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NEUTRON MEASUREMENTS IN SEARCH OF COLD FUSION

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ABSTRACT

We have conducted a search for neutron emission from cold fusion systems of the electrochemical type and, to a lesser extent, the high-pressure gas cell type. Using a high-efficiency well counter and an NE 213 scintillator, the experiments were conducted on the earth's surface and in a shielded cave approximately 50 ft underground. After approximately 6500 h of counting time, we have obtained no evidence for cold fusion processes leading to neutron production. However, we have observed all three types of neutron data that have been presented as evidence for cold fusion: large positive fluctuations in the neutron counting rate, weak peaks near 2.5 MeV in the neutron energy spectrum, and bursts of up to 145 neutrons in 500-μs intervals. The data were obtained under circumstances that clearly show our results to be data encountered as a part of the naturally occurring neutron background, which is due primarily to cosmic rays. Thus, observing these types of data does not, of itself, provide evidence for the existence of cold fusion processes. Artifacts in the data that were due to counter misbehavior were also observed to lead to long-term "neutron bursts" whose time duration varied from several hours to several days. We conclude that any experiments which attempt to observe neutron emission must include strong steps to ensure that the experiments deal adequately with both cosmic-ray processes and counter misbehavior.

INTRODUCTION

Evidence for cold fusion processes that result in the emission of neutrons from solid-state systems have been presented based on three types of neutron measurements: (1) large (> 3 σ) fluctuations[1] in the neutron counting rate; (2) bursts of neutrons detected either in very short time intervals[2] (a few hundred microseconds) or over periods of hours or days[3,4]; and (3) weak peaks[5] near 2.5 MeV in the neutron energy spectrum. Reports of large positive fluctuations in the neutron counting rate and the appearance of a peak near 2.5 MeV in the neutron energy spectrum came from experiments that initially used cold fusion cells of the electrochemical type, while the burst measurement experiments initially used temperature-cycled high-pressure gas cells. Both types of cells contained either titanium or palladium (or both), which was loaded with deuterium by hydriding or some other process.

Those of our experiments that utilized cold fusion cells used primarily electrochemical cells, although some measurements were made with temperature-cycled high-pressure deuterium cells containing titanium. A great deal of effort was spent in attempting to characterize the background, and these background measurements constitute the major results of our work.

Figure 1a shows the apparatus used in the experiment's full configuration, where the cold fusion cell was observed by a high-efficiency well counter and an NE-213 scintillator. However, for many measurements, only the well counter was used.

Measurements were performed at the earth's surface (at an elevation of approximately 2250 m) and in a room approximately 50 ft below ground. Automated data acquisition was used for all measurements. Measurements of the total neutron production were made with counting intervals ranging from a few seconds to 100 min. Except when it was necessary to show a short- or long-term feature of the data, data on the neutron counting rate were summed into 100-min intervals.

Burst measurements were made in 500-μs intervals, using a multiplicity module designed by Arnone and Brunson.[6] We selected a 500-μs interval for these measurements based on the characteristics of the well counter, as discussed below.

The barometric pressure and ambient temperature were measured for some of the data runs, and a monitor detector consisting of six 36-in. ^{3}He tubes backed by polyethylene was used for some runs.

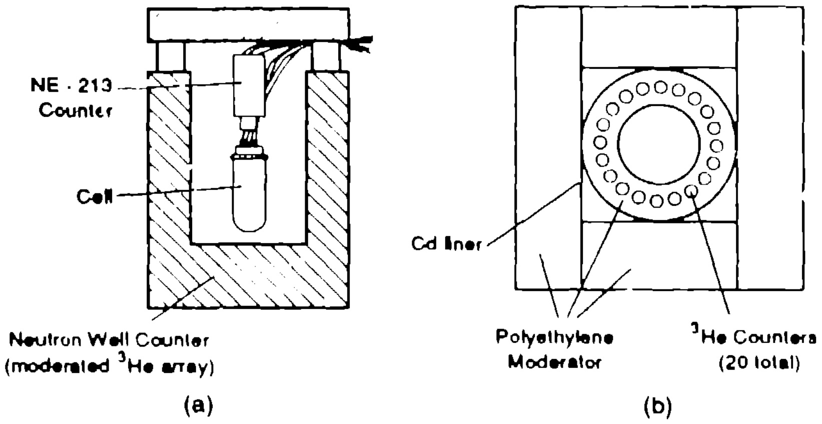

Fig. 1.
(a) Artist's conception of the system layout. Often more than one cell was present in the counter, (b) Top profile view of the ^{3}He well counter with 20 tubes.

EXPERIMENTAL APPARATUS

Figure 1b shows a top-profile view of the well counter. The complete device is about 58 cm square and 76 cm high, and consists of twenty ^{3}He tubes embedded in polyethylene. The central cavity, or well, is 19 cm in diameter and has an active depth of 40 cm. The counter is surrounded by 10 cm of cadmium-lined polyethylene to protect the counter from neutrons whose source is outside the cavity.

The twenty ^{3}He detector tubes are read out in five banks of four counters each, making the counter a segmented device consisting of five sections, or six sections when the NE 213 counter is used. This segmented arrangement proved useful in eliminating spurious data that occurred as a result of the misbehavior of one tube or one tube bank. Such behavior was occasionally observed when the ambient temperature underwent a significant change. The worst situation occurred when the counter was operated in one of the aboveground locations: a building, designed for low-neutron room return, which had three corrugated iron walls and a corrugated roof. This building underwent temperature changes of ~ 15 ° C between 6 a.m. and 5 p.m. The amplitude of the noise in the detector-preamp system changed by factors of 1 to 5, depending on the counter bank considered. In the worst cases, an increase in the counting rate of one detector bank might be observed. The other aboveground locations and the underground location had much smaller temperature variations.

The efficiency of the counter was calculated with the Los Alamos Monte Carlo code MCNP.[7] The results of these calculations (shown in Fig. 2) indicate that the efficiency is ~ 22% at a neutron energy of 2.5 MeV. Source measurements showed the counter to be about 0.4% efficient for ^{252}Cf neutrons produced outside one wall of the counter.

The well counter works by first slowing the neutrons down to thermal energies in the polyethylene, then capturing them in one of the ^{3}He tubes. If a group of neutrons are emitted simultaneously in the well, about one-half of those detected are detected in 50 µs. Thus, to detect all of the neutrons in a burst with high probability, the multiplicity module was operated in 500-µs intervals.

The Tennelec TC-175 preamp outputs are processed by Tennelec 202BLR amplifiers and LeCroy 623B discriminators for presentation to the multiplicity module. In addition to the event multiplicity and the total neutron counts per interval, the multiplicity module also stores the number of neutron counts detected by each of the five detector banks. As discussed above, this data was used to reject intervals or portions of intervals where one counter bank would begin counting at a different rate while the other four banks remained unchanged.

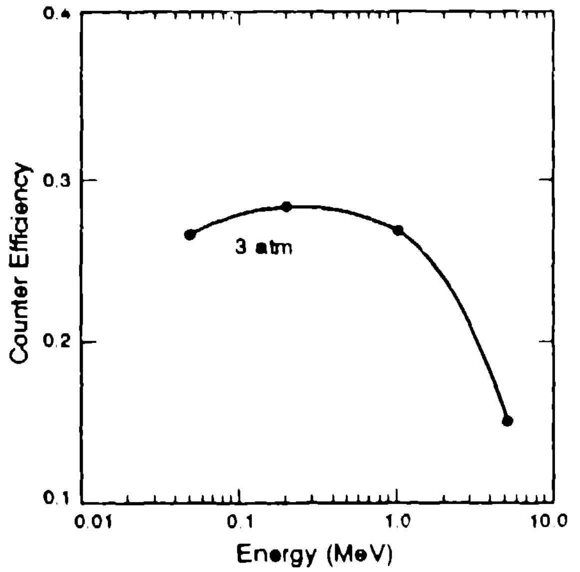

Fig. 2.
Calculated efficiency of the neutron well counter.

The multiplicity module consists of a shift register with the number of channels and the dwell time selected by the user. For these experiments, the dwell time was one microsecond and the number of channels was 500. Detected neutron counts are passed through a synchronizer to reduce pileup and then presented to the shift register. When the count exits the register 500 µs later, the register is queried via an up-down counter to determine how many counts remain in the register. The multiplicity of a given neutron event that is then obtained equals the number of neutrons left in the register (the detected multiplicity) plus one, all divided by the counter efficiency.

The output of the multiplicity module was stored in a CAMAC scaler, which was read along with other data by an IBM/PC at the end of each counting interval. The data obtained during each interval consisted of the multiplicity results, the total neutron counts observed, the number of neutron counts observed in each of the five counter segments, and the barometric pressure. These results were stored on the hard disk for future analysis, and a hard copy was printed out. The background counting rates for the well counter varied from 0.33 counts/s in the underground location to between 1.2 and 3.5 counts/s for different locations aboveground. The aboveground data quoted in this work were all obtained at a background rate of 1.2 counts/s.

The NE 213 counter[8] was only employed for some measurements conducted in the underground location. When located in the top of the well-counter (see Fig. 1a), the

NE-213 detector had an efficiency of approximately 1% and a background counting rate of about 1.5 x 10^{-3} counts/s. The neutron-gamma discrimination was accomplished by standard techniques; a typical neutron-gamma discrimination spectrum is shown in Fig. 3.

The cold fusion cells used in this experiment are described in Ref. 9.

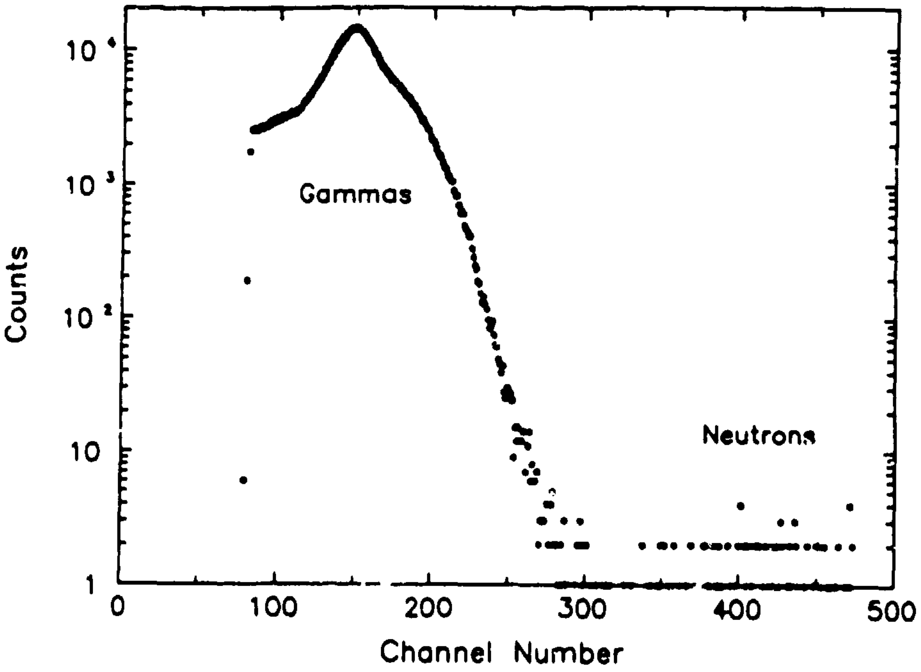

Fig. 3.
Neutron-gamma discrimination spectrum obtained with the NE 213 counter.

RESULTS

Neutron counting rates were either measured or, when shorter counting times were used, summed in 100-min intervals. Measurements were made with either one to three cold fusion cells present, with the high-pressure gas cell present, with the counter empty, or with a lead brick present in the counter. The cold fusion cells might be operating (that is, with the voltage on), or not operating. Likewise, the high-pressure cell might actually have high-pressure deuterium gas present or not, and the cell could be temperature-cycled or not (although most of these types of measurements were taken without deuterium gas present).

About 1200 h were spent observing the various cold fusion cells, and no evidence for neutron production by processes other than those seen as part of the background was obtained

The approximate sensitivity of this experiment may be estimated from the cell characteristics and the background counting rates We assume that a positive result would be achieved if a 3-σ excess in the neutron count rate were observed in 8 h of counting time, which implies that an observed excess of 0.01 counts/s would be required in the underground location, and an observed excess of 0.02 counts/s would be required

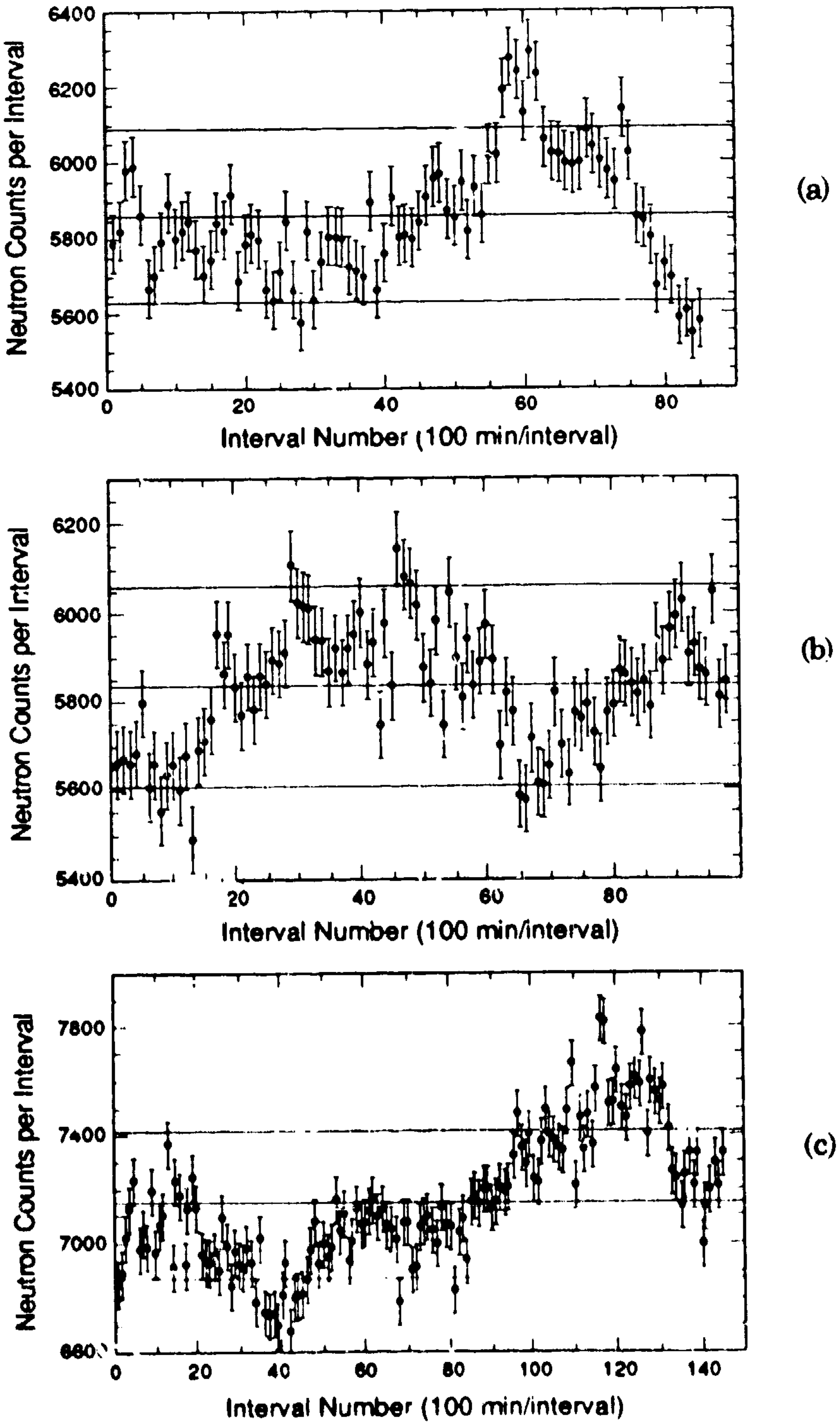

Fig. 4

Typical neutron counts obtained aboveground per 100-min counting interval with (a) the well counter empty, (b) the empty high-pressure gas cell in the counter, and (c) a lead brick in the counter.

aboveground. These detected neutron rates correspond to excess emitted (or production) rates of 0.05 counts/s and 0.10 counts/s, respectively.

The cold fusion cells typically contained about 10 g of palladium, charged to a level of about 0.6 deuterium atoms per palladium atom. Assuming one neutron is produced for every two fusions, these numbers imply that a rate of ~ 6 x 10^{-24} fusions per deuterium pair per cell per second must be present underground to produce the necessary rate. Because the measurements often involved two or three cells in the counter at one time, the estimated sensitivity of some of the experiments is near 2 x 10^{-24} fusions/s in the underground location, and about a factor of 2 worse in the aboveground locations.

Figure 4 shows typical neutron results obtained in one of the aboveground counting locations. These data were obtained with the counter empty; with the high-pressure cell present (but without deuterium gas or any titanium); and with the lead brick present. The data were generally obtained over periods of 80 to 200 intervals (about 6 to 14 days of counting time). The three solid horizontal lines on each figure represent the average number of counts and the (approximate) plus and minus 3-σ levels for each counting period.

The three data sets in Fig. 4 all exhibit the same features; that is, they exhibit an excess number of fluctuations of more than + 3 σ, 34 intervals out of a total of 328, and even the remaining data varies in a nonstatistical fashion. Positive fluctuations of up to 5 σ are present in the data obtained with the empty counter, and fluctuations of up to 8 σ are seen when the lead brick is used.

A substantial portion of the variation in these three data sets (as well as the other data sets obtained at this location) is due to fluctuations in the barometric pressure. This is shown in Fig. 5, where the barometric pressure is plotted along with the neutron data from Fig. 4. A strong negative correlation between the barometric pressure and the neutron counts per interval is clearly visible. Figure 6 shows linear fits to plots of the neutron counts per interval vs the barometric pressure for each of these data sets. Values of -0.76%/mm of Hg, -0.75%/mm of Hg, and -0.85%/mm of Hg are obtained for the respective data sets. An average value of -0.80%/mm of Hg was obtained for all data sets. This average value of -0.80%/mm of Hg is slightly smaller than the value of -0.94%/mm of Hg reported by Simpson et al.[10]

Typical data obtained in the underground counting location are shown in Fig. 7. These data were obtained with the electrochemical cells present (both operating and nonoperating); with the high-pressure gas cell present but empty; with the lead brick present; and with the counter empty. The barometric pressure was not recorded during these runs. The behavior of the data is far more statistical in these data sets and in all of the data collected in this counting location. For example, in Fig. 7, only 2 of 551 counting intervals are more than ± 3 σ from the mean value for that counting interval.

These results are interesting because fluctuations in the barometric pressure are still present (aboveground), but the data behave in a much more statistical fashion. One explanation is that the size of the effect is smaller underground compared to the statistical accuracy of the data; that is, aboveground a typical daily fluctuation in the barometric pressure of 3 to 4 mm of Hg represents about a 3-σ effect, whereas, below ground this represents only about a 1- to 1.5-σ effect. Thus, the different counting locations present situations in which the fluctuations in the pressure represent significant and small contributions, respectively. There may be another factor that contributes as well: ^{3}He counters of the type used in this experiment are known to have minimum counting rates unrelated to the detection of neutrons by the counter. These background counts are due to the alpha and beta decay of naturally occurring radioactive contaminants in the tube walls. The rates at which these events take place in this experiment are unknown, and the low count rates in this work may emphasize these

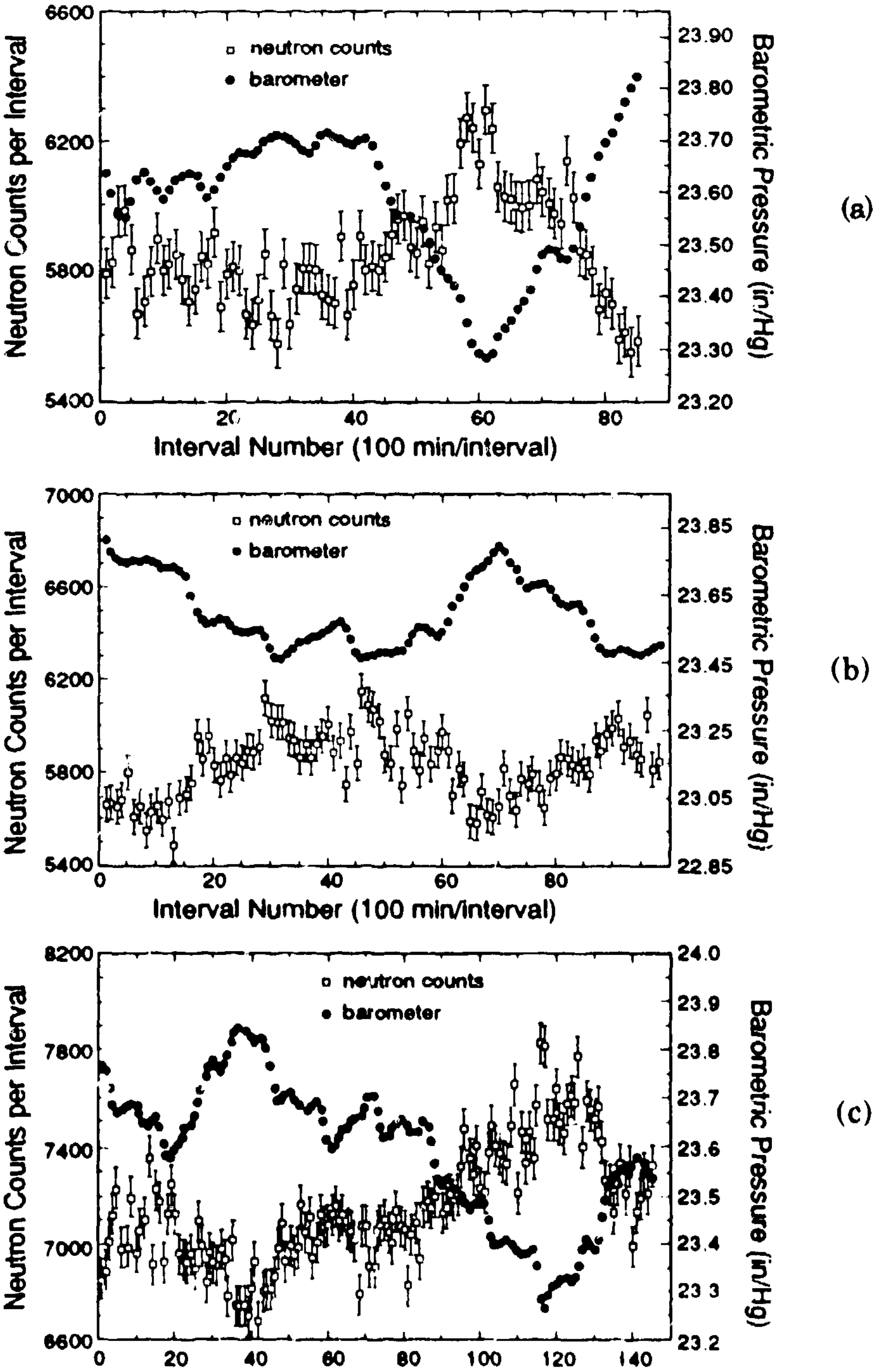

Fig. 5

Barometric pressure measurements plotted with the neutron counts from Fig. 4. Data are obtained with (a) the well counter empty, (b) the empty high-pressure gas cell in the counter, and (c) a lead brick in the counter.

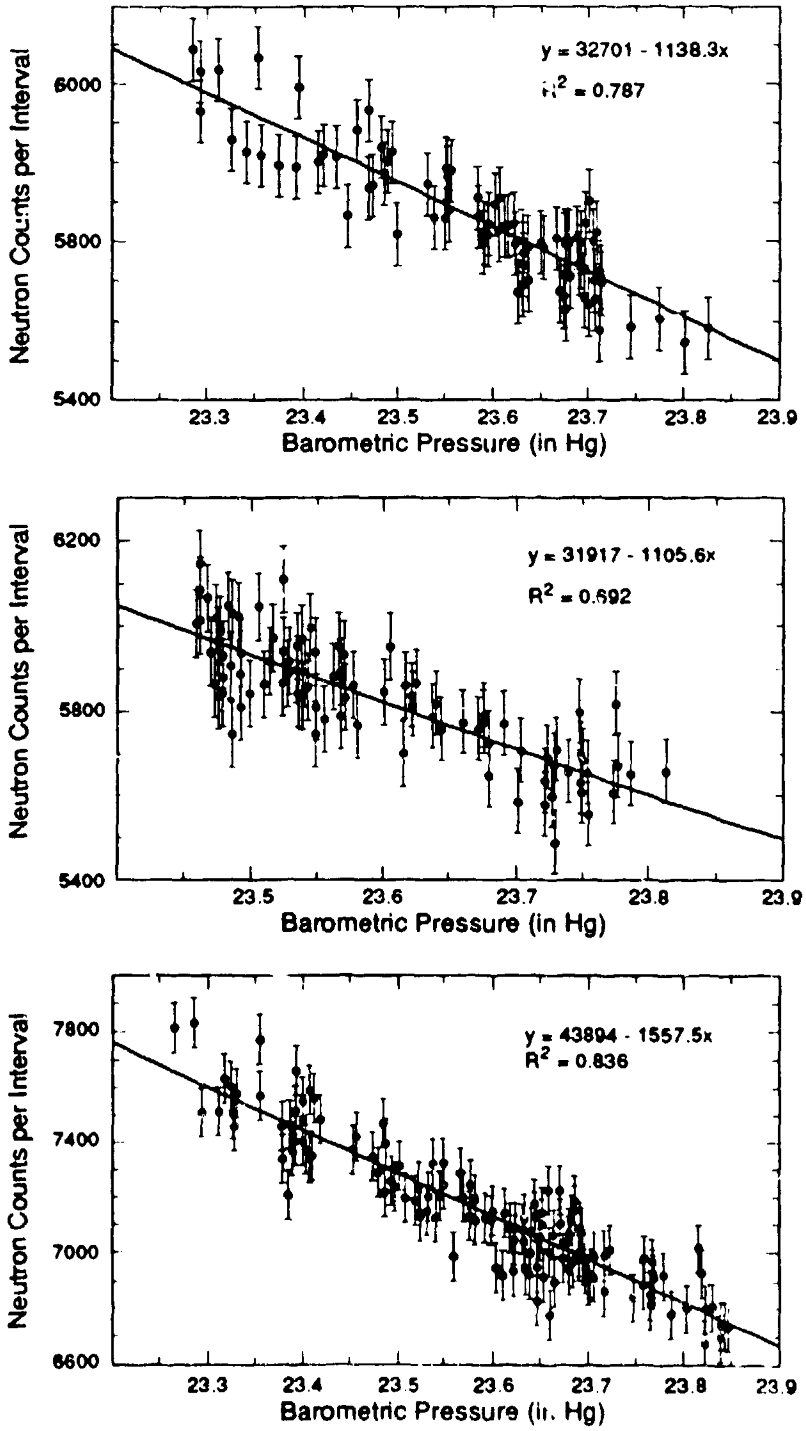

Fig. 6

Fits to the barometric pressure (in inches of Hg) vs neutron counts for the data presented in Fig. 5. R^2 is the square of the linear correlation coefficient. The slope of the curve in % per mm of Hg is obtained by dividing the coefficient of x in the figure by the product of 0.254 and the average value of the neutron counts per interval.

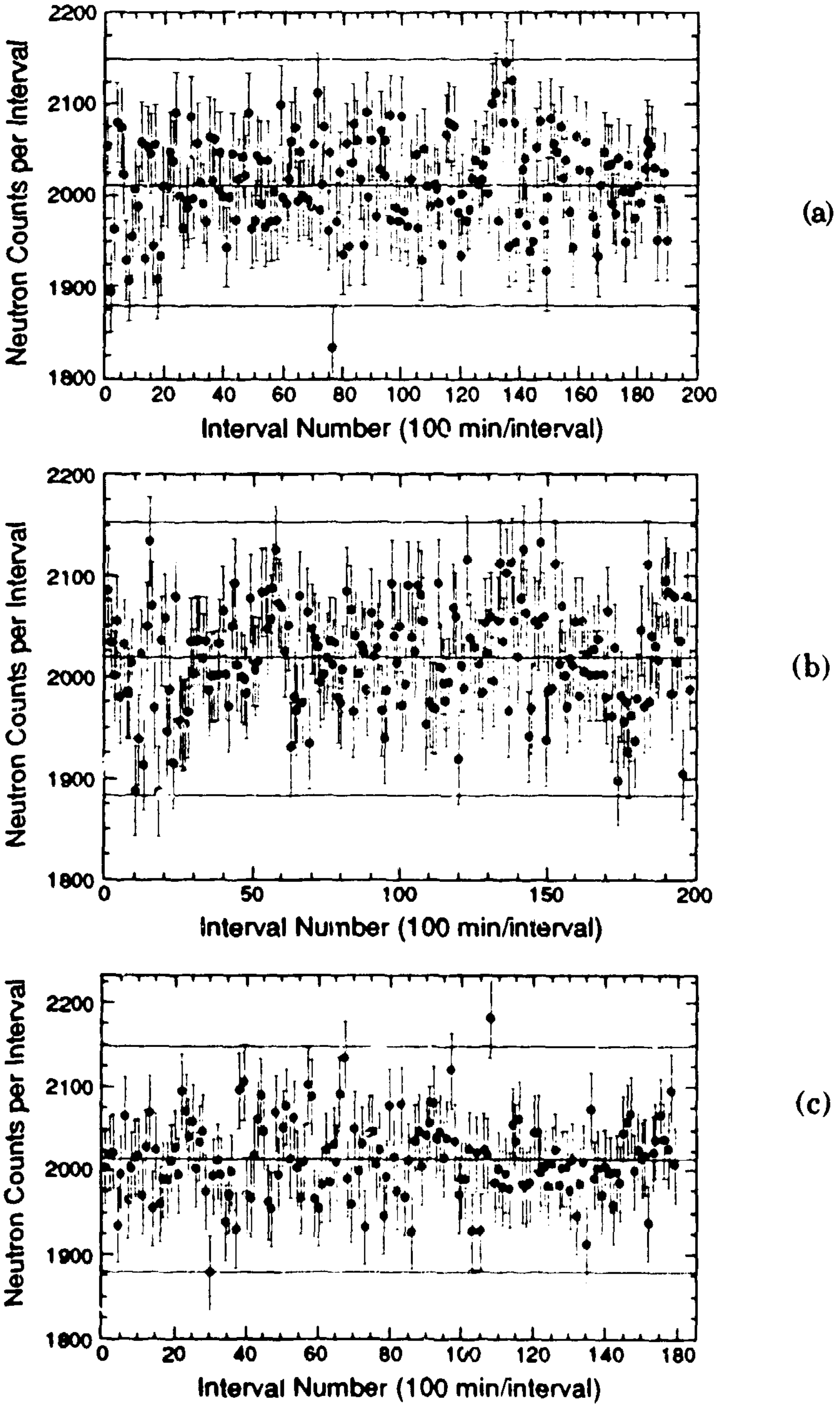

Fig. 7.

Typical neutron counts obtained below ground with (a) electrochemical cells in the well counter, (b) the empty high-pressure gas cell in the counter, and (c) the counter empty. The three solid lines represent the average number of counts obtained for that run and the (approximate) plus and minus 3-σ levels.

effects. The presence of these events would have the impact of adding an additional random source to the singles counting rate, which would tend to mask the effect resulting from the variation in the barometric pressure. This could explain both why our measured variation is slightly smaller than that of Simpson et al., and why the variation is not more apparent in the data collected in the underground location.

An upper limit estimate for the size of such an effect can be made by assuming that the count rate of 0.33 counts/s measured at the underground location is entirely nonneutronic. Clearly this is conservative because burst events, discussed below, are still observed underground. Based on this assumption, the value of -0.80%/mm of Hg would increase by about 25%.

Even larger effects than those already presented in Fig. 4 are possible if the data is properly binned. Figure 8 shows what could happen if, by chance, the initial intervals of the empty counter 14 run (shown in Fig. 4a) were used to establish a background counting rate. In constructing the data presented in Fig. 8, the first 2 days (28 intervals) of empty counter 14 were used to establish the background counting rate per 400 min. Using 400-min intervals rather than 100-min intervals decreases the statistical uncertainty by a factor of 2. This background rate was then subtracted from the rates determined for each subsequent 400-min interval in the empty counter 14 run and all of the 400-min intervals obtained in the pressure cell 8 run. These two runs were taken consecutively.

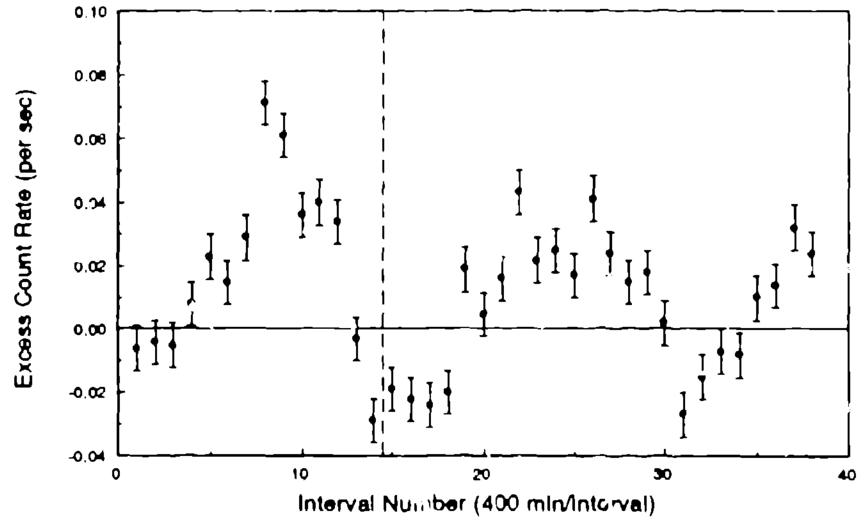

Fig. 8.
Excess count rates obtained for the empty counter 14 and pressure cell 8 runs. These runs were taken consecutively, and the dashed line in the figure shows when the empty high-pressure gas cell was added to the counter.

The data in Fig. 8 show strong positive fluctuations of up to 10 σ. A selection of other runs produces even larger effects, for example, the lead 12 run, which produces up to 20-σ effects using this procedure. To achieve statistically significant results such as these, the experiment must be conducted such that the statistical uncertainty is made small compared to the 3% to 12% enhancements that fluctuations in the barometric pressure produce. Figure 8 shows one way in which this could happen: the count rate is high enough to produce 1% statistical accuracy in a few hours. A second way in which this could happen in a lower count rate experiment is presented in Fig. 9, which shows a period of time (about a week) when the base-line barometric pressure remained approximately constant, while a local minimum (which occurred at about 5 p.m. MDT) was seen daily. During a period when the barometric pressure behaves as shown in Fig. 9, an unfortunate pattern of collection of background and foreground data could generate either positive or negative results. For example, positive results would be obtained if cell counting took place during the day and background counting at night. The magnitude of the positive results would depend on how closely the intervals used for the cell counting corresponded to the 2 p.m. to 8 p.m. interval when the barometric pressure achieved the daily minimum.

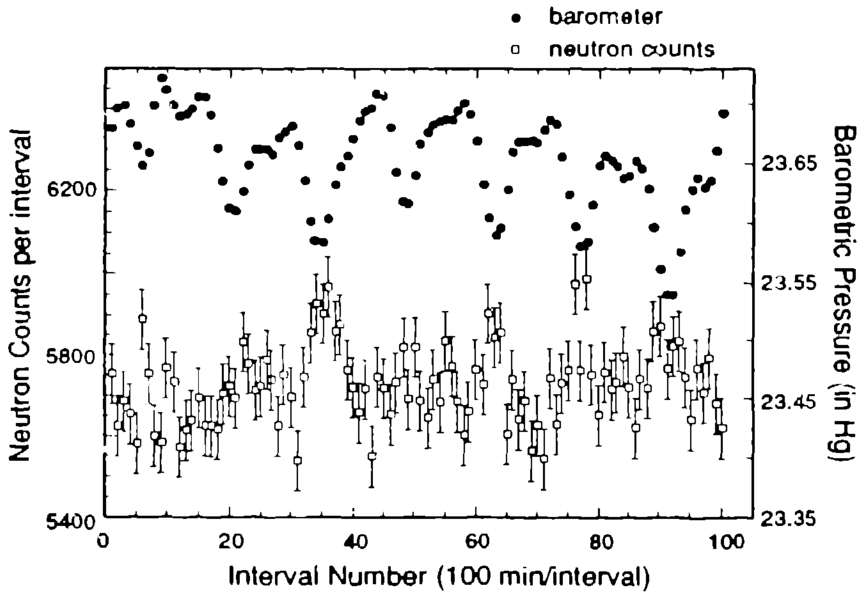

Fig. 9.
Data obtained aboveground for a period when the barometric pressure exhibited a daily minimum relative to an approximately constant base line.

The data presented in Figs. 4 and 8 could have been interpreted as long-term "neutron bursts" lasting up to 2 days. While these "bursts" are due to real fluctuations in the neutron count rate, artifacts that were due to counter misbehavior were also seen. These are discussed below.

Figure 10a shows the results obtained in the underground location for the observation of high-multiplicity events. The figure shows the rates at which various multiplicities are detected in 500-μs intervals using the multiplicity counter. These results were obtained with the counter empty; with the electrochemical cells present (both operating and not operating); with the empty high-pressure gas cell present; and with the lead brick present. Since the average neutron counting rate was 0.33 counts/s, there is negligible probability for accidental detection of three neutrons within any 500-μs interval. The estimated rate for the accidental detection of 3 neutrons within any 500-μs interval is 1.6×10^{-9}/s, or about 0.003% of the rate measured for the empty

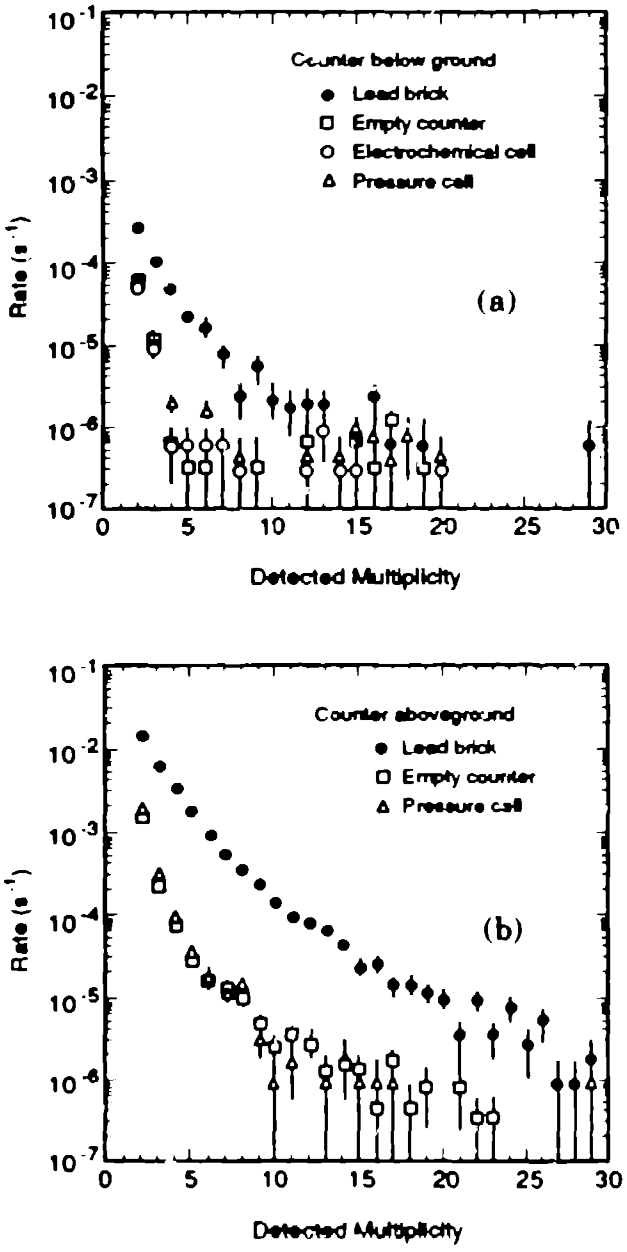

Fig 10

Rates observed for the production of high-multiplicity events obtained (a) below ground and (b) aboveground. Events whose error bars reach 10-7 in the figure are due to one detected event, and hence the error bar actually reaches to zero The multiplicity scaler overflows at 30 detected neutrons, and events of this size are not plotted in the figure One such event was detected underground, and 22 such events were detected aboveground

counter. Three detected neutrons corresponds to a two, the first data point plotted in Fig. 10a.

The actual number of neutrons present in the burst may be inferred from the following relationship:

$$N = (D+1)/\mathcal{E} \ ,$$

where N is the number of neutrons produced in the burst; D is the number detected (plotted in Fig. 10); and $\mathcal{E}$ is the counter efficiency. This efficiency is calculated to be 22% at a neutron energy of 2.45 MeV and is roughly constant over the range of 0 to near 2.45 MeV. However, if neutrons above this energy range contribute significantly to the burst event spectrum, the number of neutrons produced in the burst could be seriously under-estimated. The multiplicity seems to die out at ~ 20 detected neutrons, although two events with > 20 detected neutrons were observed. Twenty detected neutrons would correspond to a burst size of about 95 neutrons.

Figure 10a shows that results from the counter plus high-pressure gas cell and the counter plus electrochemical cells cannot be distinguished from the empty counter. This means that if a separate counter is used to determine the background, the physical characteristics of the counter are quite important. Presumably, the important physical characteristics are the cross-sectional area or the volume Using even a slightly smaller counter as the monitor could result in substantially underestimating the background rates for these burst events For example, if the background is proportional to the counter volume, using a monitor counter 16 in. on a side (compared to a counter 20 in. on a side containing the cold fusion cell) would result in a background rate estimation for the high-multiplicity events, which is low by a factor of 2.

While Fig. 10a shows that measurement results for the various electrochemical cells, the high-pressure gas cell, and the empty counter are not distinguishable in this experiment, there is a substantial increase in the rates for all multiplicities when the lead brick is present.

Figure 10b shows the results obtained at one of the aboveground locations. The average neutron counting rate at this location was about 1.2 counts/s, again predicting negligible probability (about 0.005% of the rate measured for the empty counter) for the accidental detection of 3 neutrons in any 500-μs interval. The rates at which the high-multiplicity events are seen increase by about a factor of 30 for the empty counter compared to the underground location. The rates for the lead brick increase by about a factor of 65. Aboveground, 22 events with multiplicities of 30 detected neutrons were seen. Because the scaler overflows at 30, some of these events could be larger than this number, and we infer that at least 140 neutrons were produced in these bursts. An event of this size could not be produced in an interaction with a single lead nucleus. The slopes of the measured dependencies of the rates for high-multiplicity events vs the number of detected neutrons in the event are very similar for the lead brick in the counter in both the above and below ground locations. In addition, the rates for detected multiplicities of four or less appear to suggest that the counter plus high-pressure gas cell may barely be distinguished from the empty counter in the aboveground location.

Aboveground, the rates at which the high-multiplicity events are detected increase by a factor of 10 when the lead brick is added to the counter. This compares to an increase of about 22% in the number of neutrons detected per 100-min interval, as shown in Fig. 11. While its placement within the well emphasizes the lead brick's effect, these

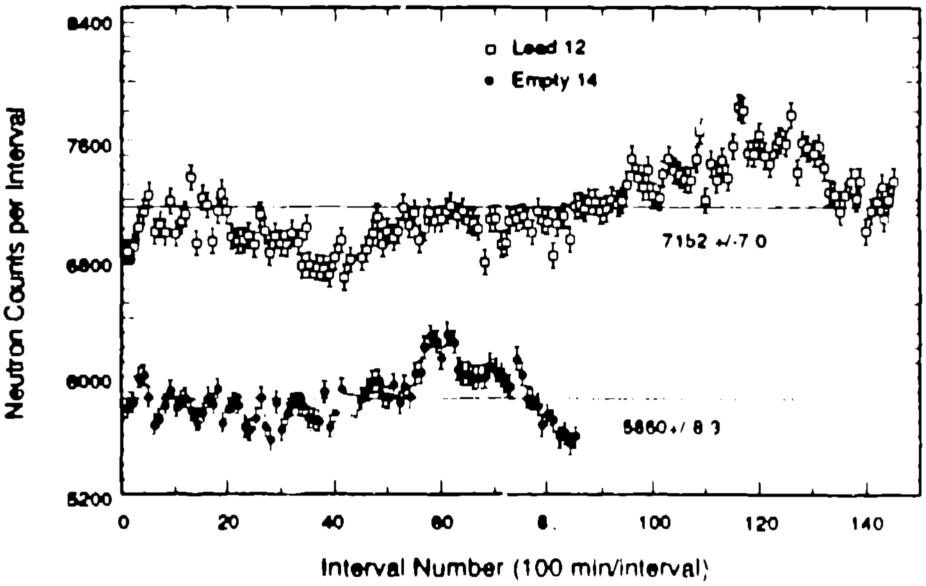

Fig 11
Data obtained during the empty counter 14 and lead 12 runs These data were obtained consecutively in the same aboveground location

results still suggest that the impact of any attempt to provide shielding for an experiment should be carefully evaluated to ensure that an opposite effect is not achieved.

Both the appearance of high-multiplicity events clearly associated with the lead brick and the strong increases in the detected rates for all high-multiplicity events seen at the surface of the earth suggest that these events are due to cosmic rays. The much lower rates observed below ground suggest that these cosmic rays are strongly attenuated by the ~ 50 ft of rock that covers the underground location. If the primary cosmic ray were a proton, it would require about 3-4 GeV to release all the neutrons in a lead nucleus at the earth's surface, including the energy necessary to penetrate the atmosphere and perhaps one or more feet of concrete contained in several intervening floors. The underground measurements would be sensitive only to those protons with energies > 9-10 GeV, assuming a density of 2 g/cm^3 for the rock.

The signature of a high-multiplicity event is a string of ones in the multiplicity scaler out to a number that equals one less than the number of neutrons detected in the event. If a stray neutron unrelated to the burst event were to be detected in that 500-μs interval, a 2 would appear in one of the scaler channels. The very low rate at which this actually happens in the experiment suggests that the burst events take place in a time period substantially less than 500 μs. The logic is that a process that produces neutrons over a period of time comparable to 500 μs would produce a significant number of these nonstandard signatures because of the 50-μs time constant associated with the counter.

A neutron spectrum obtained with the NE 213 counter placed in the throat of the well counter is shown in Fig. 12a. This spectrum was obtained in approximately three days of counting with three electrochemical cells present in the counter (but with no applied voltage). While this spectrum is impressive, a similar spectrum was obtained with the counter empty, as shown in Fig. 12b. These two intervals were the only two (of eight runs) where such structure was present. Structure in the naturally occurring

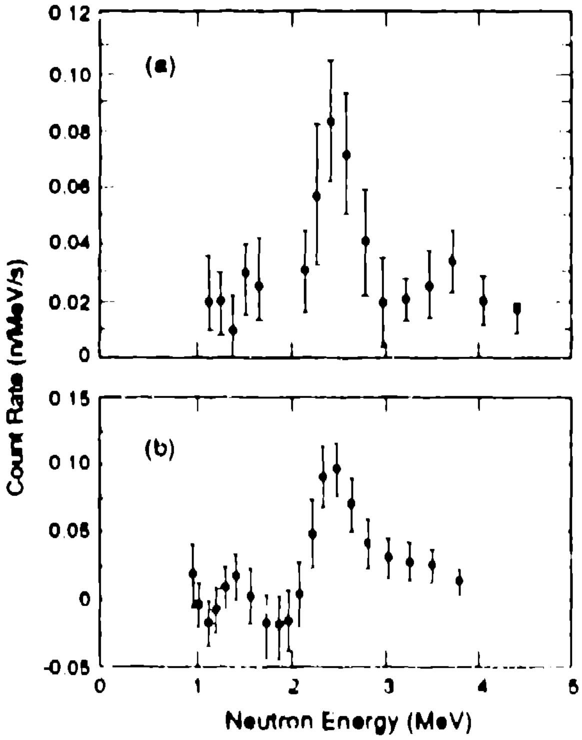

Fig. 12.
(a) Spectrum of neutrons measured with an NE 213 counter during a 68-hr run. The data were unfolded from the measured spectrum based on measured response functions for monoenergetic neutrons. The bump near 2.5 MeV is about 3 σ above background, but no excess count rate is present in the well counter data during the same interval. (b) Neutron spectrum measured with the NE 213 spectrometer but with no active cell present.

neutron energy spectrum has been seen previously.[11,12] However, this structure was both lower in energy, with a centroid of about 1 MeV, and wider than that seen in this experiment.

The appearance of such structure has been discussed by O'Brien et al.,[12] who explain the structure through the interactions of cosmic rays with various materials found near the earth, for example, the atmosphere, water, etc. Thus, while we cannot be conclusive about our results, we feel that cosmic rays provide a possible explanation for the appearance in the data of weak peaks at low energies, and that such an explanation must be conclusively excluded before the presence of other processes can be established.

Counter misbehavior in this experiment has been observed to lead to "neutron bursts," (that is, apparent increases in the neutron count rate), which last from several hours to several days. A simple method of deleting such phenomena in this work was to divide the well counter into five segments, then compare the number of counts obtained in each segment for each counting interval. An example is shown in Fig. 13, where data from two of the five counter segments (called banks) in the empty counter 13 run are shown. Counter bank 1 behaves normally, as do banks 2, 4, and 5, which are not shown in the figure. Counter bank 3, on the other hand, exhibited erratic behavior, and was removed from the data set prior to further analysis. Simultaneous misbehavior of two or more segments was never observed in this experiment. One advantage of having five segments was that only 20% of the data would be lost for the counting intervals when misbehavior occurred.

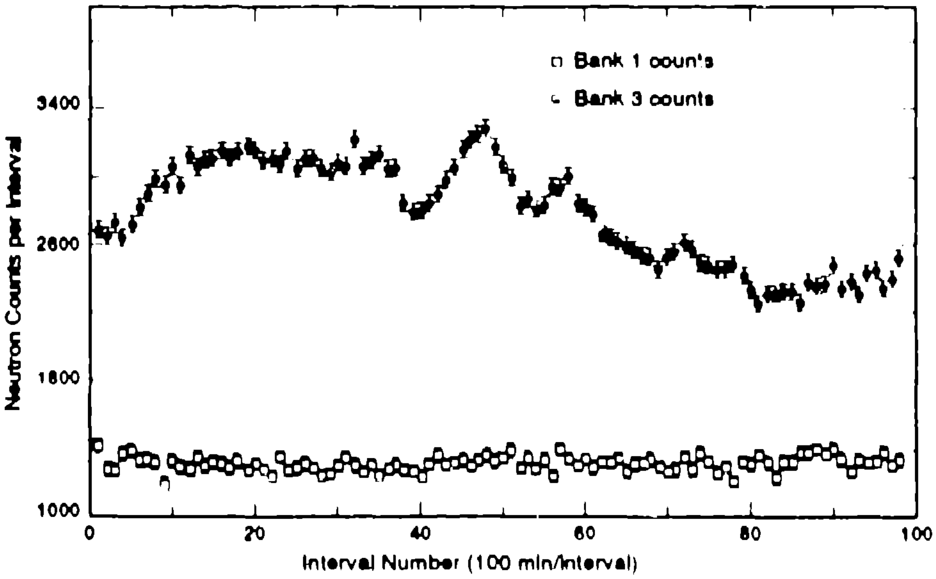

Fig. 13.
Plots of the neutron counts per 100-min interval for two of the five well counter segments.

We discovered during this experiment that the fit of the neutron counts per interval vs barometric pressure also provided a sensitive indication of counter misbehavior. Figure 14a shows the fit obtained for the empty counter 13 run, when counter bank 3 showed up to a 15% increase in count rate, corresponding to up to 0.01 counts/s. Figure 14b shows the fit obtained when this counter bank was removed from the data set. Such fits might prove useful in cases where segmentation of the counter is not feasible, if sufficient statistical accuracy of the data can be achieved.

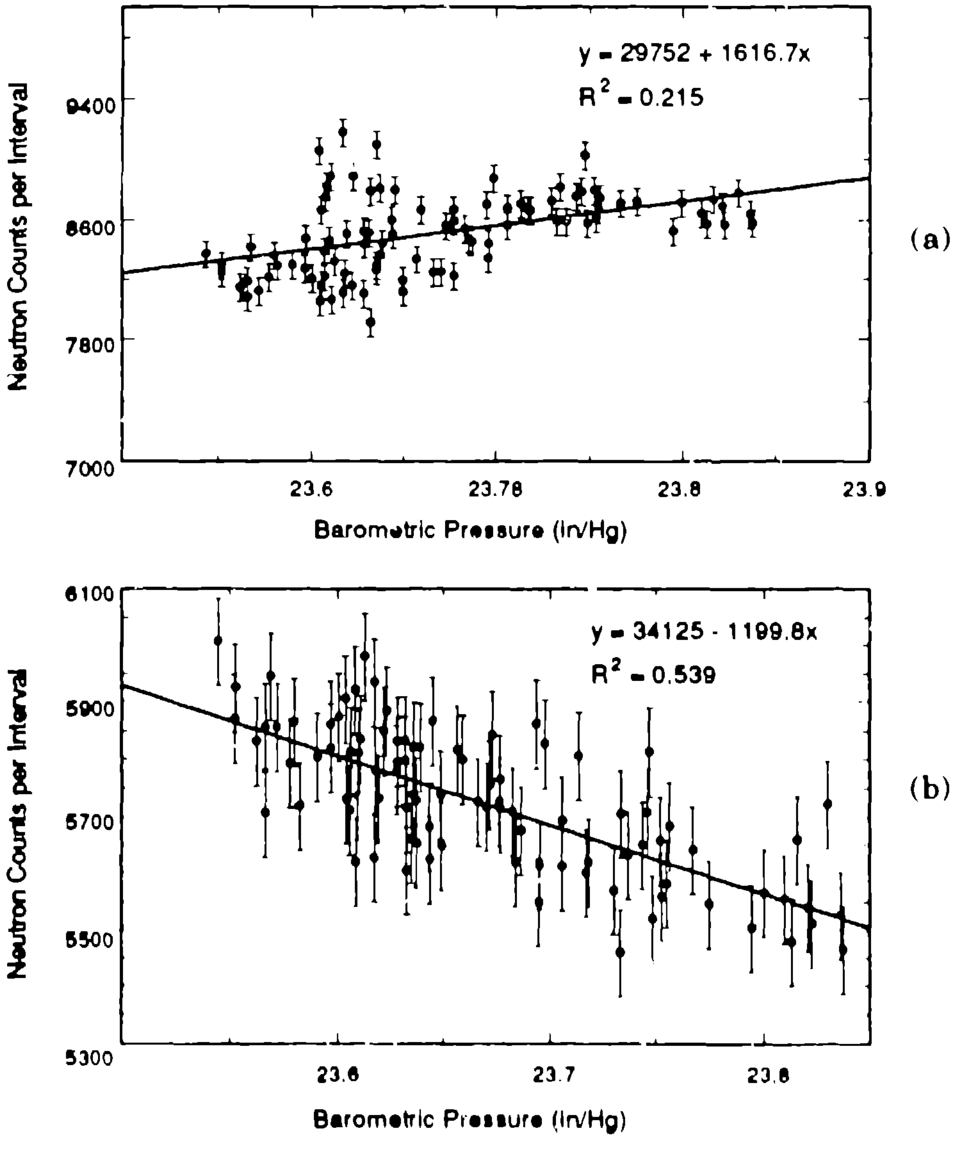

Fig 14

(a) Fit of the neutron counts per 100-min interval vs the barometric pressure when all counter segments, including bank 3 from Fig 13, are included. (b) A similar fit achieved when counter bank 3 was removed from the data set. The slope of the fitted line is -0.83%/mm of Hg

CONCLUSIONS

We have conducted a search for neutron emission from cold fusion systems of the electrochemical type and, to a much lesser extent, the high-pressure gas cell type. The experiments were conducted on the earth's surface and in a shielded cave approximately 60 ft underground using a high-efficiency well counter and an NE-213 scintillator. After ~ 6500 h of counting time, we have obtained no evidence for cold fusion processes leading to neutron production. However, we have observed all three types of neutron data that have been presented as evidence for cold fusion: (1) large positive fluctuations in the neutron counting rate, (2) weak peaks near 2.5 MeV in the neutron energy spectrum, and (3) neutron bursts of up to a detected multiplicity of 30 (about 145 neutrons produced) in 500-μs intervals. The data were obtained under circumstances that clearly show our results to be data encountered as a part of the naturally occurring neutron background, which are due primarily to cosmic rays. Thus, observing these types of data does not, of itself, provide evidence for the existence of cold fusion processes.

Artifacts in the data that were due to counter misbehavior were also observed to lead to long-term "neutron bursts" whose time duration varied from several hours to several days.

We conclude that any experiment which attempts to observe neutron emission must include strong steps to ensure that the experiment deals adequately with both cosmic-ray processes and counter misbehavior.

The cosmic-ray effects, including those resulting from interactions with the atmosphere and other materials near the earth, can be quite subtle, and we believe that the safest procedure is to attempt to remove these effects as much as possible by performing the experiment sufficiently far underground. We have shown that experiments conducted 60 ft underground have strongly suppressed, though not completely removed, cosmic-ray effects.

One effective method of detecting counter misbehavior is to segment the counter. Other ways of dealing with this problem may also be found. For example, we have shown that, if the counting rate is sufficient, a fit of the observed counts per interval of time vs the barometric pressure provides a very sensitive measure of counter misbehavior.

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