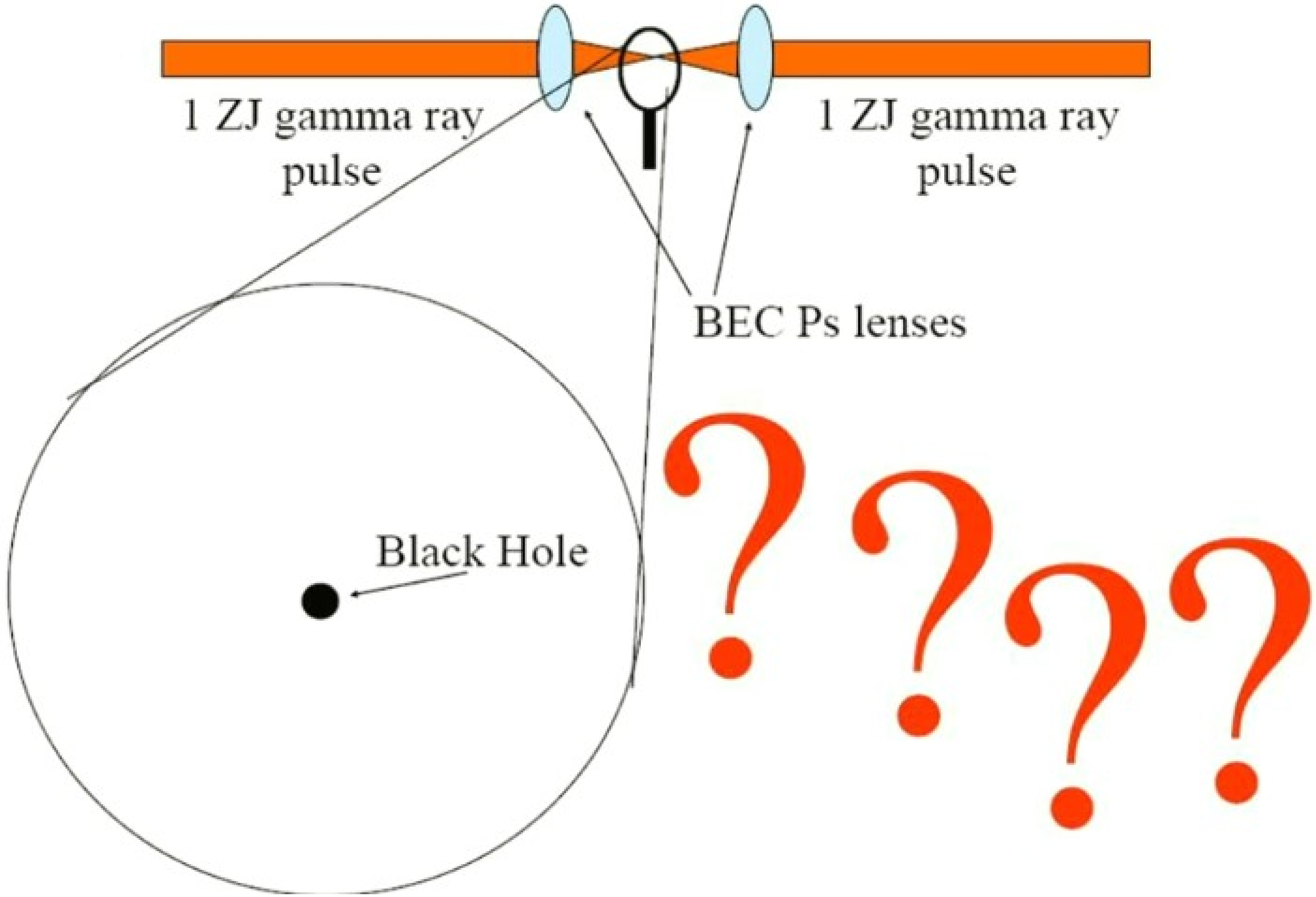
BEC annihilation gamma ray laser



This report gives the results obtained under a two year RevTek grant on the topic of Revolutionary Technology for Energy Sufficiency. The idea being explored is to use an annihilation gamma-ray laser to enable ignition of a fusion burn for actinide-free production of energy.

Summary Concept

A practical fusion energy source is the only way to energy sufficiency for the United States of America that will eliminate the strangle-hold of foreign oil. The three approaches presently on the table are close to scientific break even, but are far from being practical. Plasma fusion occurs at such low densities that the experimental reactor has grown too large to be competitive. Laser fusion obtains very high fuel densities but requires the use of laser powers that do not seem to be scalable. The impact fusion concept proposes to create high densities with high speed projectiles, but so far the densities that can be achieved are not sufficient to initiate burn.

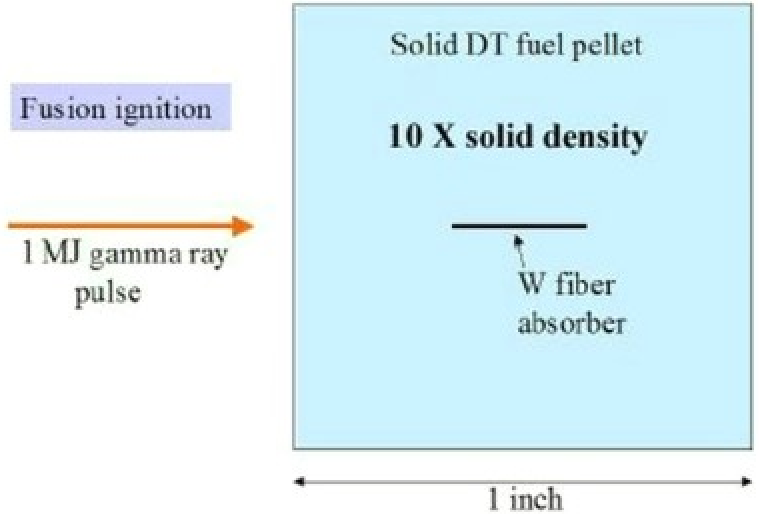


Figure 1. Ignition of a 1 inch DT fuel pellet at 10 x solid density using a 1 MJ gamma ray laser pulse.

The PI proposed reviving the impact fusion concept by using an annihilation gamma ray laser to ignite a fusion reaction in a compressed DT target, as indicated in Figure 1. The cubic inch of compressed DT shown in Figure 1 would burn in about 1 ns to yield 1,000 GJ of energy, ten times the current engineering break-even value. The process can be repeated every 1000 sec to yield a 1 GW reactor as indicated in Figure 2 or a single DT detonation could be used to set off a 1 megaton blast using a cubic meter of liquid D_2.

Figure 2. Power plant concept using periodic explosions of small DT pellets.

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Goals: The ultimate aim of the work I propose here is to perfect a powerful laser based on the coherent annihilation of a Bose-Einstein condensate of positronium [1], the hydrogen-like atoms formed from bound electron-positron pairs. Because this approach is beyond the present state of the art, I am proposing here to begin work by (i) building up the components needed for obtaining and manipulating significant quantities of antimatter, (ii) making the first experimental positronium annihilation gamma ray lasers and (iii)

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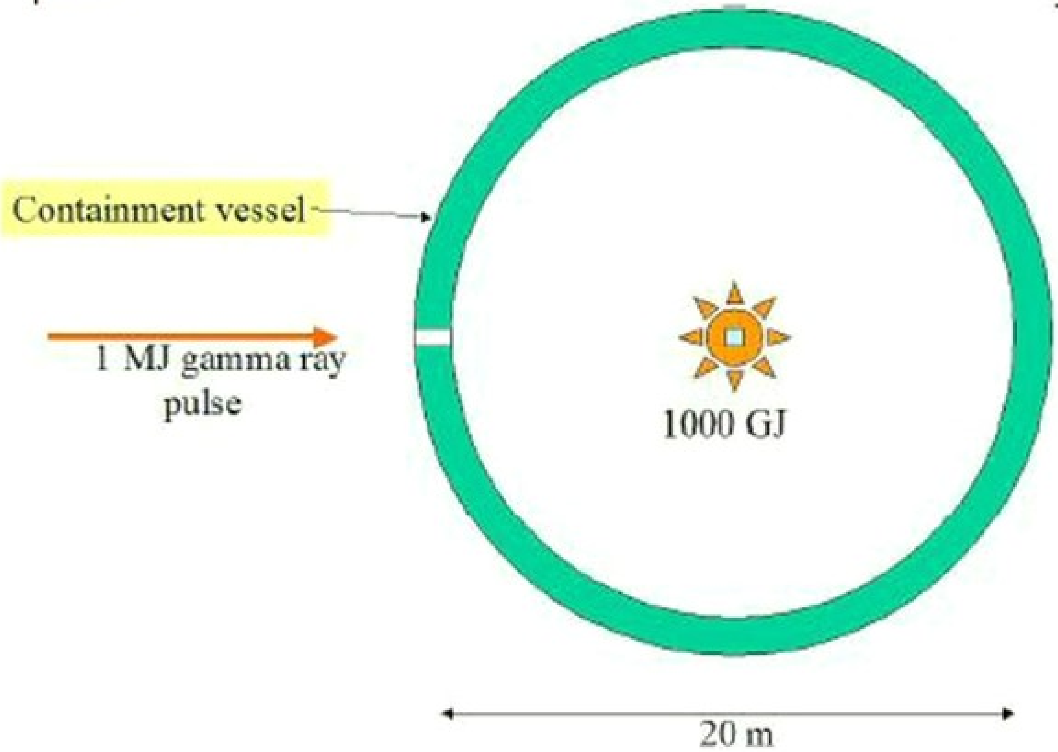

making substantial increases in our technical capabilities for using antimatter. The specific goals are:

- Form a Bose-Einstein condensate of spin-polarized triplet positronium atoms, which is a prerequisite for making an annihilation gamma ray laser, and observe its properties.
- Develop the necessary antimatter technology components including a positron storage device for storing and delivering 10^{13} positrons in a single 100 ns burst.
- Observe the stimulated emission of annihilation gamma rays which is the precursor to lasing.
- Make a positronium annihilation gamma ray laser delivering 1 Joule gamma ray pulses.
- Increase the positron storage to 10^{16} positrons and the laser energy to 1 kJ.
- Assess the prospects for scaling the technology to a system capable of delivering 1 MJ annihilation gamma ray laser pulses from a few nano-grams of positronium (10^{19} atoms).

Potential contribution to the Air Force. A powerful annihilation gamma ray laser could be used (1) as a clean igniter of fusion reactions both for energy production and for explosive devices and (2) to supply a large dose of gamma rays that would render a distant threatening object ineffective. For the latter type of applications above the earth's atmosphere, a substantial fraction of the energy of a small fusion device would be converted into a collimated beam of annihilation photons that would propagate through space and intercept the object. For power production, the positrons would be produced by conventional means via particle accelerators and stored in an accumulator for eventual use. Successful implementation of clean fusion for power production would be one of the major breakthroughs hoped for this millennium, and would nullify oil's present stranglehold to the obvious advantage of the United States of America. There are many potential roadblocks on the path to such a capability and I propose to find out as quickly as possible whether the approach is practical and cost effective by a serious program demonstrating the first positronium annihilation gamma ray lasers.

Travelling wave 203 GHz
0.1 nsec microwave pulse

first positronium annihilation gamma ray lasers.

Proposed technical approach. The annihilation of the electron and positron in a singlet positronium atom produces a pair of 511 keV photons. A collection of singlet positronium atoms of sufficient density and low enough thermal motion may be induced to annihilate coherently and thus form the basis for a gamma ray laser. [See Figure 3.] Assuming the implementation of only modest technical advances, we have the knowledge to make an annihilation laser capable of operating above the few mJ per pulse threshold level. To make a useful annihilation laser system capable of delivering 1 MJ of gamma ray energy to a 1 mm^2 target area at a distance of 100 m we need enormous technical developments in positron production, confinement, long-term storage and manipulation. I propose to explore the practicality of an annihilation laser by making the first lasers ever to be based on antimatter, by increasing the positron

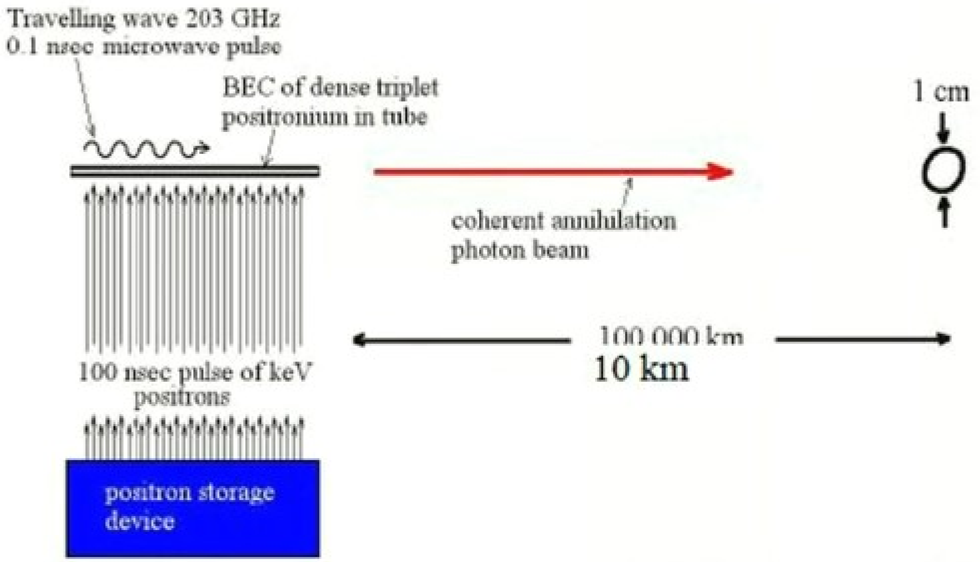

Figure 3. Annihilation laser concept. Positrons from a storage device are suddenly deposited in a tube several centimeters long and a few microns in diameter. The positrons form triplet positronium atoms that quickly cool to a few thousand degrees C and form a Bose-Einstein condensate. A microwave burst converts the positronium to the singlet state and a spontaneous annihilation photon that happens to propagate along the tube is amplified via stimulated emission to form a powerful coherent beam of annihilation photons.

production rate using a high energy accelerator and by making vastly improved traps for collecting and storing positrons.

Advantages of the proposed approach. The advantages of photons with energies of several hundred keV, loosely termed "gamma-rays", over optical energy photons for inflicting damage on a distant target or for igniting fusion reactions are:

- Gamma rays penetrate a target to a thickness of roughly 10 g/cm^2 and so impart up to two orders of magnitude greater impulse for a given energy compared to visible or infrared photons, thus leading to the fissure of large objects.
- Gamma rays are not significantly deflected by the atmosphere or its fluctuations, although absorption by the air limits the range at sea level to approximately 100 m if no means if employed for making a transparent gamma-ray channel through the atmosphere.
- The small size of the gamma-ray laser would be advantageous for steering and portability.
- A small annihilation gamma-ray laser would be fuelled by stored antimatter (positrons), which would leave no trace of radioactivity, although a GJ device might need to be based on energy derived from fusion.

Suitability of the PI for this project. The Pi is one of the world's best experimenters with positrons and has forty years of proven innovation in the field.

Plan of work. The first annihilation laser will be made in the following steps:

1. Attain Bose-Einstein condensed (BEC) positronium.
2. Make a source capable of delivering 10^{12} slow positron per second on a 1 mm target.
3. Develop a multiple trap for storing and releasing 10^{13} positrons.
4. Observe stimulated annihilation.
5. Make 1J annihilation gamma ray laser pulses.

A three year project to get through step 1 would proceed via the following tasks.

A. Year 1: Make a system for producing brightness enhanced 10 ns pulses of 10^7 5 keV positrons in a 10 μm diameter spot.

B. Year 1: Develop a method for making cavity structures in porous silica for containing BEC positronium.

C. Year 2: Make a BEC positronium target chamber with 4K cooling and optical access.

D. Year 3: Develop a laser system for detecting the BEC state via the disappearance of Doppler broadening.

E. Year 3: Characterize the positronium BEC by measuring the condensate fraction as a function of time, temperature and density.

One will note that each of the steps will be exploring interesting physics with the possibility of unexpected results and important technological applications, including for example (a) study of the time structure of a positron initiated thermite reaction, (b) measurement of Ps thermalization and diffusion dynamics, (c) observation of the giant absorption cross section associated with a coherent state localized within an optical wavelength. The first positronium BEC will be remarkable for its high critical temperature and quasi 2D behavior which will be evident in the condensate density as a function of temperature.

CONCLUSIONS

We have demonstrated progress in the production and utilization of positron pulses that can possibly be scaled up by four orders of magnitude to the point where we will be able to demonstrate stimulated annihilation. We have developed the lasers that will be useful for cooling and diagnostics as we attempt to make the first positronium Bose-Einstein condensate. We have also estimated that about 1 MJ would be required to initiate DT burn. Considerably more development would be required to achieve this goal.