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Research Article

Neutron Burst Emissions from Uranium Deuteride and Deuterium-loaded Titanium

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Abstract

This paper reports new results of anomalous neutron bursts (high-frequency neutron bursts) from deuterium-loaded titanium and uranium deuteride samples at room temperature. The number of neutrons in the large bursts is up to 2800 in an interval of less than 30 s, and the highest frequency of neutron bursts is 13 bursts in 7 min. Accidental artifact noise and cosmic-ray sources are ruled out. We suggest that the anomalous neutron bursts are correlated with deuterium-loaded metals and probably the result of nuclear reactions occurring in the samples.
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Keywords: Deuterated metals, Low-energy nuclear reaction, Neutron burst emission, Normal temperature

1. Introduction

In 1989, Fleischmann and Pons, and Jones et al. claimed the production and detection of neutrons from D–D nuclear reactions in deuterated palladium and titanium by using the electrolytic method. Since then, the actual emission of neutrons from deuterium-loaded metals has been a matter of discussion among scientists. Because of the difficulty of detecting low-level neutrons and infrequent neutron-production from nuclear reactions, the results were often contradictory or not reproducible. However, some positive results have been reported [1–4].

Measuring neutrons in low-energy nuclear reactions (LENR) requires particular care and expertise. Because of the low level and infrequency of neutron production, it is difficult to measure energy spectra at a high confidence level. Therefore, each individual neutron burst must be evaluated to determine whether its origin was electronic noise, environmental gamma-rays, cosmic-ray background, environment neutrons, accidental artifact noise or a legitimate signal.

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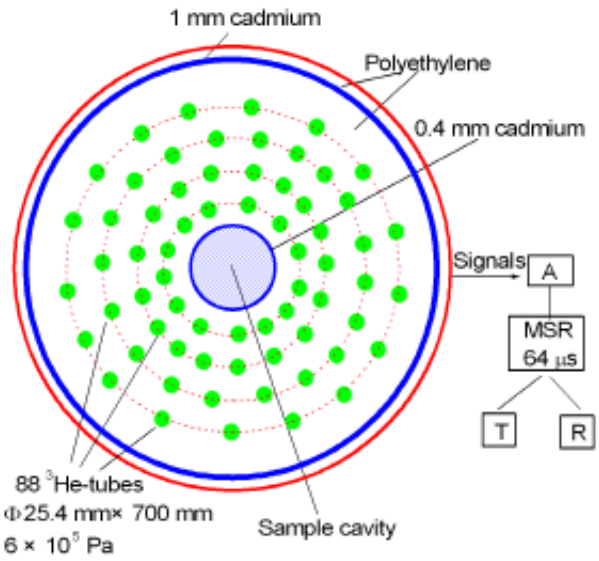

Figure 1. A top view of the neutron detector system. The A, MSR, T and R denote amplifiers, multiply shift registers, counter for time-correlated signals and counter for random signals, respectively.

In this work, measurements of neutron emission from uranium deuteride and deuterium-loaded titanium samples are carried out by using a high-efficiency neutron detector and update time-correlated (coincidence) counting technique. The experimental result provides strong evidence for neutron burst emissions from deuterated metals at room temperature. Observation of nuclear products, such as neutrons, protons and tritium in metal hydride (deuteride) [5,6]will be helpful to study the mechanism of LENR and origin of excess ^{3}He and tritium in the deep earth [7–9].

2. Experimental Details

2.1. Neutron detection

The detector has high neutron detection efficiency and a good ability to reject γ-ray background and eliminate electrical noise. The multiplicity shift register circuit [10] was used for recording both the random and time-correlated neutrons, and is able to quantitatively measure a single burst of neutrons lasting a few microseconds. The multiplicity shift register has a better ability than the common shift register [11]. It can record all time-correlated (coincidence) neutron events, not just single and double neutron events. The time interval of the coincidence gate was 64 μs in this work. The detector consists of 88 ^{3}He-tubes with pressure of 6×10^5 Pa, embedded in the polyethylene moderator (Fig. 1). The sample cavity located at the center of the detector has a diameter of 16.5 cm and height of 40 cm, and is lined with 0.4 mm cadmium. A graphite cylinder with diameter of 16.5 cm and height of 18 cm fills the bottom end of the cavity and another cylinder is used as a plug at the top of the cavity to reflect neutrons emitted from the sample. The detector body has an outside diameter of 70 cm and height of 80 cm, and the whole detector body is shielded from thermal neutrons with 1 mm of cadmium. The neutron detection efficiency was calibrated by using a ^{252}Cf neutron source (average neutron energy 2.3 MeV) and found to be greater than 50%.

Another neutron detector (also called the neutron monitor) was used for monitoring the environmental neutron background and accidental artifact noise during sample measurements. The detector consists of three polyethylene

slabs of 30 × 30 × 6 cm^3. Four ^{3}He-tubes were embedded in each slab. The relative efficiency of the neutron monitor to the main neutron detector is about 40% for detection of the environmental neutron background. The monitor has the electronic circuitry and a multiplicity shift register similar to that of the main neutron detector. Thus, the two detectors have similar sensitivity to the signals of accidental artifact noise. The two detectors were 2 m apart. The neutron monitor was used for monitoring the variation of the environmental neutron background and accidental artifact vibration noise.

There are two nuclear processes for nuclear reactions occurring in the deuterium-loaded metals: burst (time-correlated) and continuous (random or accidental) reactions. We use multiplicity shift register for recording both time-correlated neutron burst and random events.

2.2. Uranium deuteride and deuterium-loaded titanium samples

We measured two sorts of deuterium-loaded metal samples: deuterium-loaded uranium (uranium deuteride) and deuterium-loaded titanium samples. Uranium deuteride has a high D/U atom ratio of 3, which is a factor of 2 greater than D/Ti ratio. The uranium (^{238}U) metal machine-chips (about 10 g) were used to prepare the uranium deuteride sample. The procedures used for preparation of uranium deuteride were performed as described in the previous work [12]. After loading deuterium in uranium chips, the chips were broken into fine powder. The uranium-deuteride powder was sealed into a stainless-steel cylinder with an inner diameter of 2 cm and length of 18 cm, and the thickness of the stainless-steel was 5 mm. The deuterium-loaded titanium foil sample consists of a set of various types of foils. These include one deuterium-loaded titanium foil with a thickness of 0.1 mm and weight of 150 mg and the D/Ti atomic ratio in 10 μm depth of the surface layer of the foil was estimated to be 1. The other types were six Ti–Mo foils. The Ti–Mo foils were prepared by vaporizing titanium onto the molybdenum discs, which had a thickness of 0.5 mm and a diameter of 20 mm. The thickness of titanium varied from about 1.5–4.5 mg/cm^2, and the D/Ti atom ratios were $\sim$ 1.4. The total weight of titanium for all of the deuterium-loaded titanium foils was about 250 mg. All of the deuterium-loaded titanium foils were placed in a 0.5-mm thick aluminum container having a diameter of 9 and 6 cm high. The procedures for loading deuterium into titanium were described in the previous work [5]. Industrial deuterium gas was used for the preparation of the deuterium-loaded titanium samples. The experiment result shows that hydrogen isotopes in the chemical forms of DH, H_2 and H_3 were also mixed in the deuterium gas. The atomic ratio of H/D in the deuterium gas was evaluated to be greater than 5% [5]. Thus, a considerable amount of hydrogen was also loaded into the titanium together with the deuterium.

2.3. Control samples

Control experiments were carried out using uranium oxide and deuterium-unloaded titanium foil samples. The uranium oxide ($\sim$ 30 g) was sealed into a plastic square box with a volume of 50 cm^3 and a plastic thickness of 1 mm. The deuterium-unloaded titanium foil with 0.1 mm thickness ($\sim$ 3 g) is sealed into an aluminum can with diameter of 9 cm, height of 6 cm and aluminum thickness of 0.5 mm.

3. Results

Five runs were taken for the background measurements and five runs were also taken for the uranium deuterium and deuterium-loaded titanium samples, respectively. Each run lasted about 20–50 h, or about 2500–6500 cycles. The period of a cycle is 30 s.

3.1. Measurement of neutron random emissions

The results of the random neutron (including ^{238}U spontaneous fission neutrons in the samples) count rates for the samples and background are plotted in Fig. 2. The random neutron count rates for the five background runs were

measured from 1.660 to 1.775 counts/s, and the average random count rate is (1.712 ± 0.030) counts/s. The average random count rate was 1.798 ± 0.030 and 1.716 ± 0.030 for the uranium deuteride and deuterium-loaded titanium sample, respectively. As a result of ^{238}U spontaneous fission, the average random count rates for the uranium oxide and uranium deuteride samples are greater than the rates for the deuterium-loaded titanium and deuterium-unloaded titanium samples. Based on the ^{238}U spontaneous-fission neutron rate of 0.0136 neutron/s·g [10] and a neutron detector efficiency of 0.55, the neutron production rate is calculated to be 0.16 neutrons/s, or 0.88 counts/s, a value equivalent to the number of neutrons emitted from spontaneous fission in the ∼ 10 g uranium metal sample. Two runs were taken for the measurement of uranium oxide (∼ 30 g). The average random count rate for uranium oxide sample was (1.971 ± 0.03) counts/s, a value of (0.26 ± 0.03) counts/s greater than the background value. The higher value is the result of ^{238}U spontaneous fission in the uranium oxide sample. On the other hand, no difference in average count rates between the deuterium-loaded titanium sample and background is observed within an uncertainty of 2%. Therefore, no excess random neutron emission is observed for either uranium deuteride or deuterium-loaded titanium samples at the background level in this work.

3.2. Time-correlated neutron events for background

The results of time-correlated (coincidence) neutron counts versus the counting cycle in four background runs are given in Fig. 3.

These results show that the intensity and frequency of neutron bursts have irregular variations. The number of neutrons in a burst varies from about 10–750 counts or 18–1400 neutrons in the 30 s in the 5 runs. The frequency of the large bursts (more than 30 neutrons) is about 1–5 bursts per day, and time intervals between two individual bursts are longer than 2 h. The large neutron bursts may originate from spallation induced by high energy (1–100 GeV) cosmic rays in the detector body matter, i.e. polyethylene moderator and other components [1].

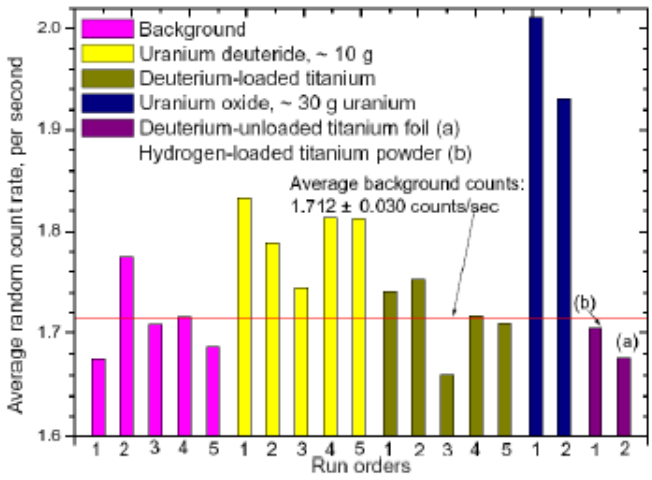

Figure 2. Random neutron count rates for sample measurements. Five runs were taken for background, uranium deuteride and deuterium-loaded titanium samples, respectively, and two runs for uranium oxide and deuterium-unloaded titanium samples, respectively.

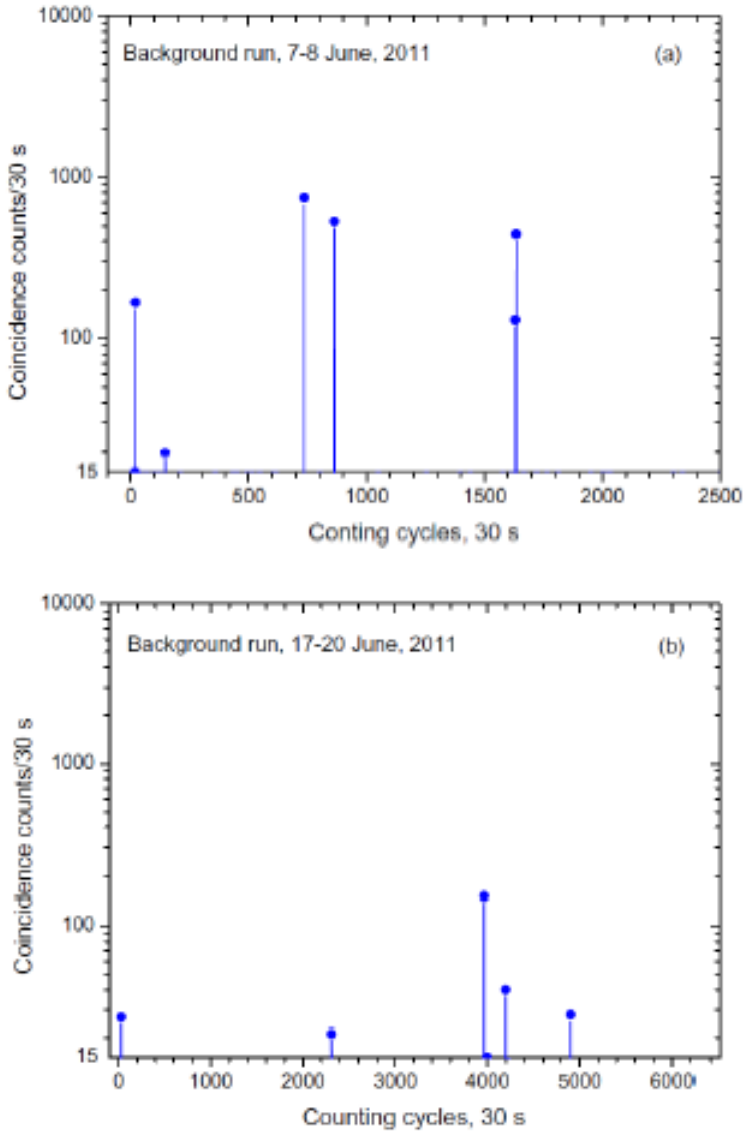

Figure 3a–b

3.3. Anomalous neutron burst emissions for uranium deuteride and deuterium-loaded titanium samples

The four results for uranium deuteride and deuterium-loaded titanium samples are plotted in Fig. 4, and the anomalous neutron bursts are shown. Eight bursts occurred between cycles 365–380 (∼ 7 min), and 13 bursts occurred between cycles 2400–2415 (∼ 7 min) for a uranium deuteride sample on 8–9 June, 2011 (Fig. 4a). Such high-frequency neutron

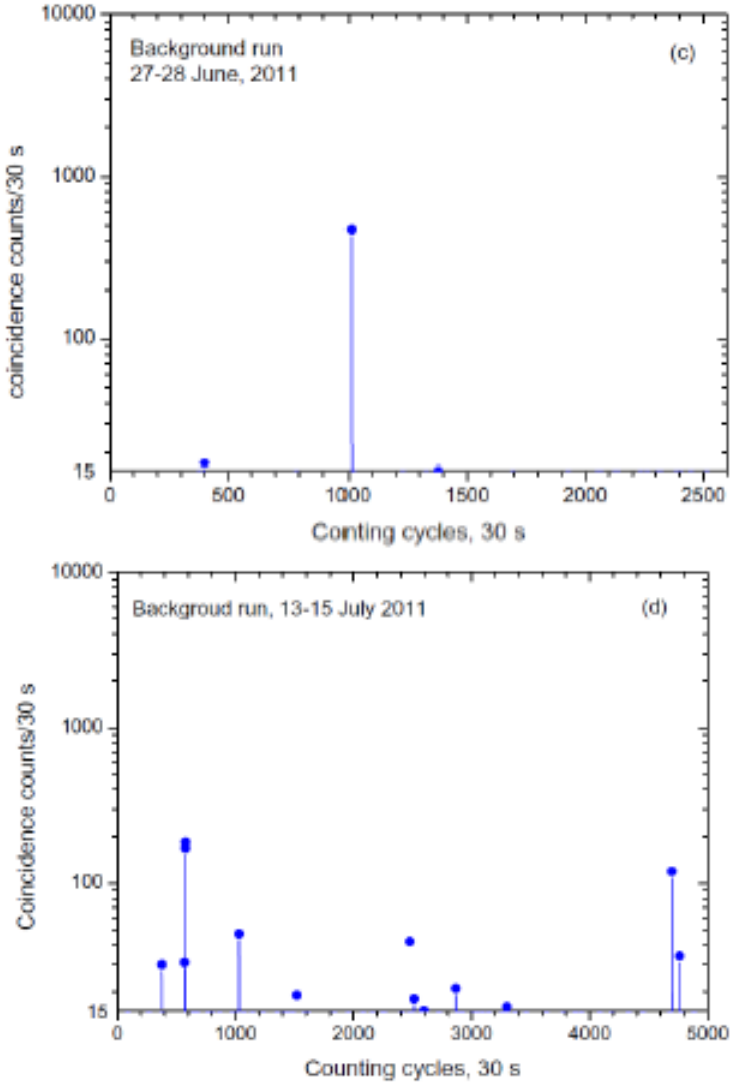

Figure 3c–d

Figure 3. Coincidence neutron counts versus counting cycles for the background measurements.

bursts have never been observed for the background runs at our laboratory, and they are not reported in the literature. The high-frequency neutron bursts are also observed for the other runs. Eleven neutron bursts occurred between cycles 1798–2949 (∼120 min), and 5 bursts occurred between cycles 2819 and 2863 (∼20 min) on 22–24 June, 2011 (Fig. 5b). The largest intensity of neutron bursts for the uranium deuteride sample was 1181 counts or 2150 neutrons in the 30 s (Fig. 5b). The high-frequency neutron bursts are also observed for deuterium-loaded titanium sample. Three bursts occurred between cycle 449 and 479 (∼15 min) and between cycles 1616 and 1624 (∼4 min), and four bursts

occurred between cycles 2511 and 2530 (∼10 min) on 11–13 July, 2011 (Fig. 4c). Six bursts occurred between cycles 2511 and 2715 (∼100 min) and five bursts occurred between cycles 5053 and 5074 (∼10 min) on 19-22 July, 2011 (Fig. 4d). The highest intensity of neutron bursts for deuterium-loaded titanium sample was 1541 neutrons, or 2800 neutrons in the 30 s (Fig. 4c). The two high-frequency neutron burst events observed on 8–9 June are enlarged in Fig. 5.

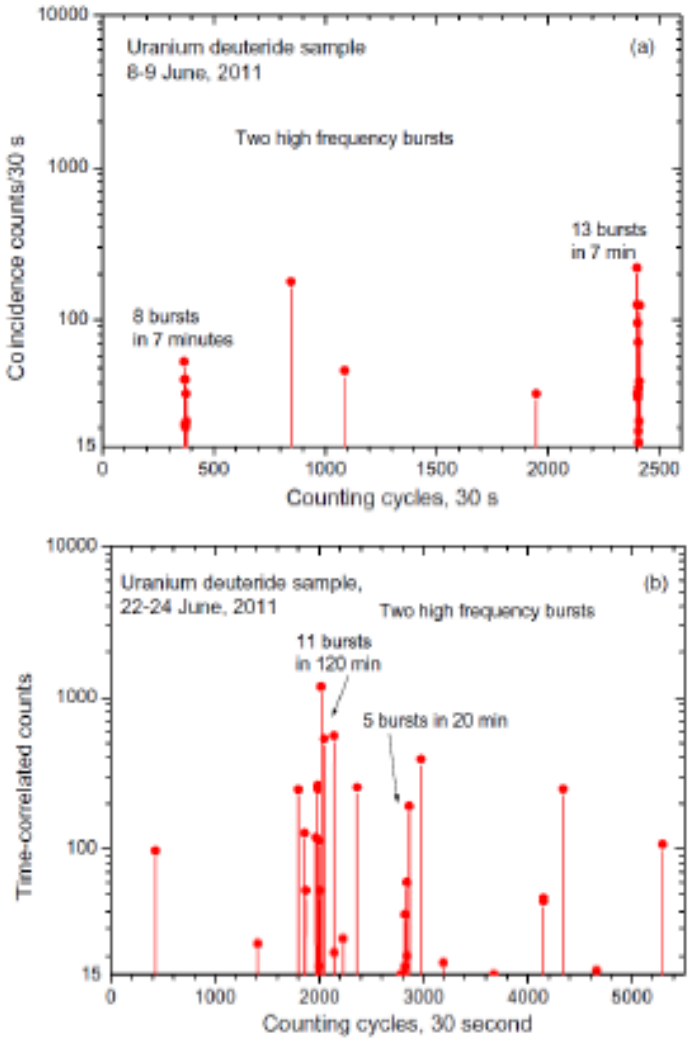

Figure 4a–b

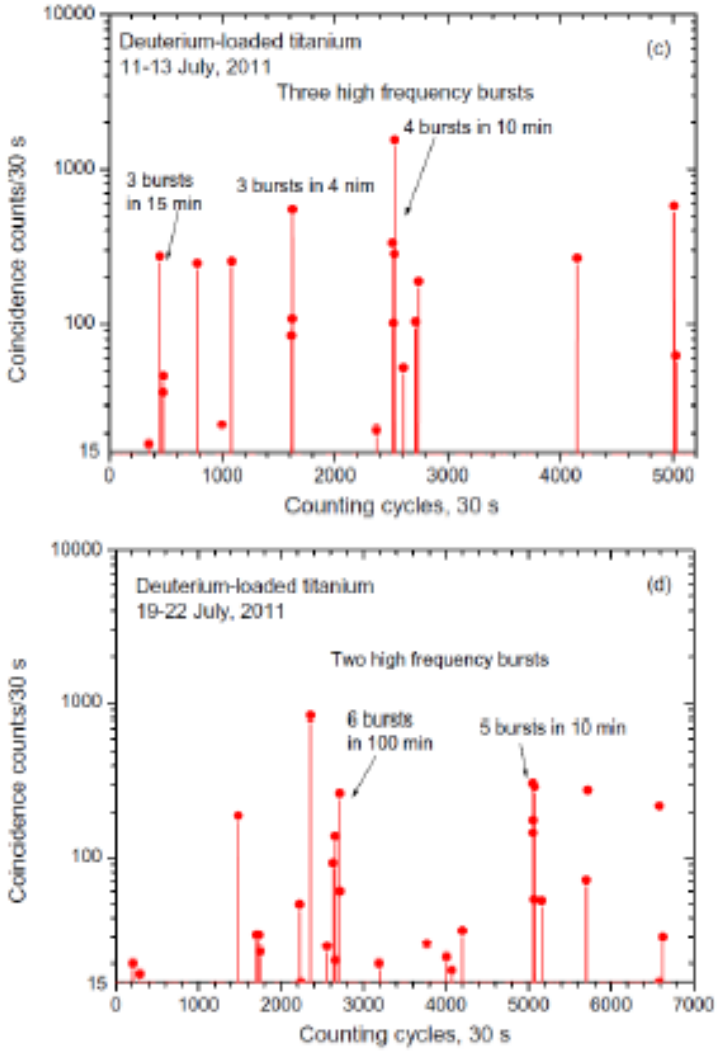

Figure 4c–d

Figure 4. Coincidence neutron counts versus counting cycles for uranium deuteride and deuteride-loaded titanium samples.

3.4. Time-correlated Neutron burst events for the control samples

Control experiments were carried out using uranium oxide and deuterium-unloaded samples. Total numbers of neutron bursts in 24 and 50 h were 4 and 10 for the uranium oxide sample on 21–22 June, 2011 (Fig. 6a) and 28 June–1 July, 2011, respectively (Fig. 6b). The total number of bursts was 12 for the deuterium-unloaded titanium foil sample in ∼50 h (Fig. 6c). No high-frequency neutron burst emissions are observed for either of the control samples.

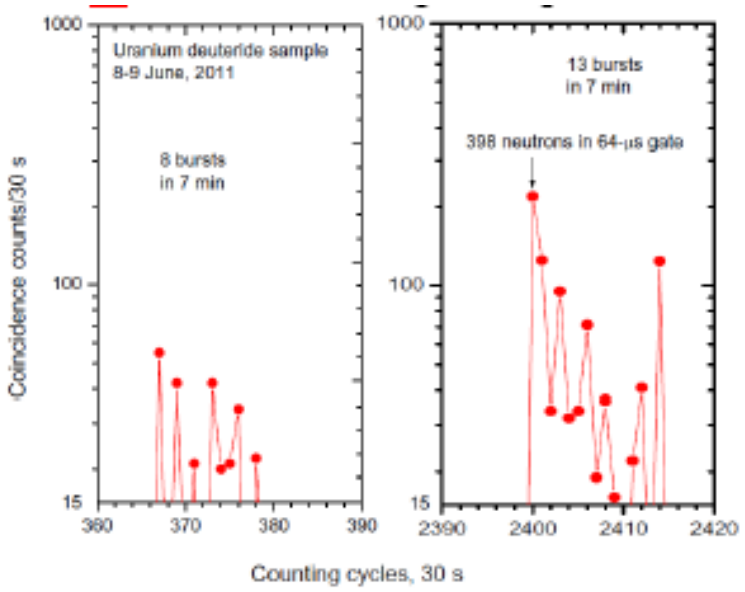

Figure 5. The two enlarged cascade neutron burst events for uranium deuteride sample (see original plot in Fig. 4a).

4. Conclusions

We have reported new results of neutron burst emission from deuterium-loaded metals. In addition to normal neutron bursts induced by cosmic-ray spallations, high-frequency neutron bursts are observed occasionally for uranium deuteride

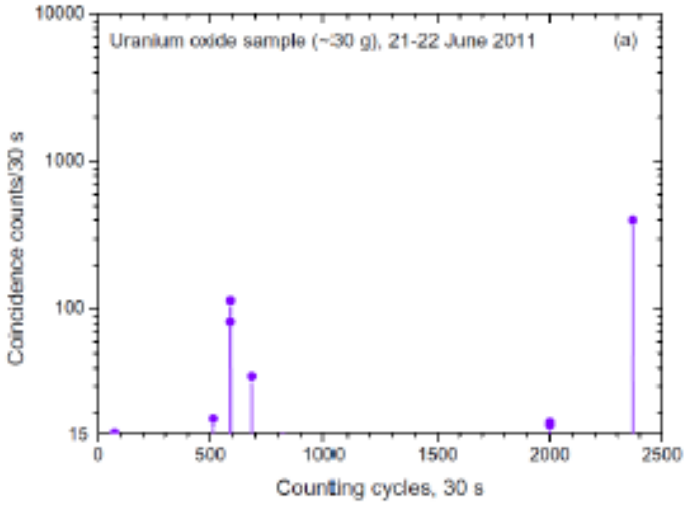

Figure 6a

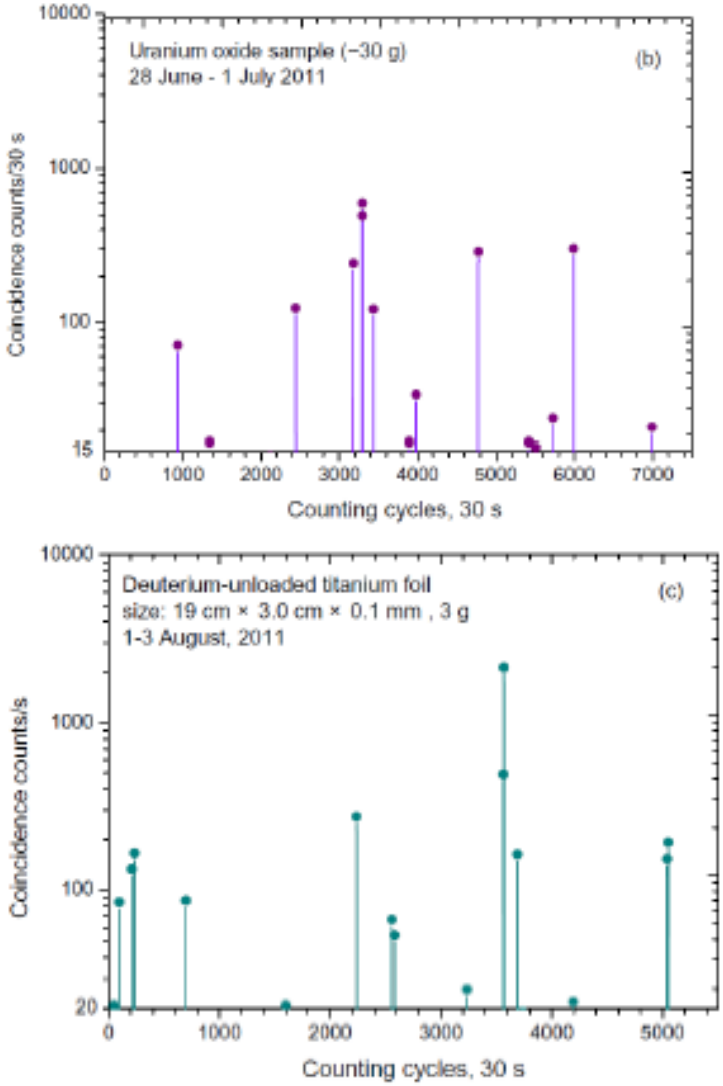

Figure 6. Coincidence neutron counts versus counting cycles for uranium oxide and deuterium-unloaded titanium samples (Fig. 6a–c).

and deuterium-loaded titanium samples. In this measurement, another neutron detector, i.e. neutron monitor, was used for monitoring the variation of the environmental neutron backgrounds and accidental artifact vibration noise. No anomalous signals were observed. Therefore, the accidental artifact burst events may be ruled out in sample measurements. We suggest that the high-frequency neutron bursts are correlated with the deuterium-loaded metals and may originate from a nuclear reaction occurring on the metal surface with a micro-nanometer size[5,13], but do not occur in the bulk materials and whole surface. The number of neutrons in the large bursts was measured as being up to 2800 in an interval of less than 30 s. On the other hand, random neutron emissions are not observed in this work.

Measurement of neutron burst emission may have special significance in understanding the mechanism of LENR and heat production. The mechanism of neutron burst emission in deuterium-loaded metals remains an open question. Although reaction mechanisms have been supposed, as yet no theory has gained wide acceptance [14].

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References

[1] H.O. Menlove, M M. Fowler, E. Careia, A. Mayer, M.C. Miller, R.R. Ryan and S.E. Jounes, The measurement of neutron emission from Ti and Pd in pressurized D_2 gas and D_2O electrolysis cells, *Journal of Fusion Energy*, vol. 9, pp. 495-506. 1990,

[2] G. Mengoli, M. Fabrizio, C. Manduchi, E. Milli and G. Zannoni, Absorption–desorption of deuterium at Pd95%·Rh5% alloy. ‡**U**: Neutron emission, *J. Electroanal. Chem.* **10** (1995) 249–260.

[3] P.A. Mosier-Boss, S. Szpak, F.E. Gordon and L.P.G. Forsley, Triple tracks in CR-39 as results of Pd/D Co-deposition: evidence of energetic neutrons, *Naturwissenschaften* **96** (2009) 135–142.

[4] S.-S. Jiang, J.-H. Li, J.Q. Wang, M. He, S.-Y. Wu, H.T. Zhang, S.-H. Yao and Y.-G. Zhao, Measurement of anomalous nuclear reaction in deuterium-loaded metal, *Chinese Phys. B* **18** (1999) 1428–1435.

[5] S.-S. Jang, M. He, S.-Y. Wu and B.-J. Qi, Anomalously high isotope ratio ^{3}He/^{4}He and tritium in deuterium-loaded metal: evidence for nuclear reaction in metal hydrides at low temperature, *Chinese Phys. Lett.* **29** (2012) 12503–1–3.

[6] S.-S. Jiang, L. Jin and M. He, A possible in situ ^{3}H and ^{3}He source in Earth's interior: an alternative explanation of origin of ^{3}He in deep Earth, *Naturwissenschaften* **97** (2010) 655–662.

[7] S.E. Jones and J.E. Ellsworth, Cold (metal-enhanced) fusion, geo-fusion, and cold nucleosynthesis, *Condensed Matter Nuclear Science*, World Scientific, London, 2005, p. 617.

[8] S.-S. Jiang and M. He, Anomalous nuclear reaction in Earth's interrior: a new field in physics science? , *Plasma Sci. Technol.* **14** (2012) 438–441.

[9] N. Ensstin, W. Harker, M.S. Krick, D.G.. Langner, M.M. Pickrell and J.E. Stewart, Application guide to neutron multiplicity counting , *LA-13422-M Manual*, Los Alamos, 1998.

[10] H.O. Menlove and M.C. Miller, Neutron-burst detector for cold fusion experiments, *Nucl. Instr. Meth*. A **299** (1990) 10–16.

[11] P. Seungwoo, D.H. Ahn, K.R. Kim and H. Chung, Characteristics of reaction between hydrogen isotopes and depleted uranium, *J. Ind. Eng. Chem*. **8** (2002) 12–16.

[12] Y.E. Kim, Theory of Bose–Einstein condensation mechanism for deuteron-induced nuclear reactions in micro/nano-scale metal grains and particles, *Naturwissenschaften* **96** (2009) 803–811.

[13] E. Storms, *The Science of Low-energy Nuclear Reaction*, World Scientific, Singapore, 2007.