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Measurement of anomalous nuclear reaction in deuterium-loaded metal*

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This paper reports on an experiment for testing natural nuclear fusion at low temperature searching for evidence of the origin of ^{3}He from natural nuclear fusion in deep Earth. The experiment was carried out using deuterium-loaded titanium foil samples and powder sample. Detection of charged particle was carried out using a low-level charged particle spectrometer. An Al foil was used as an energy absorber for identification of charged particle. Although the counting rate is very low in the experiment, the emission of energetic particle from the sample is observed and the particle is identified as a proton having energy about 2.8 MeV after exiting the titanium sample. This work provides a positive result for the emission of charged particle in the deuterium-loaded titanium foil samples at low temperature, but a negative result for the deuterium-loaded titanium powder sample. The average reaction yield is deduced to be (0.46±0.08) protons/h for the foil samples. With the suggestion that the proton originates from d–d reaction, we calculate the reaction rate for d–d reaction, and the obtained result is 1.4×10^{-24} fusion/d–d·sec. The negative result of the deuterium-loaded titanium powder sample suggests that the reaction yield might be correlated with the density or microscopic variables of deuterium-loaded titanium materials. The negative result also indicates that d–d reaction catalysed by μ-meson from cosmic ray can be excluded in the samples in this experiment.

Keywords: anomalous nuclear reaction, deuterium-loaded metal, natural nuclear fusion
PACC: 2588, 2710, 9135D

1. Introduction

In our 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 source, because of 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) in the deep Earth, after the origin of ^{3}H from atmosphere 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 try 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] The works of Jones *et al*, Cecil *et al* and Chambers *et al* are particularly relevant to the present work.[5–7] However, particle identification was problematic and irreproducibility remained a significant issue.[5] The results were not published in the mainstream journal. We try to make a measurement to check the previous works, no matter what result is, positive or negative. However, a positive result has been obtained for the deuterium-loaded titanium foil samples in the experiment. From the conventional, the d–d fusion rate of deuterium molecule is exceedingly low at low temperature, about the order of 10^{-63} per D_2 molecule per second.[8] However, the recent theories, such as Refs.[9] and [10], and experiments[5,7] show that nuclear fusion of the deuterium system is possible in metal lattices under strong restriction. The measured fusion rates for the deuterium-loaded titanium foils were published to be (10^{-21}–10^{-25}) per D_2 per second at room temperature.[5]

In this experiment, charged particle emitted from deuterium-loaded metal is measured using low-level charged particle spectrometer and the $\Delta E-E$ method is used for particle identification. The data acquisition was repeated for several times and different samples

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were measured. Because of very low counting rates, the measurements were carried out for several months.

2. Experimental details

2.1. Sample preparation

Figure 1 gives a systematic diagram for preparation of deuterium-loaded titanium sample. The deuterium gas with chemical grade is stored in the depleted-uranium bed, inside deuterium-storage chamber with 50 mm in diameter and 500 mm long. For loading deuterium, the titanium sample is placed into the reaction chamber, 30 mm in diameter and 300 mm long. The reaction chamber is evacuated to about 10 Pa and heated at 200–300 °C for degassing. Then, the temperature is increased to about 400 °C and pressurized with deuterium gas, which is released from uranium bed while heating it at about 400–500 °C. When pressurizing at about 5×10^4 Pa, inlet valve of reaction chamber is closed. A drop in pressure clearly demonstrated that the titanium sample inside the reaction chamber becomes deuterided. According to the change of the deuterium gas pressure in the reaction chamber and the weight of titanium sample, the atom ratio of D/Ti can be calculated. The average ratio depends on the thickness of Ti foil. For thickness less than 5 μm, the atom ratio of D/Ti can be reached a value around 1.2–1.4, and the ratio can be reached 1.6 for the powder sample. However, the D/Ti ratio decreases to about 0.1 for 0.5 mm Ti foil. The result suggests that most of deuterium can only be loaded near the Ti surface.

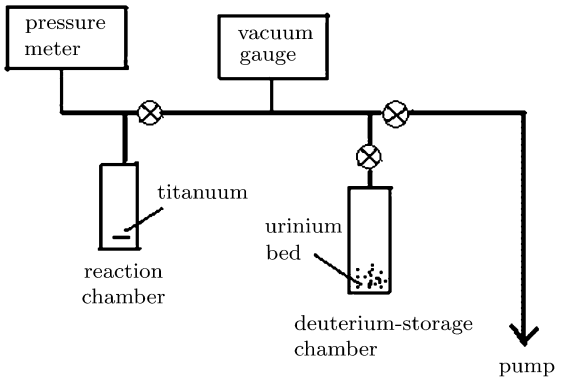


Fig.1. Systematic diagram for preparation of the deuterium-loaded titanium samples.

In this experiment, deuterium-loaded titanium foil and titanium powder samples were prepared. The D/Ti ratio is 0.4 for the foil sample having diameter of 20 mm and thickness of 0.1 mm. The deuterium-loaded titanium powder is prepared by pressing the deuterium-loaded titanium powder into a stainless steel disc with inner diameter of 20 mm and depth of 2 mm at 6 MPa. The thickness of deuterium-loaded powder sample is 163 mg/cm^2, and D/Ti ratio is 1.6. The density of deuterium-loaded powder sample is 0.815 g/cm^3, which is less than that of Ti metal (4.52 g/cm^3).

The TiD–Mo samples were also measured, which were prepared by vaporizing 1.5 μm titanium onto the surface of the molybdenum disc, 20 mm in diameter and 0.5 mm in thickness. Then deuterium was loaded into the Ti layer with same procedures as mentioned above (Fig.1). The atom ratio of D/Ti is 1.4.

2.2. Charged particle detection

Detection of charged particle is carried out by using OCTETE low-level charged particle spectrometer. 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 detector and sample are located in a vacuum chamber (Fig.2). The

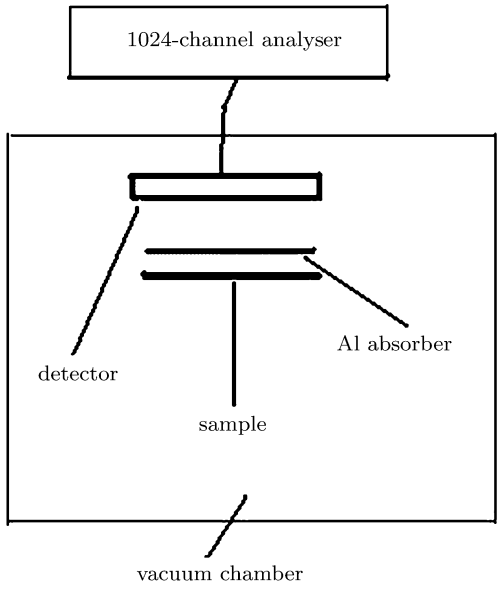


Fig.2. Outline of the detection system for measurement of charged particle. The silicon dioxide-passivated ion-implanted detectors have active-area of 600 mm^2. The depleted layer of the detectors is 100 μm.

detector efficiency was calibrated using standard point sources to be about 30% at the detector-source spacing less than 10 mm. The energy scale of 1024-channel analyser was calibrated with ^{241}Am source (5.45 MeV

α-particle) to be 8.52 keV per channel. During measurement, the chamber is evacuated to about 5 Pa. The spacing between detector and sample is about 5 mm.

The aim of this experiment is searching for proton from d–d reaction, as follows:

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

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

2.3. Charged particle identification

The $\Delta E - E$ method, based on the Bethe–Bloch equation, is used for charged particle identification. The Bethe–Bloch equation can simply be written as

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

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

In this experiment, we only consider to identify proton, ^{3}He, triton and α-particle. A 15 μm Al foil is used as energy absorber for ΔE measurement. The ΔE values for proton, ^{3}He, triton and α-particle are calculated using SRIM code.[11] The energy loss of 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. The residual energy of proton, triton, ^{3}He and α-particle is 2.65, 0.5, 0.1 and 0 MeV respectively. The quite difference of the residual energies makes identification of those charged particles easy, and the 2.65 MeV proton can be identified in the measurement.

2.4. Measurement

Four runs were taken for measurement of deuterium-loaded titanium foil sample with 0.1 mm thick, twice measurements were taken for each run in the first 3 runs for testing the stability and repeatability. In the first run, the deuterium-loaded titanium foil sample was measured, and then a re-measurement for checking the reproducibility was carried out in the third run. For particle identification, the second run was carried out with an Al foil, 15 μm thick, inserted between the deuterium-loaded titanium foil sample and the detector. The fourth run was carried out with a blank sample, i.e. a titanium sample with no deuterium.

Two kinds of other samples were also measured, the deuterium-loaded powder sample and the TiD–Mo sample.

3. Results and discussion

The spectrum of 0.1 mm deuterium-loaded titanium sample for runs 1, 2 and 3 are given in Figs.3, 4 and 5 respectively.

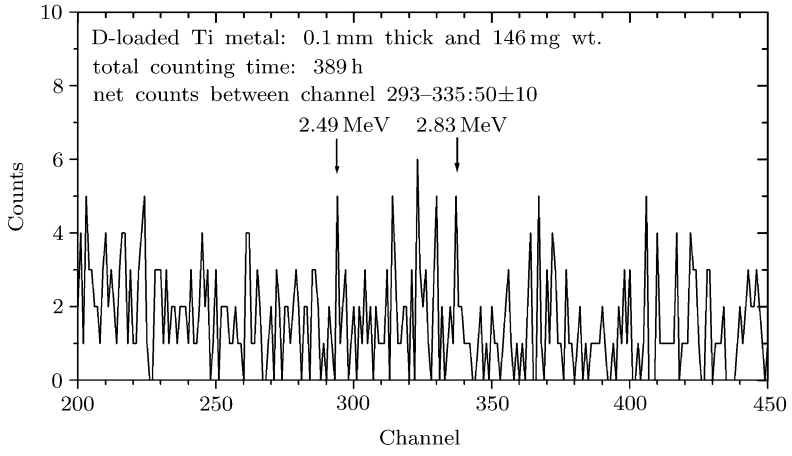


Fig.3. Spectrum of the deuterium-loaded titanium foil sample in run 1.

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 also observed around channel 370 (3.15 MeV) (Fig.3). This peak might originate from contamination by other previous radioactive samples in the detection chamber, because the peak did not appear again in the later runs. The background counts at 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 both sides of the broad peak. The total counts in the peak area after subtracting the deduced background counts are 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 for subtracting the background counts in the following runs.

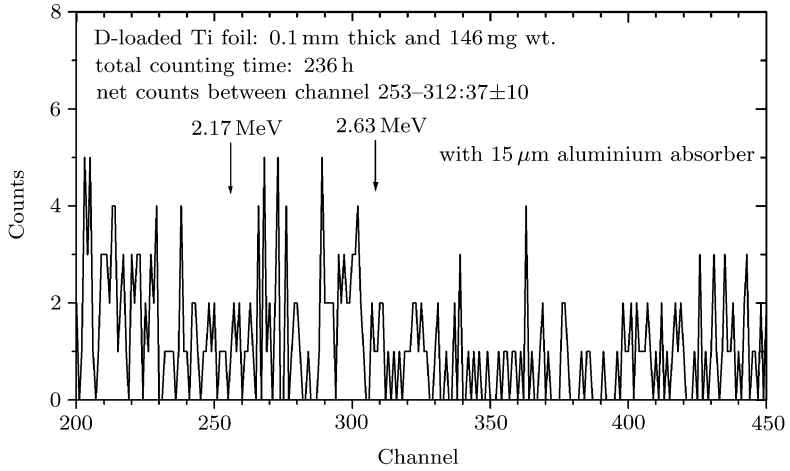


Fig.4. Spectrum of the deuterium-loaded titanium foil sample in run 2, a 15 μm Al foil inserted between detector and the sample.

For identification of the type of the particles in the peak, a 15 μm Al foil was inserted between the sample and the detector in run 2 (Fig.4). While penetrating through Al foil, overall or part of energy of charged particles may be lost in the Al foil. The value of the energy loss can be deduced from the measured residual energy. The energy loss of 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 ranging between 2.17 and 2.63 MeV and the peak width is broadened, ∼0.12 MeV greater than the peak width in run 1. The average energy of the peak is 2.40 MeV, which is 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.

For testing repeatability, the Al absorber was removed in run 3. It can be seen that the broad peak is removed back (Fig.5(a)), close to the area 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.5(a)). The spectrum of measurement in the first 94 hours in run 3 is also given in Fig.5(b). From Figs.5(a) and 5(b), it can be seen that the counting rates in the peak area are almost stable in the overall time, 189 hours, in run 3. The results indicate that after taking off the Al absorber the broad peak in run 1 can be reproduced well by run 3.

The shift of the peak in run 2 is correlated well with inserting the Al absorber. The residual energy of the charged particles in run 2 is measured to be 2.40 MeV, and the mean value of the energy in runs 1 and 3 is deduced to be 2.62 MeV. From the difference

of mean value of energy for the broad peak in runs 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 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.

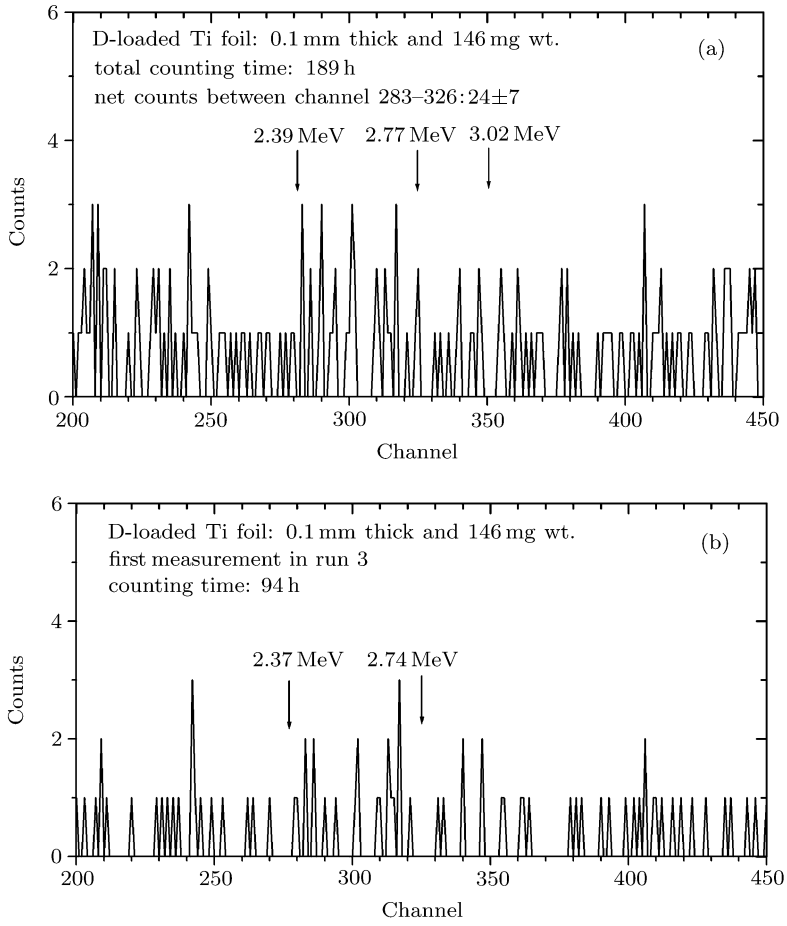


Fig.5. Spectrum of the deuterium-loaded titanium foil sample in run 3, for overall measurement time (Fig.5(a)) and for the first 94 hours of run 3 (Fig.5(b)).

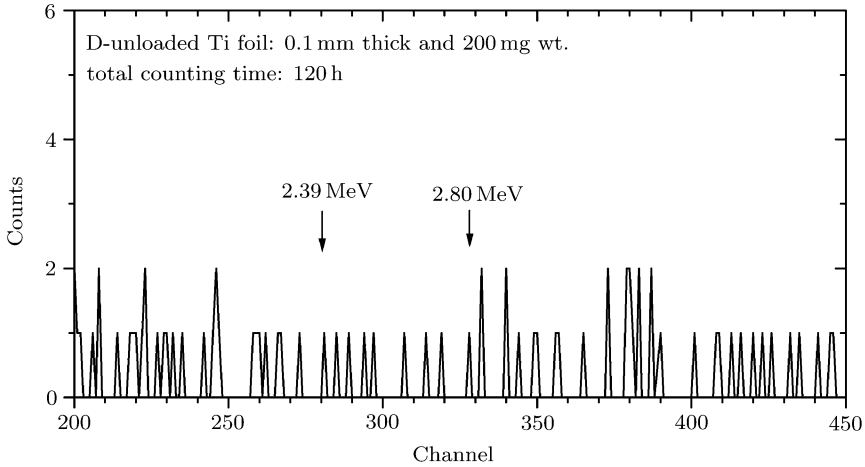


Fig.6. Spectrum of the blank sample, a titanium foil sample (20×20×0.1 mm) with no deuterium, in run 4.

The fourth run was taken with blank sample, a titanium foil (20×20×0.1 mm) with no deuterium. No counts are observed above the background level in the interesting energy range (2.39–2.80 MeV, or channel 280–340) (Fig.6). Therefore, the deuterium in the deuterium-loaded titanium foil sample should be responsible for the emission of energetic proton.

We consider that the net counts in all three broad peaks for runs 1, 2 and 3 are induced by the energetic protons released from the sample. Then, the total net counts in the three broad peaks are 131±20, at standard deviation (1σ). The average counting rate is (0.138±0.024) counts/h. Using the detection efficiency of 30%, we find that the average proton yield for the three runs is deduced to be (0.46±0.08) protons/h or $(1.28\pm0.23)\times10^{-4}$ protons/sec.

The peak widths in runs 1 and 3 are 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 energy range of 3 MeV proton in Ti, 58 μm. This result indicates that most deuterium could be only loaded in a layer about 10 μm near the surface of the titanium foil for thick sample.

The maximum energy of broad peak is measured to be about 2.8 MeV after exiting the sample, less than the original proton energy in d–d reaction, 3.02 MeV. The difference between the measured energy and the proton energy in d–d reaction is not quite clear. The same question also presents in the other work.[5] The energy scale of multi-channel analyser is calibrated by a standard ^{241}Am α-source, thus, the calibration might be needed to check by proton source at first for the question.

The fluctuation of counts within the broad peaks is observed obviously. It may be explained as a statistic variation, as a result of very low counts. The difference of background counts is also observed for the individual detectors.

Assume d–d reaction occurring only within 10 μm thickness near the titanium surface and the atom ratio of D/Ti to be 1, then the reaction rate is estimated to be 1.4×10^{-24} fusion/d–d·sec.

Two types of other samples were also measured, deuterium-loaded titanium powder sample and TiD–Mo samples.

The spectrum of deuterium-loaded titanium powder sample is given in Fig.7, and the spectrum of TiD–Mo foil samples is given in Fig.8. Unfortunately, no data can be observed above background level for deuterium-loaded titanium powder sample. On the contrary, a small narrow peak is observed clearly at energy around 2.7–2.8 MeV for the TiD–Mo sample with a thin Ti layer (1.5 μm). The net counts at the peak are calculated to be (0.058±0.012) counts/h. The ΔE (energy loss) of 3 MeV proton in 1.5 μm titanium is calculated to be about 0.05 MeV, expanded six channels or so. The observed peak width is consistent with the calculated one.

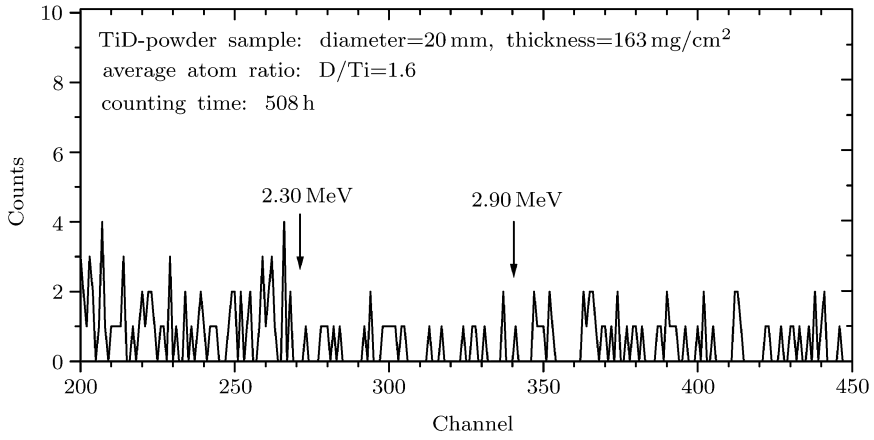


Fig.7. Spectrum of deuterium-loaded titanium powder sample.

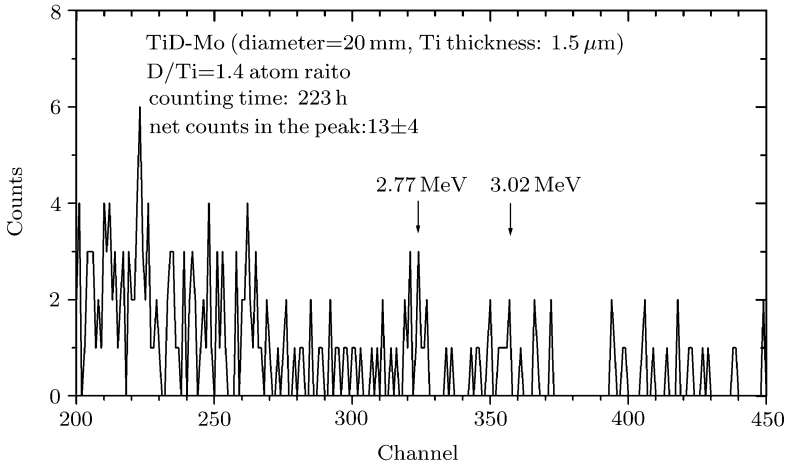


Fig.8. Spectrum of TiD–Mo sample, with titanium thickness of 1.5 μm and diameter of 20 mm, D/Ti atom ratio =1.4.

Summary: (i) The reaction yields (counts) in this experiment are very low (∼1 net count in 7.5 hours), and the low background in the energy range between 2 and 3 MeV plays a key role in this successful measurement. (ii) 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, the density of the powder sample is much less than the titanium metal as mentioned above. (iii) The results indicate that the characteristic of peaks correlates well with the loaded deuterium in the titanium, Al absorber and the thickness of the deuterium-loaded titanium samples.

4. Conclusions

The charged particles emitted from deuterium-loaded titanium metal have been detected at low temperature. The broad peak can be observed for the 0.1 mm deuterium-loaded titanium foil sample. Otherwise, a narrow peak is observed for the TiD–Mo sample, which has a thin titanium layer, 1.5 μm. The charged particle is identified as proton having energy about 2.8 MeV after exiting the samples. The energetic proton might originate from the nuclear fusion, d–d reaction. Thus, the d–d reaction rate is calculated to be 1.4×10^{-24} fusion/d–d·sec for the deuterium-loaded titanium foil sample with thickness of 0.1 mm, and the reaction rate in the TiD–Mo sample may be higher than the foil sample. However, no data are observed above background level for the deuterium-loaded powder sample. The negative result of the deuterium-loaded powder sample 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 catalysed by μ-meson from cosmic ray[12] can be excluded in the samples in this experiment.

This work provides a positive result of nuclear fusion at low temperature. Besides d–d reaction other types of nuclear reactions might also be involved. Our work may be helpful to the further study on the physical mechanism of nuclear reaction in the deuterium (hydrogen)-loaded metals, and has its importance to explanation of the energy release of solar flare and high-energy astrophysics processes.[13] Detection of anomalous x-rays and other particles are desirable. The present work also suggests that it is certainly worth doing further investigation on the origin of ^{3}He (nuclear reaction) in the deep Earth.

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