Piezonuclear Neutrons

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Abstract

We report the results of neutron measurements carried out during the application of ultrasounds to a solution containing only stable elements like Iron and Chlorine, without any other radioactive source of any kind. These measurements, carried out by CR39 detectors and a Boron Triflouride electronic detector, evidenced the emission of neutron pulses. These pulses stand well above the electronic noise and the background of the laboratory where the measurements were carried out.

1 Introduction

The application of ultrasounds of suitable frequency and amplitude to a liquid, with gas dispersed in it, brings about the process that is known as cavitation \cite{1,2}. It occurs when the micro bubbles dispersed in the liquid collapse under the spherically symmetric compressions of ultrasounds. The processes that go on during the collapse and the collapse itself are quite complex and there is a good deal of research going on in order to clarify their physical and chemical aspects. Some of the studies that have been carried on, have the target to exploit cavitation as the mean to induce deuterium-deuterium nuclear fusion...
in a liquid matrix [3]-[12]. It is known as well that mechanical waves like ultrasounds and shockwaves can induce or better catalyse nuclear reaction in radioactive elements, fission in fissile elements with emission of ionising and neutron radiation too low for the occurring transmutations or with no emission at all [13]-[17]. The research that we have carried on, although it might seem to deal with the same physical terms such as nuclear reactions, nuclear radiation and to point towards the same technological direction, it is based on different theoretical concepts, that are all presented in [18][19][20], and in this sense is moving along a parallel path with respect to the other research paths and together with them it contributes to enlarge our view and knowledge of these new physical phenomena. We carried out five experiments in the last few years. In the first three of them [21][22][23] we collected evidences of anomalous production of intermediate and high mass number nuclides within samples of cavitated water. These outcomes, that agree with those obtained by Russian teams [13]-[17], point out that ultrasounds can induce nuclear phenomena such as modifications of the nuclei, and alter secular equilibriums. A further outcome of these three experiments is that the number of protons after cavitation is conserved while the number of neutrons is not. This circumstance convinced us to carry out some experiments in order to confirm this evidence by revealing the presence of emitted neutrons during cavitation. Two sets of experiments [20] were carried out in which we cavitated water and different solutions of metallic salts, of different concentrations with diverse ultrasonic power and different geometry of the sonotrode tip and the cavitation chamber. All of these experiments succeeded in detecting neutrons. We would like to stress that all our experimental equipment and our measurements, when devoted to prove neutron emission, never involved any radioactive source or unstable nuclide unlike other experiments [3]-[12].

2 Initial evidence of neutron emission

Our first main goal was only to reveal (not exactly measure) any possible emission of neutrons from the solutions subjected to cavitation. Thus we used the CR-39 (PADC) plastic track detector that is a C_{12}H_{18}O_{7} polymer with density 1.3 g/cm$^3$ which is used for registration of heavy charged particles and is a very convenient mean of detection. Charged particles are registered directly, and neutrons are detected through a secondary recoil particles or nuclear reactions. The CR39 energy range sensitivity is very wide, from tens of KeV to hundreds of MeV. Particle tracks on the detector become visible after chemical etching and are investigated using a microscope. As we stated above, the only evidence that we could gain from the previous experiments was the non conservation of the number of neutrons which suggests a possible neutron emission, but does not say anything about their spectrum, their isotropy and homogeneity in space and their constancy in time. In this sense, a passive detector like the CR39, which is able to integrate the signals in a wide range of energy regardless of the time structure of the emission, is very useful to reveal the presence of these apparently emitted neutrons as it does not require any sort
of adaptive electronic calibration which would be necessary with an electronic detector in order to track and follow an emission that, as far as we know, could be the most variable one in terms of energy and time. Once that an initial but solid evidence of neutron emission was gathered by these passive detectors, we soon increased the quality of our investigation by moving to electronic Boron Trifluoride detectors whose evidence will be presented in this paper. In order to detect neutrons by the CR39 we used the nuclear reaction $^{10}\text{B}(n,\alpha)^7\text{Li}$ and hence spread a 2 mm layer of natural Boron (80.1% $^{11}\text{B}$, 19.9% $^{10}\text{B}$) on the CR39 detecting surface which had to convert neutrons into alpha particles, following a well known technology [24, 25, 26]. These Boron-CR39 detectors were used in our experiment during the cavitation of a 10 ppm solution of Iron Chloride FeCl$_3$ in which we conveyed ultrasonic power for 90 minutes. The ultrasounds released in the cavitation chamber had a stable power of 130 Watts at a frequency of 20 KHz in order to induce cavitation according to the Rayleigh-Plesset equation [2]. Two Boron-CR39 detectors were placed facing each other one at each end of a diameter of the cavitation chamber and both facing the area were cavitation took place at 2 cm from it. Of course two more CR39 detectors without Boron layer were placed beside each of them in order to compare the response. Two more detectors, one with an unscreened CR39 and the other with Boron-CR39 were used as reference and placed in a different area with respect to the zone where cavitation was taking place. In order to have an idea of what the traces should look like on these detectors after etching, four more detectors were irradiated by neutrons using as source, the fast neutron nuclear reactor TAPIRO at Casaccia ENEA Rome, the neutron equivalent dose conveyed onto the detectors was 2.1 $\mu$Sv through a diagnostic neutron channel. In Fig.1 we present the outcomes of these series of experiments. The Boron-CR39 with code E89627 was placed with its detecting surface orthogonal to the neutron channel of the nuclear reactor TAPIRO with its centre on the channel axis. It clearly shows the expected tracks at its centre (a 50 magnification photo is presented as well for a better vision). The other three CR39 used to measure the background around the nuclear reactor do not show any thick track and the number of tracks on them is much lower than that on the E89627. The CR39 detectors with code H40502 and H40514 were used with the cavitation chamber and show tracks absolutely compatible with that produced by the neutrons of the nuclear reactor.

We would like to highlight one difference between the E89627 and the other two CR39 (H40502 and H40514). It is quite reasonable to state that the distribution of the tracks on the central part of the E89627 is nearly circular around the thick track. This is the

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1Not knowing what kind of neutron spectrum to expect from the cavitated solution, as already stated, we decided to produce our comparison model of traces by a source whose spectrum were the widest possible, i.e. a nuclear reactor. According to reference [24], these kind of detectors can detect fast, epithermal and thermal neutrons with different sensitivities of course. Hence the integral effect, due to almost the whole neutron spectrum on the detectors, would be traces whose quantity and shape would be compared to those obtained from the piezonuclear reactor.

2The chemical etching of the CR-39 foils was carried out in a 6.25N NaOH (Carlo Erba standard) solution at 90°C for 4.5 hours according to the specifications given by the firm FGM Ambiente which provided them
Figure 1: The first column shows the Boron-CR39 detector irradiated by the nuclear reactor TAPIRO at Casaccia ENEA with a neutron dose of 2.1 $\mu$Sv (upper row: magnification X 10 - lower row: magnification X 50), the second and third columns show the two Boron-CR39 detectors that were next to the cavitation chamber during the application of ultrasounds (upper row: magnification X 10 - lower row: magnification X 50).
consequence of the cylindrical channel through which it was irradiated, that produced a neutron flux with a cylindrical symmetry\(^3\). Hence, this distribution and the thick track were gradually generated along the irradiation time. Conversely, the other two CR39 do not show any particular distribution of tracks which is consistent with the lack of any preferred direction of neutron emission from the volume where cavitation was taking place. As to what one might expect, the emission should be isotropic. Despite that, on the two CR39 detectors there are two thick tracks at the centre of the chips which perpendicularly faced the centre of the cavitation volume. We reckon that this difference can be considered as a strong hint to state that the neutron emission is not continuous but, conversely, takes place with neutron pulses.

### 3 Measurements of the emission of neutron pulses

Having achieved several positive evidences of neutron emission from cavitation, we decided to refine our research by performing the same measurements by a Boron Trifluoride detector. Before presenting the experiments and their results, we would like to stress once more that the purpose of these experiments has been to measure the emission of neutrons during the cavitation of solutions of stable elements. It might seem, on an experimental basis, that our work made its first move from that stream of research which investigates the induction of nuclear fission in fissile elements and/or nuclear fusion in light elements\(^3\)\(^-\)\(^17\) by mechanical compressions like ultrasounds. However, before presenting our experimental outcomes, we would like to warn the reader that, both on the theoretical and experimental side, our research diverges from that stream and it concentrates on absolutely stable elements\(^4\) according to the suggestions of our theoretical predictions\(^18\)\(^-\)\(^20\) which indicate that nuclear processes can be induced in stable nuclides too only by suitable mechanical waves, i.e. without any application of radioactive or nuclear active substances. We cavitated 250 ml of a solution of Iron Chloride FeCl\(_3\) by applying to it 130 stable Watts of ultrasonic mechanical vibration at 20 KHz for 90 minutes. The cavitation chamber was a vessel of Schott Duran\(^6\) BoroSilicate glass\(^27\) and the truncated conical sonotrode that conveyed ultrasounds was made of AISI grade 304 steel. The immersion of the sonotrode in the solution was 5 cm\(^5\). During cavitation we measured neutron emission by the Wedholm Medical 2222A Boron Trifluoride neutron monitor\(^28\) and ionising radiation and in particular gamma radiation by UMo LB 1236 monitor whose energy range is from 30 KeV up to 2 MeV and which gives both equivalent dose and equivalent dose rate in a wide range from 50 nSv/h up to 10 mSv/h\(^29\). The neutron monitor was calibrated by an Americium Beryllium standard source contained

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\(^3\)The axis of the cylinder was perpendicular to the CR39 squared chip and passing through its centre.

\(^4\)These stable elements are all but deuterium, since we are not looking for Deuterium-Deuterium fusion.

\(^5\)Further details about the geometry of the sonotrode and the cavitation chamber and about their exercise are contained in three patents owned by the Consiglio Nazionale delle Ricerche (CNR) (National Council of Researches of Italy) now published in\(^32\)\(^-\)\(^34\).

\(^6\)Further details about the geometry of the sonotrode and the cavitation chamber and about their exercise are contained in three patents owned by the Consiglio Nazionale delle Ricerche (CNR) (National Council of Researches of Italy) now published in\(^32\)\(^-\)\(^34\).
within a suitable lead and steel shielding box in order to obtain outside of it and in contact with it an equivalent dose rate of neutrons of $1.5 \pm 0.2 \, \mu\text{Sv/h}$\textsuperscript{6}. The BF$_3$ neutron monitor was placed in contact with this shielding box that contained the AmBe source and its position was decided in order to present to the neutron flux a geometrical effective surface of 142 cm$^2$ perpendicular to it. We registered the number of counts from the BF$_3$ within 100 seconds. Many of these counting runs were carried out (sample size $\geq 30$) and we found out that the mean number of counts within 100 seconds was $100 \pm 15$ (mean $\pm$ standard deviation) i.e. about 1 count per second (which corresponded to an accumulated equivalent dose of $0.040 \pm 0.009 \, \mu\text{Sv}$ (mean $\pm$ standard deviation) in 100 seconds\textsuperscript{7}. These two pieces of information allowed us to control that the BF$_3$ monitor was working in accordance with the manufacturer specifications. A dose of $0.040 \pm 0.009 \, \mu\text{Sv}$ in 100 seconds corresponds to an equivalent dose rate of $1.44 \pm 0.32 \, \mu\text{Sv/h}$ which is conformal to the dose rate of $1.5 \pm 0.2 \, \mu\text{Sv/h}$ declared for the shielded source. Besides, being the mean number of counts per second equal to 1 count/sec, the neutron sensitivity coefficient is given by dividing it by the corresponding dose rate 1.44 $\mu\text{Sv/h}$. Then, the neutron sensitivity of the BF$_3$ is $0.7 \, \text{cps}/(\mu\text{Sv/h})$ which is conformal to what is declared by the manufacturer (0.35 - 0.5 cps/(\mu\text{Sv/h}) see \textsuperscript{28}). Once that the correct operation and calibration of the neutron monitor were established, we carried out two kinds of measurements in order to determine the flux in cps/cm$^2$ (counts per second per square centimetres) corresponding to the electronic noise of the whole measuring apparatus and then the flux corresponding to the background of the lab where the actual measurements had to be carried out. The measurements to establish the electronic noise were carried out in a shielded empty bunker of high density concrete where the whole electronic equipment was brought and where the BF$_3$ was surrounded over $4\pi$ steradians by a further shield of polyethylene blocks. Several 90 minute long measurements (the same interval of the actual measurement) were carried out (sample size $\geq 30$) and the mean number of counts during 5400 seconds (90 minutes) was $20 \pm 5$ (mean $\pm$ standard deviation). We decided to use the pessimistic value of 25 and hence we got 0.005 cps for the electronic noise of the whole apparatus which corresponds to a value of $0.03 \cdot 10^{-3}$ counts/(sec cm$^2$). Then we measured the laboratory background flux. The measurements were carried out with the same pulse collecting procedure that was going to be used in the actual measurements. We carried out ten 180 minute (10800 seconds) long measurements during which we registered the number of pulses every 5 minutes (300 seconds) in order to get an idea of the fluctuations of the flux during 180 minutes. The flux turned out to be fairly constant around a mean value of 1.5 counts within 300 seconds (i.e. $0.03 \cdot 10^{-3}$ counts/(sec cm$^2$)) with some maximum fluctuations equal to 4.2 counts within 300 seconds (i.e. $0.1 \cdot 10^{-3}$ counts/(sec cm$^2$))

\textsuperscript{6}This equivalent dose rate value is given by the manufacturer and refers to a new source. The Americium-241 Beryllium neutron source, that was used for the BF$_3$ calibration, was a four year old standard source which, considered that the Americium-241 half life is of 432.2 years, can be considered as new.

\textsuperscript{7}According to the manufacturer \textsuperscript{28}, the pulses can be collected from the neutron monitor by a BNC connector which collects the pulses before the micro-computer which calculates the equivalent dose and equivalent dose rate. The equivalent dose and dose rate are collected instead from and RS232 output after the micro-computer.
counts/(sec cm$^2$)). In order to put ourselves in the most pessimistic conditions we decided to assume this maximum value as the laboratory background flux. The electronic noise value $0.03 \cdot 10^{-3}$ counts/(sec cm$^2$) and the background flux $0.1 \cdot 10^{-3}$ counts/(sec cm$^2$) were summed and the result $0.13 \cdot 10^{-3}$ counts/(sec cm$^2$) was adopted as the error to be attributed to each measured value. The experimental set-up lay-out is schematically presented in Fig.2. The BF$_3$ detector is placed next to the cavitation chamber and its position with respect to the zone of cavitation where the neutrons are expected to be emitted was the same it had with respect to the AmBe source during the initial calibration tests. The gamma meter UMo 1236 was next to the bottle diametrically on the other side with respect to the BF$_3$. In Fig.3 we present an example of the neutron measurements that were carried out during cavitation, i.e. the application of ultrasounds to the 1000 ppm solution of Iron Chloride. As we already said, the pulse collecting procedure was identical to that used while measuring the background flux i.e. register the number of pulses accumulated within 5 minutes.

Let’s briefly describe the results depicted in Fig.3. The graphic is divided into two parts by a vertical line (at 92 minutes instead of 90 minutes for mere visual convenience). The left side from 0 to 90 minutes is the interval of time during which cavitation was on. The right side from 90 to 180 minutes is the interval of time during which cavitation was off but the neutron measurement went on. In both sides, some peaks stand well above the background level, pointing out that the emission of neutrons is not constant in time, but occurs in bursts of neutrons or better in pulses. In the left side of Fig.3 the first neutron pulse occurs after 40 minutes from the beginning of the cavitation and this circumstance was the same for all the cavitation runs that were carried out. More precisely, it turned out that in all cavitation runs the first neutron pulse appeared 40 - 50 minutes after switching on the ultrasounds. As to the right side of Fig.3, although the cavitation was turned off and hence one would expect that the neutron pulses would stop along with
Figure 3: The graph shows the neutron pulses obtained during one of the cavitation runs. Time in minutes is on the x-axis and neutron flux (neutrons/s cm$^2$) $\cdot 10^{-3}$ is on the y-axis. The error bars represent the sum of the pessimistic measured electronic noise of the whole measuring equipment and the pessimistic measured laboratory background flux i.e. $0.13 \cdot 10^{-3}$ counts/(sec cm$^2$).
it, there are two more peaks well above the background level. These pulses, which were emitted in all cavitation runs after about 20 minutes the cavitation had been stopped, are a hysteretic behaviour and a possible candidate explanation to this fact is that some of the piezonuclear acoustic neutrons, (those neutrons emitted during cavitation) had been absorbed most likely by the Carbon contained both in the steel sonotrode and in the materials of the supporting platforms and released after a latency (of about 20 minutes in our case) as it normally occurs in the graphite of nuclear reactors. Before drawing some conclusions we would like to point out three details that, according to us, are important in order to create as a clear and thorough picture of this new phenomenon as possible. As is well known, it exists a phenomenon called fracto-emission or fracto-fusion \cite{30,31} during which neutron bursts can be detected. Despite the fact that in most cases the cracked solids are loaded with deuterium which is not our case, that our results have nothing to do with fracto-emission has been proved by the fairly large number of cavitation runs that we carried out under different conditions. More precisely, we cavitated Aluminium Chloride and Lithium Chloride solutions applying to them the same ultrasonic power i.e. the same oscillation amplitude of the sonotrode for the same amount of time and we did not register any neutron peak like those in Fig.3 but the level of the flux was always compatible with the background. Besides, we performed different cavitation runs of the same kind of solution both without changing the sonotrode and by a new sonotrode for each run in order to test possible effects due to the sonotrode aging and damaging. No correlation of aging and damaging with neutron emission was found, allowing us to exclude any possible implication of fracto-emission. The second experimental fact that we want to highlight is related to the association between cavitation and microscopical thermonuclear fusion occurring at the bubble collapse \cite{3}-\cite{12},\cite{31}. As we have already stated, the solutions that we used and from which we obtained neutrons did not contain any Deuterium, but only deionised bidistilled water with some Iron Chloride. Besides, it seems impossible to think of H$_2$-H$_2$ fusion since the two solutions of Aluminium Chloride and Lithium Chloride and the simple deionised bidistilled water did not produce any sign of neutrons above the background level, although the first two had the same concentration of that with Iron and all of them were treated with the same ultrasonic power for the same amount of time. As we stated above ionising radiation detection was carried out in parallel with neutron detection. In particular gamma rays were monitored by the UMo 1236 detector\textsuperscript{8}. The neutron and gamma monitoring proceeded constantly in parallel for 180 minutes. The gamma response was in equivalent dose rate and equivalent dose. The variations of the gamma equivalent dose rate over 180 minutes were compared with the variations of the cps/cm$^2$ from the neutron detector and particular attention was given in order to make out possible gamma peaks around those times when a neutron pulse occurred. Neither coincidence nor correlation was found between neutron pulses and gamma equivalent dose rate and dose which were always compatible with the gamma background whose variations had been extensively studied all over the lab and were of the order of 0.14 ± 0.05 µSv/h

\textsuperscript{8}The UMo1236 was calibrated by a Cobalt-60 standard source.
(mean ± standard deviation) for equivalent dose rate and 0.22 ± 0.07 μSv (mean ± standard deviation) for equivalent dose. Eventually we briefly want to say that a careful statistical analysis of the pulse values collected in the different cavitation runs was made in order to verify that they were not normally distributed as it can be inferred from the theoretical framework [19, 20] that explains these new physical phenomena (the graphical method called normal probability plot was used for assessing whether or not the pulse values were normally distributed). The values of the flux of the neutron pulses showed in no way to have a gaussian distribution. Let’s try and put forward briefly some potential phenomenological thoughts about this lack of gaussian distribution and the microscopical mechanism that steers the neutron pulses. It has been said that the flux values of the neutron pulses collected are not normally distributed as it was ascertained by a normal probability plot test. This evidence tells us that these values cannot be considered samples of a stochastic variable with a gaussian distribution, since such a variable is affected by independent small effects whose additive contributions build the gaussian distribution. Conversely, this circumstance indicates that there are some still unknown and above all uncontrolled systematic causes that steer the microscopical mechanism (the collapse of bubbles) that produces these neutron pulses (like bubble dimensions, species and number of atoms trapped on the bubble surface etc.). The investigation of these causes is the purpose of our present and future experiments. With this in mind, we can look at the whole phenomenon of neutron pulse emission by non radioactive nuclides subjected to ultrasounds from a practical perspective and wherefrom put forward an analogy about its behaviour. It is in fact possible to imagine this phenomenon to behave like a neutron pulse generator randomly driven by a multi-filter chopper able to change the frequency of the pulses, their time duration and their intensity i.e. their flux, and the energy of the neutrons emitted (a bit like the inverse of the famous ”neutron wheel made of paraffin used by Fermi to select neutrons of different speed). In other words, we can look at this phenomenon as a multi-varied neutron pulse source.

4 Conclusions

Mechanical vibrations in the form of ultrasonic oscillations of suitable power and frequency were conveyed during 90 minutes by a steel sonotrode into a solutions made of deionised bidistilled water, Iron and Chlorine contained in a Boron Silicate glass vessel of 250 ml. The rest of the stands and racks that were used to build the experimental set-up were made of Iron, Aluminium, Polychloroprene (Neoprene), Polymethyl Methacrylate (Plexiglas) that being sold for the most different applications are not made of unstable radioactive or fissile elements or even less contain large quantities of light elements like Deuterium. Of course it goes without saying that all the neutron and gamma laboratory background measurements were intended both to fix a level of blindness for the values that we were going to collect and also to double check the remote chance of any sort of tiny activity of the above materials. With this in mind, we state that the outcomes of the
measurements presented in this letter show for the first time that mechanical vibrations can force absolutely stable nuclides (Iron is the most stable in terms of binding energy per nucleon) to emit nuclear radiation like neutrons and hence to undergo some sort of nuclear reactions. The presence of neutrons from stable nuclides, their emission in pulses, the timing of the pulses, the absence of gamma radiation and the lack of normal distribution of the values of the flux (cps/cm²) corroborate the theoretical framework [18 [19 20] on which the idea and the design of these experiments was based. Let us add that these neutrons were named piezonuclear neutrons because the phenomenon presented in this letter is brought about by mechanical pressure (piezo from the ancient Greek piezein which means to press) which affects the nucleus of stable elements and makes it emit neutrons. Let us conclude by putting forward a conjecture about these piezonuclear reactions and foretell that they can be brought about by properly compressing solid materials that contain iron (e.g. granite), for instance in one of those toughness experiments that are very common in Mechanical and Civil Engineerings. More precisely, it will be possible to measure neutron emission at the instant of fracture of the specimens of these materials as their compression increases and reaches the breaking load. According to what is being done for liquids, it will be necessary to study neutron emissions as function of the compression speed of the specimens.

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