NEUTRON EMISSIONS FROM DEUTERIDED METALS

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Evidence is presented for neutrons emanating from partially deuterated titanium foils (TiD_x) subjected to non-equilibrium conditions (charged particle results appear in a separate paper in this proceedings). Two types of deuteriding and varied currents were employed to produce the non-equilibrium conditions within the foils, and emissions lasted over long durations. Experiments were conducted in a deep underground tunnel having significant rock overburden to diminish cosmic backgrounds. Subtracting background rates and taking into account detector efficiency, we found the highest net yield to be 57 ± 13 counts/hour. Yields for all runs are reported and the theoretical fusion reaction defined. Totaling all experiments, reproducibility was 40%.

1. Introduction

The first innovations towards producing our repeatable neutron fusion emissions were provided in 1997 by F. W. Keeney[1,2] of Particle Physics Research Co. who required more advanced particle detectors and contracted S. E. Jones[3] of Brigham Young University to conduct the experiments. We were also motivated by previous work[4−6] which were not widely published, lacking repeatability which we are now evidencing. During the following experiments fast neutrons were evidenced emanating from partially deuterided titanium foils (TiD_x) subjected to the non-equilibrium conditions described. The highly sensitive detector was designed by Howard Menlove and colleagues at the Los Angeles National Laboratory, New Mexico. An additional paper[1] details complementary data for emissions of protons exceeding 2100 counts/hour and reproducibility approaching 80% using independent ion-implanted silicon detectors. We conclude unique metal processing, deuteriding techniques, and applying electrical currents to establish the non-equilibrium conditions within the foils appear to be important keys to achieving significant nuclear-particle yields and reproducibility of the results.

2. Neutron Detector and Sample Preparation

Neutron-detection experiments were conducted in a deep-underground facility in Provo Canyon near the Brigham Young University campus, having approximately 100 meters of rock overburden (minimum) to reduce cosmic rays reaching the detector. Further passive shielding was provided with numerous containers of copper/zinc over the concrete floor (about 25 cm thick) as well as bags of NaCl around and above the detector (about 30 cm thick).

In order to survey anticipated low-yield fusion reactions with a sensitive and reliable instrument, we employed a neutron detector comprised of sixteen ^{3}He-filled proportional counter tubes embedded in a polyethylene moderator; see Fig. 1. This compact, high-efficiency detector was developed by Howard Menlove and colleagues (Los Alamos National Laboratory) and built by JOMAR Corp.[4] We added a plastic scintillator core viewed by a photo-multiplier tube to permit detection of fast neutrons. Three active plastic scintillator panels were used to veto cosmic rays, further reducing background as much a possible.

Fast neutrons produced in the center of the detector generated recoil protons in the central plastic scintillator about 40% of the time. The recoil protons in turn generated light pulses detected by the photomultiplier tube. An initial neutron, after being thermalized in the scintillator and polyethylene moderator, may then be captured by a ^{3}He atom in one of the proportional-counter tubes, producing a pulse in that portion of the counter. The efficiency of the ^{3}He portion of the assembly for 2.5 MeV neutrons was 28%. Including geometrical efficiency for a test sample placed in the interior well of the detector, the overall dual-coincidence efficiency was 11%. In order to identify any spurious signals (e.g., due to high-voltage breakdown in the proportional counter tube electronics associated with humidity), the ^{3}He tubes were divided into four quadrants of four tubes each and arranged into inner and

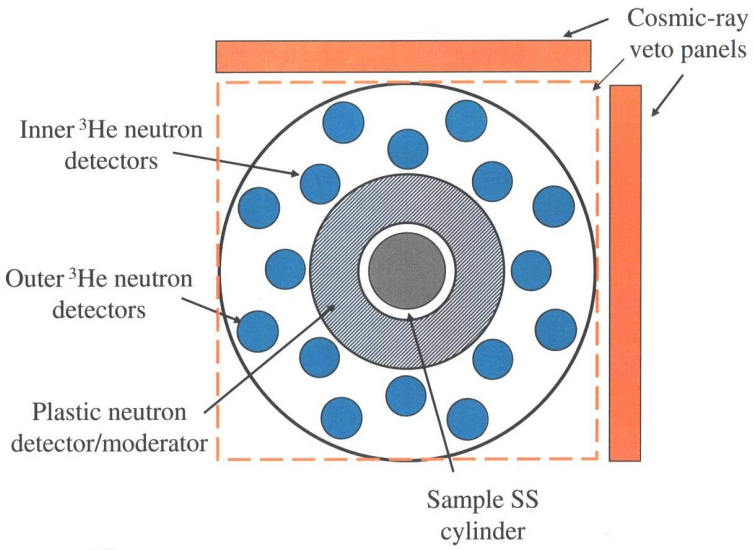

Figure 1. Neutron detector.

outer rings (see Fig. 1).

The detector was highly sensitive to neutrons, captured by ^{3}He nuclei, and nearly transparent to gamma rays. All pulses were digitized at 100 MHz using a LeCroy waveform digitizer over 160 microseconds and data stored using a PC/CAMAC system. This allowed us to analyze pulses off-line and differentiate noise (ragged shapes) from prompt neutrons detected in the plastic scintillator (narrow, with steep trailing edge), and from slow-captured neutrons (broad pulse, with width indicative of the quadrant in which the neutrons were captured). Significant neutron yields were detected when titanium foils were first processed then loaded with deuterons, either by deuterium gas-diffusion or by D_2SO_4-acid loading, and Joule-heated.

As shown in Fig. 2, two titanium foils, each 2 cm wide and 0.25 mm in thickness were cut such that one foil was 30 cm long and the other 35 cm long. The foils were first vigorously sanded using 120-grit wet/dry paper then cleaned using de-ionized water and a commercial scouring agent. The foils were then arranged in U-shaped configurations and placed in a stainless-steel cylinder 35 cm in length by 2.5 cm diameter. The longer foil was placed outside the shorter foil, and their ends connected to electrical feed-throughs connected in parallel. The feed-throughs were in turn electrically connected to dc or ac power supplies. Segments of Pyrex glass wool were used as insulation between the foils to prevent electrical contact during deuteriding.

The assembled device was placed inside a Teflon insulator to protect the neutron detector from excess heating. (We later heated the detector well using heat tapes, and found no spurious signal from heating. We also ran the same experiment repeatedly using hydrogen instead of deuterium and found no neutron emissions

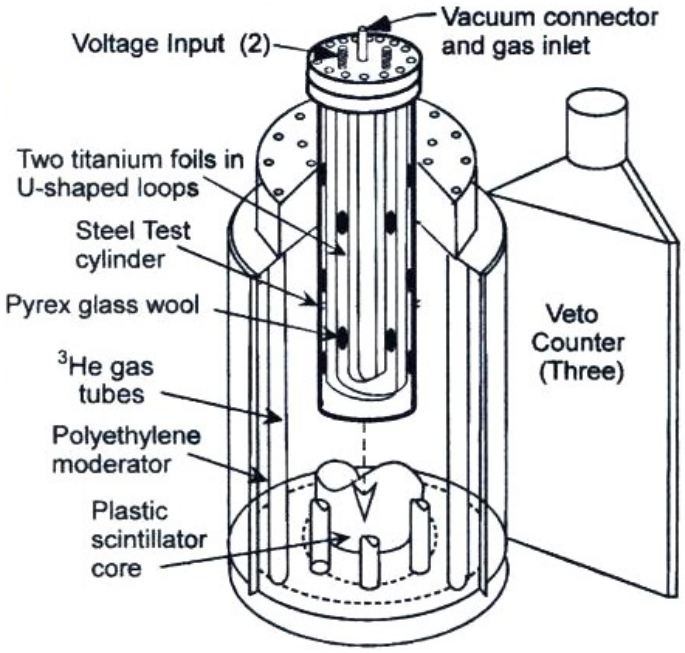

Figure 2. Interior view of neutron detector with test device inserted.

above background levels.) Next, the cylinder containing Ti foils was evacuated to approximately 100 millitorr while a current was applied to heat the foils and induce outgassing. (The temperature of the foils inside the cylinder was not measured.) After one hour of outgassing, the cylinder was pressurized with deuterium gas at one atm for five minutes, then re-evacuated. Having thus cleaned and prepared the Ti foils, we admitted deuterium gas at 40 psi into the test cylinder while Joule heating then closed the inlet valve. A clear drop in D_2 pressure indicated the absorption of deuterium by the titanium foils. Clearly, deuterons entered and migrated within the metal during Joule heating by applying dc currents in the range 3 to 30 A, producing non-equilibrium conditions inside the deuterated metal.

3. Neutron Emissions From Deuterium Gas-Loaded Titanium

Figure 3 shows results from a series of runs over several months with emissions from deuterided titanium foil (TiD_x) runs (squares) along with background runs (open shapes). The background runs consisted of titanium foils with H_2 gas added and high currents (as in D_2 gas runs), runs with Ti foils in H_20/H_2S0_4, empty-detector runs, and runs using partially deuterided-Ti foils that had expired after use followed by days of dormancy. The data show that the background is well behaved and due primarily to cosmic rays with an average of 2.0 ± 0.2 counts/hour (cts/h).

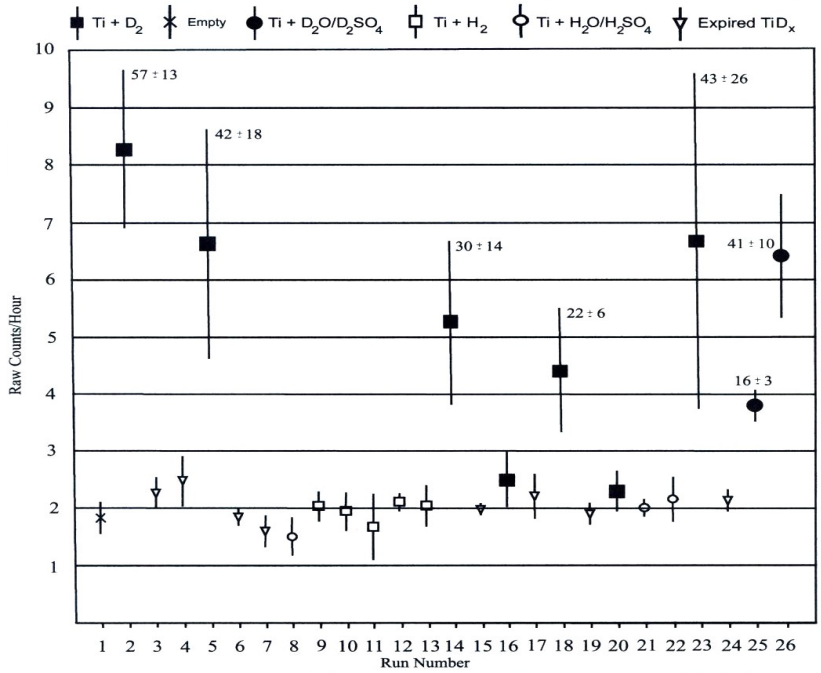

Figure 3. Observed neutron yields from a series of deep underground experiments. Filled square = Ti+D; X = empty; filled circle = Ti+D_2O/D_2SO_4; open square = Ti+H; open circle = Ti+H_2O/H_2SO_4; open triangle = TiD_x.

After a preliminary background test (Run 1), our first TiD_x experiment (Run 2) in this series applied 30A dc through the two Ti foils in pressurized D_2 gas. This first run lasted 4.36 hours and 36 events were detected for an observed count rate of 8.3 ± 1.4 cts/h as measured using the dual-coincidence neutron counter, with a prompt signal in the plastic scintillator followed by a signal in a ^{3}He counter. Run 2 produced an observed count rate about four times the background rate. When the background rate was subtracted from the Ti-D rate, we found a net yield of 6.3 ± 1.4 cts/h, and dividing by the dual-counter efficiency of 11%, the actual yield was 57 ± 13 cts/h.

A count rate this high in our deep-underground facility can be seen in the ^{3}He counter alone, so as a check we evaluated the yield with that counter by itself: 91.8 cts/h for Ti-D - 78.5 cts/h for background = 13.3 cts/h. Dividing this result by the efficiency of the ^{3}He detector alone yields 13.3/0.28 = 48 ± 17 cts/h, in close agreement with the dual-counter yield.

As a further check, we examined rates in the inner ring of eight ^{3}He tubes versus the outer ring of eight tubes. The inner/outer count ratio for backgrounds was nearly 1.0, meaning that background counts show up in the inner and outer rings in nearly equal numbers as expected for cosmic-ray-events. This same ratio (background-subtracted) is 1.8 for energetic neutrons from a plutonium source

placed in the detector well for calibration. The ratio for neutrons generated inside the detector well is higher since neutrons tend to be captured primarily in the inner tubes closest to the neutron source. For Run 2 just discussed, this same inner/outer-counter ratio was 1.7 ± 0.3, in good agreement with the 1.8 ratio found with in-well source neutrons. This agreement provided evidence that the neutrons indeed emanated from inside the detector well where the TiD_x sample was located. Thus, the data strongly suggest these neutrons arose from nuclear reactions occurring inside current-carrying TiD_x as it underwent simultaneous Joule heating, deuteriding, and phase changes, one possibility being the d-d fusion reaction

$$\mathrm{d} + \mathrm{d} \rightarrow \mathrm{n}(2.45\ \mathrm{MeV}) + {}^{3}\mathrm{He}(0.82\ \mathrm{MeV}). \quad (1)$$

Two background runs followed and were consistent with other background runs. We next ran a second set of Ti foils in D_2 gas as before and obtained a count rate of 6.6 ± 2.0 cts/h (Run 5, Fig. 3). Dividing by the dual-detector efficiency, this implies an actual rate of 42 ± 18 cts/h above background. The rate in the ^{3}He counter alone was (86.5 - 78.5)/0.28 = 29 ± 26 cts/h above background. Due to the large statistical error in this instance, not much can be learned from this counter alone, underscoring the merit of our detector coincidence method (above). Due to safety concerns, all runs with pressurized D_2 gas were kept to a few hours.

The third Ti-D experiment (Run 14 in Fig. 3) yielded 5.3 ± 1.5 cts/h; the actual yield corrected for detector efficiency was 30 ± 14 cts/h. The fourth Ti-D experiment (Run 16) was consistent with the background rate. The fifth Ti-D experiment (Run 18) yielded a raw 4.4 ± 1.2 cts/h, for an actual yield of 22 ± 6 cts/h with an inner/outer count ratio of approximately 1.8. This is again consistent with fusion neutrons emanating from the TiD_x foils inside the counter. The rate in the ^{3}He counter itself worked out to (91 - 78.5)/0.28 = 45 ± 20 cts/h above background. The sixth TiD_x experiment was consistent with background. The final experiment of the series (Run 23), was cut short and showed a raw rate 6.7 ± 2.9 cts/h and an actual rate of 43 ± 26 cts/h.

We conclude from these experiments that compelling evidence for fast neutron production was obtained when Joule-heated titanium foils were exposed to high-pressure D_2 gas. A helpful feature was the segmentation of the neutron detector, which facilitated background rejection and provided important information regarding the origin of emitted particles. These neutron results, with repeatability in the 40% range**,** corroborate those obtained independently with the energy-dispersive charged-particle detector systems reported elsewhere.[1]

4. Neutron Emissions From Deuterium Acid-Loaded Titanium

In another approach (Run 25, Fig. 3), two U-shaped titanium foils were placed inside a test tube, 29 mm in inner diameter and 23 cm in length so as to be suitably matched to the center well of the detector. The test tube was enclosed on its top with a rigid stopper. Provision was made for applying electrical currents through

Table 1. Run conditions and results for TiD_x runs shown in Fig. 3.

foreground run no.	loading method	A (dc amps)	actual yield in neutron cts/h
2	D_2 Gas	30	57 ± 13
5	D_2 Gas	30	42 ± 18
14	D_2 Gas	30	30 ± 14
16	D_2 Gas	15	5 ± 5
18	D_2 Gas	20	22 ± 6
20	D_2 Gas	20	3 ± 4
22	D_2 Gas	42	43 ± 26
25	D_2O/D_2SO_4	11	16 ± 3
26	D_2O/D_2SO_4	3	41 ± 10

leads extending through the stopper. Deuteriding was enhanced by first scrubbing both sides of the 0.25 mm thick foils with abrasive wet-dry paper about 100-grit aluminum oxide, wetted during the process with de-ionized water and a commercial detergent, then rinsed and dried. The two foils were separated by approximately 3 mm during the experiments. Deuteriding was accomplished by placing a 1:5 mixture of D_2SO_4/D_2O in the test tube after the foil was admitted. The acid attacked the titanium-oxide surface, and deuterons entered the metal as Ti ions entered the solution. Soak periods of approximately two hours were allowed before Joule heating by dc current, as indicated in Table 1.

This particular experiment using a deuterated-acid loading method is worth considering in some detail. After about 24 hours into the run, it was clear the count rate for Run 25 was nearly twice the background level. We let the run continue (after assuring complete safety), stopping at 48.3 hours. The overall count rate was 3.8 ± 0.28 cts/h, compared with the background of 2.0 ± 0.2 cts/hr. So the net yield was 1.8 ± 0.34 cts/h, and dividing by the efficiency of 0.11, we find an actual yield of 16 ± 3 cts/h. The count rate in the ^{3}He-type counter by itself was 82.4 - 78.5 [background]$/0.28 = 14 \pm 3$ cts/h. The two calculated yields are in good agreement, and both are significant due to the high numbers of counts obtained during the 48.3 hour run. The d-acid-loading approach produced about 20% repeatability overall at the 2.3-sigma level. Control experiments were conducted under the same conditions using H_2O and H_2SO_4 with no evidence for neutron emissions above background.

In a modification of this approach, titanium-662 chips were loaded into a test tube in layers, alternating with copper granules, and a 1:5 mixture of D_2SO_4/D_2O in the test tube was then added. When Joule heating was applied to the mix, a yield of 41 ± 10 actual cts/h was registered (shown as run 26 in Fig. 3), which is clearly significant statistically. However, based on experimental evidence with several types of deuterium-bearing metals under various non-equilibrium conditions, we concluded that Joule-heated, gas-loaded TiD_x foils gave better repeatability.

5. Conclusion

Data presented in this paper provide strong evidence for a significant effect consistent with low level emission of neutrons from d-d fusion in metals. The highest measured rates in thin TiD_x foils fall within the 41 ± 10 to 57 ± 13 cts/hr, the lowest rate being $3 \pm$ cts/hrs. The effects were seen in 40% of trials using an excellent detection systems designed by Menlove (LANL) in use at BYU. Several different methods of sample preparation were applied. Observed yields varied greatly, chief reasons due to the difficulty of duplicating foil preparations and deuteriding processes exactly. Based on known solid state and nuclear physics, d-d fusion is not expected in TiD_x. Hence, we consider these experimental results to represent a new and unique physical process noted in Equation 1. We have shown that special treatments are important to produce the recorded effects; such as metal processing, grooving foil samples, gas and acid loading, and applying strong dc currents to enhance non-equilibrium conditions within foils. The relative importance of each treatment requires further study. However, the data suggest application of electrical current provides more consistent results, higher yields and enhanced repeatability.[1] It is possible other nuclear reactions besides d-d fusion are involved. Also important are diminishing of cosmic background and availability of a neutron detection system designed for very low counting rates.

Summarily, among the advances represented by this work are significant nuclear particle yields at low temperatures and over long durations, neutron particle identification, and interesting repeatability. It is speculated that microscopic variables in the foils, such as lattice/defect variations and surface conditions, prevented totally 100% reproducibility. Nevertheless, repeatability is sufficiently high that others should be able to reproduce these results.

Acknowledgments

The authors acknowledge support and useful input from Bart Czirr, Howard Menlove, Lawrence Rees, Lee Hansen, James Thorne, Robert Routsong, Joseph Young, Wes Lifferth; Seth, David and Nathan Jones.

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