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RESULTS OF AN ATTEMPT TO MEASURE INCREASED RATES OF THE REACTION ${}^2\text{D} + {}^2\text{D} \rightarrow {}^3\text{He} + \text{n}$ IN A NONELECTROCHEMICAL COLD FUSION EXPERIMENT

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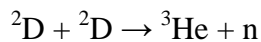
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ABSTRACT

An experiment was performed at the Lewis Research Center to look for evidence of deuterium fusion in palladium. The experiment, which involved introducing deuterium into the palladium filter of a hydrogen purifier, was designed to detect neutrons produced in the reaction



as well as heat production. The neutron counts for deuterium did not differ significantly from background or from the counts for a hydrogen control. Heat production was detected when deuterium, but not hydrogen, was pumped from the purifier.

The experiment was conceived during the height of the interest in cold fusion from March 1989 to June 1989, and was designed to use immediately available apparatus. The lack of neutrons during heat production (indeed during any of the experiments) seems to rule out a neutron producing fusion reaction.

INTRODUCTION

Two research teams announced in March 1989 that they had discovered evidence of nuclear fusion occurring at low temperatures (refs. 1 and 2). The first team of Fleischmann and Pons announced the observation of electrochemically induced “cold fusion” of deuterium. This fusion was reported to occur in electrolytic cells constructed from palladium-rod cathodes and platinum-wire-mesh anodes in heavy water. The authors reported measuring heat exceeding the input of electrical energy to the cells and detecting neutron counts larger than the background count. There are two common fusion reactions in deuterium:



The second reaction is the source of neutrons.

It is an understatement to say that the reports of cold fusion were exciting. Deuterium is a fairly abundant isotope of hydrogen, the most common element in the universe. Hence, cold fusion of deuterium would be an inexhaustible source of energy. It is also challenging to try to explain how palladium would enhance fusion of deuterium or deuterium ions in the first place. Fusion is normally highly improbable at room temperature, being inhibited by the mutual Coulomb repulsions of nuclei. Fusion can occur by tunneling through the Coulomb barrier. Equivalently, nuclear wave functions overlap to some extent in spite of the barrier. The tunneling probability is a strong function of the width of that barrier. The width of the barrier depends in turn on electrostatic shielding by extranuclear particles such as electrons or muons. Heavy, negatively charged particles such as muons shield for smaller nuclear separations, smaller barrier widths, and greater wave-function overlap than do the ubiquitous, light electrons. Muon catalyzed fusion is a recognized although presently impractical process. (ref.3) How palladium would reduce the barrier width with electrons as the shielding particles is a mystery.

An experimentally puzzling result was the failure of Fleischmann and Pons to detect enough neutrons for the heat measured, assuming fusion was occurring. The two authors reported neutron counts only 3 times higher than expected from cosmic rays and 7 to 10 orders of magnitude less than would be predicted from the heat generated. (ref. 1)

At the height of the cold fusion excitement, the authors of this TM were able to assemble the apparatus necessary to perform an experiment designed to look for evidence of the second reaction. There were two circa 1965 neutron detectors used to measure biological doses of neutrons. There were hydrogen purifiers which purify hydrogen by passing it through the wall of a heated palladium tube. There was a thermocouple attached to the palladium tube in a purifier for monitoring the thermal effects reported in reference 1. There was vacuum equipment for evacuating and outgassing the purifiers, and there was a source of deuterium gas.

The authors performed an experiment to determine whether the neutron-detector count for palladium in the presence of deuterium gas differed significantly from the background neutron-detector count. The experiment was repeated at different palladium temperatures and deuterium fill pressures. A control experiment was performed using hydrogen. The thermocouple was monitored during pumping, filling, and counting to detect thermal effects.

This experiment differs from the experiment reported in ref. 1 by using deuterium gas in a hydrogen purifier rather than heavy water in an electrolytic cell. Subsequent to the start of this experiment, the interest in cold fusion has declined, in part because of the failure of Fleischmann to repeat the results of ref. 1 in another experiment and the failure of others to find significant evidence of cold fusion (ref. 4). For the benefit of those who do not wish to read further, we state that our neutron-detector counts for palladium in vacuum, palladium in deuterium, and palladium in hydrogen did not differ significantly and we were unable to detect evidence of the second reaction. There was however one difference in thermal behavior between deuterium and hydrogen in the purifier.

The remainder of this TM discusses the experimental setup, results, and conclusions.

DESCRIPTION OF APPARATUS

A block diagram of the experimental setup is shown in fig. 1, and a photograph is shown in fig. 2. The deuterium from the fill bottle was transferred into the hydrogen purifier through a gauged pressure regulator. A vacuum pump was used to purge the fill lines and the purifier.

The hydrogen purifier was a Johnson-Matthey model HP-25 containing an estimated 25 cm of Pd (private communication). The Pd is in the form of a thin-walled tube. Hydrogen normally is passed through the wall of the tube for purification. Both inlet and outlet were pressurized with deuterium for the experiment, thereby maintaining both sides of the wall at the same pressure. The Pd is contained in a thermally insulated metal can together with an electric heating element and a thermocouple. The heater is provided to maintain the Pd at 370°C (700°F) during the purifier's normal use as a hydrogen purifier. The thermocouple is connected to a digital temperature readout on the front panel. This type of construction, having the Pd enclosed within a temperature monitored, insulated chamber, made it convenient to look for evidence of the heating reported by Fleischmann and Pons (ref. 1). The heater also made it possible to run the experiment at elevated temperatures, and the enclosure to run the experiment at elevated pressures. The purifier was small enough that a large fraction of the neutrons produced by the second reaction could be detected by external detectors.

The neutron counters were Tracerlab model BP-1 portable neutron monitors (colloquially called "Snoopies"). The detector consists of a proportional counter (50 cm active length), filled with BF₃, surrounded by a 20.6 cm diameter by 23.9 cm long cylinder of low density polyethelene. Neutrons interact with the B in the proportional counter to produce alpha particles and ⁷Li nuclei. These charged particles ionize the fill gas, and the resulting electrons are accelerated by the high electric field close to the anode wire leading to the counting of an event. The cross section for the ¹⁰B(n,α)⁷Li reaction is small for high energy neutrons such as those produced by deuterium fusion. The function of the polyethelene is to slow down high

energy neutrons. The neutrons lose energy via elastic collisions with the hydrogen atoms in the polyethylene until they reach energies in the eV range. At these energies, the reaction cross section has increased by a factor of about 1000.

The polyethylene jacket surrounding the proportional counter also contains a thin cylinder of a rubber like material impregnated with naturally occurring boron. This cylinder reduces the sensitivity of the SNOOPY to low energy neutrons, in order to more closely match the response of tissue over the energy range from thermal to 10 MeV. Unfortunately, there is also a decrease in the ability of the SNOOPY to detect deuterium-fusion neutrons.

The detectors were placed as close as possible to the palladium cell. A 5 μ Curie ^{252}Cf source, placed at the position of the palladium, resulted in a counting rate of about 10^2 per minute.

The detectors have outputs which allow them to be used with event counters so that the cumulative number of events detected over a period of time can be recorded. We used this mode of operation for the experiment. The batteries normally used as a power source were replaced with regulated power supplies.

EXPERIMENT AND RESULTS

Preparation consisted of using a diffusion pump to pump all the ports of the purifier with the Pd of the purifier at a temperature of about 370°C (700°F). The initial pumping was to about 10^{-6} T for about 4 hours. The ports of the purifier were then valved off and the purifier was connected to the setup. Subsequent pumping was with a roughing pump only. However, a final fill of deuterium or hydrogen was always preceded by filling and pumping three times.

The actual experiment consisted largely of counting and monitoring temperature.

The plan was to determine whether there was a significant difference between the count with deuterium or hydrogen present and a background count. Background counts were made with an evacuated cell and were recorded on four separate occasions. The results in chronological order are graphed in figs. 3 - 6. The graphs show count rate versus counting time for the two detectors. Detector #1 is the black cylinder and meter to the right of the hydrogen purifier (fig. 2), and detector #2 is the cylinder and meter to the left of the purifier. The purifier is the box with the valves and tubes extending from it.

The cumulative counts for each detector were observed and divided by the total elapsed time from the start of the particular run. The resulting counting rate was plotted as a function of elapsed time.

The first background count, shown in fig. 3, was performed before deuterium was introduced into the purifier. The error bars represent plus and minus one standard deviation estimated by assuming that the counts are a Poisson distributed random process. Counts

were recorded throughout this work at somewhat irregular intervals; all results have been graphed.

Figure 7 summarizes best the significance of the background measurements. The figure shows the difference between the final counts in figs. 4, 5, and 6 and the final count of the first background measurement (fig.3). The count difference is plotted against the actual time of the final count as measured from the beginning of the experiment. The count differences differ from zero by as many as 2 standard deviations (Fig. 7b). Hence, with deuterium present, we are disinclined to consider differences of less than 3 standard deviations to be significant.

The results at various deuterium fill pressures and Pd temperatures are graphed in figs. 8 - 13. The time from the beginning of each run is plotted along the abscissa and the difference between the count rate and the background count rate is plotted along the ordinate. The final value of a background count chronologically closest to the end of a run is selected. Figure 9 shows results only for detector #1, since the event counter for detector #2 malfunctioned (the displayed count incremented by 2 or more per event) during that run. Again during the run of June 26 - June 30, multiple counts were observed on event counter #2 (Fig. 11b). The counter was replaced for subsequent runs.

Runs were made with cold fill pressures of deuterium ranging from 69 kPag (10 psig) to 552 kPag (80 psig) and with Pd temperatures ranging from room temperature to 389°C (732°F). The count difference did not exceed 2 standard deviations, except when counter #2 malfunctioned and exhibited multiple counting (fig. 11).

Figure 14 shows the results of a control run performed with ordinary hydrogen. The maximum difference is about 1 standard deviation.

Neither deuterium nor hydrogen showed neutron counts significantly different from background. The thermal results are somewhat more interesting.

A temperature increase always occurred as deuterium or hydrogen was introduced into the hydrogen purifier, after it had been pumped down. However, a temperature rise also occurred with deuterium as the gas was being pumped out of the purifier. For example, the purifier was filled with D₂ at a temperature of 383°C (722°F) and a pressure of about 1,380 kPa (200 psia). The lines to the purifier had been pumped down, and the purifier was to be evacuated prior to running another background count. As the valve on the hydrogen purifier was cracked open, the temperature began to rise. We continued to open the valve slowly; by the time the valve was fully open (10 or 15 seconds), the temperature had increased to 400°C (752°F) before it began to decrease. During this time, the temperature control setting remained at 720°F, and the temperature rise was much more rapid than was possible using the electric heater. Neither neutron detector registered any counts during the time heating occurred.

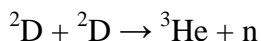
After proceeding with the background count, the purifier was refilled with D₂ at 374°C (705°F) and 1,380 kPa (200 psia). Another neutron count was taken for 10 days, and the purifier was again evacuated, but this time the heater control temperature was reduced to

24°C (75°F). This was done to preclude any possibility that a temperature rise might be due to unintended operation of the electrical heating element. Because the possibility now existed that the Pd element would crack if it were allowed to cool without being evacuated, the valve was opened fully as soon as the lowered control temperature was set. This time the temperature dropped from 374°C (705°F) to 370°C (698°F) and then slowly increased back up to 375°C (707°F), again indicating heating as the deuterium was removed from the palladium. As before, no neutrons were registered by either detector during the time the heating occurred.

The above cycle of background count, neutron monitoring with the purifier at 374°C (705°F) and 1,380 kPa (200 psia), and evacuation was then repeated using ordinary H₂ as a control. In the case of hydrogen, there was no evidence of self heating as the hydrogen was withdrawn from the purifier; the temperature dropped quickly as the valve was opened, and continued to drop when the valve was fully opened.

CONCLUDING REMARKS

This experiment to look for evidence of the second deuterium fusion reaction



in Pd showed a negative result even at the rather low level of significance of 3 standard deviations. Differences of 1 or 2 standard deviations were observed in the background count as well as when deuterium or hydrogen was present in the hydrogen purifier.

One can only speculate about the source of the heating which occurs when D₂ and not H₂ is removed from the Pd. The lack of neutrons during the heating (indeed during any of the experiments) would seem to rule out the second reaction as an explanation.

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1. Fleischmann, M.; and Pons, S.: Electrochemically Induced Nuclear Fusion of Deuterium. J. Electroanal. Chem., vol. 261, 1989, pp. 301-308.
2. Jones, S. E.; et. al.: Observation of Cold Nuclear Fusion in Condensed Matter. Nature, vol. 338, Apr. 1989, pp. 737-740.
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4. Levi, B. G.: Doubts Grow as Many Attempts at Cold Fusion Fail. Physics Today, Jun. 1989, pp. 17-19.

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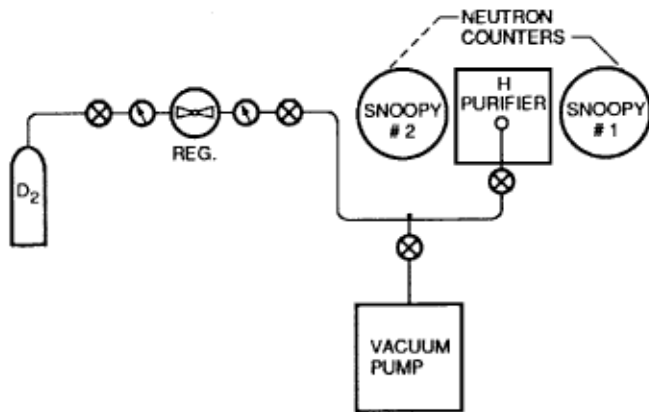


Figure 1. Block diagram of experimental setup showing vacuum and fill lines as well as hydrogen and neutron detectors.

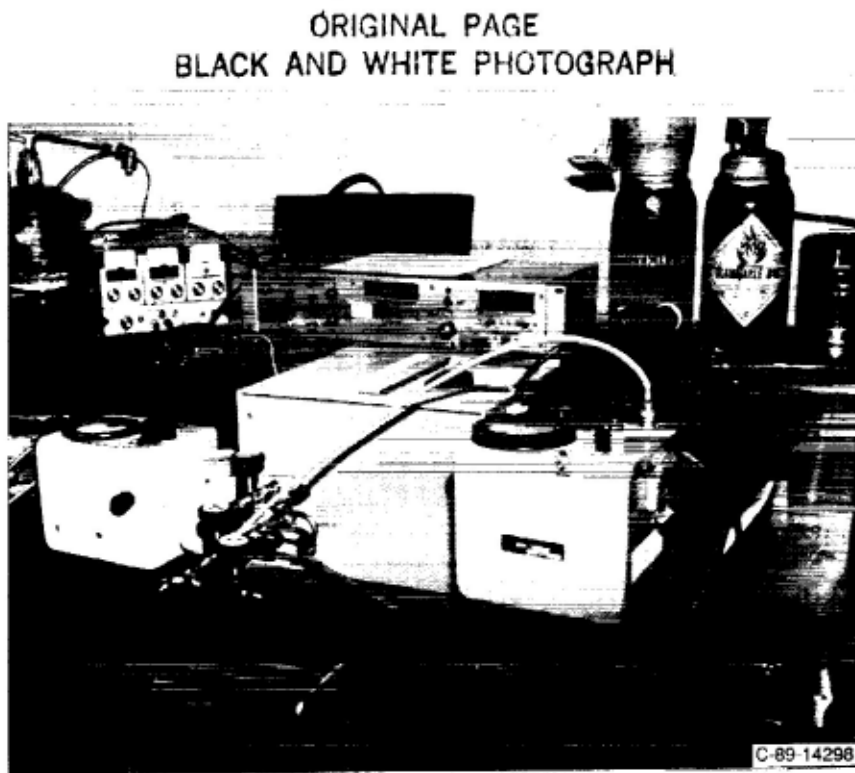


Figure 2. Photograph of experiment showing hydrogen purifier flanked by two neutron detectors.

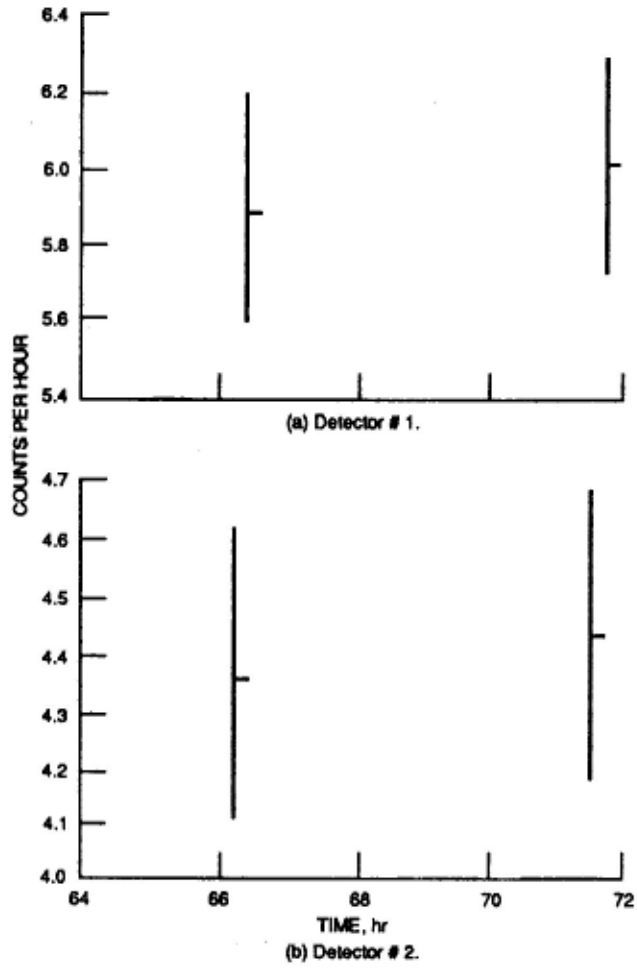


Figure 3. Background count in counts per hour for June 9 - June 12.

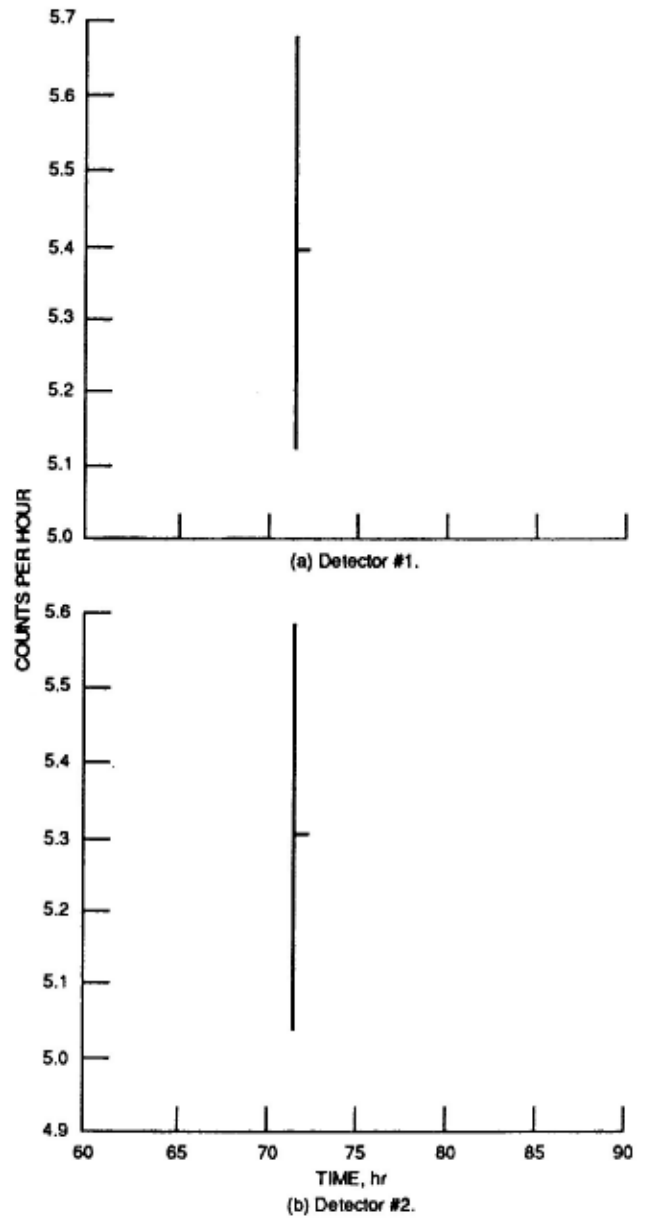


Figure 4. Background count in counts per hour for June 23 - June 26.

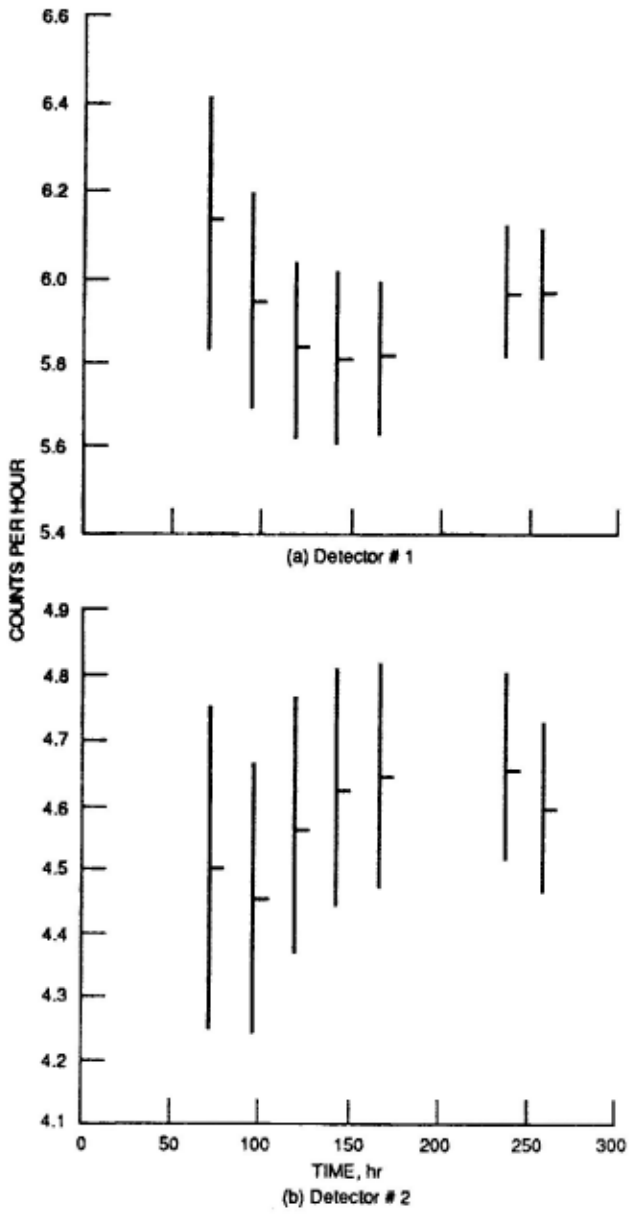


Figure 5. Background count in counts per hour for July 7 - July 18.

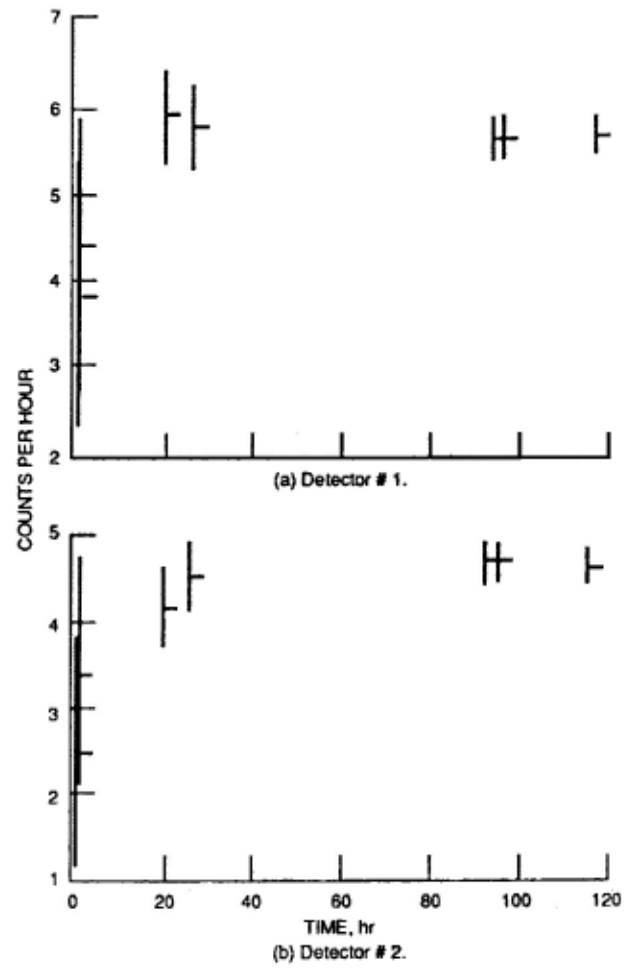


Figure 6. Background count in counts per hour for July 27 - August 1.

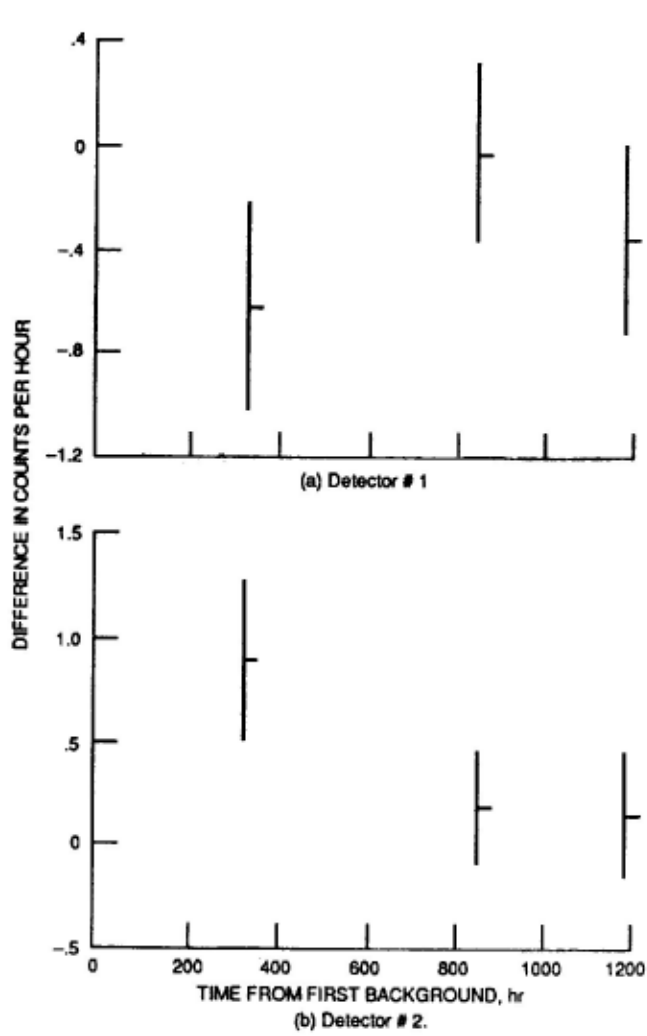


Figure 7. Variation in background count as a function of time from first background measurement. Differences are for final counts minus final count of June 9 - June 12.

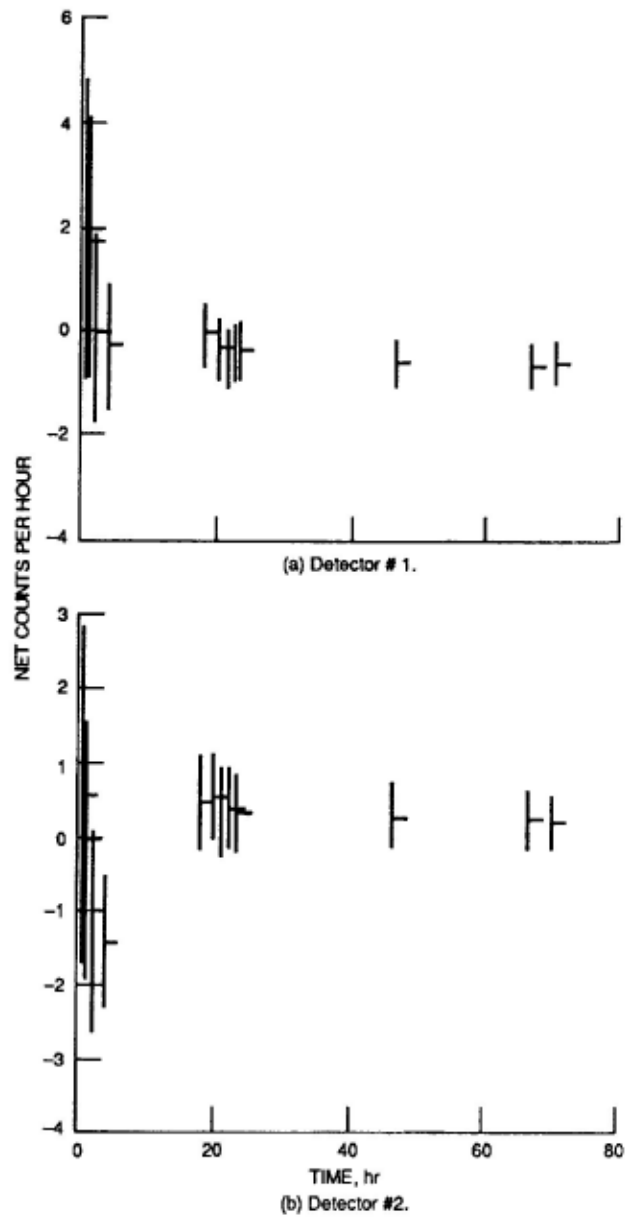


Figure 8. Net Count In counts per hour for a deuterium fill of 69 kPag (10 psig) and palladium element at room temperature. Measured from June 12 - June 15.

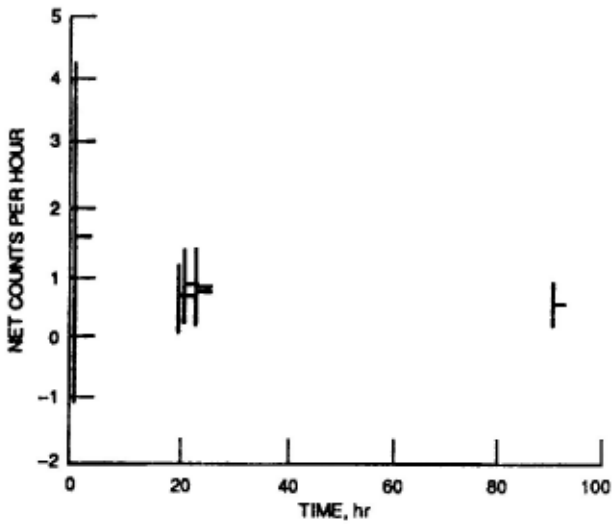


Figure 9. Net Count in counts per hour for a deuterium fill of 69 kPag (10 psig) and palladium element at 142°C (288°F). Detector # 1 only. Measured from June 15 - June 19.

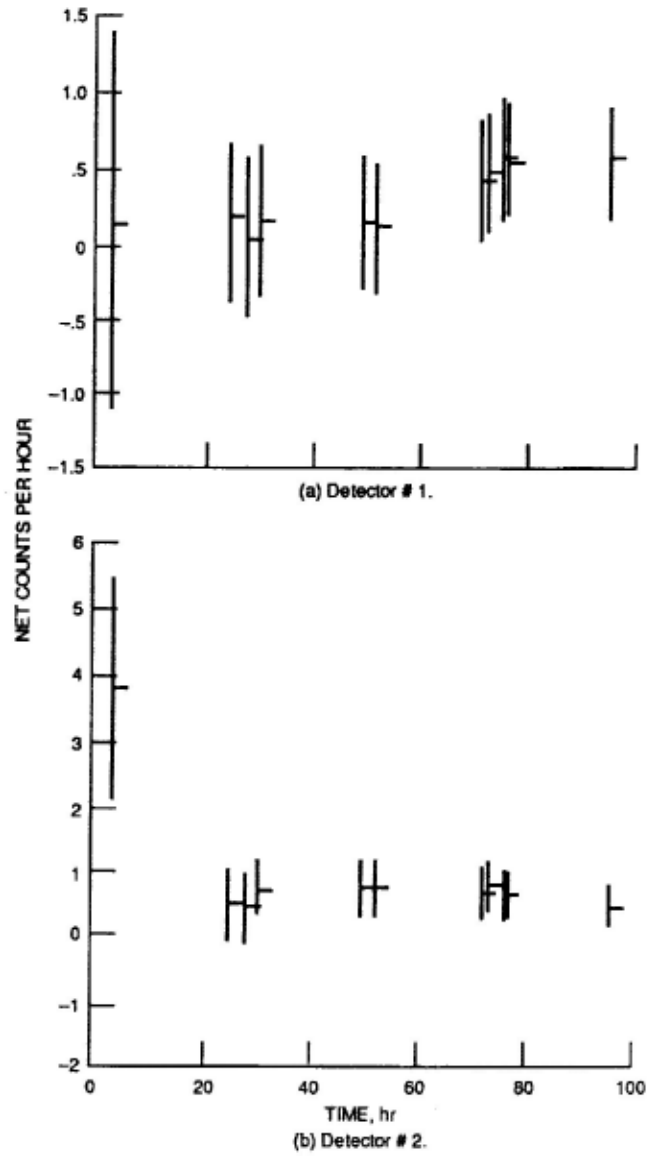


Figure 10. Net count in counts per hour for a deuterium fill of 69 kPag (10 psig) and palladium element at 389°C (732°F). Measured from June 19 - June 23.

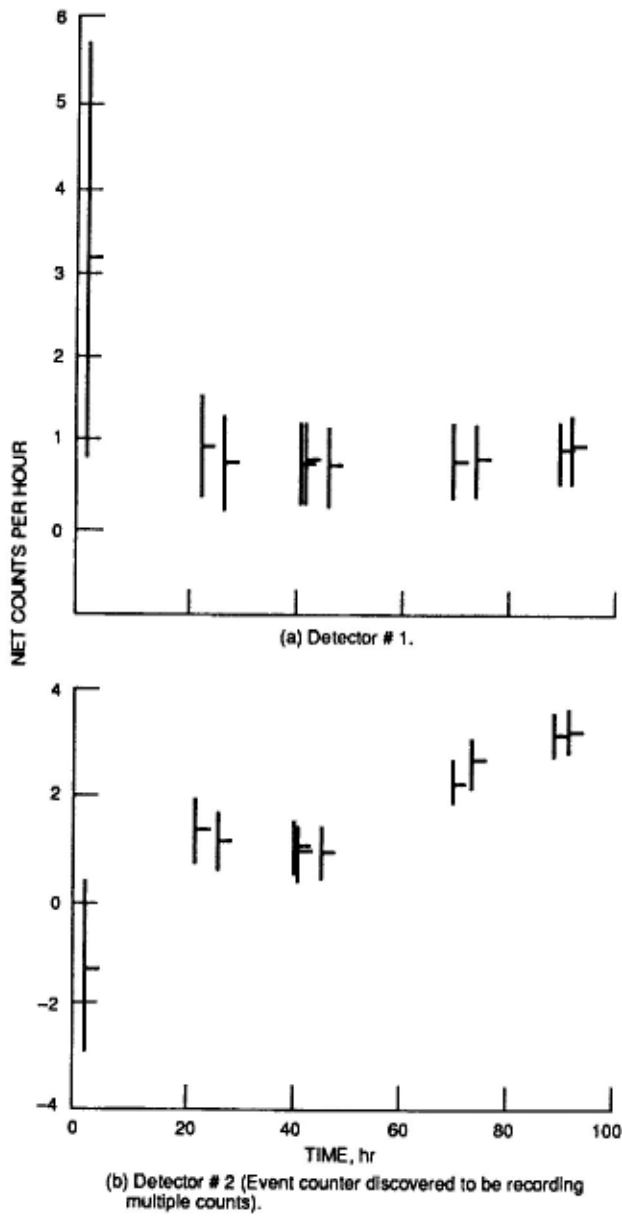


Figure 11. Net count in counts per hour for a deuterium fill of 552 kPag (80 psig). Palladium temperature during fill was 33°C (91°F). Palladium temperature while counting was set at 210°C (410°F). Measured from June 26 - June 30.

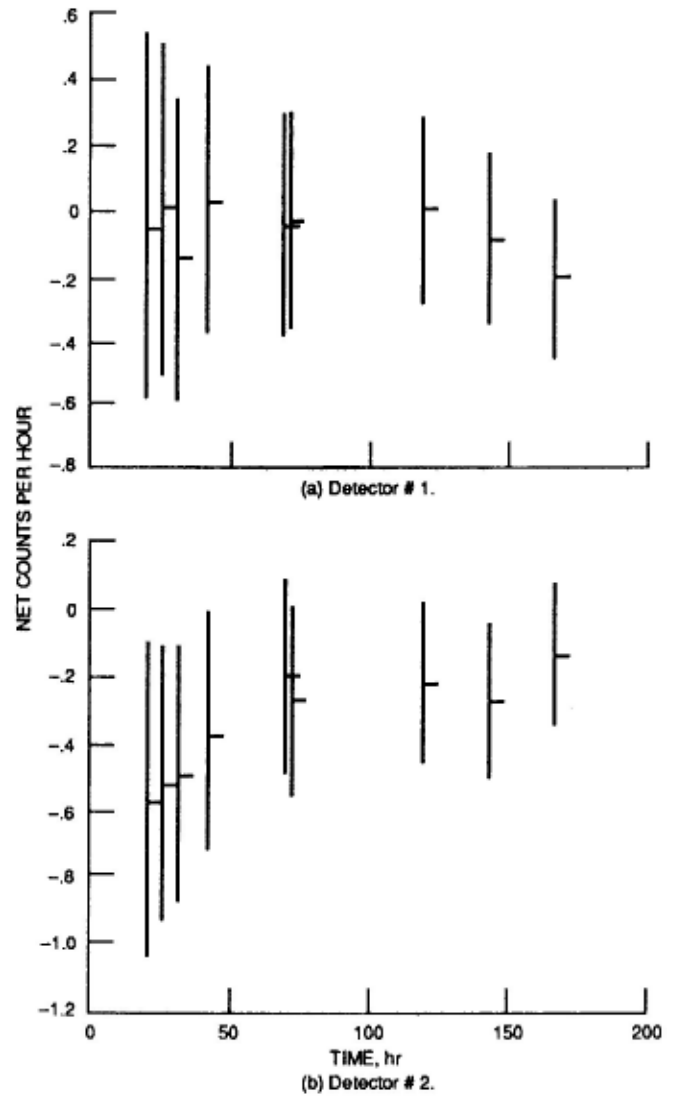


Figure 12. Net counts per hour for fill conditions the same as in figure 11, but for palladium temperature increased to 382°C (720°F). Measured from June 30 - July 7. New event counter for detector # 2.

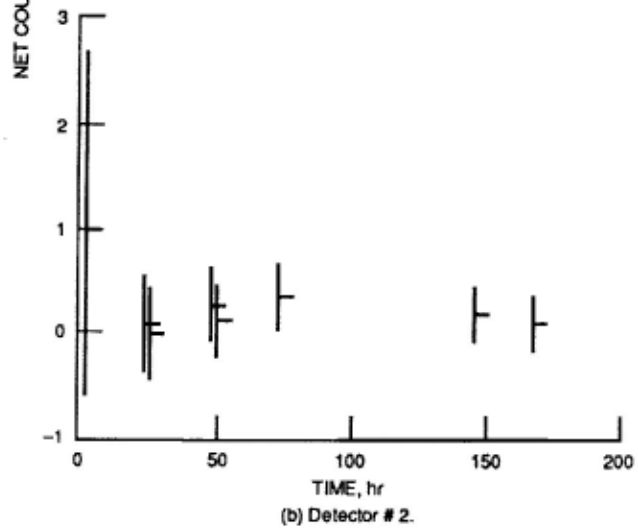
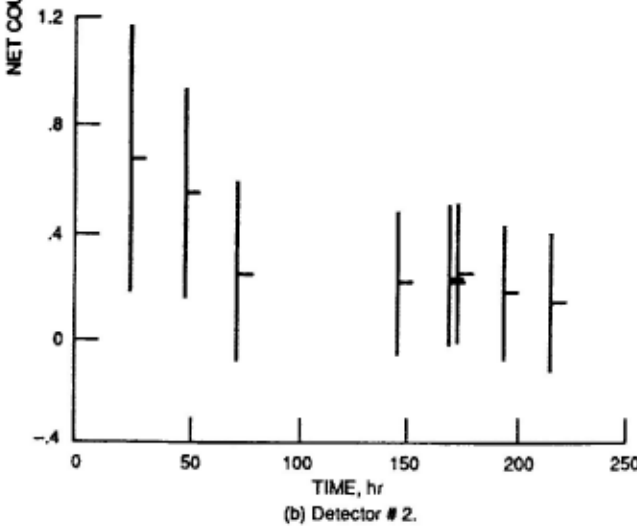
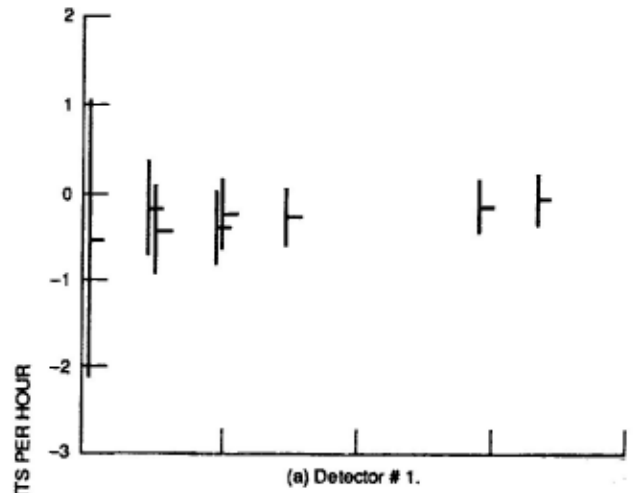
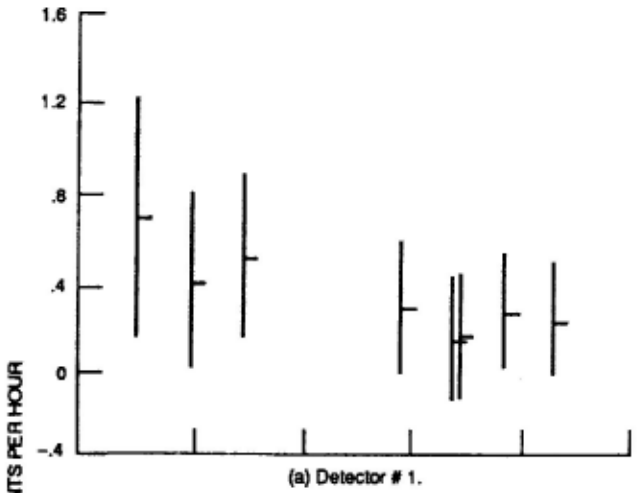


Figure 13. Net counts per hour for a deuterium fill of 552 kPag (80 psig). The palladium temperature during fill was 32°C (90°F). The palladium temperature while counting was 371°C (700°F). Measured from July 18 - July 27.

Figure 14. Results for the hydrogen control. The fill pressure was 552 KPag (80 psig). The palladium temperature during fill was 35°C (95°F). The palladium temperature while counting was 371°C (700°F). Measured from August 1 - August 8.



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