FUSION INDUCED BY ENERGY-INTENSIVE MULTIFUNCTION CAVITATION IN CONJUNCTION WITH POSITRON IRRADIATION

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ABSTRACT

This review summarizes the development of multifunction cavitation technology and assesses future applications for this process. The focus is on attempts to increase the surface strength and functionality of various metals and plastics and to elucidate the conditions that can induce nuclear fusion by cavitation. An experimental setup capable of producing cavitation fusion based on positron-irradiated laser-assisted high-field energy-intensive functional cavitation is described, having the same basic structure as a prior device without positron irradiation. A combination of water jet, ultrasonic and magnetic field energy sources has been found to increase the sonoluminescence intensity and to theoretically exceed the threshold required for the D-T fusion reaction. This paper describes the incorporation of positron and laser energy sources to this system as a means of further increasing the internal temperature and pressure values of bubbles. Specifically, a Na-22 positron beam source was placed in the upper part of the reaction vessel in the direction of the magnetic field such that positrons were imparted to cavitation bubbles floating on the surface of degassed heavy acetone. These positrons were partially annihilated by interactions with electrons via the Compton effect to generate gamma-rays and energy via the reaction $e^+ + e^- \rightarrow 2\gamma + 1.02$ MeV. This energy promoted the D-T chain reaction D + T → 4He + n + 14 MeV to increase the probability of cavitation fusion.

Keywords: Cavitation Fusion, Multifunction Cavitation, Positron Irradiation

1. INTRODUCTION

Approximately 90 years have passed since the discovery of the positron and more than 60 years since positrons were first used in the study of condensed matter. During this time, there have been many studies regarding the electronic structure of alloys, such as Fermi surfaces, that have taken advantage of the properties of positrons, including research on lattice defects. Important experimental methods within this field were developed in the 1980s, including two-dimensional angular correlation, positron beams Brandt et al. (1983), Schultz and Lynn (1988) Additional progress in experimental techniques occurred in the 1990s. As an example, high-efficiency two-dimensional angular correlation techniques were devised, making it possible to perform higher resolution assessments of high-temperature superconductors and semiconductor defects in shorter time frames. In conjunction with these advancements, high-intensity, high-quality, low-speed positron beam technologies were developed both in Japan and elsewhere. These beams have allowed the analysis of near-surface defects and interfaces as well as the determination of depth profiles. Other associated techniques have included slow positron diffraction, positron annihilation Auger electron spectroscopy and positron microscopy Ishii (1993), Puska and Mieminen (1994), Asoka-Kumar et al. (1994), Dupasquier et al. (1995).

The positron (e^+) is the antiparticle of the electron. It is an elementary particle that has the same mass as an electron and the same absolute charge value but the opposite charge sign. Radioisotopes such as ^{22}Na and ^{58}Co are often used as positron sources in laboratory work and the present study employed ^{22}Na for this purpose. The positrons resulting from the β^+ decay of ^{22}Na (positron and neutrino emission (positive beta decay, positron decay) tend to exhibit a continuous spectrum with a maximum energy of 540 keV and an average of 220 keV. In the case that fast (white) positrons are incident on a metal surface, these particles will penetrate to a depth of approximately 0.1 mm and are slowed down to thermal energy within a time span of approximately 1 ps. This phenomenon generates thermal positrons. These thermalized positrons diffuse over a distance of approximately 10^{-7} m in a crystalline metal before they are annihilated by combining with one of the many surrounding electrons. The lifetime of these thermal positrons in on the order of 100-200 ps and these annihilations emit two gamma rays (γ_1 and γ_2), each with an energy of 511 keV and moving in nearly opposite directions. Positrons in bulk metals do not form specific bound states with electrons. However, in molecular or ionic crystals, annihilation can also occur from the positronium state. Because the positron has a positive charge, it will move away from the positive ions that constitute a metallic crystal. Therefore, positrons (also known as Bloch positrons) moving through a crystal containing conduction electrons represent the primary annihilation partners for ions. Positrons that arrive at sites at which positive ions are missing, such as atomic vacancies, microvoids (three-dimensional vacancy clusters less than 1 nm in size), voids or surfaces will be captured and disappear.

Room-temperature ionic liquids (RTILs) are widely used and a number of methods for indirect observation of the microscopic properties of these materials have been developed. A positronium (Ps) atom, meaning a combined positron and electron, can act as a microscopic probe in this regard. Specifically, a Ps atom in an RTIL will be in a different state than that in a molecular liquid and the effect of temperature on this Ps atom is also likely to be completely different. Positrons can be injected into a liquid from above its surface and the effect of temperature on the positron lifetime near the liquid surface and in the bulk can be assessed. On this basis, prior work has investigated the state of Ps atoms in an RTIL together with the effect of temperature on the surface structure of the IL Zhou et al. (2012).

Along with the development of techniques using positrons to evaluate lattice defects on material surfaces as described above, the use of these particles for surface modification to improve surface strength has also progressed. Shot peening is a type of injection processing intended to impart work hardening and compressive residual stress to a metal. These effects occur as a consequence of plastic deformation based on the collisions of the metal with numerous small spheres made of steel or non-ferrous metals and travelling at high speeds Okido et al. (2002). This technology has previously been applied to prevent stress corrosion cracking of metals. In initial studies, this effect was used to improve the tensile residual stress in weld zones by generating compressive residual stress in the reactors and internal structures of nuclear power plants. However, shot collection after processing was found to be less than 100%. On this basis, water jet peening (WJP) using water originally present in the reactor Saitou et al. (2003), Yoshimura et al. (2007) was developed as a means of improving the process, and this technology has since been applied at various nuclear power plants in Japan. Prior work by our group also demonstrated that the corrosion resistance of steel could be improved using mechanochemical cavitation technology (MC-WJP) Yoshimura and Sato (2014) based on the use of an ejector nozzle and addition of a small amount of chemicals.

Various approaches to cold fusion research have been proposed to date Yoshimura et al. (2018d). Taleyarkhan et al. carried out ultrasonic cavitation trials using deuterated acetone (C_3D_6O) and measured the amounts of tritium and neutrons generated from these processes Taleyarkhan et al. (2002), but other researchers were unable to replicate these experiments. Our own group performed theoretical and experimental studies aimed at assessing the possibility of bubble nuclear fusion. This prior work developed a technique referred to as multifunction cavitation in which ultrasonication is combined with water jet energy Yoshimura et al. (2016a), Yoshimura et al. (2016b), Yoshimura et al. (2018a), United States US Patent No. 10,590,966: Yoshimura (2020). This technology was subsequently used to investigate the bubble fusion phenomenon and it was determined that fusion can occur in the case that the initial bubbles rapidly expand and contract Yoshimura et al. (2018b), Yoshimura et al. (2018c).

It is possible to increase the internal temperature and pressure of cavitation bubbles by applying concentrated ultrasonic radiation from the periphery of a conventional WJC jet rather than from only one direction Yoshimura et al. (2021b). This technique was used to develop an energy-concentrating multifunction cavitation system in which five ultrasonic transducers are arranged around a water jet. Work by our group showed that a narrow 0.1 mm nozzle can replace the standard 0.8 mm nozzle to reduce the quantity of deuterated acetone used in the bubble fusion process when performing surface modification. In other research, a magnetic field and laser energy were also superimposed on the water jet Yoshimura et al. (2021a), Yoshimura et al. (2022b). The resulting ultra-high-temperature, ultra-high-pressure cavitation surpassed the threshold values of 1.0×10^{10} K and 1.0×10^{8} MPa required for the D-T nuclear fusion reaction Yoshimura et al. (2021a). Our group additionally developed laser assisted magnetic field energy-intensive concentrated multifunction cavitation (LMEI-MFC) apparatus Yoshimura (2023a) for the surface modification of materials. The configuration of this apparatus was almost the same as that of the LMEI-MFC fusion device, except that a vacuum was applied for the purpose of degassing and either pure water or tap water could be employed for surface modification. The LMEI-MFC fusion device initially incorporated a 0.1 mm nozzle although a larger version with a nozzle diameter of 0.8 mm and a flow rate of 7 L/min was also designed Yoshimura et al. (2021b), Yoshimura et al. (2021c), Yoshimura et al. (2021d), Yoshimura et al. (2021e), Ijiri et al. (2022a), Ijiri et al. (2022b), Ijiri et al. (2021a), Ijiri et al. (2021b), Ijiri et al. (2021c), Ijiri et al. (2019). A larger water jet nozzle diameter has been found to increase the cavitation diameter generated in the water jet, although the flow rate is also increased. This is disadvantageous because deuterated acetone is expensive and so the flow should be as low as possible. As the cavitation diameter becomes smaller, the microjet impact pressure during bubble collapse decreases but the impact pressure due to the Lorentz force can compensate for this change. It should be noted that positrons incident on condensed phases such as water and other liquids will have short penetration depths because these substances do not contain the same defects found in crystalline solids. The cavitation bubbles that rise to the surface of heavy acetone during degassing are in a state in which the thin bubble walls are balanced by the surrounding liquid pressure, the internal air pressure and the Laplace force. The probability of passing positrons through the metastable thin bubble walls is considered to be high.

2. MATERIALS AND METHODS

Figure 1 shows a schematic diagram of the cavitation fusion apparatus developed by our group. In this apparatus, the reaction vessel has a heptagonal pyramidal shape that is similar to a widening cone. This shape was originally devised with the intention of using a swirling nozzle Yoshimura et al. (2018d), Yoshimura et al. (2022f) to generate a swirling flow around a conical water jet as a means of reducing pressure. The sonoluminescence output Yoshimura (2023a), Yoshimura et al. (2023b) resulting from the emission of photons from multibubbles in the PLMEI-MFC (Positron and Laser assisted Magnetic field Energy-Intensive concentrated multifunction cavitation) can also be monitored. As an alternative to heavy acetone, a mixture of standard acetone and heavy acetone is injected into the reactor at 40 MPa. The resulting cavitation jet is subjected to ultrasonic irradiation around its periphery. The bubbles in this system undergo isothermal expansion at low sound pressures and rapid adiabatic compression at high sound pressures. This repeated expansion and compression generates ultra-high-temperature, high-pressure cavitation. Consequently, the liquid inside the bubbles is vaporized and subsequently undergoes thermal decomposition such that free deuterium and oxygen atoms/ions are generated. Although the system is operated under a vacuum, residual atmospheric nitrogen and argon may be included in the liquid wall. Argon has a high ionization energy but may nonetheless undergo ionization under these conditions as a result of the concentrated energy that is employed. Placing powerful neodymium magnets around the reaction vessel imparts a high magnetic field to the jet such that the charged bubbles experience a Lorentz force and collide at high speeds. Furthermore, in the case that the cavitating jet is irradiated with a laser beam at a wavelength of 450 nm, ionization in the charged bubbles is promoted due to multiphoton excitation. As a consequence of the synergistic effect obtained from rapid contraction due to the adiabatic compression of the bubbles and high-speed collisions between the bubbles, the pressure and temperature required for nuclear fusion are exceeded. Collisions of deuterium atoms, D, with one another generate helium atoms, He, neutrons, n, tritium atoms, T, and protons. As D and T collide the reaction D + T → 4He + n + 14 MeV also occurs.

Disintegration is a phenomenon in which high-speed particles are expelled from an atomic nucleus such that a different element is produced. In some such cases, a neutron from the nucleus can change into a proton in conjunction with the emission of an electron (e^-) via the process

($n \rightarrow p^+ + e^- + \bar{\nu}$). It is also possible for a proton to change to a neutron with the emission of a positron (e^+) via the reaction $p^+ \rightarrow n + e^+ + \nu$. These emitted electrons are referred to as β-rays (or β-particles) and this phenomenon is known as β-decay. Here, $\bar{\nu}$ and ν are so-called anti-neutral and neutral particles (that is, neutrinos). In any decay, the kinetic energy possessed by the ejected β-particles will be $E = \frac{1}{2}mv^2$ and the ejection velocity, v, will differ for each decay such that the energy distribution will be a continuous spectrum.

Charged particles and electromagnetic waves will interact with matter such that they lose energy (or velocity) and eventually stop moving. Alpha rays (that is, beams of ^{4}He, which comprises two protons and two neutrons) readily ionize solid targets and so can be stopped by a single sheet of paper. In contrast, β-rays can travel for several meters in air depending on their energy and will penetrate plastic to a depth of approximately 1 cm and aluminum to a depth of 2 to 4 mm. Gamma rays and X-rays have much greater penetrating power than α-rays and β-rays, although again this depends on the beam energy, and can travel several tens of meters in air. These radiation types can only be stopped by thick plates of dense metals such as lead or iron. Uncharged neutrons lose energy through collisions and are then absorbed by interactions with matter. That is, neutrons lose energy (as represented by velocity) by colliding directly with the atomic nuclei that make up matter. Energy is most effectively lost when colliding with protons (meaning hydrogen nuclei) of approximately the same mass.

The neutrons generated in such experiments were detected by a neutron counter installed at the same position as the photon counter monitoring the luminescence intensity from bubbles in the PLMEI-MFC apparatus shown in Figure 1. These neutrons were able to pass through obstacles such as a thin iron plate but, in doing so, generated γ-rays that had to be controlled. Therefore, the entire apparatus was surrounded by high-density polyethylene containing diboron trioxide (B_2O_3), which exhibits a high neutron shielding effect. Regulatory requirements restricted the total effective radiation dose to 1 mSv or less per week. It should be noted that, for this device to serve as a practical energy source, the kinetic energy of the neutrons would be converted into thermal energy.

Figure 1

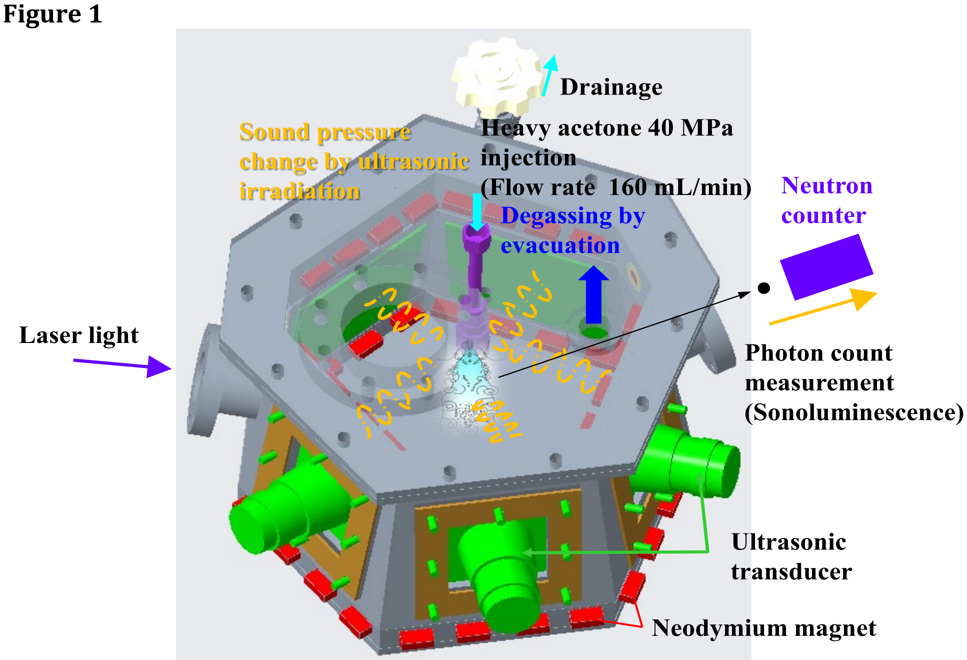

Figure 1 Positron Irradiation (PLMEI-MFC) Cavitation Fusion Equipment.

As shown in Figure 2, a ^{22}Na positron beam source is placed in the direction of the magnetic field such that the positrons follow Fleming's left-hand rule and move toward the surface of the degassed heavy acetone. These neutrons are subsequently captured with a certain probability in cavitation bubbles that float on the liquid surface. The image in Figure 3 demonstrates cavitation that appears on the surface of the acetone during degassing. The apparatus employed a NA351 source provided by the Japan Radioisotope Association. The disc-shaped source was sandwiched between films made of the polyimide Kapton® (having a thickness of 7.5 μm) and positrons were emitted in almost all directions. This source is typically used for positron annihilation experiments in conjunction with a vacancy analysis technique for materials such as metals. It has a half-life of 2.6 years and emits β-rays at 546 keV in addition to γ-rays at 1.275 MeV. The decay of ^{22}Na to ^{22}Ne causes positrons to be emitted according to the reaction ${}^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + e^{+} + \nu_{e}$. If the positrons are emitted in the 4π direction, the β^+ rays emitted below the direction of the magnetic field will bend toward the liquid surface and come into contact with cavitation bubbles rising to the liquid surface. It is not clear at present whether Ps atoms are formed when positrons enter through the bubble walls, which are balanced by the surrounding liquid and the Laplace force. In the present apparatus, the liquid phase is prevented from contacting the Na-22 source by a transparent plastic membrane.

The Na-22 source provided a radioactive output of 1 MBq and so no special management protocols were required. Figure 4 plots the number of photons emitted per second as determined using H9319-02 photon counting heads (Hamamatsu Photonics K.K.) with and without the positron source under a blackout curtain blocking external light. In the absence of positrons, the photon count was approximately 5500 photons/s but increased to 14,000-48,000 photons/s when positrons were captured by the counting heads. In the case that X-rays or γ-rays collide with electrons, additional energy may be imparted to the electrons causing a change in the wavelength of the original X-rays or γ-rays (meaning that these rays have lost energy). This phenomenon is known as the Compton effect and is also responsible for the partial annihilation of positrons in the present apparatus. After a positron enters a bubble, it is immediately annihilated by combining with an electron, leading to the generation of two gamma-ray photons according to the equation $e^{+} + e^{-} \rightarrow 2\gamma + 1.02$ MeV. This energy promotes the D-T chain reaction (D + T → 4He + n + 14 MeV). In addition, using a laser light port, a slow positron beam Brandt et al. (1983), Schultz et al. (1988) can be applied to cavitation bubbles in the heavy acetone to generate cavitation nuclear fusion.

Figure 2

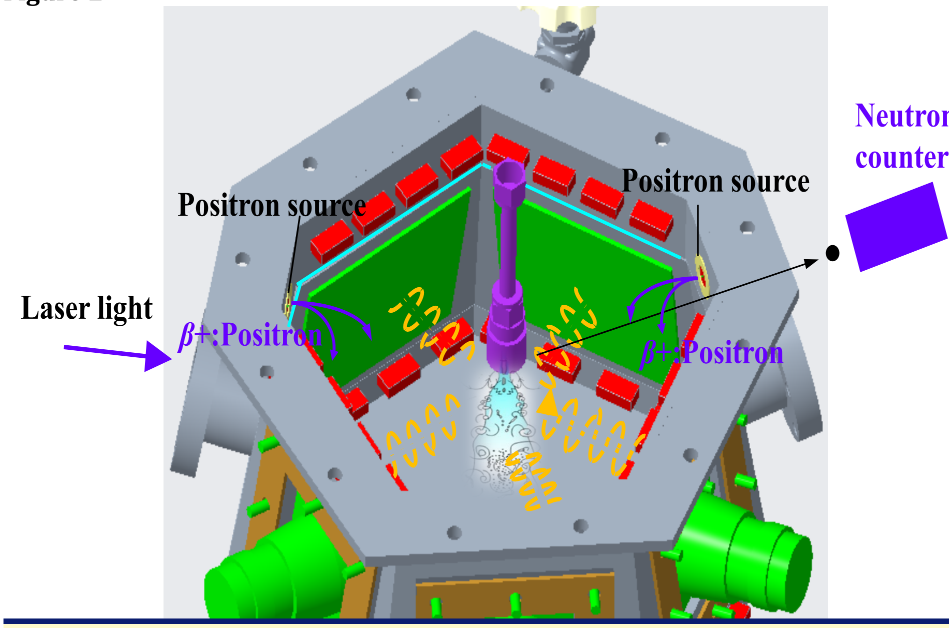

Figure 2 Positron Irradiation (PLMEI-MFC) Cavitation Fusion Equipment (The Upper Flange Hidden).

Figure 3

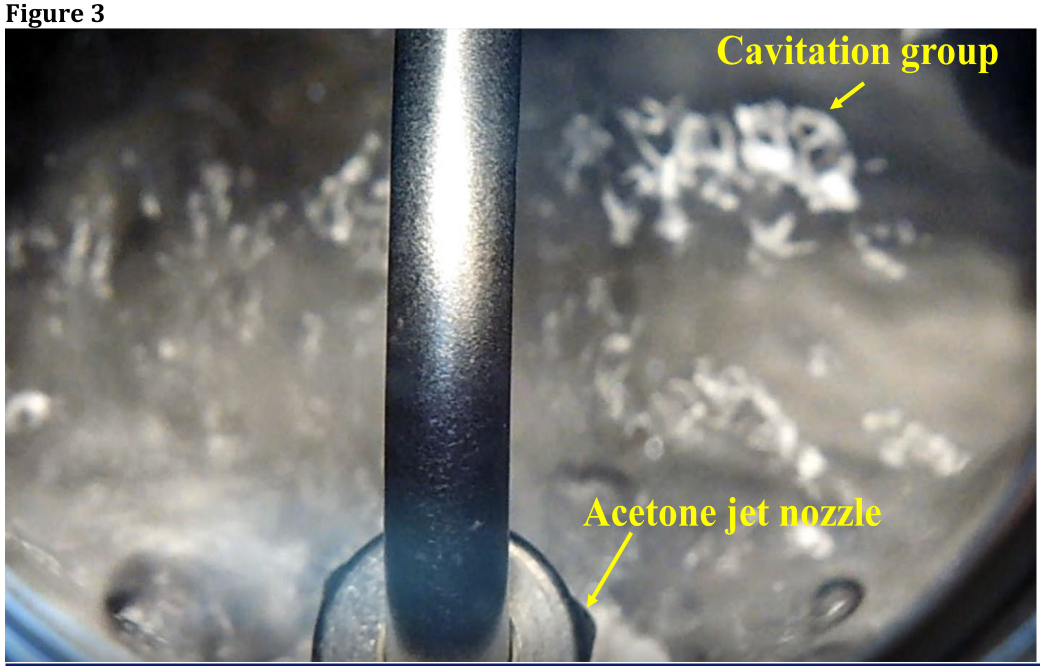

Figure 3 Cavitation Groups Observed on Acetone Surface During Degassing.

Figure 4

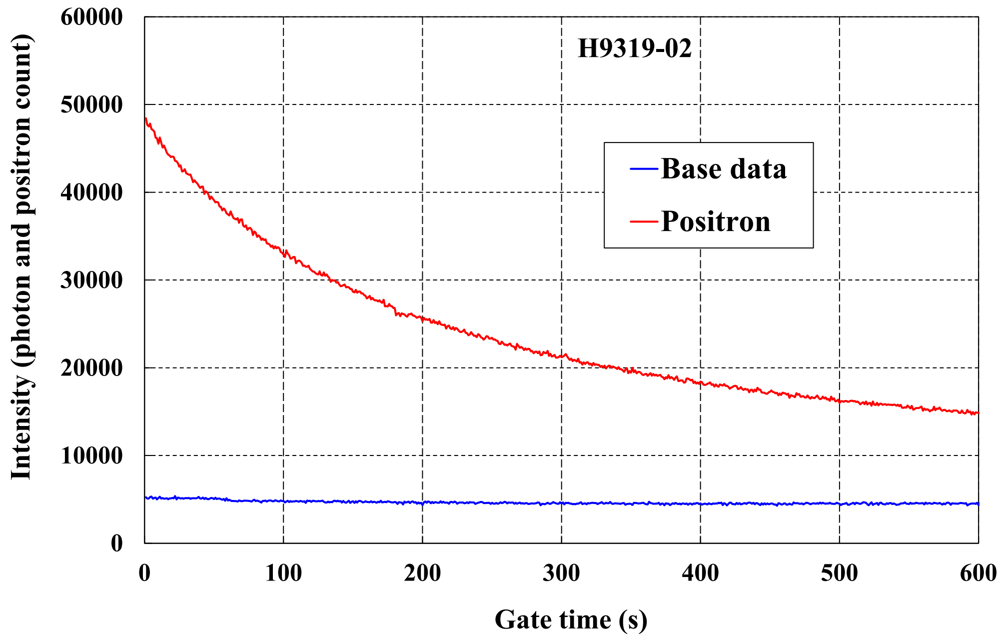

Figure 4 Positron β+ Ray Emissions Over Time as Measured Using a Photon Counter.

A radiation monitor (Iwatsu Electric Co., Ltd., Radiation Dose Monitor SV-2000) was used to measure gamma rays from the positron source. The measurement range was from 0.001 to 9.999 μSv/h with a minimum display resolution of 0.001 μSv/h. The background radiation level in the laboratory was determined to be 0.62-0.65 μSv/h. Prior work by Taleyarkhan irradiated heavy acetone and standard acetone held in a cylinder with neutrons both with and without cavitation. This work indicated that neutron irradiation in conjunction with the cavitation of deuterated acetone increased the amount of neutrons generated. However, the effects of factors such as reflection of the neutron beam were not fully evaluated Taleyarkhan et al. (2002), Seife (2002). In the present PLMEI-MFC apparatus, neutron generation from numerous bubbles in pure water was investigated based on the continuous flow of a liquid jet without neutron irradiation during the cavitation process. Although this study could not be experimentally approached because our laboratory has not a radiationshield environment, the luminescence intensity increased as the energy imparted to the system was increased such that the temperature and pressure of bubbles subjected to a water jet, ultrasonication and a magnetic field as energy sources theoretically exceeded the thresholds required for the fusion D-T reaction Yoshimura et al. (2021). Both laser and positron energy were added in these trials and further improvements in emission intensity were observed, suggesting that the internal bubble temperatures were further increased. In addition, multiphoton excitation was induced by the laser irradiation and the collision pressure between bubbles was therefore expected to be increased. Reactions between positrons and electrons in the bubbles promoted intra-bubble nuclear fusion, thus further raising the possibility of achieving cavitation fusion. Experimental verification of these phenomena is urgently required.

CONFLICT OF INTERESTS

None.

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