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Ultrasonic Piezonuclear Reactions in Steel and Sintered Ferrite Bars

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We report the results of piezo-energy emissions in the form of neutron bursts measured during the application of ultrasounds to sintered ferrite (α-Iron) and steel bars using an original experimental device. The measurements, carried out by HDS-100GN and by a Microspec2 neutron probe, confirmed neutron emission repeatability from inert iron-rich media and the absence of gamma radiation. In addition, energy spectra of neutron emission during the application of ultrasounds are shown as well. After neutron detection, Energy Dispersive X-ray Spectroscopy (EDS) analyses were conducted, showing semi-quantitative evidences of iron decrease and the possible occurrence of nuclear reactions of a new type in correspondence to meso-craters (burns) localized on the external surfaces of the bars. Finally, similar evidences may be observed at the Earth's crust scale where well distinguishable neutron emissions and anomalous chemical changes in correspondence to major earthquakes and micro-seismic activity may be considered to explain the significant iron depletion characterising seismic areas and the Earth's crust evolution.

KEYWORDS: Piezonuclear Reactions, Neutron Emission.

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1. INTRODUCTION

In the last few years repeatable neutron emissions have been observed during ultrasonic cavitation in liquid solutions containing iron[1,2] and successively in compressive and cyclic tests of inert iron-rich rocks.[3–11] These evidences suggest that pressure waves, suitably exerted on inert medium of stable nuclides, generates nuclear reactions of a new type producing clear and reproducible energy emission (piezo-energy) in the form of asynchronous and anisotropic neutron bursts.[1–19]

The piezo-energy emissions observed in liquids and due to cavitation took place thanks to the presence of iron atoms contained in aqueous solutions of iron chloride or nitrate.[1,2] Successively, similar results have been also obtained in natural rocks due to brittle failure of specimens by static (catastrophic collapse) or by cyclic-fatigue tests using low (2 Hz), intermediate (200 kHz) and high (20 kHz) frequency.[3–11] The proportionality observed between the iron concentration in liquid solutions and the neutron emission levels has been confirmed by the experimental evidence in natural rocks (granitic stone, basalt, and magnetite), where different amounts of iron oxides are contained.

In particular, the greater the iron content, the higher the piezo-energy emissions in the form of neutrons.[1–8] The regularity of this evidence can be observed first of all in the iron chloride liquid solutions, where neutron pulses reached a level up to 2.5 times the laboratory background level detected before the experiments.[1,2] As mentioned before, similar results have been observed during experiments involving granitic, basaltic, and magnetite stones subjected to static and cyclic loading. During these experiments, it was noted that the greater the size and the slenderness of the specimens, the higher the neutron burst emissions detected during the tests. In particular, granitic (2.62 kg m^{-3}) specimens (FeO $\sim$1.5%) gave neutron burst emissions up to 10^1 times ($28.0\pm0.2\times10^{-2}$ cps) higher than the measured background noise ($3.8\pm0.2\times10^{-2}$ cps) during the brittle rupture of the specimens.[3–8] The basaltic material (3.00 kg m^{-3}), characterized by a higher content of iron (FeO $\sim$15%), produced piezoneutron bursts with

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an equivalent dose rate up to 10^2 times ($2.62 \pm 0{,}53$ μSv/h) the average background level ($37.87 \pm 9{,}47$ nSv/h) in correspondence to the brittle compressive failure of the tested specimens. Finally, magnetite specimens, characterized by a very high content of iron (FeO $\sim$75%), subjected to fracture experiments, reached a neutron emission level up to 10^3 times (935.49 ± 233.87 nSv/h) the background level measured before the experiments (5.76 ± 13.44 nSv/h).[3–11]

In addition, the well distinguishable neutron emissions observed during the laboratory experiments, could be extrapolated to the Earth's crust scale.[17–19] Very recently, in fact, neutron emissions during microseismic activity and before major earthquakes have been measured.[20–24] At the same time, anomalous chemical changes involving elements such as Fe, Ni, Al, Si, amd Mg may be recognized during the Earth's Crust evolution just in correspondence to periods characterized by the most intense tectonic activity.[18,19] From this point of view, it is also interesting to emphasize that anomalous phenomena such as iron and nickel depletions,[25–28] that have affected the geomechanical and geochemical evolution of the Earth's Crust, should be considered as an indirect evidence of piezonuclear reactions.[18,19]

From all the supporting evidences just recalled, the piezo-energy threshold seems to be reached when two different conditions occur:

(i) the presence of iron in the liquid solutions or in the solid specimens;

(ii) the right level of energy density (energy per unit volume).

In both liquids and solids the two conditions previously reported are sufficient to obtain appreciable neutron emissions and macroscopical evidences of changes in the mass percentage of the existing elements, and even, in several cases, with the appearance of new elements after the experiments.[13–17]

In the present paper, the first condition (iron concentration) is maximized considering Ferrite and steel bars (Fe mass content $\sim$92%) subjected to ultrasounds through a new instrumental device, a "piezo-energy reactor" (R-1-S), released by Startec Ltd in 2009. The aims of the presented experiments are: confirming the repeatability of piezo-emissions in solid iron compounds; verifying that gamma rays are absent in correspondence to piezo-energy (neutron) emissions; detecting the energy spectra of neutrons associated to this new kind of nuclear reactions obtained without any kind of radioactive or deuterated component. This work represents the natural continuation of the experiments conducted with solutions containing iron and chlorine as well as with natural rocks in compression, considering pseudo-homogeneous media composed prevalently of Fe (α-Iron and steel bars). As reported in the pioneer work by Cardone et al.,[1,2] also in this case we emphasize that all our experimental equipment and measurement devices never involved any radioactive source or unstable nuclide unlike other experiments.[29–38]

2. EXPERIMENTAL SET-UP

The experimental set-up is based on a particular "reactor" constituted of an ultrasonic generator similar to that used in the previous experiments on liquids[1,2,39–41] and adapted, in this case, for solid specimens. The apparatus is composed by a "piezo-energy reactor" (R-1-S) designed and assembled by Startec Ltd during the St. Ambrose Project in 2009. This device was optimized for piezo-energy emissions in the case of solid bars. The apparatus is composed by a column of piezoelectric transducers mechanically connected with a conical truncated sonotrode aligned with the specimen (see Fig. 1). Moreover, the upper structure could be moved vertically, by a pneumatic system, in order to change the contact strength between the conical sonotrode and the bar and varying the transmitted power. The Ferrite and steel bars, used in the experiment, were held in the upright position by a dielectric cylinder.

The upper tip of the bar and its lower tip, where the bar stands, have a symmetrical design. They both possess a cavity in order to optimize the contact of the bar with the sonotrode in the upper part and with the reflector in the lower part (see Fig. 1). These contacts were designed in order to produce inside the bar a stationary wave.

Ultrasounds were applied to six iron bars, four made of sintered Ferrite (α-Iron) and two made of steel with hardened surface by carbon and dysprosium carbide, all of them having the same shape and geometry with a circular cross section of 20 mm of diameter and a length of 200 mm (see Fig. 2(a)). The bars were subjected to ultrasounds with a frequency of 20 kHz (amplitude

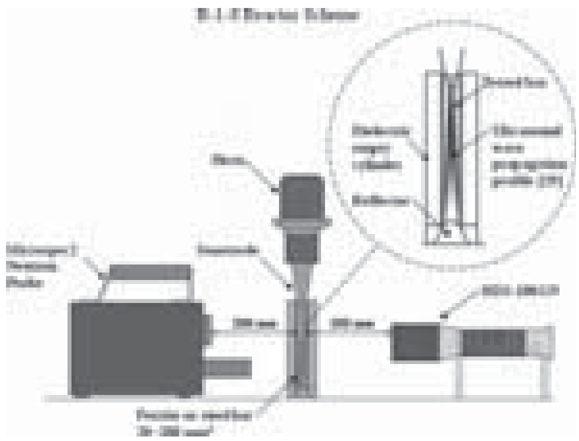

Fig. 1. The apparatus is composed by a "piezo-energy reactor" (R-1-S) designed and assembled by Startec Ltd during the St. Ambrose Project in 2009. The apparatus is composed by a column of piezoelectric transducers mechanically connected with a conical truncated sonotrode aligned with the ferrite or steel bar. Two different types of neutron measurement devices were used during the experiments. An electronic solid-state detector HDS-100GN by Mirion Technologies used also for gamma ray detection and a Microspec2 Neutron Probe by BTI for neutron spectrum analysis.

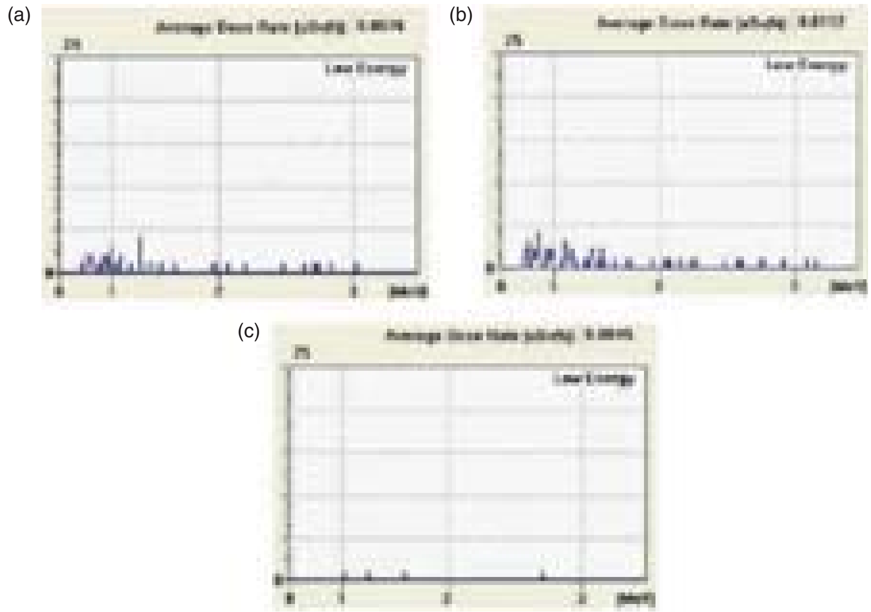

Fig. 2. Examples of the neutron burst spectra produced by the ultrasound solicitation of sintered Ferrite (a) and steel bars (b). The energy interval ranges approximately from 0.5 to 1.5 MeV. (c) The neutron spectrum of the background detected in the same laboratory where the experiments were conducted is reported as well.

oscillation of 15 μm) and a power of 19 W for about 60 minutes.

Two different types of neutron measurement devices were used during the experiments. The first one is an electronic solid-state detector HDS-100GN by Mirion Technologies.[42] This device has the particular feature to have gamma and neutron independent channels. It is constituted by a detector and a spectrometer with CsI(Tl) scintillator for low energy gamma rays and silicon diode for high energy ones and, on the other hand, neutron detection is obtained using a LiI(Eu) scintillator. The HDS-100GN was used during the experiments to detect the neutron emission and at the same time to verify the absence of gamma ray during the bursts of neutrons. The second device is a Microspec2 Neutron Probe by BTI.[43,44] This device is made up of the multichannel Microspec2 with a Neutron Probe composed by two detectors: an ^{3}He detector with energy range from thermal neutrons up to 800 KeV and a liquid scintilator Na_{231} for neutrons detection with an energy range from 500 KeV to 20 MeV. The experimental set-up is shown in Figure 1. The two detectors are positioned at a distance of about 200 mm from the monitored bar and the longitudinal wave profile is reported according to the experimental data (see Fig. 1).[45] According to their calibration certificates, the two detectors were calibrated by a standard source of AmBe at the Euratom Ispra Laboratory. Before their use, it was verified the compatibility of the readings of the two instruments with their calibration certificate.

3. EXPERIMENTAL RESULTS

The results obtained from the experiments conducted with the electronic solid-state detector HDS-100GN confirm the repeatability of asynchronous and anisotropic neutron bursts well above (~250%) the higher value of the measured background level. These measurements appear to be a further corroboration of the first piezo-energy emission evidences obtained in cavitated liquid solutions containing iron and in natural rock failure in compression. Moreover, these evidences show that, like in iron-rich natural heterogeneous rocks (granite and basalts), ultrasonic loading of pseudo-homogenous media (sintered α-Iron and steel bars) produces emission of neutrons with no concomitant emission of gamma rays. Another fundamental consideration regards the timing of emissions. For the tested bars herein shown the first appreciable neutron emission was observed about 5 minutes after the beginning of the experiments (switch on of the R-1-S piezo-energy reactor). In the first experiments conducted on solutions of iron salts the first appreciable emissions were detected between 40 and 50 minutes from the beginning of the application of ultrasounds. The first well-distinguished neutron burst (about twice the background level) in granite solid specimens subjected to ultrasounds was observed at about 100 minutes from the beginning of the test. The rapidity of occurrence of the first neutron burst seems to be strictly correlated with the concentration of iron. On the other hand, the amplitude of the piezo-energy emission seems to be related to the energy amount driven into the system by the

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external cyclic[1,2,6–8] or static[3–8] mechanical loadings. From this point of view, the particularly high level of piezo-energy emissions (up to 50 times the background level) observed in natural rocks with a very high iron content (basalts), appears to be related also to the capability of the material to accumulate a higher level of piezo-energy density and then abruptly release it in a very localized volume of the solid during brittle failure of rocks. In this case, the heterogeneity of rocks played a key role in increasing the brittleness and influencing the timing of ruptures.[3–8]

The second neutron detecting device used during the experiments (Microspec2 Neutron Probe) allowed to measure the spectrum of neutron bursts observed during the ultrasound application into the Ferrite and steel bars. Two examples of the spectra of neutron bursts produced by the application of ultrasounds into sintered Ferrite and steel are shown in Figures 3(a) and (b) together with the neutron spectrum of the background detected in the same laboratory where the experiments were conducted (see Fig. 3(c)). The energy interval ranges approximately from 0.5 to 1.5 MeV. The spectral distributions of neutrons obtained with the bars exhibit a fairly clear log-normal behaviour which distinguishes them from the background spectrum. However, the poor height of the bars of the histograms in Figures 3(a) and (b) may be explained considering two causes. The first one lies with the very poor efficiency possessed by active detectors (like ^{3}He and liquid scintillator) in detecting neutron bursts, as we have noted and reported in previous experiments. Due to their dead times, they tend to miss consecutive bursts or miss the entire height of a burst. The second reason has to do with the fact that the bursts of neutrons are not isotropically emitted over 4π steradians, but, conversely, each burst is emitted along a space direction that changes for every burst. With this in mind one understands that a neutron monitor will be able to detect only those emitted bursts which are aligned with it.

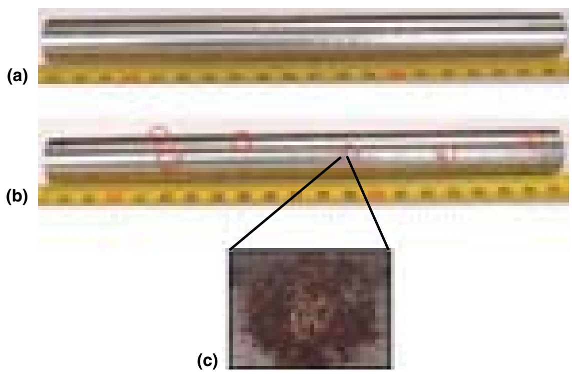

Fig. 3. (a) All the tested elements present the same shape and geometry with a circular cross section of 20 mm of diameter and a length of 200 mm. (b), (c) After the experiments well distinguishable meso-craters or burns could be recognised on the external surface of the tested bars. These burns present circular shapes and a variable dimension from 2 to 3 mm of diameter.

In every experiment, after turning off the ultrasounds and extracting the bar from the dielectric cylinder, we noticed well distinguishable meso-craters or burns on its external surface (see Figs. 2(b) and (c)). These burns, accessible to visual inspection, presented a circular shape and a variable dimension from 2 to 3 mm of diameter. Their appearance is that of a brownish spot with annuli disposed around the centre (Fig. 2(c)). These spots were analysed by means of semi-quantitative compositional analysis performed by energy-dispersive X-ray spectroscopy (EDS) in order to recognize possible compositional variations between the burns and the undamaged surfaces of the bars. A ZEISS Supra 40 FESEM equipped with an Oxford INCA energy-dispersive X-ray detector (Si(Li)) with a resolution of 133 eV @ (MnKa) was used with an energy of 20 KeV. The results obtained for the composition of burns were compared with the compositional analysis of points localized far from the brownish spots and which did not show any kind of alteration. In Figures 4(a) and (b) the analysed surfaces are shown. In the EDS analyses three spots are considered for both the undamaged and damaged (burns) conditions. The results, summarized in Table I, show that after the application of ultrasounds and the detection of piezoneutron emission,

Fig. 4. (a) EDS result obtained on three different spot analyses on undamaged surface of the bar. (b) The same number of analyses were conducted on three spots localized on a burned surface. These analyses evidenced a strong Fe decrease and an almost equal increase in C and O content (see Table I). The disappearance of Dy in the burned surface is accompanied by the appearance of new elements (see Table I).

there were macroscopical evidences of changes in the mass percentage of the existing elements and the appearance of new elements as well. It is important to note that, similar evidences had been already recognized in the case of liquids[13,14] and solids,[6–11,16] but in the present case the changes are particularly intense and measurable. In particular, an important reduction of iron content was observed on the burned surface with respect to the content of iron found in the areas not interested by damage (burns) (see Figs. 4(a) and (b)).

The comparison of the semi-quantitative results showed reductions in Fe (−47.47%) and Dysprosium (Dy) (−4.12%), that disappears, and appreciable increases in C (+17.43%) and O (+29.27%) that was not present before. In addition, the appearance of Na, Mg, Al, S, Cl, K, and Ca was observed in the "burned" areas after the application of ultrasounds. In particular, the iron decrease seems to be almost perfectly balanced by the carbon and oxygen increases (see Table I). In particular, the global mass percentage decrease of Fe and Dy of about 51.59% seems to be counterbalanced by the C and O increases (−46.70%) plus the appearances of the new elements amounting to about 5%. After the EDS analyses the areas interested by the burns and mesocraters were subjected to a pickling procedure with hydrochloric acid (HCl 33%). After this procedure the burns were not removed, which made us conclude that these areas are not composed primarily of iron compounds removable by this method. Finally, the significant evidence shown for Fe decrease and O and C increases and the appearance of Ca (see Table I) could be explained considering that, on the damaged surfaces, the following piezonuclear reactions could have taken place:

$$\mathrm{Fe}_{26}^{56} \rightarrow 3\mathrm{C}_{6}^{12} + \mathrm{O}_{8}^{16} + 4 \text{ neutrons} \tag{1}$$

$$\mathrm{Fe}_{26}^{56} \rightarrow 2\mathrm{C}_{6}^{12} + \mathrm{O}_{8}^{16} + 3\mathrm{H}_{2}^{4} + 4 \text{ neutrons} \tag{2}$$

$$\mathrm{Fe}_{26}^{56} \rightarrow \mathrm{Ca}_{20}^{40} + \mathrm{C}_{6}^{12} + 4 \text{ neutrons} \tag{3}$$

Table I. Semi-quantitative EDS analyses performed on undamaged and damaged (burn and mesocraters) surfaces.

Before ultrasounds		After ultrasounds	
Element	Mass %	Element	Mass %
C	**2.37**	C	**19.80**
–	–	**O**	29.27
–	–	**Na**	1.20
–	–	**Mg**	0.19
–	–	**Al**	0.53
Si	**0.21**	Si	**0.49**
–	–	**S**	0.27
–	–	**Cl**	1.61
–	–	**K**	0.54
–	–	**Ca**	0.68
Mn	**0.66**	Mn	**0.47**
Fe	**91.92**	Fe	**44.45**
W	**0.53**	W	**0.50**
Dy	4.12	Dy	–
Cr	0.18	Cr	–

4. FROM THE LABORATORY TO THE EARTH'S CRUST

The evidence reported for the steel bars subjected to ultrasounds could be extrapolated from the laboratory to the Earth's crust scale, where rocks with different iron contents are subjected to seismic and micro-seismic events.[17–19,46–48] In the preparation zone of an impending earthquake, strain in collapsing pores, grain boundary slippage, and micro-fractures may cause Acoustic Emissions (AE) in a frequency range up to 300 kHz.[47–49] Recent evidences of neutron emissions in correspondence to earthquakes lead to consider also the Earth's Crust, in addition to cosmic rays, as being a relevant source of neutron flux variations.[20–24] Neutron emissions exceeded the neutron background up to 1000 times in correspondence to seismic events with a Richter magnitude equal to the 4th degree.[7,49] These measurements could be put in correlation with the evidence of iron depletion counterbalanced by the presence of lighter elements just in correspondence to seismic active areas of our planet.[7–11,17–19] From this point of view it is interesting to note that the iron decrease and the increases of other elements, before absent and shown in Table I for the steel bar, may be observed also at the Earth's crust scale just in correspondence to the most active faults and subduction lines of our planet. In particular, the localization of Al and Fe mineral reservoirs seems to be closely related to the geological periods when different continental zones were formed.[50,51] The geographical locations of the main bauxite mines show that the largest concentrations of Al reservoirs can be found in correspondence to the most seismic areas.[52–55]

Evidence of piezonuclear reactions can be also recognized considering the Earth's composition and its way of evolving throughout the geologic eras. From 4.0 to 2.0 Gyrs ago, Fe could be considered one of the most common bio-essential elements required for the metabolic action of all living organisms.[25] Today, the deficiency of this nutrient suggests it as a limiting factor for the development of marine phytoplankton and life on Earth.[25,27,28] Elements such as Fe and Ni in the Earth's protocrust had higher concentrations in the Hadean (4.5–3.8 Gyr ago) and Archean (3.8–2.5 Gyr ago) periods compared to the present values.[25–27,56–63] The Si and Al concentrations instead were lower than they are today.[26,50,58,62,63] A clear transition from a more basaltic condition (high concentrations of Fe and Ni) to a sialic one (high concentrations of Si and Al) can be observed during the life time of our planet.[50,56,58,63–67] The most abrupt changes in element concentrations appear to be intimately connected to the tectonic activity of the Earth. From the data reported in recent papers,[25–27,56–63] a decrease of ∼7% in Fe and ∼0.2% in Ni concentrations can be observed between the Hadean period (4.5–3.8 Gyrs ago) and the Archean period (3.8–2.5 Gyrs ago).[50,56,58,63–67] At the same time, Al and Si concentrations increase of ∼3% and ∼2% respectively.

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Similarly, a global decrease of ~5% in the concentrations of Fe (~4%) and Ni (~1%) and a global increase of about 3% in the concentrations of Si (~2%) and Al (~1%) are shown between the Archean period (3.8–2.5 Billion years ago) and more recent times.[19] The balances between heavier (Fe and Ni) and lighter (Si and Al) elements could be considered as perfectly satisfied taking into account a virtual increase in Mg similar to that of Si over the Earth's lifetime.[18, 19]

5. CONCLUSIONS AND PERSPECTIVES

The anomalous reactions, which were conjectured on the basis of the piezoneutron emissions and on the EDS results on burns, could be caused by different phenomena such as: microplasma produced by high piezo-energy concentration, cavitation of gas bubbles contained in the solid in analogy to liquids, or other mechanisms. Additional tests will be conducted to understand more deeply the physical phenomenon that undergoes this new type of nuclear reactions. In future experiments neutron and X-ray diffractometry analyses could be useful to verify the damage of the crystalline structure in correspondence to meso-craters and burns after the application of ultrasounds. Neutron activation measurements could be used to recognize additional evidences of anomalous transmutations in the meso-craters. Moreover, considering the asynchronous and anisotropic nature of neutron pulses, a new kind of neutron detector must be designed in order to perform more accurate measurements. As a first approximation, according to this requirement, measurements of anisotropic neutron emissions could be performed considering an array of neutron detectors disposed on a solid angle covering at least 2π steradiants. A further perspective is to perform piezonuclear experiments comparing degassed and undegassed solids in order to evaluate the possible cavitation of entrapped gas inclusions. Finally, the results presented in this paper offer a further evidence that the scarcity of iron concentrations in the Earth' crust in seismic areas and the significant iron depletion observable during the Earth's Crust evolution over time could be explained by piezonuclear reactions similar to those assumed for the steel bar. Earthquakes are often anticipated by a microseismic activity with AE in a frequency range up to 300 kHz.[47] These ultrasonic solicitations may be considered as the catalyzing mechanism for the piezoenergy emissions from the laboratory as well as from the Earth's crust, where mechanical phenomena of fracture, crushing, fragmentation, comminution, erosion, friction occur during seismic events.

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