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Research Article

Piezonuclear Neutrons from Iron

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Abstract

We report the results of neutron measurements carried out during the application of ultrasounds to bars of iron and Steel. Like in our previous similar works with cavitated solutions of iron, neutrons were emitted in bursts and the spectrum of this peculiar emission was measured for the first time. A further and very interesting outcome of these experiments was the unexpected appearance of circular, macroscopical and regular damages on the lateral surface of the bars which was not directly in contact with the sonotrode. The superficial elemental micro-analysis on these spots showed some interesting and macroscopic departures of the concentration of chemical elements from that of the undamaged surface, which may suggest that, along with the emission of neutrons, some transmutations occurred as well.
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1. Introduction

In the last six years, we carried out experiments about piezonuclear reactions [1,2] in which we applied ultrasounds to solutions of water containing atoms of iron and from which, thanks to cavitation, that brings about a violent bubble collapse, we obtained neutron emission. In the wake of these experiments we decided to move our experimental campaign a bit further and apply ultrasounds to bars of iron or steel instead of to solutions of iron. We hypothesized that a similar process to bubble collapse in liquids might take place in solid bars too, due to the gas that they absorb during the casting process and that forms gas porosity. This conjecture was supported by some interesting experimental evidences obtained by a research team at the Polytechnical University of Turin [3–5]. They applied pressure by a press onto granite samples up to their brittle fracture. The fracturing sample was surrounded by neutron detectors both passive

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(bubble detectors) and active (^{3}He). At fracture both types of detectors always recorded a burst of neutrons many times higher than the measured neutron background. According to our phenomenological model, thanks to the phenomenon of cavitation, which makes the bubble of gas, contained in the liquid, collapse abruptly, the atoms of iron entrapped in the interface gas-liquid of the bubble get accelerated towards eachother as the bubble collapses. The theory proposed by two of us (F. C. and R. M.) [9–11], predicts that if the bubble collapse succeeds in concentrating the iron atoms in a certain region of space, within a certain time interval and with an amount of energy greater than 367.5 GeV , these atoms undergo a new type of nuclear reactions which we baptized piezonuclear reactions. As to the cavitation process in solids, we imagined that the gas porosity within the metallic lattice be made of tiny bubbles of gas whose interface gas-metal is entirely made of iron atoms. Ultrasounds exert a pressure on these micro-cavities and bring about a process that can generate the energy–space–time conditions needed to start piezonuclear reactions. On the basis of this heuristic conjecture, we designed our experimental set-up by taking advantage of the experience gained in the experiments with ultrasounds and solutions [1,2,12–14], but aware of the big differences between iron in a solution and solid iron.

2. Experimental Set-up

The experimental set-up was made of an ultrasonic machine, called reactor R-1-S, pretty much similar to that one used in our previous experiments [1,2,12–14]. This reactor was suitably designed and assembled by Startec Ltd. It had a converter unit with piezoelectric ceramics and a truncated conical sonotrode mechanically connected to it. A suitably designed metallic frame held the converter-sonotrode unit aligned with the iron bar to be treated by ultrasounds Fig. 1.

Moreover this frame could be shifted vertically and a pneumatic system allowed one to vary the contact strength between the sonotrode and the bar and hence vary the transmitted power. The bar was held in the upright position by a dielectric cylinder through which the bar was inserted. The shaping of the top and bottom tip of the bar was studied and made in order to have within it both a direct and a reflected wave. Since these two waves are longitudinal waves moving along the same direction but in opposite verses, the transverse planes of the bar with respect to its length find themselves squeezed between these two waves (patent pending on the experimental equipment) [15].

3. Neutron Measurements

The experiments we carried out had three main targets: check whether neutrons would be actually emitted by such a different device with respect to solutions of water and iron; obtain for the first time the neutron spectrum of these emissions; check the time of the beginning of neutron emission. This last information had to be correlated with that of the previous experiments [1,2], where neutrons began to be emitted after 40–50 min. We will come back to this point later on. We used two types of neutron detectors: a neutron counter HDS-100GN by Mirion ^{TM} (Ref. [6]) and a neutron spectrometer MICROSPEC2 ^{TM} Neutron Probe by BTI [7,8]. The former is a gamma detector and spectrometer with CsI(Tl) scintillator for low energy gamma rays and silicon diode for the high-energy ones. Besides, it contained also a neutron detector with a LiI(Eu) scintillator. The latter is made up of two parts: the multichannel MICROSPEC2 ^{TM} and the neutron detector Neutron Probe with an He^3 counter for thermal neutrons up to 800 keV and a liquid scintillator for neutrons from 500 keV to 5 MeV .

We put in contact the sonotrode and the tip of the bar like in Fig. 1 and applied a pressing force on it, so that the transferred ultrasonic power into the bar was 19 W. The frequency of ultrasounds was 20 kHz like in the previous experiments with solutions, and the amplitude of the vibration of the sonotrode tip was 15 μm. We treated two different types of bars: bars made of sintered Ferrite (α-iron) and bars made of steel with hardened surface by carbon steel and Dysprosium carbide. All of them were treated with the same ultrasonic parameters just mentioned. The two instruments, HSD-100GN and MICROSPEC Neutron Probe were brand new and had their own calibration certificates. By a standard source of AmBe at the Euratom Laboratory Ispra it was verified the compatibility of the readings of the two instruments

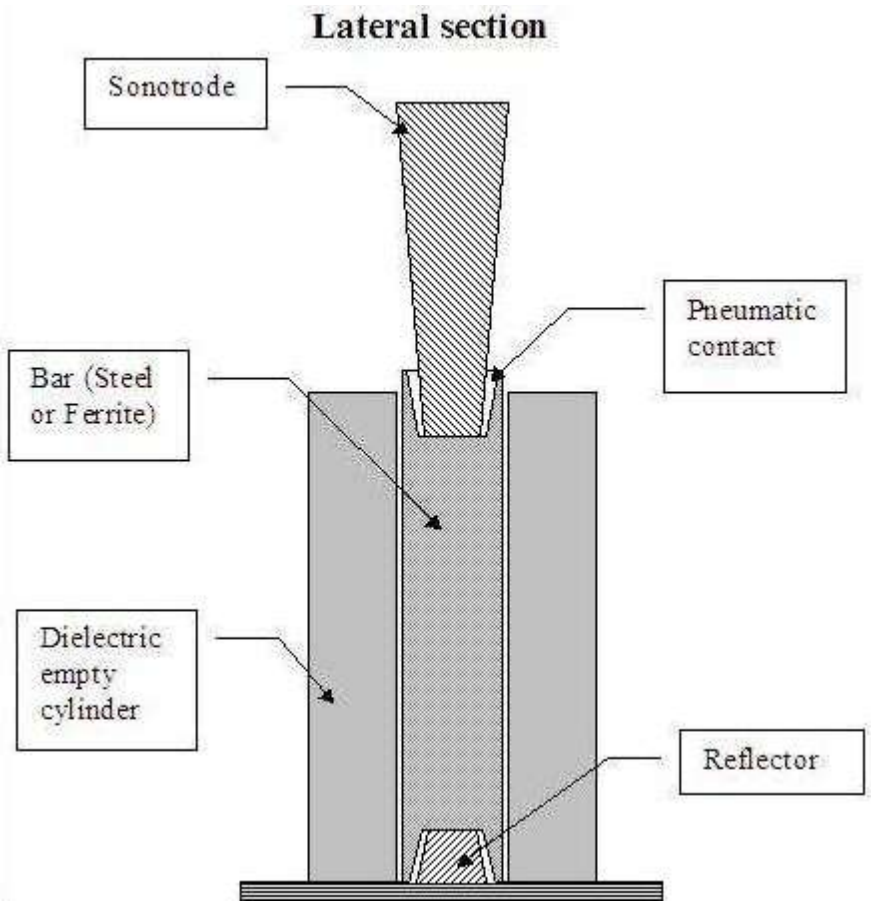

Figure 1. Experimental set-up. Lateral section.

with the certification. First of all, we carried out prolonged measurements by the HDS-100GN with ultrasounds turned off, in order to get a fairly long history of the neutron background variations. Besides, by turning on ultrasounds, with the sonotrode not in contact with the bar, we checked that both of the measuring instruments were not affected by the operation of the ultrasound machine. In all of the measurements of neutrons with ultrasounds turned on, a couple for each bar, several neutron bursts were detected. The height of these bursts were 25% higher than the maximum value of the neutron background. This was the first evidence that we meant to obtain by the HDS-100GN. The second information, that could be obtained by this instrument, had to do with the instant of time when the first neutron burst would appear. In the previous experiments [1,2], as we stated above, neutron emission began about 40–50 min after ultrasounds had been turned on. In this case, conversely, the first burst appeared always within about 5 min after the turning on of ultrasounds. Let us make the meaning of this evidence more explicit. In the experiments with solutions of iron the density of the liquid was about 1 g/cm^3,the first burst appeared after about 40–50 min of ultrasounds and the transferred ultrasonic power was about 130 W. Conversely, always working at the same frequency, in the solid case

the mass density is that of the iron, 7.8 g/cm^3, the first bursts appeared after about 5 min and the transferred ultrasonic power was about 19 W. We report these numbers in Table 1. Very interestingly, we see that when the density of the material increases to eight times, the interval of time and the power to obtain neutrons decreases with the same factor.

Table 1. Comparison between liquids and solids – Density of the material, Minutes for the first bursts of neutron to appear, Power of ultrasounds.

–	Density	Minutes	Power
Liquids	1	40	130
Solids	7.8	5	19
Liquids/Solids	$\approx$ 1/8	$\approx$ 8	$\approx$ 7

This evidence is interestingly in agreement with the prediction of the theory as to the relation existing between the occurrence of piezonuclear reactions and the amount of energy present in the system, the system being nuclei per unit volume i.e. mass density. Necessary but not sufficient condition for piezonuclear reactions to take place is to overcome a threshold of energy in a suitable volume or, in other words, a threshold of energy density, which is more promptly overcome in denser materials.

As we reported above, the HDS-100GN was also equipped with a gamma detector by which we could check the absence of any peak of gamma rays consequent to the detected neutron bursts. After the completion of these measurements by the neutron detector, we began the measurement of neutron spectrum, within the same experimental set-up. In Fig. 2 we present two neutron spectra obtained during 1 h of application of ultrasounds to one bar of ferrite (a) and one bar of steel (b) and in (c) the neutron spectrum of the background, i.e. with ultrasounds turned off.

The difference between the two spectra (a) and (b) with the spectrum (c) can be easily spotted. Moreover, the spectra (a) and (b) have a fairly clear lognormal shape which, from an intuitive and qualitative point of view, gives a fairly sound evidence of the existence of the phenomenon.

4. Bar Damages

We present here a further interesting evidence that appeared on the lateral surface of the bars and that was completely unexpected. As is visible in Fig. 1, in the experimental set- up, the bar treated by ultrasounds, was held vertically with its axis aligned with that of the sonotrode by an empty cylinder made of dielectric material. Once the bar was pulled out of the empty cylinder, we noticed, with great surprise, that on its lateral surface peculiar circular spots had appeared as in Fig. 3.

As is possible to see from Fig. 3, the ruler next to the bar clearly shows that these amazingly circular spots have a diameter that ranges from 2 to 3 mm. The surface of the bar on them is rougher and the roughness increases moving from the border of the circle to its centre. All of the spots have a fairly good circular simmetry at the unaided eye. While the colour of the bar is metallic grey as it normally is for steel, the predominant colour of these spots is brownish in a ring bound by two concentric circles and whitish in a circular central area. At a first sight, neither the distribution of these circles on the lateral surface of the bar had any particular symmetry, nor the distances between the centres of two spots apparently had any proportionality among them and/or with the dimensions of the bar. We would like to stress that these spots showed up on all of the bars, but they were more clearly visible on the bars of carbon steel. If one considers this last fact, i.e. a carbon steel bar, together with the ultrasonic energy conveyed into the bar, that was 19 W, one cannot be but puzzled. From a metallurgic point of view such a power, applied to the bar in the experimental conditions mentioned above, is just too low to produce these damages on a bar whose surface had been hardened by carbon steel and Dysprosium carbide. However, the first thing that we checked was the presence of any possible ferric

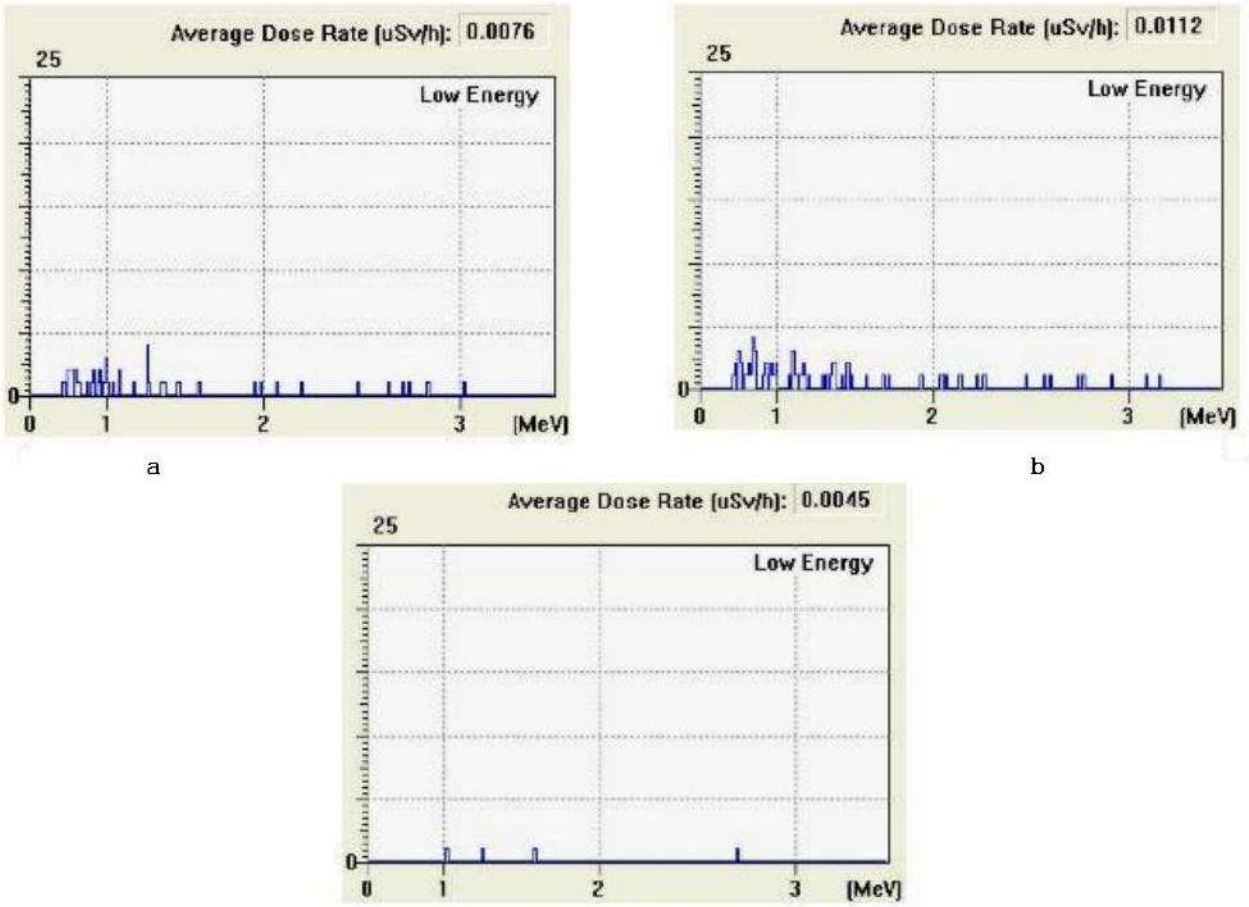

Figure 2. (a) Neutron spectrum from the bar of Ferrite, (b) Neutron spectrum from the bar of steel and (c) Neutron spectrum of the background.

oxide or hydroxide on the damaged surface. We decided to treat some of the bars with these circular spots by a solution of hydrochloric acid at 33%. We immersed the bars into the solution and kept them submerged for 1 h. Once we took them out of the solution of HCl and rinsed them, we noticed straight away that this treatment had had no effects on the damaged parts, whose morphology and colour had not changed. In order to obtain further information about the features of these damaged parts, we performed on them a semi-quatitative micro-analysis by a Zeiss Supra 40 FESEM with the electron beam at 20 keV and equipped with an Oxford INCA energy dispersive X-ray detector Si(Li) whose resolution at MnKα is 133 eV. Of course, we analysed by the same technique some areas of the undamaged surface as well and found out a sound homogeneity of the concentrations of elements.

In Fig. 4 we show the magnification of one of the damaged parts with the three spots where the EDX microanalysis was performed.

Figure 3. (a)–(b)–(c).

In Table 2, the concentrations in weight of the elements are reported. Particular attention has to be paid to the variations of carbon, oxygen, iron and dysprosium. In Table 2, we reported the values of concentration that were obtained at the centre of the circular damage. In Fig. 5, we show two EDX spectra obtained on the undamaged surface of the bar and on one of the damaged spots. Beyond the amazingly macroscopic variation of concentration of the four elements mentioned above, some other elements appeared that were not part of the superficial composition of the bars. We highlight the remarkable fact that the decrease in weight of iron seems to be counterbalanced by the sum of the increase in weight of carbon and oxygen.

5. Discussion of the Results

Let us first remark the lack of gamma emission higher than the background, that conforms to the outcomes of our previous experiments [1,2]. Some discussion is duly needed both for the neutron spectra and for the peculiar marks that appeared on the surface of the bars. Let us refer to Fig. 2. Despite the fairly clear difference between the spectra a and b and the spectrum c, one might be dissatisfied with the poor height of the bars of the histograms a and b. Two main reasons can be presented as the possible explanations of this fact. First of all, from our experience of measurements of this kind of peculiar neutron emission which happens in bursts [1,2], that stick out over a neutron background, we can state that the detection efficiency of active detectors is very poor. This is due to their dead times that make them miss some consecutive bursts or miss the entire height of a burst and to the software that controls them which tends to average

Table 2. Concentration in weight of elements before and after ultrasound treatment. Particular attention has to be paid to the amazing variations of Carbon, Oxygen, Iron and Dysprosium.

Before ultrasound		After ultrasound	
Element	Weight%	Element	Weight%
C, Carbon	2.37	C, Carbon	19.80 !!!
–	–	O, Oxygen	29.27 !!!
–	–	Na, Sodium	1.20
–	–	Mg, Magnesium	0.19
–	–	Al, Aluminium	0.53
Si, Silicon	0.21	Si, Silicon	0.49
–	–	S, Sulfur	0.27
–	–	Cl, Chlorine	1.61
–	–	K, Potassium	0.54
–	–	Ca, Calcium	0.68
Mn, Manganese	0.66	Mn, Manganese	0.47
Fe, Iron	91.92	Fe, Iron	44.45 !!!
W, Tungsten	0.53	W, Tungsten	0.50
Dy, Dysprosium	4.12 !!!	–	–
Cr, Chromium	0.18	–	-

the bursts to the neutron background. The second reason has to do again with the emission in bursts. These bursts are not isotropically emitted over 4π steradians, but they are rather concentrated along a direction in space that apparently changes for every burst, as it is well evident in Fig. 3 where the damage spots on the bar are randomly scattered on its surface. With this in mind one understands that a neutron monitor will be able to detect only those bursts emitted aligned with it and will miss all the others. Let us now move to the second evidence of these experiments, that is the presence of macroscopical damages on the surface of the bars. The comparison of the X-ray microanalyses performed both on undamaged parts of the surface and on damaged ones showed macroscopical variations of the concentration of iron, oxygen, carbon and dysprosium and the appearance of elements that were not initially present. Let us refer to Table 2: the percentages of disappeared iron and dysprosium are 47.47% and 4.12%, respectively, while the percentages of appeared carbon and oxygen are 17.43% and 29.27%, respectively. Very interesting is the balance between the concentration of the disappeared iron and appeared carbon and oxygen, in particular:

$$\text{disappeared iron } 47.47\% \simeq 46.70\% \text{ appeared (carbon + oxygen).}$$

If one counts in the decreasing of dysprosium and the appearance of other elements as in Table 2, one finds out the following balance of concentrations:

$$\text{disappeared (iron + dysprosium) } 51.59\ \% \simeq 51.72\ \% \text{ appeared (carbon + oxygen + the rest).}$$

The emission of neutrons, that was detected during the application of ultrasounds to the bars, certainly raises many questions of theoretical but also of phenomenological and experimental nature; for instance, as to where these bursts were emitted from. The macroscopical damages on the surface of the bars along with the variations and balances of the concentration of elements might be the possible answer to these questions. More explicitly one may think that the first balance means that iron turned into carbon and oxygen and the second balance means that iron plus dysprosium turned into carbon, oxygen and the other elements. The use of the verb "turn into" was done in purpose, since we did not want to use either the word fission nor the word lysis, nor the fusion nor the word synthesis. Both of them remind too much of the well-known nuclear processes which, according to our theory [9,11], have nothing to do with the nuclear processes in a piezonuclear reaction. Piezonuclear processes take place in the microscopically deformed spacetime that surrounds

the nuclei, hence the various calculations to establish whether a nuclear reaction is endothermic or exothermic, based on the binding energy per nucleon, are not valid in this context, since the variation of the space time deformation, that occurs during the process, contributes to the energy balance. From this perspective we can give some examples of the piezonuclear reactions that might take place. We want to stress that, by presenting the following reactions, we are in no way stating that these are the actual reactions that took place. The purpose is just to put forward a new type of nuclear reactions trying to follow the hints that nature gives us through experiments. If we consider the first balance between iron, carbon and oxygen, we can hypothesize the following reactions:

$$^{56}\mathrm{Fe}_{26}^{30} \rightarrow 3\ ^{12}\mathrm{C}_{6}^{6} + \ ^{16}\mathrm{O}_{8}^{8} + 4\ ^{1}\mathrm{n}_{0}^{1},$$

$$^{56}\mathrm{Fe}_{26}^{30} \rightarrow 2\ ^{12}\mathrm{C}_{6}^{6} + \ ^{16}\mathrm{O}_{8}^{8} + 3\ ^{4}\alpha_{2}^{2} + 4\ ^{1}\mathrm{n}_{0}^{1},$$

Otherwise, if we consider dysprosium together with iron, the possible reactions might be:

$$^{164}\mathrm{Dy}_{66}^{98} + \ ^{56}\mathrm{Fe}_{26}^{30} \rightarrow 2\ ^{12}\mathrm{C}_{6}^{6} + \ ^{16}\mathrm{O}_{8}^{8} + \ ^{23}\mathrm{Na}_{11}^{12} + \ ^{35}\mathrm{Cl}_{17}^{18} + \ ^{27}\mathrm{Al}_{13}^{14} + \ ^{40}\mathrm{Ca}_{20}^{20} + \ ^{1}\ \mathrm{p}_{1}^{0} + 2\ ^{4}\alpha_{2}^{2} + 34\ ^{1}\mathrm{n}_{0}^{1},.$$

These reactions, that do not have to be read as fission or fusion as stated before, produce neutrons as experimentally ascertained and alpha particles as well. If the latter were produced by piezonuclear reactions that take place on the surface of the bars, it should be easy to detect them. If these kind of reactions, starting from medium weight or heavy

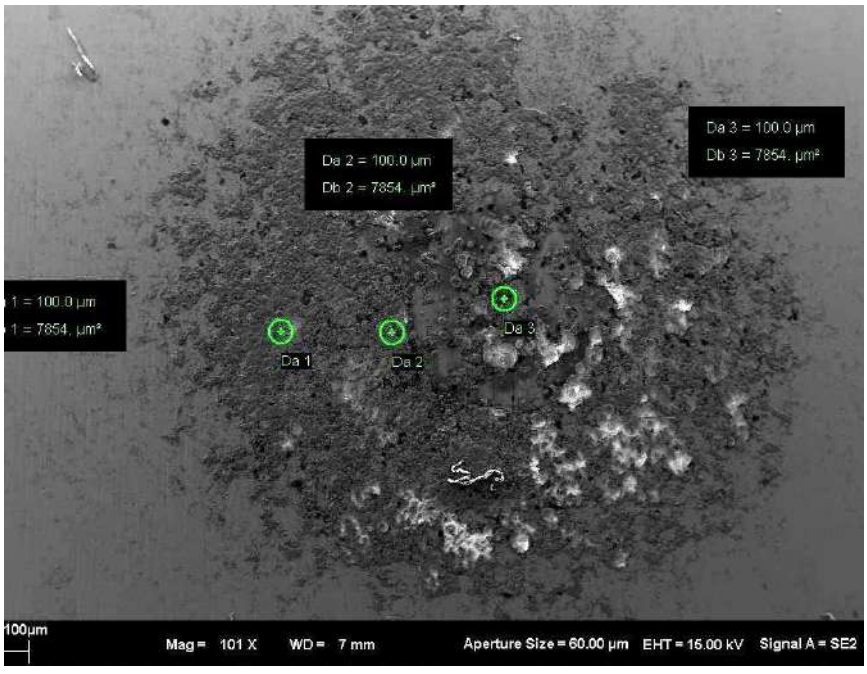

Figure 4. Magnification 101x of one of the damaged parts with the three spots where micro analysis was performed.

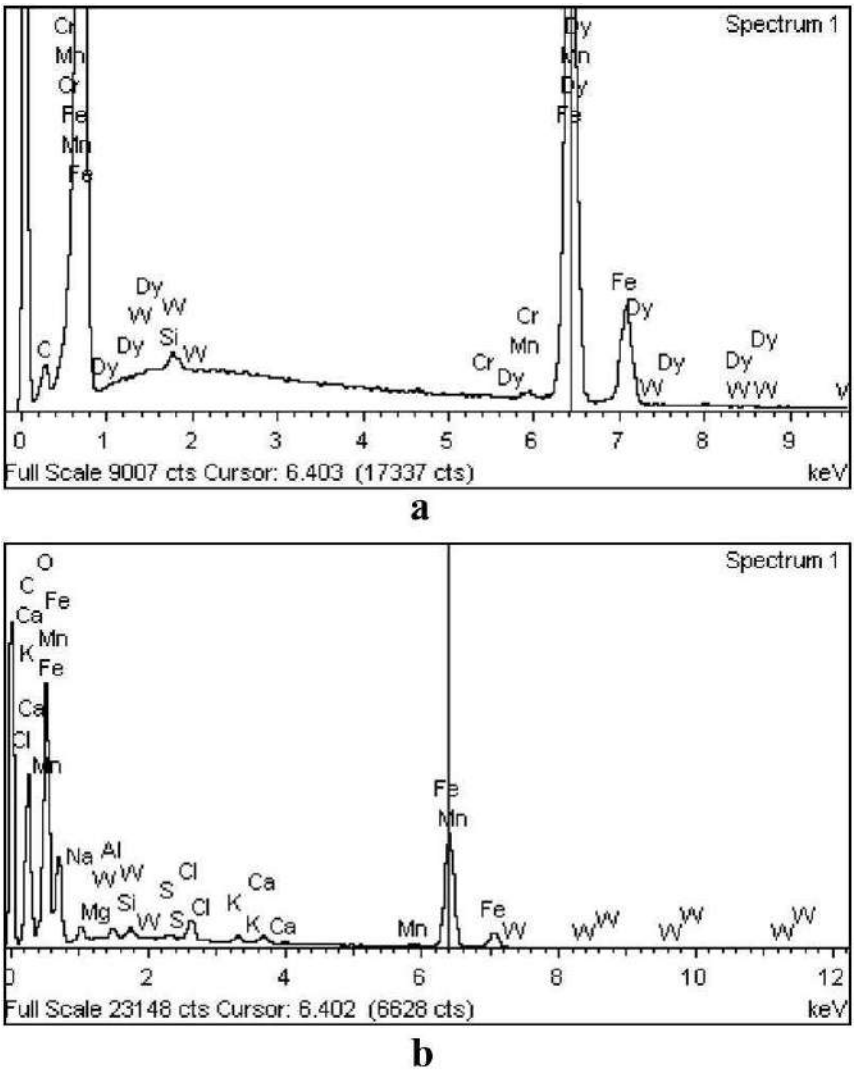

Figure 5. Two examples of EDX spectra. In (a) is shown the spectrum of elements on the undamaged part of the surface. In (b) is shown the spectrum of elements on the central spot of one of the circular damaged zones.

nuclides and yielding lighter ones, take place also in CMNS/LENR experiments, one might argue that these alpha particles might account for the extra Helium [16], whose measured quantity is usually higher than that expected to be produced by d–d fusion. Besides, the presence of these alpha particles might also account for some of the extra heat [16] due to their high linear energy transfer (LET) in the condensed matter where these reactions take place.

Let us make one last consideration about the processes that may occur during the application of ultrasounds to the bars. We are strongly convinced that the volumes where most of the mechanical energy gets released and converted are both the grain boundaries and the microcavities that contain gas. The metallic lattice can elastically absorb and release energy but not these two kinds of discontinuities. From this point of view, we cannot disregard the chance that the released energy can locally (microscopically) increase the temperature and generate the suitable conditions for a microplasma to ignite. In this sense, it will be necessary to discern whether the piezonuclear neutrons, that were measured, were produced by a microplasma, generated by a quantistic cavitation at nuclear dimensions, or by the local deformation of space-time generated by a suitable local density of energy. From this point of view, further experiments will have to be performed on degassed and non-degassed solids.

6. Perspectives

The evidence of transmutations of macroscopical quantities of elements are certainly encouraging to carry on these kinds of experiments with solid bars that could be made of different compositions but always containing iron, in order to study the way of making these transmutations predictable. In this respect, we would like to report a private communication [17] in which the researchers showed us their results of neutron measurements during the application of ultrasounds to basalt, a rock containing iron. With all of this in mind, it is just one step forward to imagine similar experiments on bars of radioactive metals in order to check whether these 'piezo-transmutations' make them loose their radioactivity by the catalysis of ultrasonic piezonuclear reactions in close analogy with what was found out in radioactive liquids treated by ultrasonic cavitation [17].

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