NEGATIVE RESULTS AND POSITIVE ARTIFACTS OBSERVED IN A COMPREHENSIVE SEARCH FOR NEUTRONS FROM "COLD FUSION" USING A MULTIDETECTOR SYSTEM LOCATED UNDERGROUND

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Received July 3, 1989
Accepted for Publication July 18, 1989

A search for neutrons from deuterium "cold fusion" systems (both electrochemical and high-pressure gas cells) was conducted in an underground laboratory using three highly sensitive neutron detectors composed of $^3$He gas proportional counter tubes embedded in polyethylene moderators. Any neutron emission from a test cell would be simultaneously observed in all three detectors in a known proportion. The counting system can detect random, continuous emission at a rate of $<100$ n/h, and short bursts of as few as 35 neutrons. None of the cold fusion systems tested emitted neutrons at these levels. Occasional anomalous groups of counts were observed in individual detectors that closely mimicked both continuous and burst emission. These anomalies were identified as spurious detector artifacts rather than true detection, because counts were not observed in the appropriate proportion in all three detectors. The use of multiple detectors simultaneously observing the test system in a very low background environment can effectively identify spurious artifacts that might otherwise be interpreted as evidence of neutron emission and may be essential to the demonstration of low-level neutron production from cold fusion systems.

SUMMARY

A high-sensitivity neutron detection system designed to rigorously identify low-level neutron emission has been in use since May 17, 1989, at an underground laboratory on Kirtland Air Force Base in New Mexico to diagnose "cold fusion" studies employing both high-current electrochemical cells and high-pressure gas cells that were temperature cycled using liquid nitrogen. The characteristics of the test cells are described in Refs. 1 and 2.

No neutrons in excess of the very low background have been identified, either in bursts or continuous emission. The system is capable of detecting continuous emission at a level of $<100$ n/h and can identify bursts as few as 35 neutrons emitted in a time $<1.14$ s. Any neutron emission from a test cell would be simultaneously observed in all three detectors in the system in a known proportion.

Events were observed in a number of tests that closely mimic the neutron emission reported by others.3,4 Because counts were not simultaneously produced in the correct proportion in all three detectors in those events, we were able to show that they were actually spurious artifacts of the counting system. Had we employed just one detector at a time, we might have been misled into interpreting the artifacts as "neutron emission." We observed those infrequent and spurious events at one time or another in each of the three detectors. The extent of these artifacts became apparent only when the detector was removed from the normal laboratory background (induced primarily by cosmic rays) and placed in the underground laboratory.

EXPERIMENTAL ARRANGEMENT

The experimental geometry is shown in Fig. 1. The test cells were located between two physically identical neutron detection arrays electrically connected to provide three independent neutron detection channels. This arrangement was surrounded by at least 6.4 cm of high-density polyethylene in all directions for shielding against background neutrons. Each detection array consists of 11 gas proportional counter tubes (2.5-cm diam × 40-cm long, filled with 10 atm $^3$He gas) embedded in a 38- × 24- × 7.6-cm polyethylene moderator. The tubes are arranged as shown in the cross section in Fig. 1. The outside of the moderator is covered with cadmium to eliminate externally produced thermal neutrons. Fast neutrons that penetrate the cadmium can be moderated to thermal energies by collisions inside the polyethylene. Some fraction of the thermal neutrons produced inside the moderator is captured in the $^6$Li gas and detected via the $^6$Li($n$,p) reaction. The products of this reaction, a proton and a triton, produce an electrical pulse that is amplified and pulse-height analyzed to separate the $^3$He reaction pulses from those produced by electronic noise and by gamma rays. This separation becomes critical in the case of very low-level neutron detection, since
extraneous effects can contribute pulses in the same pulse height range as the $^3$He reaction. All 11 tubes of one array were electrically connected to form one channel of neutron detection, designated channel 1. In the second array, the five tubes in the same plane were electrically joined to form channel 2. Channel 3 consisted of the remaining six tubes. A neutron source located between the arrays emitting randomly would produce counts in all three channels.

The overall efficiency of the detector arrangement was measured in situ by placing a $^{252}$Cf neutron source (average energy of ~2.3 MeV) emitting 71 000 n/s at the center of the test cell. The detectors have essentially the same response to the $^{252}$Cf source as to 2.5-MeV neutrons from deuterium-deuterium fusion. The overall efficiency of the system (the sum of the counts in the three channels per 100 neutrons emitted from the source) is 9.2% for arrays spaced 14 cm apart to accommodate the electrochemical cells. With a spacing of 2.5 cm, as used in some of the tests with high-pressure gas cells, the efficiency was measured to be 15%.

The counts observed in channels 1, 2, and 3 were in the proportion 1.0:0.57:0.49, respectively, with the $^{252}$Cf source in place. A neutron source of similar energy located between the arrays would produce counts in a similar proportion.

The neutron detection system was assembled at an underground laboratory on Kirtland Air Force Base in New Mexico. The site provides >50 m of overburden in all directions and produced a 200-fold reduction in the neutron background. For essentially all of the time that experiments were being conducted, the average count rate, with and without test cells in place, was $10 \pm 1$ count/h summed over all three channels. This is equivalent to a fusion source emitting ~100 n/h. The observed counts in channels 1, 2, and 3 are in the proportion 1.0:0.44:0.49, which differs from the proportionality for the $^{252}$Cf source. This result indicates that the pulses arise from a different source or location, as would be expected for background neutrons coming from the surroundings rather than from between the arrays. This result is also consistent with the possibility that the pulses arise, at least in part, from artifacts that differ from channel to channel.

A SEARCH FOR NEUTRON EMISSION

The system criteria for identification of neutron emission were (a) counts in excess of the background rate in all three channels over the time period of interest and (b) a distribution of counts among the channels that is consistent with neutron emission from between the arrays. The calibration with the $^{252}$Cf neutron source indicated that the counts in channels 1, 2, and 3 should be near the proportion 1.0:0.57:0.49 and that the sum of the counts in channels 2 and 3 should be about equal to the counts in channel 1 for neutrons with the expected energy. The number of counts in each channel was collected and recorded in 10-min intervals. No data that met the system criteria were observed in hundreds of hours of counting with dozens of experiments. However, a number of observations were made of count sequences that would have appeared to be neutron emission if only one detector at a time had been in operation.

Consider the data of Fig. 2. If channel 1 had been the only detector monitoring the experiment in the time interval out to ~5 h, we might have been misled into claiming a "positive neutron emission." Detailed examination of the data showed that in no 10-min interval did the counts in the three channels of neutron detection approximate the distribution expected for a neutron source located inside the detector array. Summation of all the counts in the 5-h interval also showed that these counts were not due to neutron emission from the experimental cell. Similarly, in Fig. 3 the rise in counts in channel 2 in the time interval after 600 min is not matched by counts in the other detectors. We therefore conclude that these counts are not due to neutron emission from the experiment in progress.

There are a great many possible sources of such spurious pulses, but only a few are mentioned here. In the case of the pulses observed in Figs. 2 and 3, the occurrence rate of such events was observed to greatly decrease after the high voltage applied to all the tubes was reduced from 1600 to 1200 V and readjustment of the electronics. A number of isolated instances of sudden counts in only one or occasionally two of the three detectors were recorded. All three detectors were checked and found not to be microphonic (pulses induced by acoustic or motion disturbances) in the aboveground laboratory. However, after several days in the underground laboratory, detectors 1 and 2 were found to be occasionally microphonic. Many such spurious results would tend to be ignored or tests would be redone in aboveground laboratory operation. We have observed similar effects with several other detectors of similar design. By careful adjustment of the pulse-height discrimination setting, we were able to reduce the background count rate in one experiment by 40%, while losing only 10% of the neutron detection efficiency. There are undoubtedly other possible causes of spurious pulses that are important only at very low levels of detection and may be obvious only at locations of very low background with unusually long observation times. We have concluded that it may be nearly impossible to conclusively demonstrate that any single neutron detector used for low-level studies is completely free of the sources of such spurious pulses and that multiple simultaneously operating detectors are required.

A SEARCH FOR BURSTS

Following suggestions kindly provided by S. E. Jones of Brigham Young University and H. O. Menlove of Los Alamos National Laboratory, we examined our data taken with 10-min resolution for bursts of neutrons. A small number of 10-min intervals with counts recorded in all three channels were found, at a rate consistent with the random coincidences expected for the observed background rate of the detectors.
We then initiated a series of tests involving both electrochemical and high-pressure gas cells\(^1\) in which the counts in each channel were collected every 1.14 s, the shortest time resolution available in our recording system without extensive modifications. This time interval would include any bursts of shorter duration, and if a positive result were obtained, could indicate the need for a shorter coincidence time. The system criteria for the identification of bursts of neutrons were (a) simultaneous counts in all three channels, (b) a distribution of counts among the channels that is consistent with neutron emission from inside the detector array, and (c) intensity or regularity sufficient to rule out a singular isolated event, which could be a random background coincidence such as might be caused by a cosmic-ray shower at or near the detectors. The calibration with the \(^{252}\text{Cf}\) neutrons indicated that the counts in channels 1, 2, and 3, for very low intensity, should be in the approximate proportion 2:1:1 and that the counts in channel 1 should approximately be equal to the sum of the counts in channels 2 and 3. Since the overall efficiency of the system in this configuration was \(
abla 12\%\), the efficiency for the least efficient channel was \(
abla 3\%.\) This implies that a randomly oriented burst of 35 neutrons or more would be likely to produce a count in each channel. In >300 h of counting with multiple cells in place, there were only four events of interest, as shown in Table I.

Events A and B, which occurred in different experiments, are clearly spurious, since they exhibit a distribution of counts among the channels that is inconsistent with neutron emission from inside the detector array.

Events C and D are at the very limits of detectability of the system and occurred in the same experiment, separated by 16 h. While event C does not include a count in channel 3, at this low count rate it should be statistically considered. No counts were recorded in any channel for several minutes before or after event C, and no coincident counts in any two channels were recorded for the \(5\) h prior to event C or for the following hour, at which time the experiment was concluded. Event D was the only coincidence that approximated the expected distribution among the three channels. No counts were recorded in any channel for several minutes before or after this event, and no coincidences in any two channels occurred in the \(4\) h before or after this event. We therefore conclude that events C and D are spurious events, because they do not directly meet the system criteria and are isolated singular events that are not reproducible. As was mentioned above, some natural background coincidences might occur due to

### Table I

<table>
<thead>
<tr>
<th>Event</th>
<th>Channel 1</th>
<th>Channel 2</th>
<th>Channel 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2703</td>
<td>3496</td>
<td>157</td>
</tr>
<tr>
<td>B</td>
<td>2095</td>
<td>5222</td>
<td>80</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 2. Data indicating artifact in detector 1.
cosmic-ray showers at or near the detectors, at a rate difficult to predict. The causes of these spurious events are not clearly identified at this time, although the effects mentioned previously would apply. We intend only to demonstrate that these results do not support the emission of bursts of neutrons.

The identification of artifacts, such as those discussed here, in our detectors suggests an examination for similar artifacts in the detecting systems used by others who have reported detecting low-level neutron emission. It has been our experience that a pulse-generating system requiring pulse amplification and analysis will encounter spurious counts at some level. It would be tedious and time consuming to demonstrate that a given detector was completely free of every conceivable artifact in exactly the experimental situation at hand. It is also difficult, or even impossible, to exactly reproduce the experimental situation in every pertinent detail when measuring at the limits of detectability. We therefore suggest that multiple, independent detectors simultaneously monitoring the test system is a most effective, and perhaps the simplest, methodology to circumvent the problem of rare but crucial artifacts encountered at the limits of detectability. Other experiments using multiple independent neutron detectors of a different type have also found no emission and suggest that the events identified as neutron emission can be explained by cosmic-ray interactions.5

ACKNOWLEDGMENTS

The able assistance of K. B. Pfeifer, D. L. Overmyer, W. M. McMurtry, and P. E. Havey is much appreciated by the authors.

The underground laboratory at Kirtland Air Force Base was kindly provided through the good offices of Lt. Col. David A. Newburg, U.S. Air Force, Commander, 3098th Aviation Depot Squadron, Kirtland Air Force Base, New Mexico.

This work was supported by the U.S. Department of Energy under contract DE-AC04-76DP00789.

REFERENCES


The collection of technical notes on cold fusion that appear in this issue represents the third group in the series that resulted from our call for technical notes on this topic [Fusion Technology (FT), Vol. 16, p. 116, August 1989]. As a result of that notice, which also appeared in the Magnetic Fusion Energy network, ten technical notes appeared in the September issue, eight in November, and four in December 1989. A wide variety of topics have been covered, ranging from theoretical studies of mechanisms to reactor designs and energy conversion schemes. While quite speculative, all of these technical notes fell within the guidelines provided to the reviewers. The final set of papers resulting from the call will appear in the January 1990 issue. While it is not our plan to issue a new call, the policy to have speculative papers reviewed under the guidelines issued earlier will remain in force. Consequently, we still wish to encourage authors to take advantage of the possibility for quick publication of speculative articles through submission of a technical note to FT.

The numbers of papers cited above show a clear drop in interest in the area after the initial excitement died down. That should not be interpreted, however, as proof that the phenomenon does not exist. Indeed, at the time I am writing this comment (September 1989), there seems to be mounting evidence (such as the detection of tritium, neutron bursts, etc.) that fusion can take place in cold solids. However, the details of the mechanism (or mechanisms) have not yet been adequately explained and are further confused by the fact that different phenomena may have been observed in various experiments. Some phenomena such as electric field acceleration during crack propagation would not seem to provide favorable scaling to large energy production. On the other hand, some of the other mechanisms that have been considered appear more favorable for such applications. In any case, the physics of what is going on remains a wide-open issue that deserves continuing research and fewer premature news releases. Indeed, workers wishing to publicize their results, in my opinion, should consider a scholarly publication through a technical note in FT rather than a news item in a newspaper. While the reviewers are accepting speculative papers, they have been holding high standards relative to originality, creativity, factual accuracy, etc. Thus, reviews have provided an important feedback to authors, which is a time-proven element in the scientific process.

George Miley