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Anomalous Neutron Burst Emissions in Deuterium-Loaded Metals: Nuclear Reaction at Normal Temperature *

JIANG Song-Sheng(蒋崧生)**, XU Xiao-Ming(许小明), ZHU Li-Qun(祝利群), GU Shao-Gang(顾少刚), RUAN Xi-Chao(阮锡超), HE Ming(何明), QI Bu-Jia(祁步嘉)

China Institute of Atomic Energy, P. O. Box 275 (49), Beijing 102413

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Conventional nuclear fusion occurs in plasma at temperatures greater than 10^7°C or when energy higher than 10 keV is applied. We report a new result of anomalous neutron emission, also called cascade neutron burst emission, from deuterium-loaded titanium and uranium deuteride samples at room temperature. The number of neutrons in the large bursts is measured as up to 2800 in less than a 64-μs interval. We suggest that the anomalous cascade neutron bursts are correlated with deuterium-loaded metals and probably the result of nuclear reactions occurring in the samples.

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In 1989, Fleischmann and Pons[1] and Jones *et al.*[2] 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 the scientists. Because of the difficulty of detecting low-level neutrons and the infrequent neutron-production from nuclear reactions, the results were often contradictory or not reproducible. However, positive results were also reported.[3–6]

Measurement of neutrons in low-energy nuclear reaction (LENR) requires a 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. 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 an updated 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)[7–9] will be helpful to study the mechanism of LENR and the origin of excess ^{3}He and tritium in the deep Earth.[10–12]

The detector has a high neutron detection efficiency and a good ability to reject γ-ray background and eliminate electrical noise. In addition, a multiplicity shift register circuit provides both random and time-correlated neutron counts and is able to quantitatively measure a single burst of neutrons lasting a few microseconds. The detector consists of 88 ^{3}He tubes (6×10^5 Pa) embedded in 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 a diameter of 16.5 cm and a 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 for the reflection of neutrons emitting from the sample. The detector body has an outer diameter of 70 cm and height of 80 cm, and the whole detector body is shielded from thermal neutrons with 1-mm cadmium. The neutron detection efficiency was calibrated by using a ^{252}Cf neutron source (average neutron energy 2.3 MeV) to be greater than 50%.

Another neutron detector (also called a neutron monitor) was used for monitoring the environmental neutron background and accidental artifact noise during sample measurements. The detector consists of three polyethylene slabs with sizes of $30 \times 30 \times 6$ cm, and four ^{3}He tubes were embedded in each of the slabs. The relative efficiency of the neutron monitor to the main neutron detector is about 40% for detection of the environmental neutron background. The neutron monitor has electronic circuitry and a multiplicity shift register similar to that of the main neutron detector. Thus, the two detectors may 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 backgrounds and accidental artifact vibration noise.

There are two nuclear processes for nuclear reactions occurring in the deuterium-loaded metals: burst

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**Corresponding author. Email: ssjiang@ciae.ac.cn

(time-correlated) and continuous (random or accidental) reactions.[13] We use a multiplicity shift register for recording the both time-correlated neutron bursts and random events.[14] The multiplicity shift register has an ability to record all time-correlated (coincidence) neutron events, not just single and double neutron events.[15]

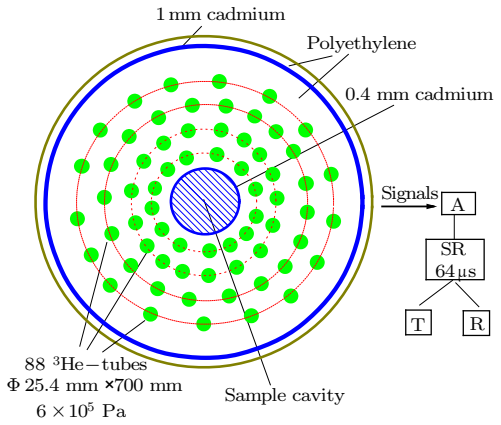

Fig. 1. A top view of the neutron detector systems. A, SR, T and R denotes amplifiers, multiply shift registers, time-correlated counters, and random counts, respectively,

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 higher than the D/Ti ratio. Uranium (^{238}U) metal machine-chips (about 10 g) were used to prepare the uranium deuteride sample. The procedures used for the preparation of uranium deuteride were performed as described in the previous work.[16] After loading deuterium in uranium chips, the chips were all 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 consisted of a set of different foils. One deuterium-loaded titanium foil had a thickness of 0.1 mm and weight of 150 mg, and the D/Ti atomic ratio in the 10 μm depth of the surface layer of the foil was estimated to be 1. The others 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 the titanium varied from about 1.5 to 4.5 mg/cm^2, and the D/Ti atomic ratios were ∼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 settled into a 0.5-mm-thick aluminum container having a diameter of 9 cm and height of 6 cm. The procedures for loading deuterium into titanium were described in the previous work.[7] Industrial deuterium gas was used for preparation of the deuterium-loaded titanium samples. The experimental 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%.[8] Thus, a considerable amount of hydrogen was also loaded into the titanium together with the deuterium.

The control experiment was carried out by using uranium oxide and deuterium-unloaded titanium foil samples. The uranium oxide (∼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 (∼3 g) was sealed into an aluminum container with a diameter of 9 cm, height of 6 cm, and aluminum thickness of 0.5 mm.

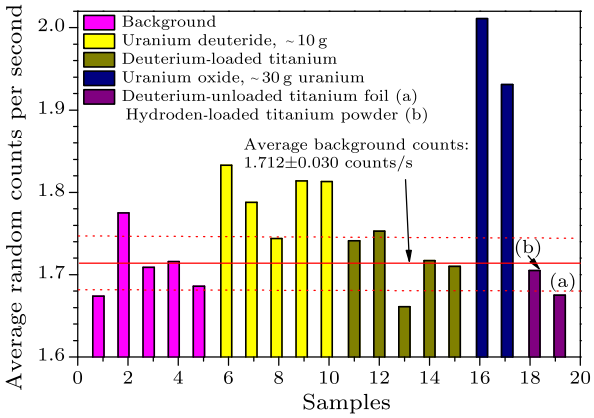

Fig. 2. Random neutron count rates for background runs, uranium deuteride, deuterium-loaded titanium, uranium oxide, and deuterium-unloaded titanium foil samples. See text for details.

Five runs were taken for the background measurements in June–July 2011, and five runs were also taken for the uranium deuteride and deuterium-loaded titanium samples, respectively. Each run lasted about 20 to 50 h, or about 2500 to 6500 cycles. The period of a cycle was 30 s.

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 measured to be 1.798 ± 0.030 and 1.716 ± 0.030 for the uranium deuteride and deuterium-loaded titanium samples, 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. According to a ^{238}U spontaneous-fission neutron rate of 0.0136 neutron/s·g[14] and a neutron detector efficiency of 0.55, the neutron production rate is calcu-

lated 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 measurement of uranium oxide (∼30 g). The average random count rate for the uranium oxide sample was measured to be (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 of average count rates between the deuterium-loaded titanium sample and the background is observed within an uncertainty of 2%. Therefore, no excess random neutron emission is observed for uranium deuteride and deuterium-loaded titanium samples at the background level in this work.

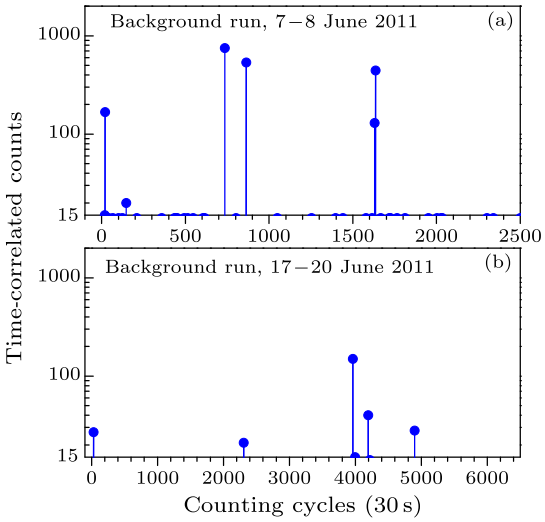

Fig. 3. Time-correlated neutron counts versus counting cycles for the background measurements.

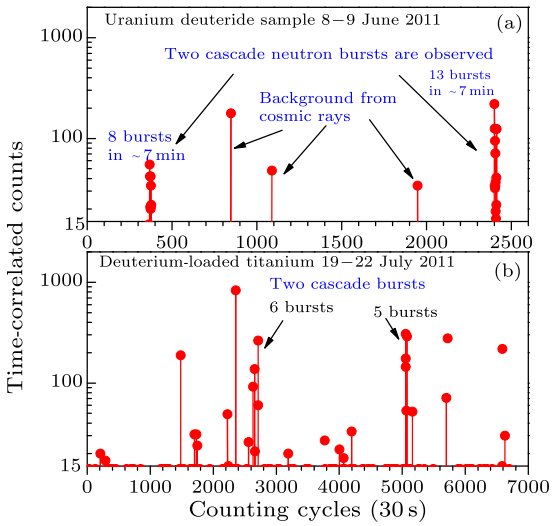

Fig. 4. Time-correlated neutron counts versus counting cycles for uranium deuteride and deuterium-loaded titanium samples (Figs. 5(a) and 5(b)).

The results of time-correlated neutron counts versus counting cycle in two background runs are given in Fig. 3. The results show that the intensity and frequency of neutron bursts have irregular variations. The number of neutron in a burst varies from about 10 to 750 counts or 18 to 1400 neutrons in 64 μs gate in the 5 runs. The frequency of the large bursts (neutrons larger than 30) is about 1-05 bursts per day, and the time intervals between two individual bursts are larger than 2 h. The large neutron bursts in the background may originate from spallation induced by the nuclear reaction of high energy (1–100 GeV) cosmic rays with the detector body matters, i.e., the polyethylene moderator and others.[3]

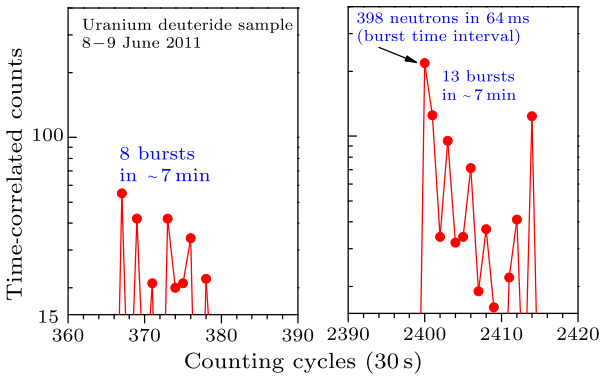

Fig. 5. The two enlarged cascade neutron burst events for the (a) uranium deuteride and (b) deuterium-loaded titanium samples. See the original plot in Fig. 4(a).

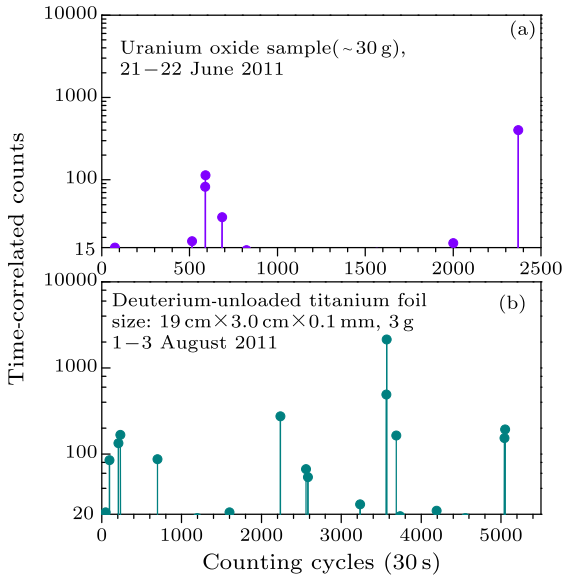

Fig. 6. Time-correlated neutron counts versus counting cycles for uranium oxide and deuterium-unloaded titanium foil samples (Figs. 5(a) and 5(b)).

Two results for uranium deuteride and deuterium-loaded titanium samples are plotted in Fig. 4, and anomalous cascade neutron bursts are observed in the measurements. Eight bursts occurred between cycles 365–380 (∼7 min), and 13 bursts occurred between cycles 2400-2415 (∼7 min) for the uranium deuteride

sample in 8–9 June 2011 (Fig. 4(a)). These high frequency neutron bursts, also called cascade neutron bursts, have never been observed for the background runs at our laboratory and never reported in literature. The largest intensity of neutron bursts for the uranium deuteride sample was measured to be 1181 counts, or 2150 neutrons, in 64 μs gate in 22–24 June 2011. Two cascade neutron bursts were observed for the deuterium-loaded titanium sample in 19–22 July 2011 (Fig. 4(b)). Six bursts occurred between cycles 2511 and 2715 (∼100 min) and five bursts occurred between cycles 5053 and 5074 (∼10 min). The largest intensity of neutron bursts for the deuterium-loaded titanium sample was measured to be 1541 counts, or 2800 neutrons, in 64 μs gate in 11–13 July 2011.

The two cascade neutron burst events observed in 8–9 June 2011 are enlarged in Fig. 5.

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

In summary, we have reported a new result of neutron burst emission from deuterium-loaded metals. In addition to normal neutron bursts induced by cosmic-ray spallations, cascade neutron bursts are observed occasionally for the uranium deuteride and deuterium-loaded titanium samples. After accidental artifact noise and cosmic-ray sources are ruled out, we suggest that the cascade 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,[7,17] but do not occur in the bulk materials and the whole surface. The number of neutrons in the large bursts was measured as being up to 2800 in less than 64-μs interval. 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 LE N R 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 a wide acceptance.[18]

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References

[1] Fleischmann M and Pons S 1989 *J. Electroanal. Chem. Interfac. Electrochem.* **261** 301
[2] Jones S E Palmer E P, Czirr J B, Decker D L, Jensen G L, Thorne J M, Taylor S F and Rafelski J 1989 *Nature* **338** 737
[3] Menlove H O, Fowler M M, Careia E, Mayer A, Miller M C, Ryan R R and Jones S E 1990 *J. Fusion Energy* **9** 495
[4] Takahashi A, Takeuchi T and Wanatabe M 1990 *J. Nucl. Sci. Technol.* **27** 663
[5] Mengoli G, Fabrizio M, Manduchi C, Milli E and Zannoni G 1995 *J. Electroanal. Chem.* **10** 249
[6] Mosier-Boss P A, Szpak S, Gordon F E and Forsley L P G 2009 *Naturwissenschaften* **96** 135
[7] Jiang S S, Li J H, Wang J Q, He M, Wu S Y, Zhang H T, Yao S H and Zhao Y G 2009 *Chin. Phys.* B **18** 1428
[8] Jiang S S, He M, Wu S Y and Qi B J 2012 *Chin. Phys. Lett.* **29** 012503
[9] Biberian J P 2007 *J. Nucl. Energy Sci. Tech.* **3** 31
[10] Jiang S S, Jin L and He M 2010 *Naturwissenschaften* **97** 655
[11] Jones S E and Ellsworth J E 2005 *Condensed Matter Nuclear Science* (London: World Scientific) p 617
[12] Jiang S S and He M 2012 *Plasma Sci. Technol.* **14** 438
[13] Hora H H, Kelly J C, Patel J U and Prelas M A 1993 *Phys. Lett.* A **175** 138
[14] Ensstin N, Harker W, Krick M S Langner D G, Pickrell M M and Stewart J E 1998 *LA-13422-M Manual* (Los Alamos)
[15] Menlove H Oand Miller M C 1990 *Nucl. Instrum. Methods* A **299** 10
[16] Seungwoo P, Ahn D H, Kim K R and Chung H 2002 *J. Ind. Eng. Chem.* **8** 12
[17] Kim Y E 2009 *Naturwissenschaften* **96** 803
[18] Storms E 2007 *The Science of Low Energy Nuclear Reaction* (Singapore: World Scientific)