Jiang, S. *New results of charged particle released from deuterium-loaded metal at low temperature*. in *ICCF-14 International Conference on Condensed Matter Nuclear Science*. 2008. Washington, DC.

New results of charged particles released from deuterium-loaded metal at low temperature

Songsheng Jiang [+], Jinghuai Li, Ming He, Shaoyong Wu, Jianqing Wang, Hongtao Zhang, Shunhe Yao, Yonggang Zhao, Chen Wang

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

[+] *Corresponding author, E-mail: ssjiang@ciae.ac.cn*

Abstract

We have suggested that the mantle ^{3}He and ^{3}H might have originated from natural nuclear fusion (d-d and d-p reaction, or other reactions) in deep Earth. Encouraged by this new idea, we tried to recreate nuclear fusion at low temperature in the laboratory. This paper describes charged particles emitted from the deuterium-loaded titanium foil and powder at low temperature. Although the counts are very low (about 0.13 counts/h), fortunately, broad and narrow peaks are observed for the deuterium-loaded titanium foil and TiD-Mo sample respectively. The charged particle is identified as proton having energy of about 2.8 MeV after exiting the sample. We suggest that the proton might originate from d-d reaction in the samples. Then the d-d reaction rate is calculated to be 1.4×10^{-24} fusion/d-d· sec for the deuterium-loaded titanium foil sample. On the other hand, no charged particles were observed above the background level for deuterium-loaded titanium powder sample. Therefore, this work provides a positive result of nuclear fusion for the metal foil samples, but a negative result for the powder samples. The negative result of the deuterium-loaded titanium powder sample suggests that the reaction yield might be correlated with deuterium density, or it may be correlated with microscopic variations in the deuterium-loaded titanium materials. The negative result also indicates that d-d reaction catalyzed by μ-meson from cosmic ray can be excluded in this experiment. The present work may be helpful to the further study on the physical mechanism of nuclear fusion in deuterium (hydrogen)-loaded metals and also helpful to the study of origin of ^{3}He in the deep Earth.

1. Introduction

In the recent work [1,2], we demonstrated that the excess ^{3}H in the volcanic Lakes Nemrut (Turkey) and Laacher (Germany) might be released from the mantle, based on the correlation of excess tritium (^{3}H) with mantle ^{3}He and other mantle gases. We have suggested that the mantle ^{3}He and ^{3}H might originate from natural nuclear fusion (d-d and d-p reactions, or other reactions) in the deep Earth, after ^{3}H originating from atmospheric and conventional nuclear reactions are excluded, and the correlation between constant ^{3}He/^{4}He ratio and ^{3}He/heat ratio in the hydrothermal vent fluids at Mid-Ocean-ridges is considered. [2] Encouraged by this new idea, we tried to recreate natural nuclear fusion at laboratory. Since 1989, there have been a number of serious attempts to observe nuclear effect in metal deuterides. [3, 4] Particularly relevant to the

present work are Jones *et al.*, Cecil *et al.* and Chambers *et al.*, [5-7]. However, particle identification was problematic and irreproducibility remained a significant issue. [5] The results were not published in a mainstream journal. Our goal was to check these previous claims. We obtained a positive result for the deuterium-loaded titanium foil samples.

In the conventional view, the d-d fusion rate of deuterium molecule is exceedingly low at low temperatures, roughly on the order of 10^{-63} per D_2 molecule per second. [8] However, recent theories, such as references [9] and [10], and experiment [5] and [7] show that nuclear fusion of the deuterium system is possible in metal lattices under strong restriction of the metal electrons. The measured fusion rates for the deuterium-loaded titanium foils were reported to be (10^{-21} - 10^{-25}) per D_2 per second at room temperature. [5]

In this experiment, charged particles emitted from the samples were measured using a low-level charged particle spectrometer, and the ΔE-E method was used for particle identification. The data acquisition was repeated several times and different samples were measured. Because of the very low counting rates, the measurements lasted for several months.

2. Experimental details

2.1. Sample preparation

Figure 1 shows a diagram of the system used to prepare the deuterium-loaded samples. Chemical-grade deuterium gas is stored in a depleted-uranium bed, inside the deuterium-storage chamber (50 mm diameter, 500 mm length). To load deuterium, the titanium sample is placed inside a reaction chamber (30 mm diameter, 300 mm length). The reaction chamber is evacuated to about 10 Pa and heated at 200-300°C to degas the sample. The temperature is increased to about 400°C, and the chamber is pressurized with deuterium gas, which was released from the uranium bed by heating it to about 400-500°C. When the pressure reaches about 5×10^4 Pa, the inlet valve of reaction chamber is closed. A drop in pressure clearly demonstrated that the titanium sample inside the reaction chamber become deuterided. Based on the change in gas pressure and the weight of titanium sample, the atomic ratio of D/Ti can be calculated. The average ratio depends on the thickness of Ti foil. For a thickness less than 5 μm, the atomic ratio of D/Ti is around 1.2-1.4, and the ratio reaches 1.6 for the powder sample. However, D/Ti ratio decreases to about 0.1 for the Ti foil with 0.5 mm thickness. The result suggests that most of deuterium can only be loaded near the Ti surface.

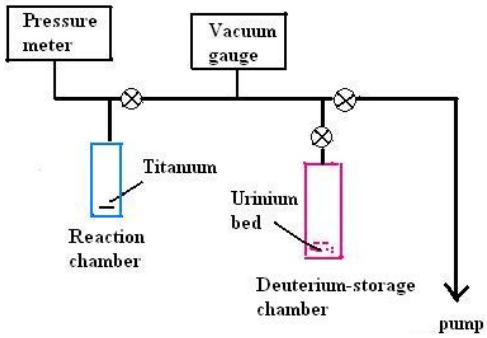

Figure 1. Systematic diagram for preparation of deuterium-loaded titanium samples.

2.2. Charged particle detection

Detection of charged particle was carried out using OCTETE low-level charged particle spectrometer. The silicon dioxide-passivated ion-implanted detectors with active-area of 600 mm2 were used. The depleted layer of the detectors is 100 μm. The detector and sample were located in a vacuum chamber (Fig. 2). The detector efficiency was calibrated using point sources to be about 30% at the detector when the source was less than 10 mm from the detector. The 1024-channel analyzer was calibrated with a ^{241}Am source (5.45 MeV α-particle) to be 8.52 keV per channel. During measurement, the chamber was evacuated to about 5 Pa. The spacing between detector and sample was about 5 mm.

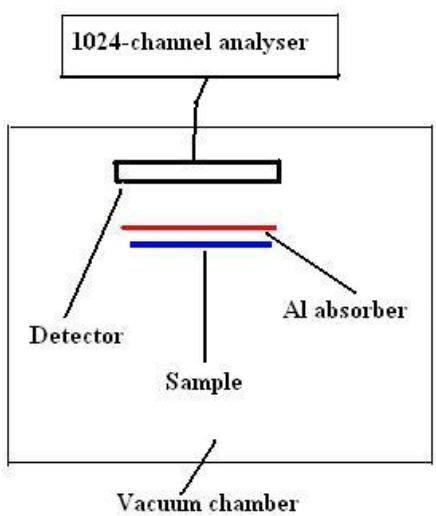

Figure 2. Outline of detection system for measurement of charged particle. The silicon dioxide-passivated ion-implanted detectors with active-area of 600 mm^2 are used. The depleted layer of the detectors is 100 μm.

The aim of this experiment is search for proton from d-d reaction, as follows:

$$d + d \rightarrow p\ (3.02\ \text{MeV}) + T\ (1.01\ \text{MeV}). \quad (1)$$

The range of 3.02 MeV proton in Si is calculated to be 91 μm using SRIM code [11]. While a 3-MeV proton penetrates the depleted layer of the Si detector, it should be stopped in the layer.

2.3. Charged particle identification

The ΔE-E method, based on Bethe-Bloch equation, is used for charged particle identification. The Bethe-Bloch equation can expressed simply as:

$$\Delta E \cdot E/M \propto Z^2 \quad (2)$$

Here ΔE and E is energy loss in the matter and overall energy of charged particle respectively. M and Z is the mass and atomic number of particle respectively.

In this experiment, we consider only how to identify protons, 3He, tritons and α-particles. A 15 μm Al foil was used as energy absorber for ΔE measurement. The ΔE values for proton, ^{3}He, triton and α-particle are calculated using SIRM code. [11] The energy loss for 3-MeV proton, triton, ^{3}He and α-particle in the Al foil is calculated to be about 0.35, 2.5, 2.9 and 3 MeV, respectively. Thus the type of particles can be identified from the measured ΔE (or residual energy) value. It can be seen that the residual energy of the proton, triton, ^{3}He and α-particle is 2.65, 0.5, 0.1 and 0 MeV respectively. The pronounced difference of the residual energies makes identification of those charged particles easy in the measurement.

3. Measurement

3.1. Deuterium-loaded titanium foil sample

Four runs were performed measuring deuterium-loaded titanium foil sample (0.1 mm thick). Two measurements were made in each of the first 3 runs, to test stability and repeatability. In the first run, the deuterium-loaded titanium foil sample was measured, and then in the third run it was measured again to check reproducibility. To identify particles, in the second run an Al foil of 15 μm thickness was inserted between the deuterium-loaded titanium foil sample and the detector. A fourth run was carried out with a blank sample; i.e., a titanium sample with no deuterium. The spectrum of the sample for run 1, 2 and 3 are shown in Figs. 3, 4 and 5 respectively.

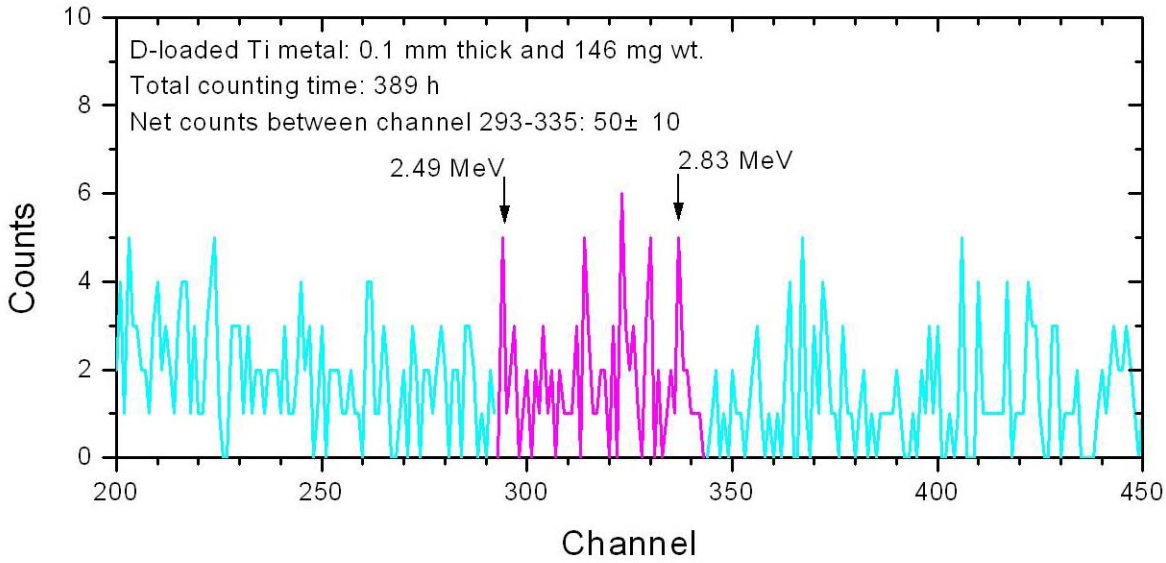

Figure 3. Spectrum of the deuterium-loaded titanium foil sample in run 1.

Although the counting rate is low, a broad peak above the background is observed, ranging from 2.49 to 2.83 MeV, with average energy of 2.66 MeV (Fig. 3). In this run another peak is observed around channel 370 (3.15 MeV) (Fig. 3). This peak might originate from contamination by other radioactive samples previously used in the detection chamber, because the peak did not appear again in the later runs. The background counts in the low energy region (less than ~2.0 MeV, or channel 250) are mainly induced by the tail effect of the electronic noise.

The background counts in the peak area are deduced from the average counts of the neighbouring channels close to the both sides of the broad peak. The total counts in the peak area after subtracting the deduced background counts is defined as net counts. The net counting rate in the broad peak is deduced to be 0.129±0.032 counts/h in run 1. The same procedure is used to subtract the background counts in the following runs.

To identify the type of the particles in the peak, an Al foil was inserted between the sample and the detector in run 2 (Fig. 4). The energy loss of a 3-MeV proton in the Al foil is calculated to be 0.35 MeV. Therefore, the residual energy is about 2.65 MeV. A broad peak is also observed in run 2, but the peak is shifted and broadened (Fig. 4). Due to energy loss and dispersion of the charged particle in the Al absorber, the peak is shifted between 2.17 and 2.63 MeV and the peak width is broadened, ~0.12 MeV greater than in run 1. The average energy of the peak is 2.40 MeV, about 0.18 MeV smaller than the value in run 1. The net counting rate in the broad peak is 0.157±0.046 counts/h.

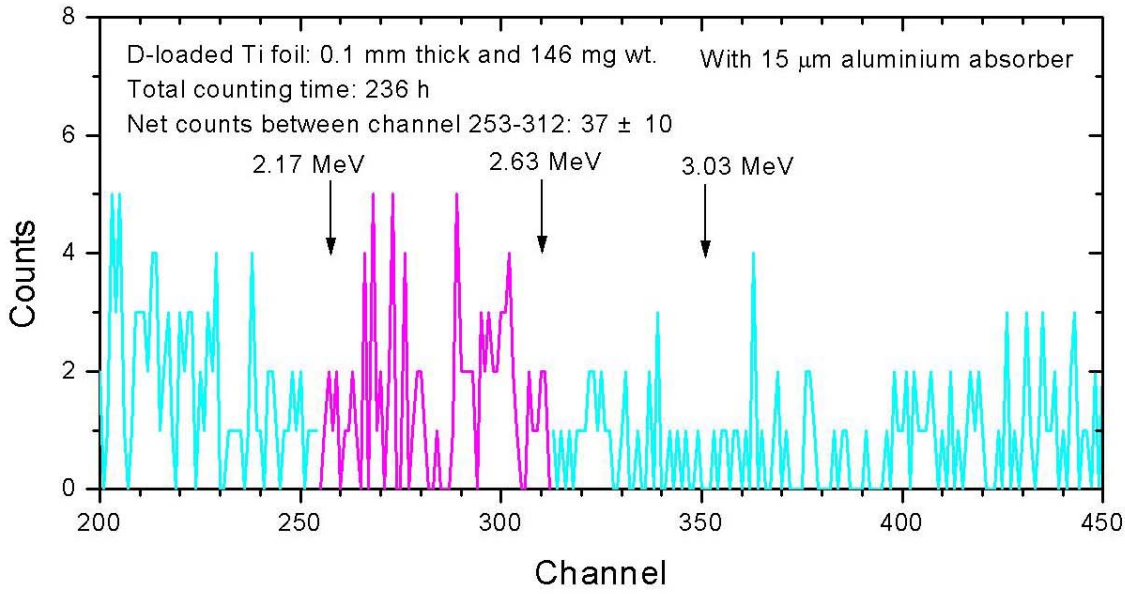

Figure 4. Spectrum of the deuterium-loaded titanium foil sample in run 2, with a 15 μm Al foil inserted between detector and the sample.

To test repeatability, the Al absorber was removed in run 3. It can be seen that the broad peak returns (Fig. 5a), close to the area it was observed in run 1. The peak ranges from 2.39 to 2.77 MeV, and average energy of the broad peak is 2.58 MeV. The net counting rate in the broad peak is 0.127±0.036 counts/h (Fig. 5a). The spectrum of measurement in the first 94 hours in run 3 is also given in Fig. 5b. From Fig. 5a and 5b, it can be seen that the counting rates in the peak area is almost stable in the overall time of 189 hours, in run 3. The results indicate that after removing the Al absorber, the broad peak in run 1 was closely reproduced in run 3.

The shift of the peak in run 2 is well correlated with the insertion of the Al absorber. The residual energy of the charged particles in run 2 is measured at 2.40 MeV, and the mean value of the energy in run 1 and 3 is deduced to be 2.62 MeV. From the difference of the mean value of energy for the broad peak in run 1 and 3 (with no Al foil) and run 2 (with Al foil), the energy-loss of charged particle passing through the Al absorber is estimated to be 0.22±0.15 MeV, a value that is consistent with the calculated value (0.35±0.10 MeV) for 3 MeV proton. Therefore, the observed charged-particle should be 3 MeV proton released from the sample.

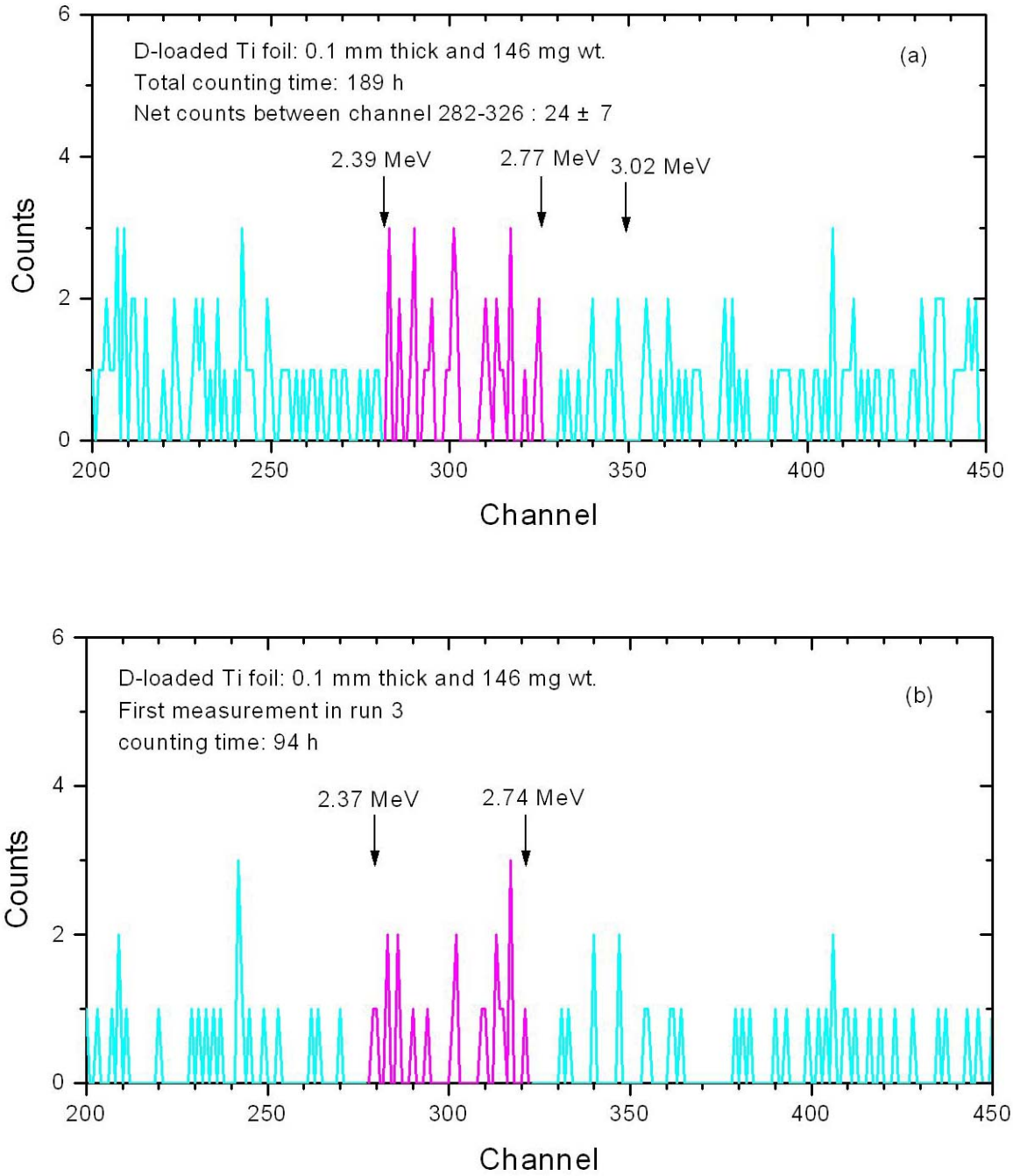

Figure 5. Spectrum of the deuterium-loaded titanium foil sample in run 3, for overall measurement time of 189 hours (Fig. 5a) and for the first 94 hours of run 3 (Fig. 5b).

The fourth run is made with blank sample: a titanium foil with no deuterium, 0.1 thick, 200 mg. No counts are observed above the background level in the energy range of interest (2.39-2.80 MeV, or channel 280-340) (Fig. 6). Therefore, the deuterium in the titanium foil is apparently the source of the charged particles emitted from the sample in the previous runs.

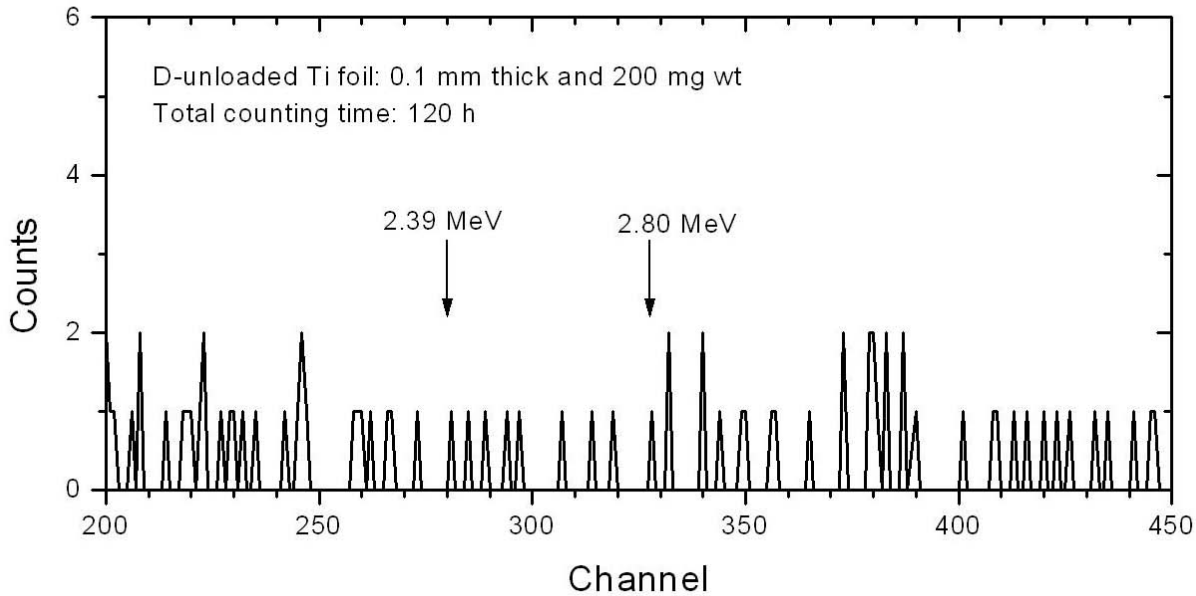

Figure 6. Spectrum of the blank sample, a titanium foil sample (20×20×0.1 mm) with no deuterium, in run 4.

We believe that the net counts in all three broad peaks in run 1-3 are induced by energetic protons released from the sample. The total net counts in the broad peaks for run 1, 2 and 3 are 102±18, at standard deviation (1σ), and the value is greater than 3 σ. The average counting rate is 0.138±0.030 counts/h. Using the detection efficiency of 30%, the average proton yield for the 3 runs is deduced to be 0.46±0.11 protons/h, or $1.28\pm0.31\times10^{-4}$ protons/sec.

The energy width in run 1 and 3 is about 0.34 and 0.38 MeV respectively, which indicates that the proton may come from a layer of about 10 μm thickness near the titanium surface, less than the range of 3-MeV proton in Ti, 57 μm. The result indicates that most of the deuterium can only be loaded in the layer within about 10 μm of the titanium foil surface, in thick samples.

Assuming a d-d reaction is occurring within 10 μm of the titanium surface, and the atomic ratio of D/Ti to be 1, the reaction rate is estimated to be 1.4×10^{-24} fusion/d-d·sec.

The maximum energy of broad peak is about 2.8 MeV after exiting the sample, which is less than 3.02 MeV, the proton energy in a d-d reaction. It is not clear why the measured energy and proton energy in a d-d reaction are different. The same question was raised by other work. [5] The energy scale of multi-channel analyzer is calibrated by a standard ^{241}Am α-source, thus a calibration with a proton source might be needed to answer this question.

The fluctuation of counts within the broad peaks is clearly observed. It can be explained as a statistic variation, a result of the very low counts. Background variations with the detectors are also observed.

3.2. Deuterium-loaded powder sample

The deuterium-loaded titanium powder sample was prepared by pressing the powder into a stainless steel disk (inner diameter 20 mm, depth of 2 mm) at 6 MPa. The thickness of

deuterium-loaded titanium powder sample is 163 mg/cm^2, and the D/Ti ratio is 1.6. The density of deuterium-loaded powder sample is 0.815 g/cm^3, less than the Ti metal (4.52 g/cm^3).

The spectrum of deuterium-loaded powder sample is given in Fig. 7. The measurement was taken for 3 times for checking the reproducibility. The total measurement time was 508 hour. The result shows that no effect can be observed above the background level for the long-duration measurements in three runs.

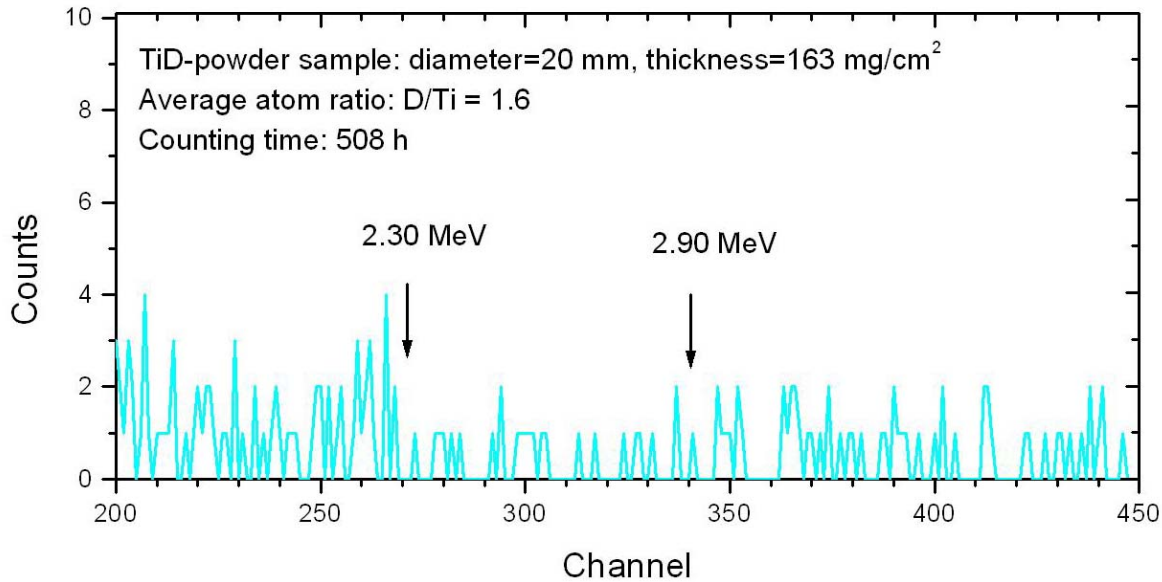

Figure 7. Spectrum of deuterium-loaded titanium powder sample.

3.3. TiD-Mo sample

The TiD-Mo sample was prepared by vaporizing 1.5 μm titanium onto the surface of the molybdenum disk (20 mm diameter, 0.5 mm thick). The deuterium was loaded into the Ti layer with the technique described in section 2 and shown in Fig. 1. The atomic ratio of D/Ti is 1.4.

The spectrum of TiD-Mo sample is given in Fig. 8. A small narrow peak is observed clearly at the energy level of around 2.7-2.8 MeV. The net counts at the peak is calculated to be 0.058±0.18 counts/h. The ΔE (energy loss) of a 3-MeV proton in 1.5 μm titanium is calculated to be about 0.05 MeV, covering 6 channels or so. The observed peak width is consistent with the calculated one. This result gives a further evidence for charged particle emitted from deuterium-loaded titanium metal at low temperature.

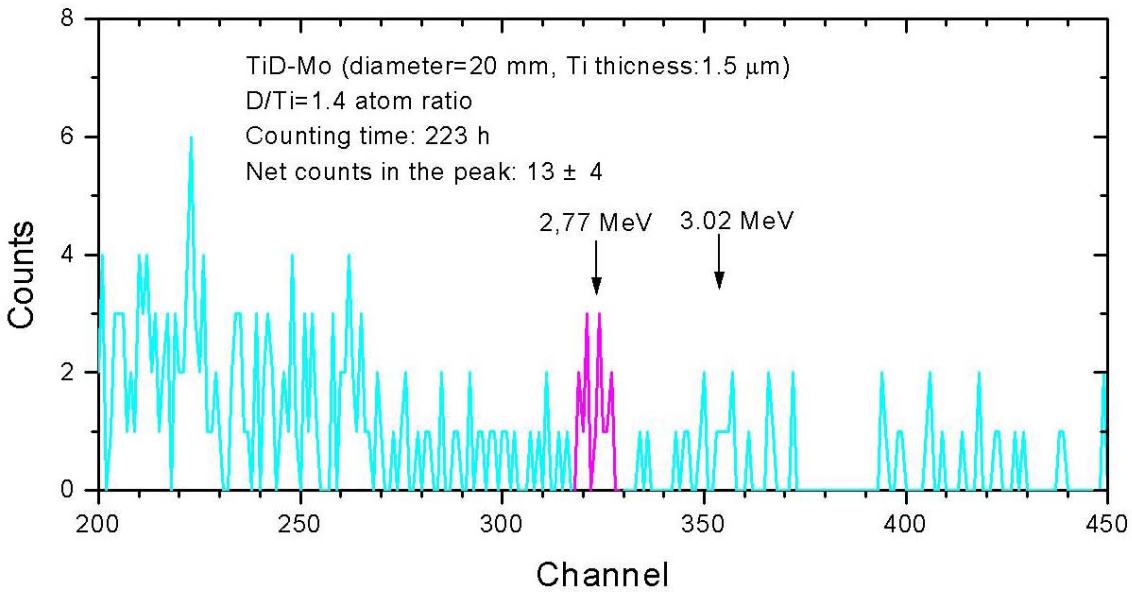

Figure 8. Spectrum of TiD-Mo foil sample, with titanium thickness of 1.5 μm and diameter of 20 mm, D/Ti atomic ratio =1.4.

4. Conclusions

From the experiment described above we can see that: (1) The reaction yields (counts) in this experiment are very low (~1 net count in 7.5 hours). (2) The energy range between 2 MeV and 3 MeV having low background plays a key role in this successful measurement. (3) The negative result of deuterium-loaded powder sample (Fig. 7) suggests that the reaction yield might be correlated to the density or microscopic variables of deuterium-loaded titanium materials, for the density of the powder sample much less than the titanium metal as mentioned above. (4) The results indicate that the characteristic of peaks correlate well with the loaded deuterium in the titanium, Al absorber and the thickness of the deuterium-loaded titanium samples.

The results show that the charged particles emitted from deuterium-loaded titanium metal have been detected at low temperature, and the charged particle is identified as proton having energy about 2.8 MeV after exiting the sample. The energetic proton might originate from the nuclear fusion, d-d reaction, and the d-d reaction rate is calculated to be 1.4×10^{-24} fusion/d-d·sec for the deuterium-loaded titanium foil sample. No data is observed above background level for the deuterium-loaded titanium powder sample. The negative result suggests that the reaction yield might be correlated with the density or microscopic variables of deuterium-loaded titanium materials, and also indicates that d-d reaction catalyzed by μ-meson from cosmic rays [12] can be excluded in the experiment.

This work provides a positive result of nuclear fusion at low temperature. Besides the d-d reaction, other types of nuclear fusion reactions might also be involved. This work may be helpful to the further study of the physical mechanism of nuclear reaction in the deuterium (hydrogen)-loaded metals. The present work also suggests that it is worth doing further investigation on the origin of ^{3}He nuclear reactions in the deep Earth.

Acknowledgments

We thank Professor Li X Z for valuable comments. We also thank Professors Qi Bujia, Zhu Jiazheng and Dr. Diao Lijun for helpful discussion, and Dr. Wang Zhiqiang and Mr. Luo Hailong for providing the TiD-Mo samples.

This work supported by President Foundation of China, Institute of Atomic Energy, No. YZ0714.

References

1. Jiang S S and He M, Evidence for tritium production in the earth interior, *Chinese Sci. Bulletin* 53(2008)540-547.
2. Jiang S S, He M, Yue W H and Liu J, Tritium released from mantle source: implication for natural nuclear fusion in the earth interior, 2008, *J. Fusion Energy* DOI: 10.1007/s10894-008-9149-y,.
3. Fleischmann M, Pons S and Hwkins M 1989 Electrochemical induced nuclear fusion of deuterium, *J. Electroanal. Chem.* 261(1989) 301-308.
4. Jones S E, Palmer E P, Czirr J B, Decker D L, Jensen G. L, Thorne J M, Taylor S F and Rafelski J, Observation of cold nuclear fusion in condensed mater, *Nature* 338 (1989) 737-740.
5. Jones S E, Keeney F W, Johnson A C, Buehler D B, Cecil F E, Hubler G., Hagelstein P L, Ellsworth J E and Scott M R, Charged-particle emissions from metal deuterides, *in 10th National conference on cold fusion. Cambridge*, MA: LENR-CANR.org, 2003.
6. Cecil F E, Lui H, Beddingfield D and Galovish C S, Observation of charged particle bursts from thin-titanium foil, *American Institute of Physics Conference Proceedings 228*, NY, p. 375-383, 1991.
7. Chamber G. P, Hubler G. K and Crabowski K S, Search for Energetic Charged-Particle-Reaction Products During Deuterium Charging of Metal Lattices, *American Institute of Physics Conference Proceedings 228*, NY, p. 383-395, 1991.
8. Koonin F E and Nauenberg M, Calculated fusion rates in isotopic hydrogen molecules *Nature* 339 (1989) 690-691.
9. Li X Z, Tian J, Mei M Y and Li C X, Sub-barrier fusion and selective resonant tunneling Penetration of deuteron into Coulomb potential barrier of neighbouring deuteron under several restriction condition *Phys. Rev.* 2000, **C** 61:024610-6.
10. Zhang Y M and Li J Q *Acta Physica Sinica* 51(2002)1244-1247, (in Chinese, with English abstract).
11. Ziegler J F SRIM-2006, http//:www.srim.org.
12. Jackson J D Catalysis of nuclear reaction between hydrogen isotopes by μ^- mesons, *Physics Review* 106(1957) 330-339.