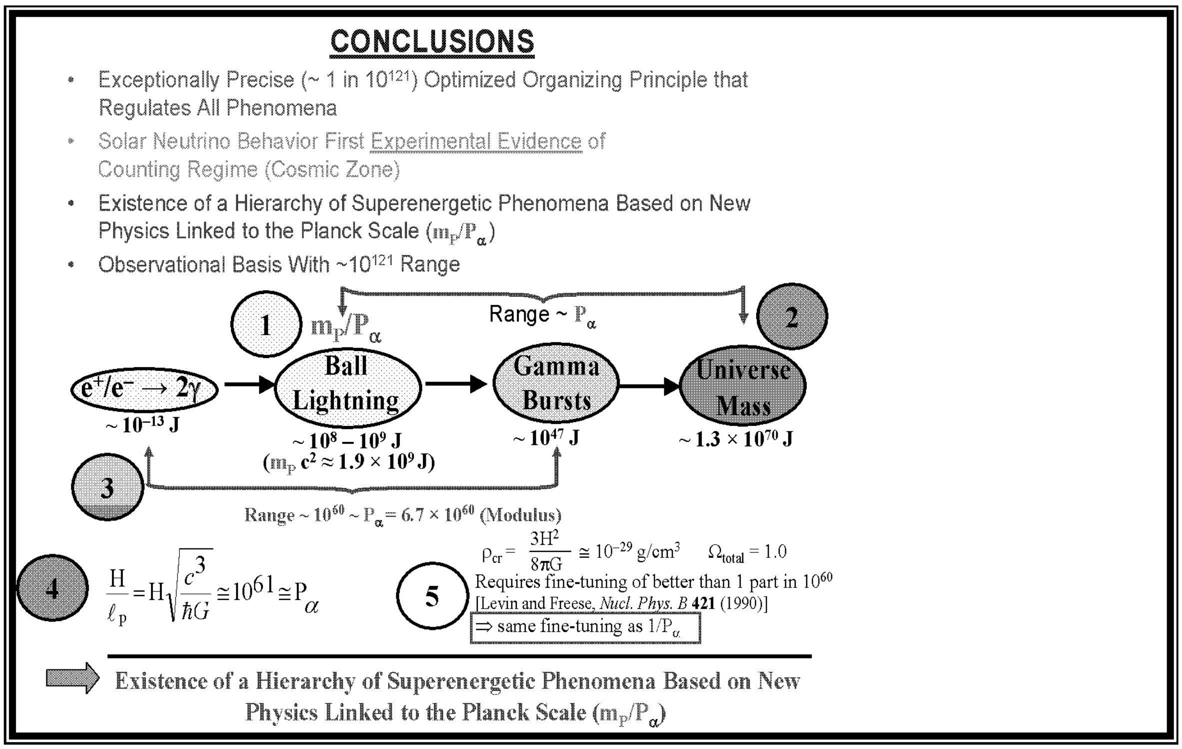
HFPS-3 is about to enter Phase II.
HFPS-4 and 5 are suitable for a large lab.
HFPS-X might be possible.

Dr. Paul L. Csonka, University of Oregon, spoke on the topic of "INTENSE POSITRON SOURCE with ENERGETIC ELECTRONS TRAVERSING UNDULATOR" . He proposes positron generation using gamma rays from undulators mounted on major high energy storage rings. The main source of positrons (fast particles) seems to be pair production. He showed calculations of positron currents of between 10^{14} and 10^{17} per second and suggested the resulting fast particles could be moderated with an efficiency of 0.001 to 0.1 by one or another of proposed schemes. Accelerators existing and planned for other purposes could be adapted relatively easily for high flux positron production.

6.0 Other Topics

6.1 Exotic Energy and Power Concepts

Dr. Charles Rhodes, University of Illinois, illustrated relationships between levels of energy, power density of known physical phenomena that covers a scale of $1:10^{121}$ in known instances. While some parts of this range have been exploited, Dr. Rhodes points out that many other parts of this vast range are available for study, and potentially scalable to energetic applications of interest:



6.2 4th Generation Nuclear Weapons

Dr. Don Linger, DTRA, postulated a new generation (post-Cold War) that would have little-to-no fission yield and therefore would be both radiologically clean and (perhaps) treaty compliant. Such low yields could be used against tactical targets and hard targets as well as for high altitude weapon effects. The US must be cognizant of such capabilities and the implications of such weapons potentially in the hands of our adversaries, both near-pear and developing nations.

6.3 Intelligence Perspective

(b)(6) **Intelligence Community,** gave remarks on advanced energy sources from the intelligence perspective. He is aware of concerns for the US maintaining an ability to steer high quality research to topics and objectives critical for national security.

In a connected concern, he also spoke of the inability to pursue answers to important questions because of lack of technical understanding, the inability to properly prioritize issues and finally, a lack of qualified workers in these fields. He supported the advanced work being discussed in this workshop as both critical data to be acquired and as important training for the rising generation of scientists and engineers.

7.0 Feedback from Panel of Experts

The Honorable Dr. H Smith, Dr. Jack Davis, Dr. Fred Wikner, and Dr. Gerald Yonas served as subject matter experts and provided their overall review of the Workshop. Their findings and recommendations are summarized in the table below:

	Advisory Board Findings	Advisory Board Recommendations
Isomers	• **Nuclear structure is complex and poorly understood** • **Experiments are ad hoc- not systematic: some interesting data but no triggering observed**	• **Conduct large scale computer simulations like ASCI (not DTRA, NSF or DOE)** • **Experiments-long term; guided by theory, funded by NSF and DOE**
LENR	• **There is good evidence of excess heat and transmutation** • **New theory by Widom shows promise; collective surface effects, not fusion** • **Low energy implantation of ions**	• **Careful experiments confirm and expand data base** • **Expand theory field with more participants** • **Other experiments included**
Anti-Matter	• **Systematic approach required: how to manage it** • **Experiments will require substantial increments**	• **Not suitable for DTRA, a combat support agency.**
Nuclear Weapons	• **DoD needs low residual radiation weapon; DOE knows how to RDT and produce them**	• **US DOE should proceed; DOD should provide requirements**
General Observations	• **Agency staffs and services are increasingly risk adverse**	• **Defense research establishment must think creatively about new concepts**

8.0 Workshop Summary

The High Energy Workshop endeavored to assemble the recognized experts in each of the energy categories to survey the state-of-art. The presentations did elucidate the state of science but of course were limited in depth based on time available. At the end of the Workshop, an early summary or "Hot Wash" debrief was presented to the senior DTRA leadership on the salient points made in the two days presentation. It is included in Appendix B.

Nuclear Isomers research has not yet provided evidence of reliable and effective triggering mechanisms. Production seems feasible, though engineering development is needed to scale up to practical amounts of material. The complexity of isomeric excited states and their induced depletion paths leads us not to expect too much from better theory or intense calculational efforts.

Yet, one cannot help but be intrigued by potentially gaining access to such highly energetic states for military applications. At this stage, modest investments related to the study of isomers and the physics of de-excitation would appear to be prudent. Also, improvements in experimental methods and diagnostic tools may be warranted.

Clearly, isomer production is not now the greatest roadblock to a proof-of-principal demonstration and should not be pursued at this time. A more fundamental issue is demonstration of a robust triggering approach. Here more experimental work is useful if focused on development of techniques for analyzing gamma spectra and measurement of depletion rates. Equally important would be innovative approaches to nuclear structure and transition probabilities. Weapons applications based on isomeric payloads are premature and should not be pursued.

Low Energy Nuclear Reactions are showing some remarkable progress with respect to energy (excess heat) production and transmuted element detection, but experiments remain only thinly reproducible. LENR also suffers from a basic lack of understanding of the governing physics.

There is also a compelling need for a theory that can explain production rates and lead to specific electrode treatments and electrolyte compositions and predictions of reaction power, energy and products. The Widom theoretical construct appears promising, but lacks robust experimental verification and rigorous peer review.

NET: Widom-Larsen theory published in peer-reviewed Eur. Phys. J. C nine months before, March 2006

The polarizing history of LENR is a detriment to expanding research efforts and it seems unlikely that deployable/useable devices could be expected within a five to ten year horizon. Some low-level funding by 6.1 agencies seems appropriate, both to exploit the possibility of a breakthrough and to monitor other (international) research in this field. Nonetheless, DTRA should not go it alone; rather, it should provide the leadership to build interagency research consortia with a focus on fostering improved research facilities and rigorous experimental protocols.

Anti-Matter research has provided encouraging results to suggest that positrons, in the form of positronium, may be efficiently stored with reasonable lifetimes. Clearly, stable sources of Ps capable of generating intense gamma pulses could have numerous interesting military applications. Methods to package Ps with longer life times and useful densities will require considerable experimentation and development, as will achieving efficient and affordable positron production methods.

A modest 6.1 program would keep DTRA in play on any future decisions regarding the feasibility of weaponizing anti-matter.

4th Generation Nuclear Weapons Concepts appear to be attractive for a number of military objectives, especially in situations needing low yield and low residual radioactivity.

(b)(3):10 USC 128

The military effectiveness of such weapons will need to be characterized in detail in concert with suitable concepts of operation. The policy implications, in terms of how such weapons may be used and whether they meet current legal strictures and arms control restrictions, must also be examined. In view of this concern, expressed by several members of the Expert Panel, a cursory review of the current legal definition of nuclear weapons was commissioned by DTRA and is provided in Appendix D.

Given the congressional restrictions on pursuing new nuclear weapons concepts, it is not clear what DTRA's role should be other than to stay abreast of new developments in this area, as a hedge against technology surprise and a new wave of proliferation. Also, a review of the potential implications to the U.S. national security posture, should such weapons be developed by others, would appear to be well advised.

A **Workshop Summary Report** briefing was compiled following the workshop and was presented to DTRA sponsors of the workshop. It is provided in Appendix C.

9.0 Recommendations

Novel Energy Strategy: The Expert Panel noted that there many potentially interested agencies and that DTRA, as a new 6.1 agency, will need to find its niche. It is recommended that DTRA form and/or participate in an Interagency Novel Energy Working Group. Partnering agencies would include DTRA, DOE/NSSA, the National Laboratories, DHS, DARPA, NSF, and the Service Labs. The charter would be to coordinate budgets for maximum return and chart a course that would accelerate development of advanced energy concepts.

Isomer Energy Storage: The extraordinary claims regarding the de-excitation of Hf^{178m2} appear to have been thoroughly discredited. Nonetheless, it may be warranted to fund some basic research to continue screening candidate isomers, to develop an improved understanding of the physics of isomer de-excitation, and to explore de-excitation methods other than x-ray stimulation. There are no likely near-term military applications of nuclear isomers.

LENR: LENR still suffers from negative publicity associated with Cold Fusion and is viewed as being conducted outside the domain of legitimate, mainstream science. Nonetheless, the persistent and increasingly repeatable demonstrations of excess heat and transmutation suggest that there is something here worth pursuing. DTRA should not do so alone, but rather foster consortia that would help bring discipline and rigorous experimental protocol to this field. Additionally, efforts to better understand the physics of LENR as well as the development of first-principle predictive models are encouraged.

Anti-Matter: The challenge of stable storage of positrons in the form of positronium may be surmountable but progress to date has been modest. Near-term applications of this technology appear to be ill-advised. Additionally, the large parasitic mass associated with the storage of positronium and the small amount that can be stored, even under the most optimistic projections, effectively limits the system-level energy density. Nonetheless, some basic 6.1 research should be invested in keeping the effort alive. Perhaps an alliance between DTRA and NSF would be useful in this regard.

4th Generation Nuclear Weapons: DTRA, in cooperation with NNSA and with the approval of OSD, should consider supporting a few pilot studies to explore the potential applications of 4th generation nuclear weapons to meet projected future national security needs, explore the potential impact of such weapons if they were to be used against U.S. forces or infrastructure, and examine their overall policy implications.

Appendix A
Workshop Participants

(b)(6)

(b)(6)

Appendix B
Hot-Wash Briefing to DTRA
December 13, 2007

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High Energy Workshop

Expert Panel Findings and Recommendations

12-13 December 2006
Defense Threat Reduction Center
Fort Belvoir, VA

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Findings & Recommendations
Anti-matter

- Findings
  - System approach required: How big is it??
  - Experiments will require substantial investments
- Recommendations
  - Not suitable for DTRA, a combat support agency

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Findings & Recommendations
Nuclear Weapons

- Findings
  - DoD needs low residual radiation weapons
  - DOE knows how to
    - RDT&E and Production
- Recommendations
  - DOE should proceed
  - DoD should provide requirements

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Findings & Recommendations
General Observation

- Finding
  - Agency staffs and Services are increasingly risk adverse
- Recommendation
  - Defense research establishment must think creatively about new concepts

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Appendix C
Summary Report Of High Energy Workshop

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High Energy Workshop
Sponsored by DTRA/ASCO

12 – 13 December 2006
Defense Threat Reduction Center
Ft. Belvoir, VA

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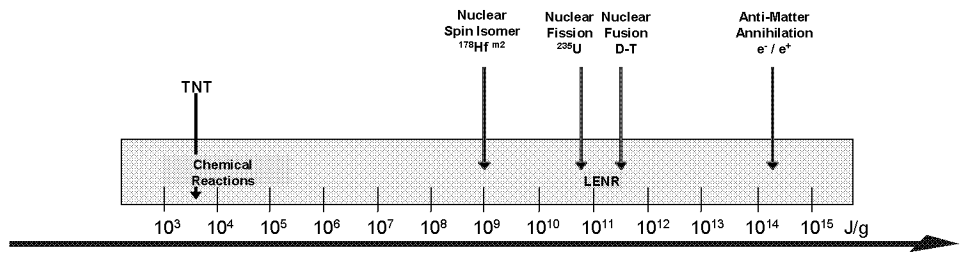
Workshop Objectives

- Survey and assess the S&T of highly energetic materials, whose energy is released via nuclear and subatomic processes ($>10^6$ eV/unit-event)
  - Nuclear Isomers
  - Low energy nuclear reactions (LENR)
  - Anti-matter Annihilation
  - Advanced nuclear fission and fusion
  - Exotic/Extreme Physics



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Key Considerations

- Should these topics be included as part of a balanced investment portfolio in "Disruptive Energetics?"
  - Do we understand the underlying physics sufficiently well to proceed with confidence?
  - Do the potential pay-offs outweigh the risks?
- What should be the focus of the investment?
  - Well-defined, refereed, repeatable experiments?
  - Proof-of-concept tests?
  - Theoretical investigations?
  - Other?
- What are the potential applications?
  - Could these topics underwrite game-changing improvements in warfighting?
- What are the potential risks?
  - How many orders of magnitude of the specific energy density is likely to be lost to system-level packaging?
  - What criticisms should we anticipate from scientists, from the DoD bureaucracy, from Congress, ...?
  - Will these topics bump up against nuclear arms control agreements?

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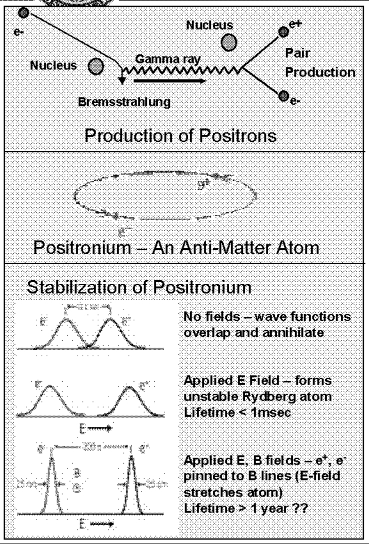
Anti-matter – The Basics



- Positrons annihilate with free electrons producing two soft (0.51 MeV) gamma rays (no radioactive products/residues)
  - Energy density for PEC is 1.8×10^{14} J/g, compared to 4.7×10^{3} J/g for TNT and 8.2×10^{10} J/g for ^{235}U fission
  - 1 μg of positrons ~40 kg of TNT
- Positrons produced via bremsstrahlung and pair production (requires linac or synchrotron)
- Positrons stored as neutral positronium
  - No space charge forces to deal with
  - Positronium stabilized by crossed E and B fields
  - Quantum theory predicts stable Coulomb states of positronium with lifetimes of one year or longer
  - Ps storage in Penning traps and silica aerogels
- Potential applications include blast-frag effects, EMP, gamma ray laser, bioagent defeat, propulsion etc.

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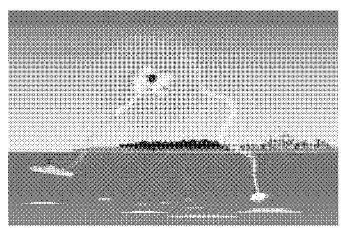
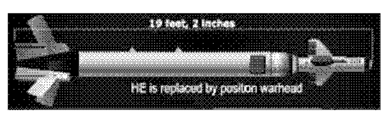
DARPA Proposed Applications for Positronium Payload*

- A non-nuclear near-miss-to-kill interceptor for ballistic and cruise missile defense
  - Direct hit not necessary
  - Radiation kill of electronics and bioagents
  - 0.3 ns risetime (b)(3):10 USC prevents circumvention
  - One μg burst can be lethal to 300m against unshielded electronics (upset & latchup); other lethality mechanisms operate at shorter ranges
  - Only millisecond collateral RF interference effects



- A killer of bioagents in small bunkers
  - Promptly kills bioagents prior to dispersal
  - 1 μg burst has a lethal radius of 2 meters against anthrax, the hardest case (radius for rendering sterile is greater)



** Briefing by Martin Stickley, 5 June 2006*

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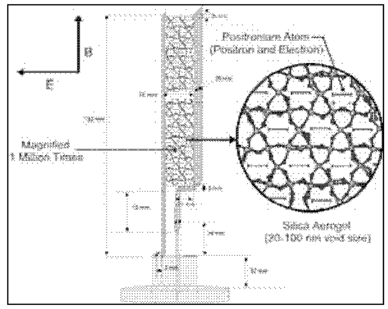
Technical Challenges

The DARPA Ps Weapon Prototype consists of 10^{21} positrons stored (as Positronium), at a density of 1μg/liter, with an energy equivalent of 180 MJ (40 kg TNT, 25x volumetric)

- Challenges
  - Positronium production
    - Plant capital and operating costs ($77M - $200M per year)
    - Output of 10^{22} to 10^{24} Ps per year
  - Long-term Ps storage (30 yrs) at militarily useful densities (180 MJ/l)
    - Create stable states of Ps that prevent self-annihilation
    - Penning trap for accumulation and cooling
    - Silica aerogel storage for weapons application
  - Cost per weapon
    - $200K - $1.5M



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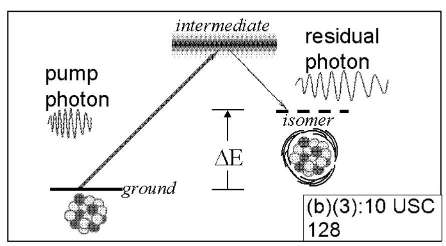
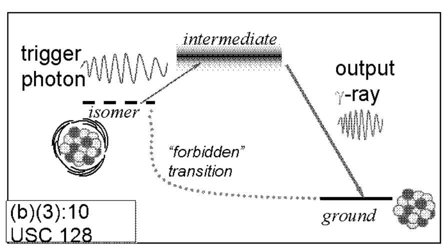
Nuclear Isomers – The Basics

- Nuclear isomers are metastable excited nuclear states with energy densities approaching nuclear fission (up to 10^9 J/g for isomers vice 10^{11} J/g for nuclear fission)
- Nuclear isomers are long lived with mean lifetimes ranging from a few μsec to 1000s of years
- Fuel production is harder than for SNM
- Isomers can be de-excited to release energy by x-rays, neutrons, ions, ...
  - Demonstrated in ^{180}Ta and ^{197}Au
  - Triggering physics not well understood
  - Energy break-even is improbable
- Potential applications
  - Weapons and portable energy sources if triggering energy is low





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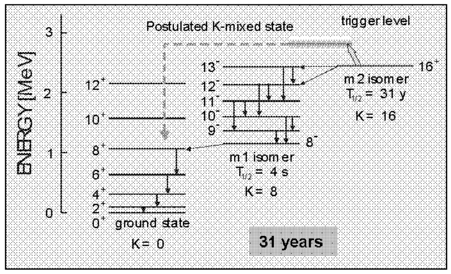
The Hafnium Controversy

- $^{187}Hf^{m2}$ is attractive isomer
  - 2.4 MeV above ground state
  - Half-life of 31 years
- In 1999 collaboration led by Carl Collins (UT, Dallas) reports in Phys Rev Letters evidence that 10-keV x-ray photons can de-excite $^{187}Hf^{m2}$, triggering a prompt cascade of 2.45-MeV gamma-rays
  - Claimed existence of k-mixed state some 20-60 keV above the m2 state
- All attempts to reproduce Collin's results failed
- Strong theoretical arguments against triggering of $^{187}Hf^{m2}$
  - Isomer is in high spin state (J=16, K=16) – selection rules for E-M decay severely inhibit transitions with large changes in K
  - Theoretical nuclear x-ray absorption cross sections too low by $x10^6$
- Even if triggering were possible, difficult to envisage chain reaction for explosive applications



Where to next?

- Achieve closure for $^{128}Hf^{m2}$??
- Nuclear structure studies (K-mixing)
- Other isomers
- Other triggering mechanisms

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Potential Isomers for Consideration*

Isomer	$T_{1/2}$ (yr)	E_{isomer} (kV)	$E_{trigger}$ (kV)	Availability
^{108m}Ag ^{110m}Ag	418 0.68	109 118	46.4 72.9	$^{X}Ag(n,\gamma)\ ^{X+1}Ag$ (51.8% ^{107}Ag, 48.1% ^{109}Ag)
^{180m}Ta	infinite	75	1010, 2800	0.012% of natural Ta (4.1% enriched from ORNL)
^{242m}Am	141	49	4, 99	$^{241}Am(n,\gamma)^{242m}Am$ (~1 g ^{241}Am from ORNL)
^{166m}Ho	1200	6	264	^{166m}Ho fully-enriched from ORNL
^{186m}Re	2 x 10^5	149	37	$^{185}Re(n,\gamma)^{186m}Re$ (96% enriched ^{185}Re from ORNL)
^{177}Lu	0.44	970	100	$^{176}Lu(n,\gamma)^{177m}Lu$ (75% enriched ^{176}Lu from ORNL)
^{178m}Hf	31	2446	10	10^{-9} g quantities from SRS Technologies, Huntsville, AL

*Source: Joe Shumer, NRL

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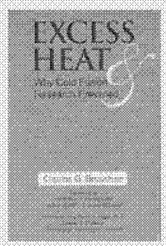
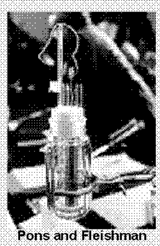
Low Energy Nuclear Reactions (LENR)




Pons and Fleishman Electrochemical Cell 1989

- Two branches of LENR
  - Excess Heat
  - Nuclear Transmutation
- Legitimate experiments by reputable researchers worldwide continue to demonstrate "excess heat" production in electro-chemistry experiments
- Other "chemistry" experiments have shown transmutation of elements and production of energetic tritons, helium and tritium
- None of these observations can be attributed to conventional chemistry
- The body of evidence supporting LENR continues to grow, but hard data still only thinly reproducible

NET: This is incorrect. The hypothesis of "two branches" is obsolete. Excess heat occurs in both D/Pd as well as Ni/H. So do transmutations.

Question: Why have LENR researchers not been killed by lethal doses of neutrons and gammas??

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New Theoretical Developments Widom-Larsen Theory

Purports to explain most LENR observations without invoking any new physics beyond the standard model.

- LENR is a manifestation of the weak interaction – it is not fusion or other forms of strong interaction
- Many-body "patches" of collectively oscillating protons or deuterons form on metallic hydride surfaces loaded with hydrogen isotopes
- Collective oscillations of the protons/deuterons start to loosely couple to the collective oscillations of nearby surface plasmon polariton (SSP) electrons, commonly found on the surface of metals
- Coupling between the two increases the local electric field to $>10^{11}$ V/m (about the same as the Coulomb fields seen by inner electrons)
- Intense local radiation field raises effective mass of SSP electrons so that they can react with nearby protons and deuterons to form neutrons
- Neutrons created collectively have huge quantum mechanical wavelengths and are almost always absorbed by nearby nuclei
- Gammas emitted as a result of neutron absorption are intercepted by SSP electrons and reradiated as much softer E-M energy

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Widom-Larsen Theory Explains ...

- Excess heat in electrochemical cells
- Nuclear transmutation abundances in electrochemical cells (total rates shown to be in agreement with experiment)
- Transmutations observed in exploding wire experiments as early as 1922

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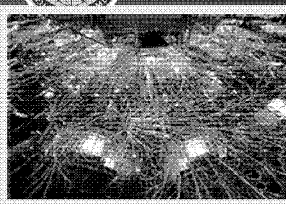
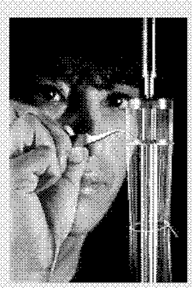
Advanced Nuclear Weapons Concepts



Sandia Z-Machine



Z-pinch Wire Array

- Tailored Output Devices
  - Nuclear-driven directed energy
    - X-ray laser
    - Kinetic projectile array
  - Enhanced radiation weapon
  - Enhanced, localized EMP
- Pure Fusion Device
  - DT pellet implosion
    - Enhanced energetic material direct drive
    - Plasma Z-pinch drive
  - Essentially fall-out free
    - Some short-lived, neutron-activated radioactive isotopes

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