U.S. Army
National Ground Intelligence Center

(U) Zero-Point Energy: Can We Get Something From Nothing?

(U) Purpose

(U) This assessment provides an overview of zero-point energy in terms of proposals to exploit the vacuum energy for applications. Worldwide research in the field is outlined and discussed. The primary purpose of this document is to separate science from pseudoscience in this controversial field.

(U) Key Points

- (U) While there are some aspects of zero-point energy (ZPE) that may be useful for specific applications, it is not a viable source of energy for vehicle propulsion or "free energy" inventions—a highly disputed idea that has garnered defense spending in the past.
- (U) The most useful property of ZPE for practical application is the Casimir force, which weakly attracts small particles or conducting plates.
- (U) ZPE holds promising potential for practical application through the Casimir force in various applications of nano- and micro-electromechanical systems (NEMS and MEMS).

(U) What is Zero-Point Energy?

(U) Zero-point energy (a very general term) is the lowest energy that a given quantum mechanical system can have (i.e., the ground state of the system). In quantum field theory, it refers to the energy of the vacuum (i.e., a space devoid of matter [the energy of "nothing"]). In this paper, we will use the abbreviation ZPE (as is commonly used by those in the field) to refer to the vacuum energy for use in applications.

(U) While it is tempting to think that the energy of the vacuum in its abundance might somehow be harvested for our general use, this is sadly not possible. Extracting energy from a ground-state system would imply that the resulting system would have a lower energy, which is a nonsensical concept given that the system is (by definition) already at its lowest energy state. Forays into "free energy" inventions and perpetual-motion machines using ZPE are considered by the broader scientific community to be pseudoscience.

(U) However, there are effects and forces arising from the vacuum energy that may be useful for future applications. The Casimir force or effect (also called the Casimir-Polder effect) is a weak attraction between objects due to the resonance of energy fields present in the space between them (diagram shown below). Since the force drops off rapidly with distance, it is most noticeable between small objects separated by small distances. The force is similar in strength to the Van der Waals force and is similarly most noticeable in everyday observations such as the ability of a gecko's feet to stick to walls.

(U) Diagram of Casimir Force Between Two Conducting Plates

(U) The fields of the vacuum are affected by nearby conducting bodies, which create a boundary condition on those fields, forcing some components to be zero on the surfaces of the conductors. This phenomenon leads to the most useful concept of the Casimir effect. The formula that defines the Casimir force per unit area between two perfectly conducting plates is as follows:

$$\frac{F}{A} = -\frac{\pi^2 \hbar c}{240 d^4}$$

(U) A is the plate area, d is the separation, c is the speed of light, and h is the reduced Planck's constant "h-bar" ("h-bar" = h/2π).[a] The negative sign shows that the force is attractive[b] (bringing the two plates closer together will lower the energy). The dependence on the fourth power of distance (along with the other constants) shows that the force is very small[c] and the presence of "h-bar" in the formula shows that the force is quantum mechanical in nature.

(U) Although this formula demonstrates a ZPE-associated force between two plates, one must be careful when considering the possibility to exploit it in order to obtain energy.[d] The only way to actually gain energy in this scenario is to allow the plates to come together (getting them apart again would then require more energy), and this action within the small separations where such forces would still be noticeable can only produce a very small amount of energy.[e] The design is not scalable to larger energies, and it is one-use-only in nature.

(U) An apt and promising application of the Casimir force is its use in nanoscale objects and mechanisms such as NEMS and MEMS. This relatively new area of research constantly faces forces and constraints that are not generally encountered in macrofabrications, making normally unnoticeable weaker forces like that from the Casimir effect essential considerations and possible enablers. The Casimir effect also has applications in basic physics such as studying the fine structure constant or the evaporation of black holes, but this paper is limited to discussions of direct practical applications.

(U) Proposed Applications for ZPE

(U) Space Propulsion

(U) While grand plans of harvesting large amounts of energy from the vacuum to propel vehicles through deep space is better suited for science fiction, it may eventually be possible to use small amounts of energy (picowatts) from the vacuum for long-term space travel. Even if it ends up costing energy to harvest it, it is not inconceivable to gain an advantage from having a particular form of energy that would present something akin to mechanical advantage. Since traveling long distances through space from one celestial body to the next would likely involve several different stages and types of thrust, it is possible that ZPE could be used for some portion of the travel through space where small amounts are required only for gradual changes in direction. Major U.S. organizations have studied this possibility, but little has come of the efforts, and support for these efforts is waning.

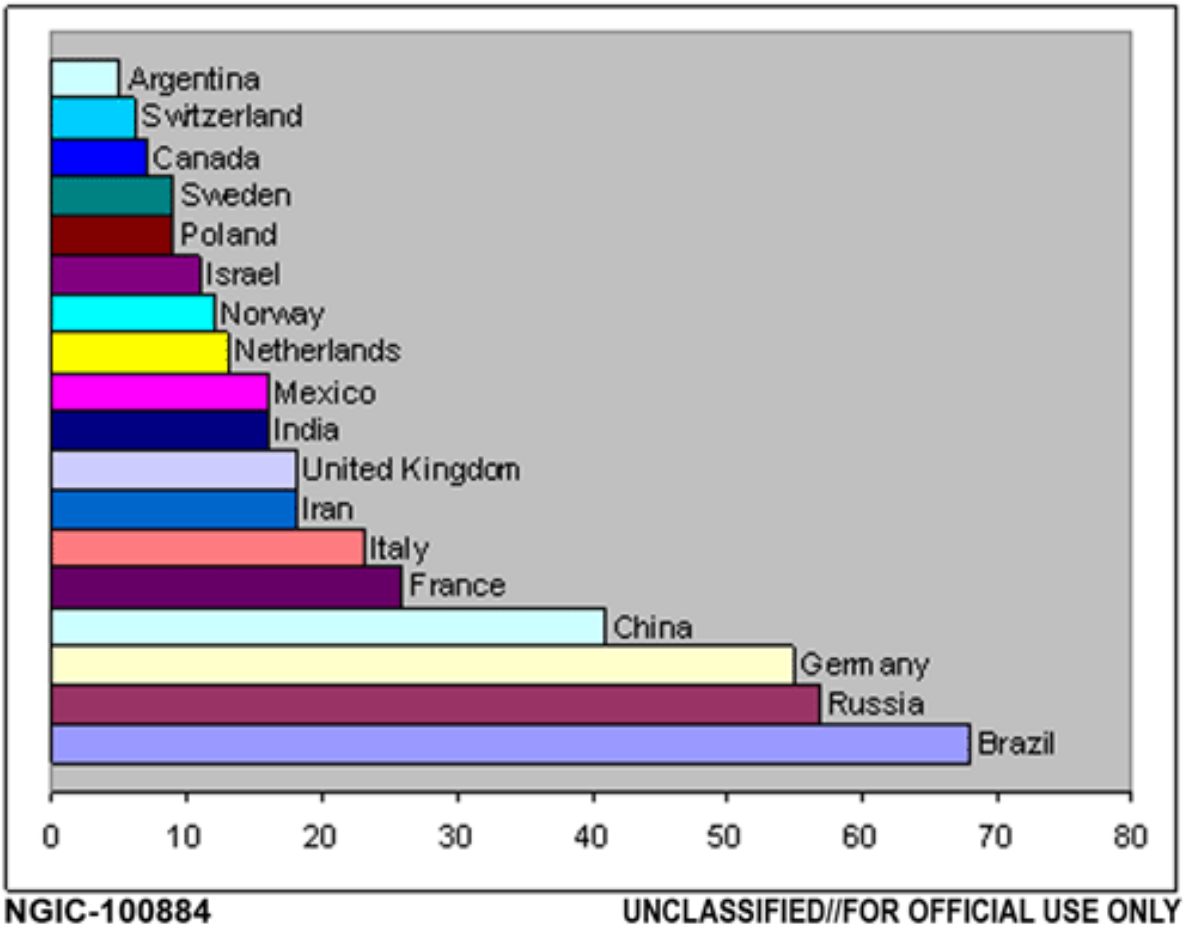
(U) Nanoscale Effects

(U) NEMS and MEMS are the most promising areas for actually exploiting ZPE because the applications involve the tiny scales and energies available through the Casimir force. Casimir force-driven ratchets and no-contact rack-and-pinion designs for micro- and nano-mechanical devices may offer the ideal solution to energy and driving-force problems on such small scales. Contactless translation components would help NEMS and MEMS avoid wear, which is a serious problem for gears and ratchets at such small scales. However, even in this case, the ZPE is not used as "free energy," but rather energy that is in a useful form at small scales.

(U) ZPE may also become useful in chemistry or biology research by creating or influencing movement of particles in liquids. Casimir-driven nanocomponents may also serve to separate particles in a fluid by their mass.

(U) Worldwide Research in ZPE

(U) Worldwide research in ZPE for use in practical applications is sporadic, conducted by countries that can afford to dabble in off-the-beaten-path studies, have serious space programs, or are doing innovative work in MEMS and NEMS research. The figure below shows the foreign countries that have produced the most journal articles on the subject.[f] The United States leads all countries with 115 publications and leads in citations as well. Foreign countries with journal publications among the ten most cited are Armenia, Brazil, France, Germany, Italy, Russia, Spain, and Sweden.



(U) Leading Foreign Publishers in the Fields of ZPE and Use of the Casimir Force

(U) Brazil, perhaps the most surprising entry on the publications chart, conducts research into measurements of Casimir force between different types of conducting plates that have varying designs. It is noteworthy that many of the researchers working in and with Brazil are Russian or originally from Russia. The Brazilian research also mirrors Russian research (i.e., studying the Casimir force using different setups of conducting plates). Both Brazil and Russia appear to be focused, at a basic-science level, on maximizing the energy obtainable from the Casimir force. A.N. Petrosyan, of the Moscow Engineering Physics Institute, and Yu.E. Lozovik, of the Institute of Spectroscopy of Russian Academy of Science, are conducting research into ZPE to create massless particles in a cavity, but the value of this research is questionable.

(U) Research in France and a collaborative effort between the United Kingdom (UK) and Iran comprise two of the most promising recent ventures in ZPE, as it pertains to MEMS and NEMS. The French are researching the possibilities of using the Casimir force to drive nanoscale ratchets in the hope of creating novel contactless translational actuation for NEMS or to move tiny objects in a liquid. The UK-Iran effort has similar goals and focuses on a rack-and-pinion powered by Casimir forces to enable contactless translation to avoid wear of the components. This work has demonstrated devices that hold up to high velocities and is a good example of valuable work in ZPE for use in practical applications.

(U) Germany has solid research programs in theoretical calculations, modeling, and experimental measurements of Casimir forces in various conducting-plate and cavity configurations. Germany's research appears aimed more at basic science than in engineering for applications.

(U) India is studying the use of the Casimir effect for MEMS devices, such as calculations of effects for different hypothetical designs, but the work is more theoretical than experimental or for practical

application.

(U) China appears to be researching several aspects of ZPE and the Casimir force, which is not surprising considering China's hopeful space program and its desire to become a bastion of scientific innovation.

- (U) Several Chinese students are working on the Casimir effect and measurement of the Casimir force at U.S. universities.
- (U) Professor Jiang Zingliu of Beijing Aeronautics and Astronautics University has given thoughts on vacuum energy at the *Fourth Session of Quantum Information Seminar* in Beijing.
- (U) The Wang Shum Ho prototype electricity generator (see figure below) was reportedly demonstrated to a few Chinese officials in January of 2007. Ho's group has a stated goal to build four 5 kW working units for the purpose of portable demonstration. While the group claims that the generator is to be based on ZPE concepts, it is unclear from the available technical information whether this is the case, and if so, what the mechanism would be to power such a device. This appears to be another "perpetual motion" proposal, but there is insufficient information to make this conclusion.

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(U) Chinese Scientist Holding an Alleged ZPE Generator

(U) Conclusions

(U) ZPE has been a controversial topic similar to cold fusion and antigravity for a number of years because of the hope it creates for "free energy" and grandiose solutions to the world's energy problems. This hope has made it sometimes difficult to separate the hype spread by pseudoscientists and inventors from very real and noncontroversial application potential of the small-scale forces

generated by the Casimir effect stemming from vacuum energy for nanoscale devices. While pockets of research in the field do exist, those with any promise for military technologies of tomorrow are less likely to affect space travel and more likely to affect future nanoscale devices.

(U) Consideration of Alternative Analyses and Contrary Evidence

(U//FOUO) As stated in the conclusion, ZPE has met with much controversy and debate. An alternate view of the topic is provided below by an analyst at Defense Intelligence Agency (DIA).

(U) Alternate View on ZPE

(U) "The topic of successfully exploiting zero point energy (ZPE) has importance because it represents a high-risk/high pay-off technology. This is not pseudo-science but a very serious discipline where very serious research is underway worldwide that range from investigating the Casimir effect, finding new alternative sources of energy, and developing a means of future long-range space travel. Efforts are currently underway at a U.S. aerospace corporation to include creating hardware to investigate using ZPE to provide energy. Finally, one would like to see experimental data and, hopefully, replication of such experiments representative of 'good' science. However, the amount of U.S. research dollars spent in this endeavor is abysmal such that even the simplest experiment cannot be performed. Although we are aware of only modest funding worldwide for this type of research, the Intelligence Community should monitor the more controversial aspects of ZPE, or we may miss an important foreign innovational leap forward, thereby leaving us vulnerable to technology surprise."

(U) **Note:** This alternate view was provided by an analyst of DIA and represents the view of this one analyst. It does not represent a DIA position.

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(U) Intelligence Gaps

- (U//FOUO) Amounts of funding provided by other countries to their ZPE and Casimir force research.
- (U//FOUO) Details of the relationship between Russia and Brazil on the topic.
- (U//FOUO) Development of indicators and warnings of a legitimate ZPE program.

Footnotes

a. (U) Plank's constant is 6.6256×10^{-34} J s.

b. (U) A recent publication by Federico Capasso et al. ("Casimir Forces and Quantum Electrodynamical Torques: Physics and Nanomechanics"--*IEEE Journal of Selected Topics in Quantum Electronics*, 13, 400-417, 2007) suggests that under certain circumstance a repulsive Casimir force could be produced. Possible applications for such a force are discussed in the paper.

c. (U) This equation is also for perfect conductors, so the force would be smaller in practical designs.

d. (U) It should also be noted that the parallel plates create an overall system that is no longer in the ground state (no longer only a vacuum) and, therefore, does not counter the definition of zero-point energy.

e. (U) For example, if A = 1 m^2 and d = 1 μm, then F = 1.3 x 10^{-3} N.
f. (U) This literature study was performed using SCOPUS to examine publications in zero-point energy with focus on the Casimir force or effect.

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