# NEUTRON EMISSION FROM $D_2$ GAS IN MAGNETIC FIELDS UNDER LOW TEMPERATURE

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We observed neutron emissions from pure deuterium gas after it was cooled in liquid nitrogen and placed in a magnetic field. Neutron emissions were observed in ten out of ten test cases. Neutron burst of 5.5 counts/s were 1000 times higher than the background counts. These bursts occurred one or two times within a 300 s interval. The total neutron emission can be estimated from the counting efficiency, and it was $10^4$–$10^5$ counts/s. The reaction appears to be highly reproducible, reliably generating high neutron emissions. We conclude that the models proposed heretofore based upon d–d reactions are inadequate to explain the present results, which must involve magnetic field nuclear reactions.

## 1. Introduction

There have been many reports of neutron generation during cold fusion experiments.[1–3] Although there have been a few negative reports,[4] most show some neutron emission. However, it seems hard to replicate, and reaction rates are very low. Shyam *et al.*[5] reported on conventional light and heavy water electrolysis with a palladium electrode. They used 16 BF3 neutron detectors to increase the chance of detection. They observed a difference in neutron emission rates between light and heavy water electrolysis. The neutron count rate was slightly higher for heavy water.

Shyam *et al.* conducted a series of experiments to detect production of neutrons from a commercial palladium–nickel electrolytic cell operated with 0.1 M LiOH or LiOD as the electrolyte, at a current density of $\sim$80 mA/cm$^2$. A bank of 16 BF3 detectors embedded in a cylindrical moderator assembly detected neutron emission. A dead time filtering technique was used to detect the presence of neutron bursts, if any, and to characterize the multiplicity distribution of such neutron bursts. It was found that with an operating Pd–$D_2O$ cell located in the center of the

neutron detection setup the daily average neutron count rate increased by about 9% throughout 1-month period, over the background value of ~2386 counts/day. This indicated an average daily neutron production of ~2220 neutrons/day by the cell. In addition, analysis of the dead time filtered counts data indicated that about 6.5% of these neutrons were emitted in the form of bursts of 20–100 neutrons each. On an average, there were an additional six burst events per day during electrolysis with LiOD over the daily average background burst rate of 1.7 bursts/day. The frequency of burst events as well as their multiplicity was significantly higher with $D_2O$ + LiOD in the cell when compared with background runs and the light water control runs.

Oya *et al.*[6] used a precise method to determine the relationship between neutron energy and excess heat. They use flow calorimetry measure excess heat generation. They showed a clear relation between heat and neutron generation. Neutron energy was in the MeV order when the excess power was generated.

The key parameters for the occurrence of the anomalous phenomena, especially excess heat generation and the emission of excess neutrons, have been investigated through a series of electrolytic experiments in Pd–LiOD (H) systems. Seven key parameters have been identified:

(1) purity of Pd cathode,
(2) shape and size of Pd cathode,
(3) processes of pretreatment of Pd cathode,
(4) electrolysis mode,
(5) electrolyte,
(6) purity of the medium,
(7) initial open-circuit voltage.

In the present work, a series of systematic experiments have been carried out with some fixed parameters. By controlling key parameters completely, an appreciable correlation between the excess heat generation and the excess neutron emission can be replicated successfully.

We have sometimes seen neuron emission with a phase transition method. This typically occurs in non-equilibrium conditions. Chicea and Lupu[7] showed the neutron emission from Ti metal loaded by deuterium gas absorption. Chicea used a simple measurement system. The sample holder includes Ti powder. The Ti metal absorbed deuterium gas and sporadic neutron generation occurred.

In several experiments, Chicea and Lupu loaded titanium samples with deuterium in gas phase, and the temperature of the samples was changed over a wide range, while neutron emissions were monitored. Neutron emissions were recorded in very low intensity bursts, but still significantly above the background. This revealed that low energy nuclear reactions in condensed matter can be produced at a low rate, which is occasionally high enough to become detectable. They observed very strong neutron emission occurred more than 10 times during 20 h. At times, the emission exceeded four times background counts.

Jones *et al.*[8] used a similar method, and they reported neutron emission from Ti metal that absorbed deuterium gas. Jones' results are very clear, showing that neutron emission only occurs with deuterium gas, not hydrogen. They presented evidence for neutrons emanating from partially deuterided titanium foils (TiDx) subjected to non-equilibrium conditions. A previous paper presented data for complementary charged-particle emissions. Metal processing and establishing non-equilibrium conditions appear to be important keys to achieving significant nuclear-particle yields and repeatability.

It is very important to confirm nuclear products to prove that cold fusion is, in fact, some kinds of nuclear reaction. Neutrons are especially suitable for this purpose. We have already published transmutations results from the electrolysis method. We have confirmed isotopic shifts in elements. We have also confirmed neutron emission during various methods of cold fusion.

We have measured the neutron energy distribution during heavy water electrolysis with a Pd electrode with a closed-cell system.[9] The cell temperature and pressure can be raised to increase deuterium absorption. We observed a clear neutron energy peak at 2.5 MeV. This indicates a possible d–d nuclear fusion reaction. The reaction rate was estimated as $10^{-23}$/dd/s.

We have used other methods to increase the probability of neutron generation. We used very high purity heavy water absorbed into a Pd wire. After the wire absorbed deuterium, hydrogen gas was admitted into the wire to stimulate the neutron generation reaction.[10] The neutron count, the duration of the release and the time of the release after electrolysis was initiated all fluctuated considerably. Neutron emissions were observed in five out of ten test cases. In all previous experiments reported, only heavy water was used, and light water was absorbed only as accidental contamination. Compared to these deuterium results, the neutron count when hydrogen is deliberately introduced is orders of magnitude higher, and reproducibility is much improved. Several analytical methods suggested some characteristic elements appearance in the electrolysis system after the neutron emission.

After filling the Pd wire with deuterium in heavy water, we took the wire and immersed it in the heavy water system. Figure 1 shows the time change for input voltage, current and electrolyte temperature. At 3000 s, we changed the voltage from 32 to 85 V. Figure 2 shows the neutron emission during this voltage change. The neutron count was 100 times larger than the background count.

The rate of neutron emission depended on the purity of heavy water. We can see neutron emission occurred at more than 90% of purity as shown in Fig. 3. We can say that we have to pay attention if you want to generate neutron emission. Because that the heavy water easily absorbs light water. The rate of neutron count was estimated as $1.5 \times 10^{-17}$/dd/s. The rate was increased $10^6$ by the conventional deuterium gas absorption method.

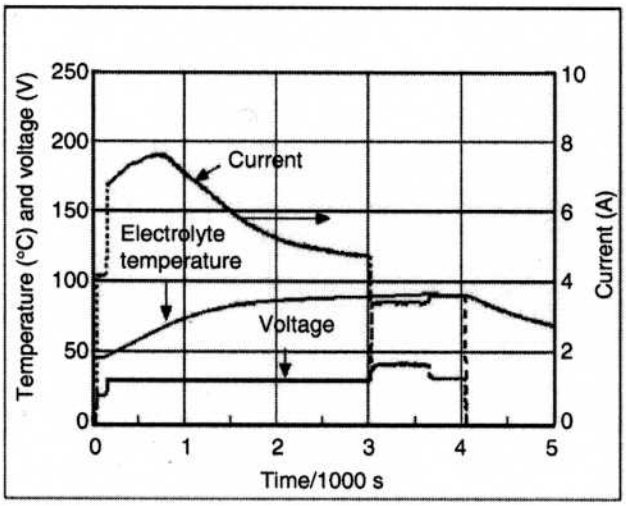


Figure 1. Parameter changes for electrolysis.

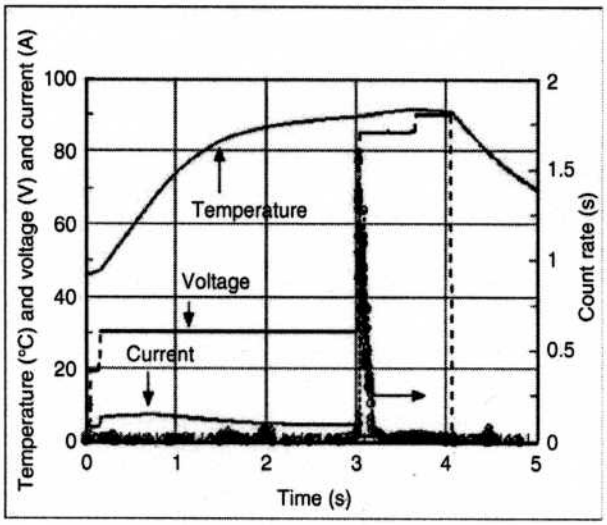


Figure 2. Neutron burst.

## 2. Experimental

The reaction cell was a Pyrex glass tube of 6 mm diameter, 3 mm inner diameter and 100 mm in length, filled with pure $D_2$ gas. A coil wound around the tube supplied the magnetic field. This magnetic coil is made from 10,000 turns of 1.5-mm diameter copper wire. Another Pyrex glass vessel of 50 mm diameter was put around the reactor tube, and filled with liquid nitrogen. The whole system was put in a stainless steel vessel 1.5-mm thick. The outer surface of the steel vessel is insulated with Styrofoam, and another layer of 1.5-mm thick stainless steel plates were placed on top of the Styrofoam insulation to prevent electromagnetic noise

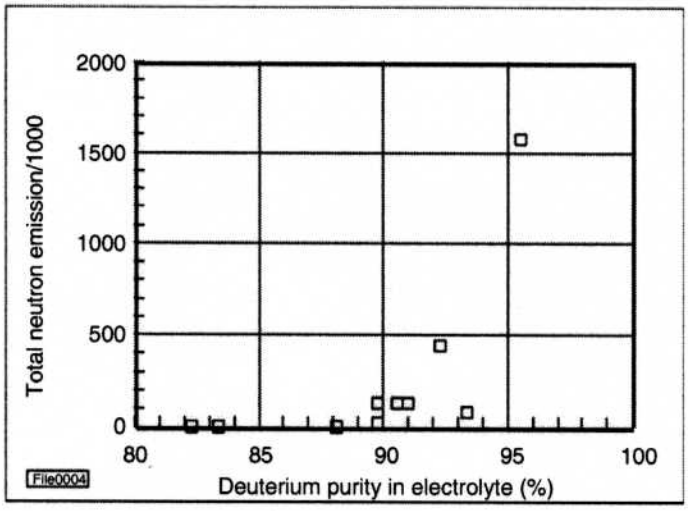


Figure 3. Dependence of neutron on purity of $D_2O$.

from reaching the neutron measurement system. The vessel was filled with liquid $N_2$ to cool the coil and the reactor tube.

The magnetic field was 8 kg at the center of the reaction tube. Power for the magnetic coil was supplied by a stable direct current power supply through a resistive wire, to control the current. The magnetic field passes through the reaction tube along its length. The height of the coil is 100 mm; the same as tube length. The current passing through the coil was increased from 0 to 100 A, which gives the change of intensity of the magnetic field from 0 to 8 kg. Neutrons were measured with three external $He^3$ detectors placed around the cell, 20 cm from the vessel walls.

The method seems rather simple. We filled the glass tube with pure $D_2$ gas. The pressure was several atmospheres, typically 3 atm. The glass tube was then cooled by liquid nitrogen. After that, we supplied a magnetic field. The temperature was kept under -196°C. The magnetic field was periodically changed, and this produced a sporadic neutron burst.

Figure 4 is a photo of the experimental system, power supply, and neutron measurement system. We used Aloka neutron survey meter TPS-451S and three He-3 detectors. The He-3 proportional detector has the energy sensitivity from 0.025 eV to 15 MeV. The sensitivity was calibrated using a standard Cf-252 neutron source.

Figure 5 shows a schematic representation of the measurement system.

The liquid $N_2$ gas cooled the reactor tube. The maximum magnetic field was 10 kg in the center of the reaction tube. The current for the magnetic coil was supplied by a stable direct current power supply through a resistive wire. The magnetic field passes through the reaction tube along the length. The height of the magnetic coil is 100 mm, that is, the same as tube length. The current passing

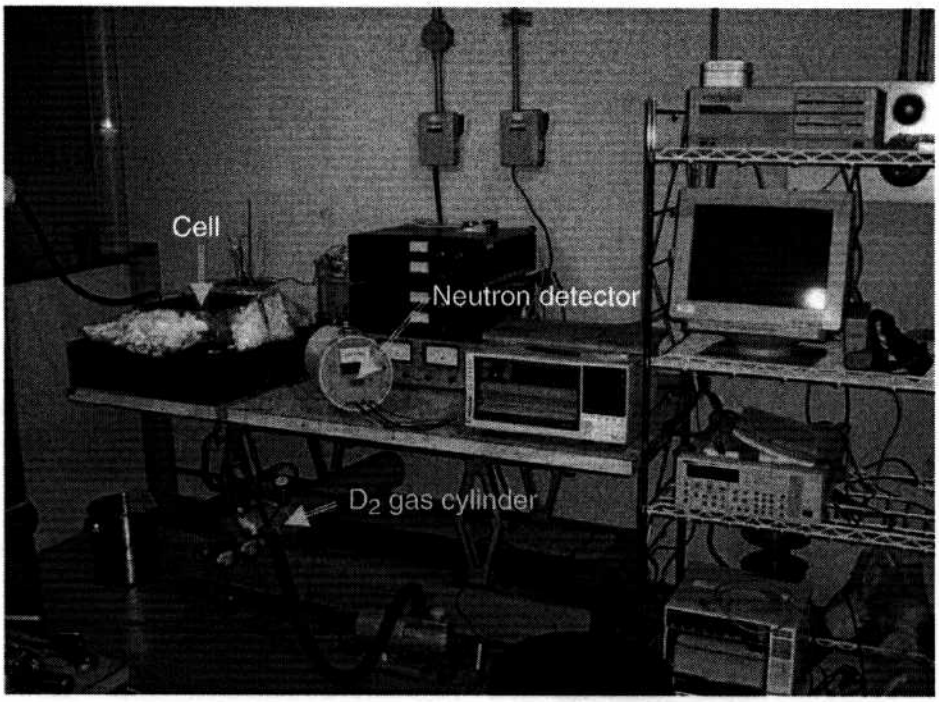


Figure 4. Photo of $D_2$ gas experimental setup.

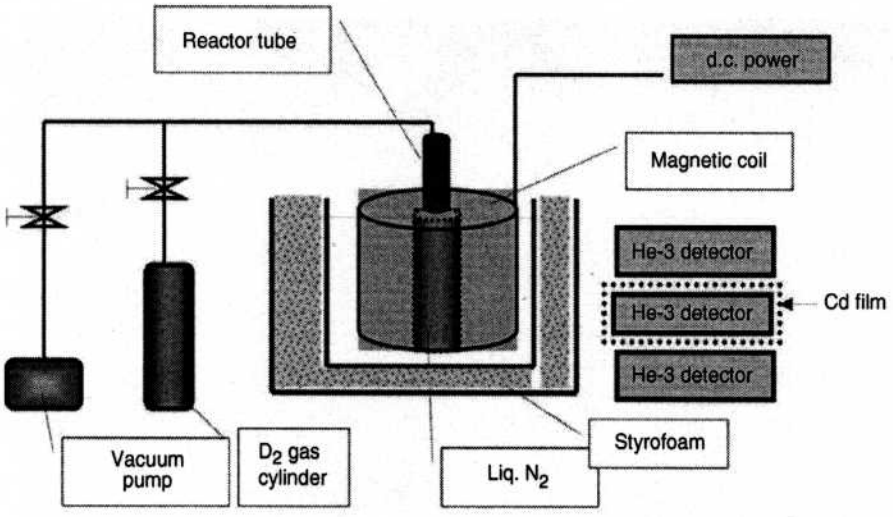


Figure 5. Schematic representation of the $D_2$ gas experimental setup.

through the coil was changed from 0 to 100 A; changing intensity of the magnetic field was changed from 0 to 10 kg.

Neutrons were measured with three external $He^3$ detectors, each 2 cm in diameter and 10 cm in length. They were placed around the cell, separated 20 cm from the

cell. All the detectors were surrounded by a cylindrical plastic neutron moderators, 12-cm diameter and 15-cm high. The detectors were inside the moderator, with the open end of the cylinder facing the cell. To reduce noise, the detectors were covered by electromagnetic shielding.

After calibration, neutrons and noise were distinguished by covering one of the detectors with 0.5-mm thick Cd film. A neutron entering through the plastic moderator will lose energy and be absorbed by the foil, while electromagnetic noise easily passes through the Cd material. The detectors were calibrated with a standard Cf-252 neutron source ($2.58 \times 10^4$ decay/s). The background count was estimated as under $0.008 \pm 0.003$ counts/s. A typical count under these conditions was $5 \pm 1$ count/s from the standard neutron source. This means the total counting efficiency is estimated as 0.0002.

Figure 6 shows the typical neutron counting rate over 10 min after 3 atm of $D_2$ gas filled the tube, a magnetic field of 8 kg was imposed, and the cell has been cooled in liquid nitrogen. The magnetic field was changed to 10 kg at 1200 s by increasing the current. About 20 s, a low-level neutron emission began, and after 50 s, a sudden neutron burst was observed. In this experiment, the reactor tube was filled the pure deuterium gas up to 3 atm, and the liquid $N_2$ was put into the vessel holding the reactor tube, and the magnetic field was imposed in the last step. In other experiments, these steps were taken in a different order.

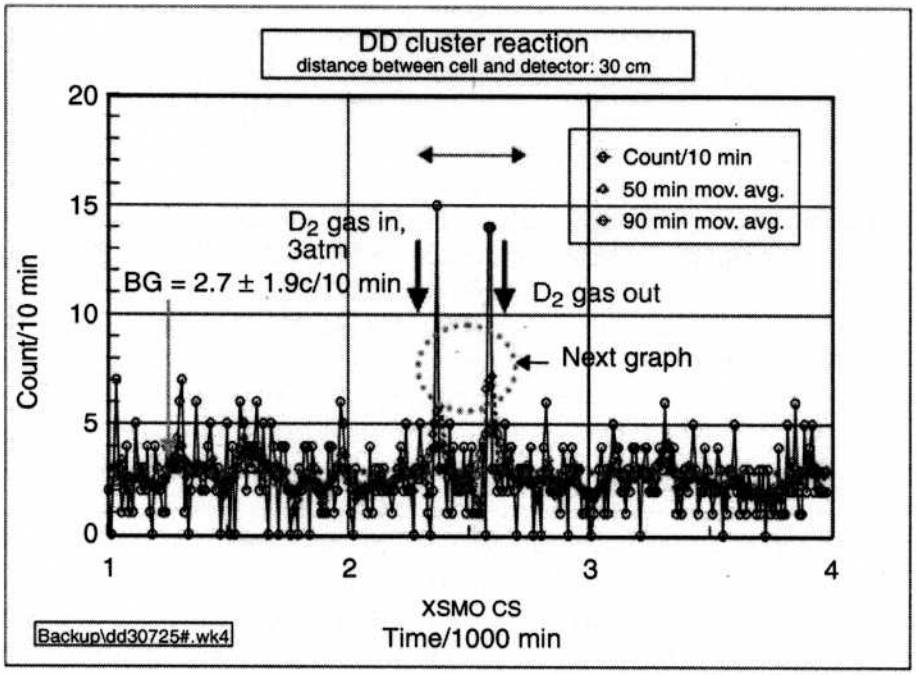


Figure 6. Typical rate of neutron count in 10 min, 3 atm $D_2$ gas, 8 kg.

In this example cooling of the deuterium gas was continued for a considerable

time and neutron emission was sporadically observed when the electromagnetic field was changed. However, in other runs, neutron emissions were observed immediately after liquid $N_2$ was added.

Figure 7 shows the real time-representation for the previous graph. Neutron emission occurred very sporadically over a very short period. So, the rate of the neutron emission changed by the accumulation time. The real counts calculated by inverse time of each emission intervals is shown here. This demonstrates that the neutron emission is very strong and very high and it sometimes almost 1000 times higher than the background counts.

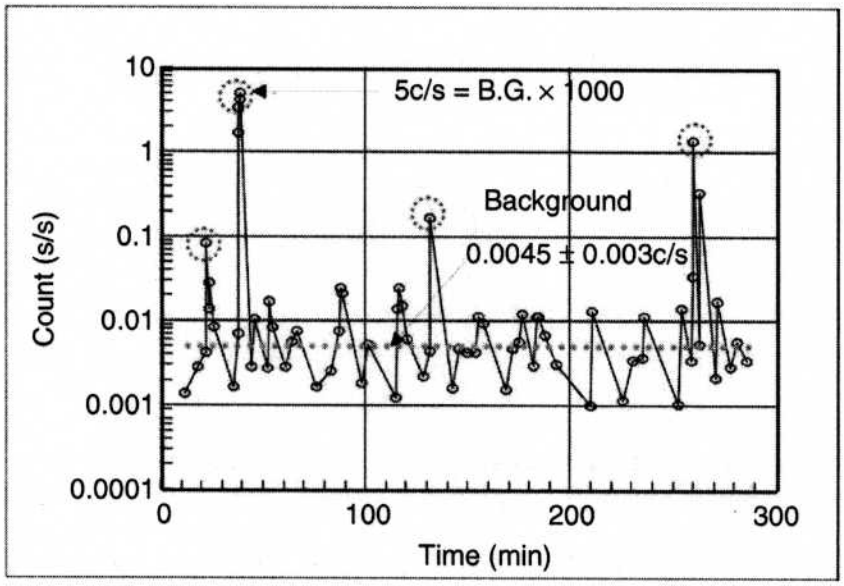


Figure 7. Real-time representation of Fig. 6.

Figure 8 shows the case of hydrogen gas at liquid $N_2$ temperature under 8 kg of magnetic field. First, the tube was evacuated and the magnetic field was fixed at 8 kg. After that, at 220 s, hydrogen gas was introduced into the tube, and the hydrogen gas was removed at 3430 s. No neutron burst was observed during the time hydrogen gas was present in the tube. We can see there are no neutron emissions exceeding background counts during the test.

Figure 9 shows another typical neutrons emission when the tube was first supplied the magnetic field and then cooled by liquid $N_2$. Here, the neutron emission occurred immediately after liquid $N_2$ was added. The count rate increased up to a peak within a few seconds and decreased a few seconds later. Total neutron emission for this brief period is estimated as $5 \times 10^5$. However, no more neutron emissions were observed after that, even when the input magnetic current was increased up to 100 A for 4000 s. In other examples, the total neutron count ranged from $10^4$ to $10^5$, and emissions lasted 1–4000 s. All cases were marked by a characteristic high

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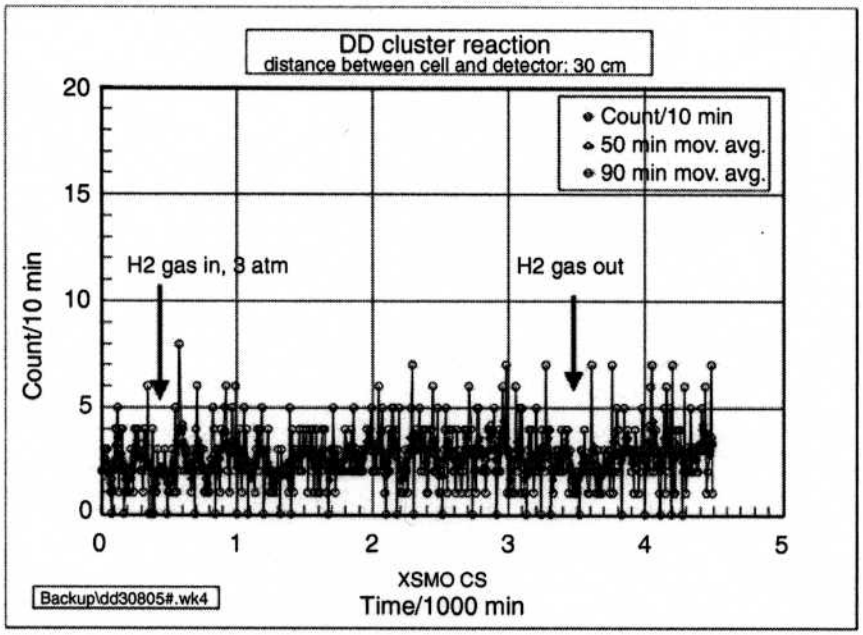


Figure 8. A case of $H_2$ gas at liquid $N_2$ temperature under 8 kg.

level of neutron emissions at first, which gradually declined.

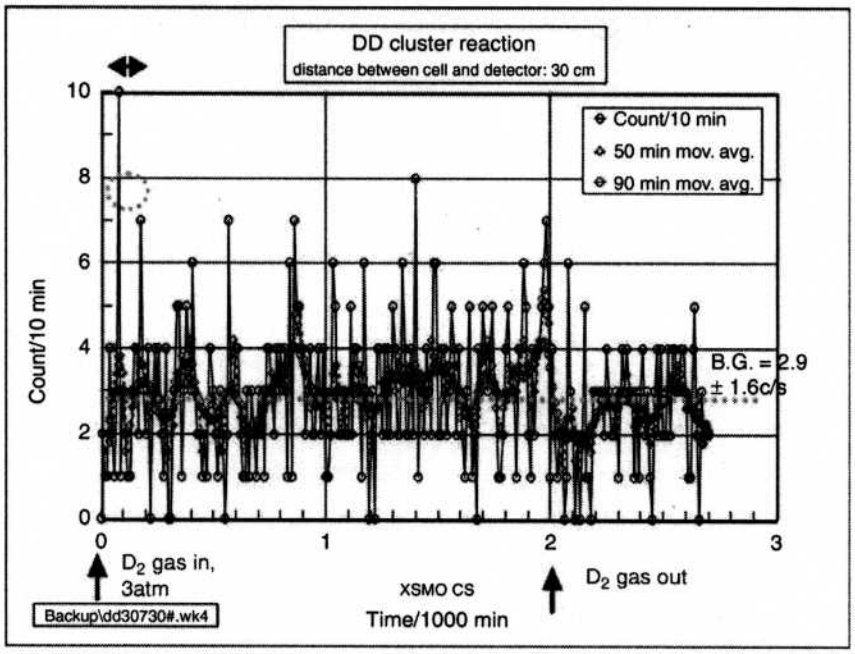


Figure 9. Rate of neutron count in 10 min, 3 atm $D_2$ gas, 8 kg.

Figure 10 shows the neutron count that was calculated in the inverse time for each neutron burst from previous figure. As shown here, the neutron burst occurred between 0 and 120 s.

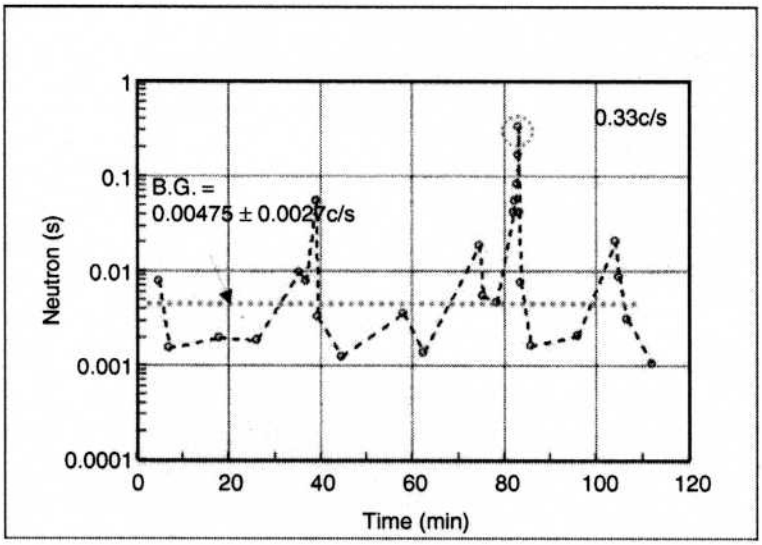


Figure 10. Real time representation of Fig. 9.

Figure 11 shows an example when the temperature was kept at room temperature, 20°C. Deuterium gas was kept in an 8 kg magnetic field. However, there were no neutrons above background.

The neutron emission measurements under various conditions are shown in Table 1. The necessary conditions to make a neutron burst were: deuterium gas, a magnetic field and a low temperature. Neutrons were not generated when one of these conditions was not met. The generation of neutrons when the intensity of magnetic field was changed has not been measured systematically. We usually kept the intensity of the magnetic field constant to avoid noise from the current change and magnetic influence on the measurement system.

Table 1. Neutron emission measurements under various conditions.

| Gas | Mag. field (kg) | Temperature (°C) | Maximum neutron count |
|---|---|---|---|
| Air | 8 | 20 | 0.016/s |
| Air | 8 | −196 | 0.01 count/s |
| Vac. | 8 | 20 | 0.01 count/s |
| Vac. | 8 | −196 | 0.009 counts/s |
| $H_2$ | 8 | 20 | 0.009 counts/s |
| $H_2$ | 8 | −196 | 0.013 counts/s |
| $D_2$ | 8 | −196 | 5 counts/s |
| $D_2$ | 8 | 20 | 0.015 counts/min |

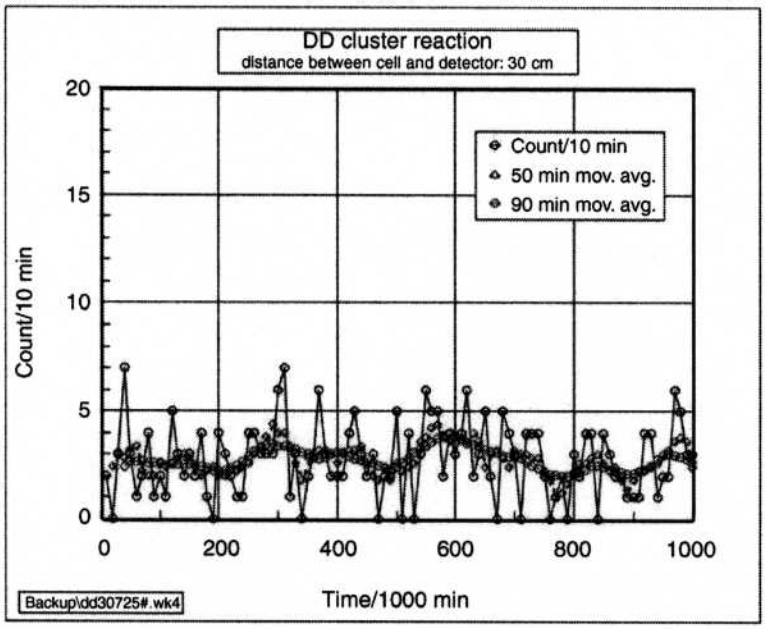


Figure 11. Rate of neutron count in 10 min, 3 atm $D_2$ gas, 8 kg but room temperature.

We have no clear conclusion regarding the relationship between magnetic field intensity and the neutron emission. However, when a magnetic field was not supplied at all, neutrons were not emitted. We conclude that the magnetic field is necessary.Neutron emissions from the cooled $D_2$ gas following a change in a magnetic field are very difficult to explain by the models proposed heretofore, which involve d+d fusion reactions. These models assume that neutron emissions occur when deuterium gas alone is present; they suggest nothing about a magnetic field or low temperature; and they predict that emissions must be accompanied by excess heat and tritium production.

## 3. Results

We have confirmed clear neutron emissions from pure deuterium gas after it is cooled in liquid nitrogen and then exposed to a magnetic field. The neutron count and duration of the emission fluctuated considerably. Repeatability was excellent, although the neutron count was sporadic.

The reason neutrons are generated under such simple conditions is difficult to explain. However, Takahashi has suggested the d–d cluster fusion theory. In this theory, deuterium atoms take a unique arrangement in the metal crystal. It may be that deuterium gas under the low temperature and magnetic field locally arrange themselves in a similar array. Then some trigger reaction, such as local temperature change, change of magnetic field, or a fluctuation of the concentration of the deuterium gas induces the local change between the interactions of the deuterium atom, inducing a weak fusion reaction.

Moreover, the reaction may be triggered by particles such as a neutrino or muon from cosmic rays. However, these scenarios are still unclear. We need more experimental works to identify what the theory is most adequate.

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