SUMMARY OF COLD FUSION RESEARCH PERFORMED BY THE NATIONAL LABORATORIES FOR THE JUNE 22, 1989 MEETING OF THE ENERGY RESEARCH ADVISORY BOARD PANEL ON COLD FUSION

"We have carried out detailed neutron detection at extremely low rates [illegible] with [illegible] spurious, continuous and burst signals in He3 not previously appreciated."

Sandia -- "We find multiple detectors provide an excellent way to exclude spurious signals which might otherwise be interpreted as evidence for cold fusion."

LLNL -- "Many spurious signals appear in one detector and not ~~a the other~~ another and this could be misinterpreted as neutrons."

AMES

1. 1 CELL: 2 RUNS: 2 WEEKS AND 4 WEEKS

   NO 2.223 MeV GAMMAS

   NO 6.257 MeV NEUTRONS

   NO 21 KeV OR 24 KeV X-RAYS

2. D2 GAS: NO NEUTRONS, BUT NOT AS SENSITIVE AS LOS ALAMOS

3. LaHD2: NO 5.493 MeV GAMMAS FROM H-D FUSION

ARGONNE

1. NO NEUTRONS (<1/SEC.):

   3 EXPTS, UP TO 3+ WEEK RUNS

   FALSE POSITIVES; E.G., UP TO 8X BACK-
   GROUND, NOT REPRODUCIBLE

   IMPROVING SENSITIVITY; E.G., TO <20%
   BACKGROUND

2. NO TRITIUM (<100/SEC.):

   <1/40 UTAH, IF ASSUME RETAINED IN D20

   1 WEEK RUN

3. NO GAMMAS (<50/SEC.): 1/1000 UTAH

4. NO CHARGED H, D, T, He-3, He-4

(<0.15 P/MIN. >120 KeV):

2 EXPTS, UP TO 10 DAY RUNS

FALSE POSITIVE

5. NO "EXCESS" PHOTONS:

1-25/SEC.--"STANDARD BUT UNEXPECTED"

6. NO HEAT (<0.1 WATT/CC):

UP TO 10 DAY RUNS, CONTINUING

UTAH CALCULATIONS CORRECT

BROOKHAVEN

1. WITH YALE:

   (A) UP TO 3 WEEK RUNS

   NO NEUTRONS, NO 5.5 MeV GAMMAS

   (B) UP TO 26 WATTS INPUT

   NO NEUTRONS, NO 23.8 MeV GAMMAS

2. D2 GAS: NO NEUTRONS, NO GAMMAS

3. 4 CELLS:

   SOME NEUTRONS AT FIRST,

   CONTINUING ANALYSIS

4. MUON CATALYSED:

MIT + BNL AND HARVARD EXPTS.

RUN ENDED 5/25

ANALYZING FOR NEUTRONS, GAMMAS AND He

5. TiFeDx UNDER D2 FOR 10 YEARS:

UNDER ANALYSIS FOR TRITIUM AND He

6. 2 WEEK RUN: NO PROTONS, NO BETAS

7. 4 CELLS: NO HEAT BUT RF

8. SOME THEORY CONTINUING

IDAHO

1. CELLS: NO HEAT, NO NEUTRONS, NO GAMMAS, NO TRITIUM

2. GAS:

   - o SETTING UP FOR H-D WITH LOS ALAMOS BASED ON KOONIN
   - o 4000 FEET UNDERGROUND (10-7 COSMICS)
   - o POSSIBLY D-T LATER

BERKELEY

1. 2 EXPERIMENTS

   NO NEUTRONS, NO GAMMAS, NO X-RAYS,

   NO CHARGED PARTICLES

   FALSE POSITIVE BURSTS

2. NO CHARGED PARTICLES

3. 5 WEEK RUN

   NO NEUTRONS

   NO GAMMAS (NO 5.5 MeV, NO 23.8 MeV)

LIVERMORE

1. A. 2 CELLS: 156 HOUR RUN

   B. 2 CELLS: 330 HOUR RUN

   NO HEAT, NO NEUTRONS, NO He-3, NO He-4

   C. 1 CELL: 167 HOUR RUN, NO NEUTRONS

2. NO HEAT, NO NEUTRONS, NO He

3. TEXAS A&M: NO He-3, NO He-4

SURFACE: Ca, C, Fe, O, Cl, Li,

Ni, Cu, etc.

4. GAS: "APPEAR TO HAVE DUPLICATED...BURSTS

OF A FEW HUNDRED NEUTRONS"

WILL CONTINUE AND TRY D-T

5. COSMIC MUONS: 10-2 BYU, AS INDICATED BY

EXPT. IN JAPAN

LOS ALAMOS

1. WITH BYU:

   - o SINGLE NEUTRONS AND NEUTRON BURSTS WITH BOTH CELLS AND GAS (<50 MICROSECOND BURSTS)
   - o OBSERVED ION/ELECTRON BURSTS IN GAS
   - o FOR GAS, WILL TRY NEUTRON COINCIDENCES, H2 CONTROL AND D-T (14 MeV NEUTRON RATIO TO 2.5 MeV D-D NEUTRON GIVES REACTION TEMP.)

2. CELLS:

- o SOME CLOSED, NO HEAT, NEUTRONS (ABOVE), MEASURING GAMMAS, X-RAY AND TRITIUM (INCLUDE TEXAS A&M).
- o D/Pd > 1

3. ELECTRON INJECTION: NO HEAT, NO NEUTRONS

4. EXPLOSIVE COMPRESSION: <10 4 NEUTRONS

5. OTHER COLLABORATIONS:

STANFORD, WASH. STATE AND "THE DOOR REMAINS OPEN TO THE UNIVERSITY UTAH"

OAK RIDGE

1. A. UP TO 3 WEEK RUNS: NO NEUTRONS

   B. 4 CELLS: UP TO 700 HOUR RUNS

   NO NEUTRONS, BUT 1 CELL: "ENERGY IMBALANCE OF ~10% FOR SEVERAL HUNDRED HOURS...DISAPPEAR... AT 5 DEGREES C INSTEAD OF 13 DEGREES C

   CONTINUING

2. 3 CELLS:

- o NO GAMMAS, NO TRITIUM
- o NEUTRONS: > 3 SIGMA, TWICE, BUT NOT REPRODUCIBLE
- o HEAT: 2 CELLS PRODUCED < 20% EXCESS HEAT FOR A FEW HOURS, BUT NOT REPRODUCIBLE

CONTINUING

3. 6 CELLS: UP TO 3 WEEK RUNS

NO NEUTRONS, NO He-4

SETTING UP CALORIMETRY

4. D2-GAS:

- "NO SUSTAINED HEAT" (HEAT BURSTS FROM Pd+D2)
- + 10% NEUTRONS TWICE (LESS SENSITIVE THAN LOS ALAMOS)

CONTINUING

PACIFIC NORTHWEST

1. 13 RUNS: UP TO 20 DAYS
   NO NEUTRONS, NO GAMMAS

2. UNDERWAY: CLOSED SYSTEM, WITH D:Pd >1
   WILL MONITOR HEAT, NEUTRONS, GAMMAS, TRITIUM, He-3 AND He-4

3. GAS: 70 HOUR RUN
   NO NEUTRONS

4. **TRITIUM ANALYSIS**

TEXAS: **UP TO 1.96 X 10 6 DPM/ML**

UTAH: **ONLY 36% INCREASE**

5. **UTAH:** **INTERMEDIARY ON ELECTRODE ANALYSIS**

OFFERED SURFACE, MICROSTRUCTURAL AND CHEMICAL ANALYSIS

6. **AT PRESENT:** **2 MANYEAR/YEAR**

PRINCETON

- o CELLS, GAS (INCLUDING Nb, ALUMINA, QUARTZ AND FELDSPAR) AND FRACTURING (e.g. ZR/A1/V PELLETS
- o NO NEUTRONS (< 1/sec.)
- o NO 5.4 MeV GAMMAS (<3/sec.)
- o CONTINUING FRACTURING NON-CONDUCTORS AND METALS WITH INCOMING GRADUATE STUDENT

SANDIA

1. UTAH TYPE CELLS: UP TO 45 DAY RUNS

   NO HEAT, NO TRITIUM, NO NEUTRONS

   CONTINING WITH CLOSED SYSTEM

2. BYU TYPE CELLS:

   NO NEUTRONS

   INCL. UNDERGROUND: 100/HR OR BURSTS OF 50

   FALSE POSITIVES

3. THIN-WALL CELL: 1/10 BYU

4. GAS: NO NEUTRONS (UNDERGROUND SYSTEM)

5. PLASMA LOADING: 0.9 D/Pd, NO NEUTRONS, NO CHARGED PARTICLES

6. ION IMPLANTATION: 1.6 D/Pd, NO CHARGED PARTICLES

7. COLLABORATED WITH ROCKWELL ON He ANALYSIS, INCL. TEXAS A&M: NO He-3, NO He-4

8. STUDIED LOADING KINETICS, D-D SPACING AND POWER BALANCE CALCULATIONS

9. SUMMARY: KINETICS SPINOFF, AND "UNEXPECTED" FALSE POSITIVE SINGLE NEUTRONS AND NEUTRON BURSTS

Report to Energy Research Advisory Board on Cold Fusion Research at the Ames Laboratory

The Ames Laboratory group has carried out a number of experiments to search for cold fusion both on Pd-D_2O cells and Ti-D_2 gas systems. Also, the compound $LaHD_2$ was examined.

In the Pd-D_2O cell experiments, the electrolyte was 0.1 molar LiOD in 99.8% D_2O. A constant current source supplied a current of 1 A and the electrolyte temperature was monitored by a thermocouple. The anode was Pt wire and in the first experiment the cathode was a rod of cast Pd 2 mm in diameter. The run lasted for ~ 2 weeks. In the second run lasting for ~ 4 weeks, the cell was kept under dry N_2 and the D_2O was replenished by a "chicken feeder." A cathode of single crystal Pd 4 mm in diameter was used. Neutrons were monitored by a BF_3 counter wrapped in Cd foil to reduce background and surrounded with paraffin. x and γ radiation was monitored by a Ge detector with a thin Be window. The range of measurements for the Ge detector was 10 keV to 7 MeV.

The results from the Pd-D_2O cell experiments were all negative. Although no calorimetry was carried out, no unusual temperature excursions were observed. A search was made for neutrons and γ-rays at 2.223 and 6.257 MeV from neutron capture in H and D, respectively. Pd x-rays at 21 and 24 keV were monitored as a signature for charged particle production. No neutron, x, or γ radiation above background levels was observed. Thus, we obtained null results for Pd-D_2O cell fusion at the level claimed by Fleischmann and Pons. The experiments, however, were not sensitive enough to test for fusion at the level claimed by Jones. By postmortem analysis of the samples, it was found that the concentration of D in the Pd electrodes maximized in about 4 hours at the level of 0.7 to 0.8 deuterons per Pd atom.

We searched for neutrons emitted from a Ti-D_2 gas system. In the experiments, 20-30 g of Ti sheet metal, in the form of strips, chips, shavings, and powder, were subjected to a series of heating and cooling cycles in which D_2 gas at pressures up to 50 atm was added to Ti at temperatures up to 1020K. TiD_x was produced with x as high as 1.9. The TiD_x was subjected to a number of cycles in which it was cooled to 77K and allowed to warm to room temperature. No neutron counts above background were observed during the temperature cycling, deuteration, or dedeuteration of the Ti sample. We did not observe neutrons at the level claimed by Scaramuzzi and coworkers, whose procedure we closely emulated. Our experiments were not sensitive enough to test the results of the Los Alamos Group presented at the Santa Fe Conference.

It has been suggested that the fusion rate for the H-D molecule might be greater than for the D_2 molecule. Therefore, we monitored a sample of $LaHD_2$ using a Ge detector to search for the 5.493 MeV γ ray emitted in the $p+d \rightarrow {}^3He + \gamma$ reaction. In a two-week run no evidence was found for emission of the above γ ray.

Our searches for cold fusion have concentrated on observations of neutron and electromagnetic radiation from Pd-D_2O cells, TiD_x, and $LaHD_2$ systems. No radiation of any kind above background was observed. These results were presented in a poster at the Santa Fe Workshop and a detailed paper is being prepared for the *Journal of Fusion Energy*.

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439 312-972-3504

June 8, 1989

Dr. David Goodwin, Technical Advisor
ERAB Cold Fusion Panel
ER-20.1, GTN
U. S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20545

Dear Dr. Goodwin:

I am enclosing a copy of the Interim Report of Cold Fusion Experiments at Argonne National Laboratory dated May 12, 1989. The two page summary at the beginning of the report should serve the Panel's needs. At this point in time a much reduced effort is continuing at ANL, principally to follow up on some calorimetry experiments and to finish up some increased sensitivity neutron detection measurements on electrolytic cells.

If I can be of further assistance, please contact me.

Sincerely,

Frank Y. Fradin
Associate Laboratory Director
for Physical Research

FYF:mao
encl.

xc: A. Schriesheim

Summary of Cold Nuclear Fusion Experiments at ANL

May 9, 1989

Experiments and calculations at Argonne have tested most of the aspects of the electrochemically induced fusion experiments of Fleischmann and Pons[1] and of Jones et al.[2] An experiment has also begun to test the fusion claims from high pressure absorption of deuterium gas in titanium, claimed by Scaramuzzi et al (Frascati, Italy).[3]

No observations at Argonne confirm the claims of cold nuclear fusion.

The work is summarized in 6 categories: measurements of neutrons, protons, tritium, gamma rays, light and heat.

1. Neutron observations

Three ANL experiments (#'s 3,4,5 in the table below) clearly show less neutron production than the rates of reference 1, but their limits of observation are higher than the rates of reference 2. Carpenter et al observe lower rates. However, they have a small electrolytic cell, and after scaling in size, their rate limit is double that of Jones et al.

Expt #	1 ref.2	2 ref.1	3 Freedman et al --> ANL	4 Carpenter et al	5 Melendres & Greenwood	units
Material	Pd/Ti	Pd	Pd	Ti	Pd	
Volume	2.4	1.2	0.3	0.2	0.8	cm^3
Surface area	?	12	6	2	3	cm^2
N(obs)	.0041	.1		<.015	<.1	sec^{-1}
Efficiency	.01	$2.4.10^{-6}$		.2	.15	
N produced	.41	4.10^4		<.075	<.7	sec^{-1}
N prod/V	.17	$3.3.10^3$		<.375	<.88	$s^{-1}.cm^{-3}$

2. Proton and charged particle observations

Rehm et al use a very small Pd cathode (area 0.5 cm^2) but observe

[1] S. Fleischmann and M. Pons, Electrochemically Induced Nuclear Fusion of Deuterium, J. Electroanal. Chem. 261, 301 (1989).

[2] S.E. Jones et al, Observation of cold nuclear fusion in condensed matter, Nature, 338, 737 (1989).

[3] Scaramuzzi et al, "Evidence of Emission of Neutrons from a Titanium-Deuterium System," submitted to Europhysics Lett.

0.15 protons/minute, for events with energies greater than 120 keV, with and without cell current. This corresponds to a rate of 5.10^{-3} s^{-1} at the source, a rate of 2.10^4 less than the rate needed for the heat production in ref.1.

Zaromb et al have found no charged particles (e.g. H^+, D^+, T^+, $^3He^{++}$ or $^4He^{++}$) of energies large enough to pass through 0.002 cm of Pd. Their lower rate limit is uncertain.

3. Tritium production

Melendres, Greenwood and Bowers measured the tritium yield as less than 100 atoms/second. Assuming that 90% of the tritium remains in the palladium, this corresponds to 1/40th of the rate compared to reference 1.

4. Gamma ray production

Melendres and Greenwood obtain an upper limit of 50 gammas/second from their cell. This is a factor of 10^{-3} of that claimed from reference 1.

5. Light production

Berry et al have observed low photon yields (typically 1-2 per second observed) in Pd cells with both D_2O and H_2O in HNO_3 with and without LiOH. The yields depend on the PH value of the electrolyte, becoming close to zero for basic solutions - this reduction in yield mimics the loss of signal seen in reference 2 for the neutron yields. Except for one experiment in D_2O and HNO_3 alone, no excess light yield above 1 photon/sec is observed.

6. Heat production

Redey et al have compared the heat production in two identical Pd/Pt cells, one containing LiOH and H_2O, the other LiOD and D_2O. After adjusting for the electrochemical potential differences, no significant excess heat production was observed over a time period of 10 days running.

A further measurement with two different Pd/D cells is now underway, and shows no excess heat production.

Nagy has checked the excess heat production calculations of Fleischmann and Pons (reference 1). Using reasonable assumptions about the electrolysis, he finds all but 2 of the excess enthalpy results correct. However, he claims that this excess heat could be produced by an (unknown) chemical reaction.

Summary of BNL Cold Fusion Research

In summary, we find no evidence in any experiment of a nuclear fusion process. In a couple of experiments there is evidence of rf emission from samples, which could mimic true counts in certain situations.

The Yale-BNL Experiment

Six NE213 neutron detectors were set up surrounding electrolytic cells with various types of electrodes and electrolytes and run for periods of up to 3 weeks. Cosmic-ray veto counters were used to reduce background induced events. The level of neutrons detected is roughly a factor of 100 below that of Jones et al. and roughly a factor of 10^6 below the original claim of Pons and Fleischmann. In addition a search for the 5.5 MeV gamma ray from the p + d reaction was made with a negative result. A paper has been accepted by Nature.

Searches With Large NaI Detectors

Electrochemical cells with Pd and Ti electrodes have been placed in 25 cm x 30 cm long NaI(Tl) annular detector which butts up against a second large 25 cm x 36 cm NaI(Tl) crystal with very high energy resolution and efficiency for up to 100 MeV gamma rays. (The particular interest was the possible existence of the 23.8 MeV gamma ray from d-d capture to He^4 plus gamma). The whole assembly is surrounded by a plastic anticoincidence shield to veto on cosmic rays. Neutrons are detected by moderating them before observing capture gamma rays on either p or I. No evidence of gamma rays or neutrons above background has been observed with up to 26 watts of input power.

In addition, many attempts with the same setup have been made to try to reproduce the Frascati measurements. Vanadium + Deuterium, Titanium + Deuterium, and FeTi + Deuterium combinations have been tried -- cycling the temperature from -200°C to +100°C and pressure of the gas from 20 psi to 250 psi. Contact with Professor Scaramuzzi of Frascati was made, who guided researchers through his process step by step. No signals above background have been seen for either gammas or neutrons.

A New Neutron Experiment

Twenty-four BF3 counters with a cosmic ray veto surround 4 LiOD electrolytic cells with Pd rods and foils. Cosmic ray veto counters are used. The setup has been run with some as yet unexplained effects. In particular, when the electrodes are first cleaned and put in the cell counts appear (believed to be rf emission) and then disappear in steady-state running of the cell. The counters have also been shown to give counts with increased humidity. Work is continuing.

Muon Catalyzed Fusion

Two experiments (MIT + BNL, Harvard) investigating muon catalyzed fusion in Pd and Ti electrodes in electrolytic cells were carried out at the stopped muon beam line at the AGS. Measurements were made of neutrons, gammas and He. The run ended May 25. Analysis is continuing.

Analysis of an Old Deuterided Sample of $TiFeD_x$

Samples of $TiFeD_x$, which have been under deuterium gas pressure for 10 years, are under analysis for both tritium and He content.

Proton Emission from Thin Foils

A 1 mm Pd foil in a D_2O solution has been studied for emission of betas and protons with a Si detector (which has a Be window) over a 2 week period. So far no unexplainable counts.

Calorimetry

Four "Pons and Fleischmann" cells have been running looking for excess heat. To date none has been observed.

In addition, a repeatable sequence involving the warming of preloaded (with either H or D) wire and sheet Pd electrodes in a constant voltage U-tube reveals detectable bursts of rf accompanying the rapid release of the adsorbed species (H or D). For equivalent electrical conditions the response of the deuterium loaded electrode occurs at a significantly lower temperature.

Theory

A number of theorists have been looking at how hydrogen is stored in various compounds. The conclusion in both theory and some experiments is that the separation distance of the hydrogen (deuterium) atoms in a metal or compound is always GREATER than the free molecule. Thus it is not clear why one would induce fusion by putting deuterium in Ti or Pd. Specific calculations are being performed on the cohesive energies of Pd and PdLi with and without deuterium. The results will be used to estimate the energy difference between the "short bond" deuterium (analogous to D_2, bond length 0.7Å) and the "long bond" deuterium (like that in Pd hydride 2.0Å).

United States Government

memorandum

Department of Energy
Idaho Operations Office

DATE: June 16, 1989

SUBJECT: Energy Research Advisory Board Update - Cold Fusion at Idaho National Engineering Laboratory

TO: Dr. David Goodwin, Special Assistant
to the Associate Director
Office of High Energy and Nuclear Physics
DOE-HQ, ER-20.1

Idaho National Engineering Laboratory (INEL) is conducting several cold fusion experiments, as described below. Our major effort has been to attempt to duplicate the University of Utah observations. We are also studying the low rate fusion effects reported by researchers at Brigham Young University and elsewhere.

Using a calorimeter, which is approximately a factor of ten more sensitive than the University of Utah's instrument, we have conducted measurements using light water, heavy water, and light/heavy water mixtures. Within the range of experimental parameters employed to date, no excess heat, excess tritium, or neutron/gamma radiation above background have been measured at our laboratory. A paper describing the INEL calorimetric experiment was presented at the Workshop on Cold Fusion Phenomena, at Sante Fe, 23-25 May 1989.

INEL, in collaboration with M. Paciotti of Los Alamos, is planning to conduct experiments attempting to duplicate the "Frascati effect," that is, the apparent generation of fusion neutrons in bursts. We plan to use protium-deuterium mixtures, since the calculations of J. Cohen at Los Alamos and S. Koonin of Caltech suggest this may enhance the rate of cold fusion. We may also try a deuterium-tritium mixture in the later phase of the experiment. The critical portion of our measurements will be conducted 4000 feet underground in an Idaho silver mine. At this level, the cosmic-ray flux is reduced by a factor of ten million. By comparison of experiments running at the surface and underground, we can measure, and subtract, the cosmic-ray background in these experiments.

For additional information please contact Dr. Stephen Lien (FTS 583-1231) or Dr. Gus Caffrey (FTS 583-4024).

Dr. Stephen C.T. Lien, Chief
Advanced Technologies Branch

SUMMARY OF STUDIES ON "COLD FUSION" AT LBL

1.) Detection of Radiation During the Electrolysis of Pd Cathodes in Heavy Water

John Porter, Materials and Chemical Sciences Division
John Rasmussen, Nuclear Sciences Division

Radiation detection experiments were conducted using a "double blind" configuration. Nominally identical, cast palladium samples were placed in identical cells labelled A and B, and the experimenters did not know which cell contained the heavy water. The electrolyte was 1M LiOD in D_2O (or LiOH in H_2O). Counting was done with two sets of detectors. Counting setup #1 was well shielded and the enclosure filled with water and paraffin to thermalize neutrons efficiently. Two intrinsic Ge detectors and one liquid scintillator neutron counter were positioned inside for x-ray, gamma, and neutron counting. Setup #2 had a ^3He neutron spectrometer and an intrinsic Ge detector for energy analysis of neutrons, gammas and x-rays. Setup #2 also had a plastic charged particle scintillator placed atop the ^3He detector to monitor the cosmic ray incidence. The twin cells A&B were exchanged every 24 hours between the two counting setups. After counting for six full days with current in both cells maintained at 100 mA (area ca. 5 cm^2), the current was raised to 250 mA for two days of counting (one day for each cell in both counting setups) and finally raised to 400 mA with the addition of sodium sulfide to poison D-D recombination on the surface. The D/Pd ratio at the end of the experiments was determined (by weighing) to be approximately 0.7. Integrated over the entire counting period, the difference in radiation emission between cells A & B (i.e., the light water cell and the heavy water cell) was within 1σ of zero. The presence of several "bursts" of apparent signal in the detectors was noted during these experiments. The use of simultaneous pulse height/shape analysis and multichannel scaling and the use of a second detector allowed the origin of the bursts to be determined as mechanical and/or electrical interference, i.e., the bursts were artifacts. These experiments established an upper limit of 1.2×10^{-23} neutrons per D-D per second. Comparable upper limits (i.e., 10^{-23}) were established for other forms of Pd as well, in particular, cold-drawn wire, electrodeposited Pd, Pd black, and e-beam evaporated Pd.

In another set of experiments, the emission of charged particles was detected using a Si surface barrier detector placed directly behind a Pd foil cathode in a cell with a "chimney" configuration. The Pd foil was 76 um with a 100 nm gold layer evaporated on the gas (detector) side as a diffusion barrier. The experimental protocol was to take the foreground counts with the foil acting as a cathode, and the background counts with the foil acting as an anode. The electrolyte was 1M LiOD in D_2O. Electrolysis was conducted at a constant current density of ca. 30 mA/cm^2. After two weeks of electrolysis, no foreground signal was detected over the background, which placed an upper bound of 7×10^{-25} protons per D-D per second. The D/Pd ratio was determined by chronocoulometry to be 0.82.

2.) Detection of Energetic Charged Particles Emitted from Pd Cathodes During Electrolysis of Heavy Water

John Porter, Materials and Chemical Sciences Division
Buford Price, Physics Department, University of California

In this experiment, CR39 plastic sheets were patterned with 100nm gold then 1um Pd using an electron beam evaporation system. Two identical electrochemical cells were formed, connected electrically in series. One cell contained 1.0M LiOH, the other 1.0M LiOD. Both electrodes in each cell were the gold-backed palladium. A constant current of 7.96 mA/cm^2 was passed through both cells; one electrode acted as the cathode and the other as the anode in each cell. After electrolysis, the electrodes were peeled away, the plastic washed with concentrated HCl and light water, dried under nitrogen, then etched and tracks identified and counted. Again, a single-blind protocol was adopted, whereby the person counting tracks was unaware of the identity of the electrode which had been in contact with the plastic. No significant differences in track density were found between the four "active" regions of the plastic or the "inactive" regions of the plastic outside the electrochemical cells placing a limit on the rate of fusion on the order of 4×10^{-24} fusions per D-D per second.

3.) Detection of Radiation from Pd Cathodes During the Electrolysis of Heavy Water

Eric Norman, Nuclear Sciences Division
Darleane Hoffman, Nuclear Sciences Division

Two types of D_2O cells containing electrodes and electrolytes similar to those described in Refs. 1 and 2 were operated over a period of five weeks. Fast neutrons were searched for using liquid scintillators and dosimetry film. Prompt gamma rays were searched for using NaI detectors; induced radioactivity in the electrodes was searched for using Ge detectors. Background measurements were conducted with the D_2O cells turned off and with an operating H_2O cell. Measurements of the masses of palladium electrodes before and after electrolysis showed that the number of deuterium atoms loaded was greater than 0.5 per Pd atom. No excess of neutrons or gamma rays above background was observed in any of the experiments. From the neutron measurements we have established an upper limit of 2.1×10^{-24} [$d+d \rightarrow {}^3He + n$] reactions per second per deuteron occurring in our Pd electrode. Similarly, the lack of 23.8-MeV gamma rays established an upper limit of 2.7×10^{-24} [$d+d \rightarrow {}^4He + \gamma$] reactions per second per deuteron in the same electrode. In some runs, a small (15%) amount of H_2O was added to the D_2O to search for the $d + p \rightarrow {}^3He + \gamma$ reaction. No excess of 5.5-MeV gamma rays above background was observed and an upper limit of 1.8×10^{-23} such reactions per proton per second in our Pd electrode was established.

1. M. Fleischmann and S. Pons, preprint

2. S.E. Jones et. al., preprint

Lawrence Livermore National Laboratory

June 16, 1989

Dr. William Woodard
Energy Research Advisory Board
U.S. Department of Energy
Washington D.C.

Dear Dr. Woodard,

Please find, as you requested, a short summary of the experimental and theoretical program at the Lawrence Livermore National Laboratory on the subject of cold fusion. Our first reactions to the initial reports of Pons and Fleischmann were those of surprise because they were inconsistent with our present understanding. However the importance of such a new approach to fusion was so great that a very large number of our scientists began in earnest to examine the reported experiments. It rapidly became clear that there were two classes of experiments.

(1) Those that measured excess heat from D_2 loaded Pd electrodes in an electro chemical cell. (Pons and Fleischmann, Srinivasan, Huggins,....)

(2) Those that measured a very small number of excess neutrons from D_2 loaded Pd electrodes in electrochemical cells, however these cells produced no excess heat. (Jones et al, Frascatti laboratory results)

Our calculations and theoretical research have shown that there is no reason to believe that D_2 in a palladium matrix should fuse and cause the observed heat or the observed neutrons. Furthermore we have been unable to measure enhanced heat production in D_2 loaded palladium-electrode electrochemical cells. In one case (Srinivasan at Texas A&M) we have examined palladium from cells that appeared to have generated excess heat but we see no evidence of fusion -- no He^3 or He^4, tritium, or neutrons.

In our experiments that fall in class (2) above, which include the initial experiments of Jones et al, we have measured no neutrons. In experiments with D_2 pressured titanium metal, we, LANL, Frascatti and others may have seen bursts of a few neutrons, but we are not yet convinced of the accuracy of these measurements. While we are convinced that this class of experiments has produced no useful fusion or accompanying heat, there are some curious observations that should be explained, but at a low funding level.

In summary we believe that at the National Laboratory level there is little additional work to do in the area of cold fusion. Please see the attached sheet for a more detailed explanation of our results. Thank you for this opportunity to describe our results.

Sincerely,

J H Nuckolls

John H. Nuckolls
Director

June 16, 1989

LLNL REPORT ON COLD FUSION

With the appearance of reports on "Cold Fusion", scientists at the Lawrence Livermore National Laboratory began an increasingly sophisticated series of experiments and calculations to explain these phenomena. These experiments can be categorized as follows: (a) simple experiments to replicate the Utah results, (b) more sophisticated experiments to place lower bounds on the generation of heat, and production of nuclear products, (c) a collaboration with Texas A&M to analyze electrodes and electrolytes for fusion by-products in a cell producing 10% excess heat (we found no by-products), and (d) attempts to replicate the Frascati experiment that first found neutron bursts when high pressure deuterium gas in a cylinder with Ti chips is temperature cycled.

We failed in items (a) and (b) to replicate either the Pons/Fleischmann or Jones phenomena, and appear to have duplicated the Frascati results, (d). Summaries of (b) through (d) are described below, as is a theory effort based on cosmic ray muons.

Electrolytic Cells

A typical experiment involved comparisons of electrolytic cells using D_2O and 0.1 M LiOD with cells using H_2O and 0.1 M LiOH. Palladium wires 1 mm in diameter were used in the two runs described below, the first were simply swaged and drawn, but since there were reports that remelting was necessary we annealed the wire for the second run for 3 hours at 600°C. The first pair of cells ran for 156 hours in a common bath, each with a 35 cm long swaged wire, with current densities starting at 90 mA/cm^2, increasing to 270 mA/cm^2, and then to 450 mA/cm^2. The slight temperature difference between the two cells remained essentially constant throughout the run, that is there was no excess heat difference between them. Using relatively low efficiency neutron detectors, no neutrons above background were observed. An analysis of the Pd for ^{3}He and ^{4}He was negative, setting limits of a few times 10^{10} atoms per gm. After cutting a length of this wire from the above D_2O cell it was run in another thin-walled cell for 4 more days with a Geiger counter near it. No counts above background were observed. A second experiment used a pair of cells with annealed Pd, and it ran for 330 hours at a current density of 230 mA/cm^2 with similar null results. Analysis of that wire showed no helium buildup either. In both cases the thermometry might have missed seeing excess heat at the 10% level.

One cell similarly prepared to the one described above was setup for sensitive neutron counting. The cell ran for 167 hours and featured a proton recoil telescope detector that eliminated all background counts, and it used a sensitive liquid scintillator (7% efficiency, absolutely calibrated, with neutron/gamma pulse shape discrimination). The latter set a limit of 0.2 neutrons/sec from the 27 g Pd wire, half the level reported by Jones at BYU with a 5 g sample.

Several other experiments with electrolytic cells were run in a second independent group. Their experiment was designed to test for helium buildup in Pd, for neutrons, and for excess heat. Calorimetry with a minimum thermal detectivity of about 2% of the input electrical power was used. Similar (null) results were found by this group. If the excess heat is a 10% effect, as observed at Texas A&M, then this calorimeter has sufficient sensitivity and no effect was observed.

Collaboration with Texas A&M

We analyzed samples of Pd from a cell run at Texas A&M by Srinivasan, who reported 340 mW heat flow into their sensitive microcalorimeter with 300 mW heat input, indicating an excess heat generation of 40 mW. However, it should be remembered that an additional power input of 150 mW was needed to separate the D_2O molecules. To the level of 3×10^5 ^3He atoms and 5×10^8 ^4He atoms in the sample (about 20 mg) there was no helium generation in the wire. This is many orders of magnitude below the level associated with 40 mW of fusion power for one hundred hours. Surface analysis with Auger and SIMS techniques revealed a substantial layer of material (Ca, C, Fe, O, Cl, Li, N, Cu and traces of other elements) plated out on the surface. These gave no clue as to possible excess heat generating mechanisms however they indicate suspicious additional electrochemical mechanisms. An analysis of the electrolyte before and after the run showed no change in the tritium level in the original electrolyte.

Neutron Burst Experiments

Experiments using pressurized deuterium cylinders loaded with Ti in various forms, similar to the Frascati experiments, were carried out by several groups at Livermore. In a large number of runs, cycling the temperature from ℓN to room temperature, the results were null. Very recently, with detector efficiency improved to 15%, with higher pressure operation to 60 Atm, and with a pair of coincidence detectors incorporating burst mode triggering in the detection circuits, one group observed what appear to be bursts of a few hundred neutrons. These do not correlate with the temperature of the cylinder at the time of the bursts, which is contrary to data from LANL. Consistent with Sandia, it requires multiple detectors and the observation of coincident signals to place some confidence in the results. Many spurious signals appear on one detector but not another, and this could be missinterpreted as neutrons. At present, the temporal signals are being studied to assure ourselves that the signals are indeed neutrons. Plans to repeat this in DT gas have been made.

Muon Theory

A theory to explain that the fusion neutrons observed by Jones etc. were generated from cosmic muons was developed here. The theory falls short by about two orders of magnitude to explain the level of neutrons seen by Jones. It was found that charge exchange with deeply trapped electrons around the Pd (or Ti) limits the muon to catalyzing at most a dozen events. In 13% of the muon catalyzed D-D reactions the muon sticks to the resulting He atom, and must subsequently be reionized by deeply trapped (a few kV) electrons. Instead, however, the muon charge exchanges. Further, experiments in Japan with accelerator generated muons, reported recently in Santa Fe, definitively set an even lower limit to muon catalyzed reactions then the above theoretical explanation.

COLD FUSION RESEARCH AT LOS ALAMOS NATIONAL LABORATORY

A broad spectrum of cold-fusion investigations is in progress at Los Alamos. Research activities include:

1. Careful low-level neutron measurements on electrochemical cells and on pressurized D_2 cylinders.

2. Systematic studies of electrochemical cells under various parameters.

3. Electron injection solid state D-D fusion in Pd-Si cells.

4. Explosive compression of D-loaded Pd.

5. Theoretical support and modeling.

NEUTRON MEASUREMENTS

Low-level neutron producing experiments have been successfully performed at Los Alamos with participation by Brigham Young University staff. Experiments have consisted of random and time correlated neutron measurements on electrolysis cells and on pressurized D_2 gas cylinders containing Ti, Pd, or V metal. Four high-efficiency neutron coincidence counting systems are located in a low background environment. The counters provide information on total and time correlated neutron production. Two of these systems have an inner and outer circle of helium-3 tubes that provide information on the average energy of the source neutrons. A neutron counter recently constructed contains three rings of helium-3 filled tubes and an overall efficiency of about 35% for ^{252}Cf spontaneous fission neutrons.

Measurements on D_2 gas cylinders containing Ti and on electrolysis cells with Pd and Ti cathodes resulted in the discovery that neutron emission does occur, but in low yield, short-lived bursts ($<50\ \mu s$). The sporadic bursts occasionally come from the pressurized D_2 cylinders with Ti, V, or Pd metal during warm-up cycles from liquid nitrogen to room temperature. It is proposed that the neutrons are resulting from local "hot fusion" associated with accelerating electrical potentials produced by microscopic fracturing and cracking in the D_2 gas-metal interactions.

Early results were reported at the Santa Fe Conference, and a manuscript describing results up to a couple of weeks ago has been submitted to Nature.

If microscopic cracking is the source of the neutrons, large numbers of accelerated electrons and ions should occur. Recently, a pressurized D_2 cylinder was modified into an ionization counter, and several bursts of ion/electron emission were observed. The next step will be to place the ion counter in a neutron counter and look for ionization-neutron coincidences.

As soon as neutrons can be produced in a reproducible manner, control experiments with H_2 gas and planned experiments with DT gas will be performed. If fusion is resulting from the electrical potential developed across microcracks, the DT reaction (14-MeV neutrons) rate should be considerably larger than the DD reaction (2.5-MeV neutrons) rate.

ELECTROCHEMICAL CELLS

Several teams are conducting experiments with electrochemical cells. This work was evolved from early attempts to duplicate the Fleischmann-Pons experiment to developing techniques to increase the D/Pd ratio in the cathode. Although several closed-system calorimeters with hydrogen-oxygen recombination are now almost ready to use, the main effort has been to develop cells that produce fusion signatures (neutrons, gamma rays and/or Pd x-rays) and obvious excess heat; the latter has not been observed. As discussed above, low-level neutron emission from Jones type cells with Ti cathodes has been observed at Los Alamos, perhaps associated with cracking in the deuterated Ti.

Substantial progress has been made in increasing the D/Pd ratio in cathodes of electrochemical cells. Both by alloying with Li or Rh, or by surface poisoning with chemical additives to the LiOD electrolyte, D/Pd ratios greater than 1 have recently been achieved.

Careful assay of the input D_2O composition, tritium buildup in the cell, and precautions to ensure that normal water vapor does not enter and dilute the cell are important aspects of these measurements. Control cells with normal water are operated in parallel. Several tritium counters are available at Los Alamos, and ^3T assay support has been provided to Texas A&M.

SOLID STATE FUSION EXPERIMENTS

The intent of this work is to take advantage of the fact that small increases in the mass of the electron can produce large increases in the D-D fusion rate.

Solid-state cells were made that allow the injection of electrons into Pd from Si. The injected electrons, under certain momentum conditions, can behave as if they had an increased mass. If the Pd is also loaded with D, the combination might enhance the conditions for fusion. The cell is constructed of alternating layers of Pd and Si powders and is pressurized with D_2. Electron injection is effected by electrical pulses and one looks for thermal effects and time-correlated neutron emission coincident with the electrical pulses. Thus far, these signatures have not been observed.

EXPLOSIVE COMPRESSION

An experiment was performed in which deuterated Pd foil was explosively compressed. Both on-line neutron counters and later counting of activation foils indicated the neutron flux was below the limits of detection ($< 10^4$ total neutrons from the device).

THEORY AND THEORETICAL SUPPORT

Considerable theoretical work has gone into the proposed fracturing process that could generate neutrons. If suitable conditions can be found that give reproducible neutron generation, the use of DT gas will help to provide an estimate of the reaction temperature at the location of neutron production. The ratio of 14 MeV neutrons from the DT reaction to 2.5 MeV neutrons from the DD reaction contains the temperature information.

OUTSIDE COLLABORATIONS

Los Alamos is currently collaborating with researchers from Stanford, Brigham Young, Texas A&M, and Washington State Universities. The door remains open to the University of Utah collaboration.

OAK RIDGE NATIONAL LABORATORY

COLD FUSION STATUS

Summary

Four groups at the Oak Ridge National Laboratory (ORNL) are currently working on "cold fusion" experiments. Three are using electrochemical cells to investigate the Fleischmann/Pons effect and one is using pressurized D_2 plus Ti or Pd to investigate the effects first reported by the Frascati group.

None of the groups has confirmed the production of excess heat or of fusion by-products (neutrons, gammas, tritium, ^{4}He). Experimental sensitivities would have clearly shown effects at the levels reported by the Utah or Frascati groups. Two of the groups would have been able to detect neutrons at the levels claimed by Jones at BYU. All of the groups have, however, observed anomalies at one time or another, some of which have not yet been satisfactorily explained, none of which constitute confirmation of "cold fusion." Details are given below under the name of each principal investigator.

1. D. P. Hutchinson et al.

Attempts to duplicate the results reported by the University of Utah began at the end of March. The first cells had Pd foil cathodes and were diagnosed for neutrons by a pair of NE-213 scintillator detectors, using n-γ discrimination, with an overall efficiency of 13% for neutron detection. No significant counts were observed corresponding to an upper limit of 10^{-23} to 10^{-24} events/sec/deuterium pair for a one-hour run. On April 11 two cells containing 3-mm o.d. cast Pd rod cathodes were started and operated for over three weeks with the same result.

A parallel calorimetry effort was begun to investigate the "excess heat" reported by the Utah group. The first two experiments utilized 6.35-mm o.d. x 100-mm extruded Pd rods obtained from Johnson-Matthey. Both rods were annealed at 900° C for four hours, and one was pre-charged with D_2 to a concentration of 60%. The current density was 250 mA/cm^2, with an electrolyte of 0.2 M ^{6}LiOD. A third cell, using an annealed 6.35-mm o.d. x 100-mm pre-charged Pd rod and 0.1M electrolyte, and a fourth cell, using a 13-mm o.d. x 100-mm cast rod in a 0.2 M electrolyte, were added later. The first two cells have been in operation for over 700 hours to date. One has indicated an apparent energy imbalance of ~10% for several hundred hours, and this apparent imbalance has been shown to disappear if the experiment is run at 5° C instead of 13° C. This effect is not understood. The calibration system is being redesigned to check for systematic errors. Approximately two weeks will be required to implement these changes. No neutrons have been observed during this period of power imbalance (upper limit 10^{-24} events/sec/deuterium pair). The remaining cells indicate power balance within ~1%.

2. C. D. Scott et al.

Three different electrochemical cells have been run using D_2O with a LiOD electrolyte and a Pd cathode. Insulated glass electrolysis cells approximately 4-cm-diam x 10 cm were used with Pd cathode rods of 0.28- to 0.55-cm-diam x 8- to 9-cm operating at 100-400 mA/cm^2. Heat removal was determined by the temperature increase of the forced flow of cooling water. Neutron flux was measured by a NE-213 scintillator with n-γ discrimination . Typical sensitivity was $\approx 3 \times 10^{-24}$ fusions/deuterium-pair/sec for a four-hour run. A NaI gamma-ray spectrometer was also used for detection of neutrons via a polyethylene converter, but it had somewhat less sensitivity. The tritium concentration was measured periodically in the electrolyte.

There have been no sustained positive results. There have been two separate occasions with two different Pd electrodes when the neutron flux exceeded three standard deviations above the background previously measured, although no simultaneous background measurements were made. There have also been two short periods of apparent excess energy, although these did not exceed 20% of the energy input or last more than a few hours.

These observations have not been reproduced and do not confirm the claimed cold fusion effects. However, the apparent unusual phenomena are interesting and will be the basis for additional investigation. The next system will utilize a continuously flowing electrolyte solution that is the heat exchange media and in situ recombination of evolved D_2 and O_2.

3. E. L. Fuller et al.

Six cells have been in operation for periods of one to three weeks. The electrolyte is 0.1 M LiOD, and the rod cathodes (five Pd, one Ti) have diameters of 6.4 mm to 10 mm. A variety of metallurgical pretreatments has been used, including cold casting, hot casting, and annealing. The cells are run at current densities which are varied in the range of 40 mA/cm^2 to 300 mA/cm^2 to see if non-equilibrium conditions trigger any unusual events.

Neutron detection, using one BF_3 counter to monitor the cells and one to monitor the background, has been used. No significant emission from the cells has been seen with this system, corresponding to a upper limit of 10^{-21} to 10^{-22} fusions/sec/deuterium pair. Analysis of cathodes for ^4He has failed to show anything above the detection limit (~10^9 He atoms) as has analysis of the off-gasses.

Apparatus is now set up for calorimetry, with an anticipated accuracy $\approx$1%. Calibrations are under way.

Extensive analysis of one previously-loaded cathode has showed interesting property changes (hardness, fractures, blistering, etc.). Additional studies are under way to evaluate the chemical and physical transformations for any possible contributions to energy balance.

4. J. G. Blencoe et al.

Experiments are in progress on the Pd-D_2 and Ti-D_2 systems at 50-350 MPa, 77-300 K to look for "cold fusion" in deuterides formed by pressurization with D_2 gas. The apparatus used is a 3/16" i.d. x 9/16" o.d. x 12" stainless steel pressure vessel that can be operated routinely at pressures as high as 400 MPa.

Diagnostics include (1) an array of three, 2" o.d. x 16", BF_3 neutron detectors immersed in a water bath with overall efficiency ~6%; (2) an internal, type-K sample thermocouple; and (3) an internal, type-K reference thermocouple located approximately 4" above the sample thermocouple. The neutron flux, D_2 pressure, sample and reference thermocouple readings, and bath temperature were recorded continuously at time intervals ranging from 6 seconds to 10 minutes.

Results obtained so far indicate no effect at the levels reported by Frascati and range from negative to ambiguous at the levels reported by Los Alamos. No sustained heat production has been observed in any experiment. Thermal pulses that persist briefly after pressurizing Pd with D_2 gas are attributable to small amounts of chemical heat released when Pd and D_2 react to form Pd deuteride. No sustained neutron flux above background was observed in any Pd-D_2 experiment. Two separate periods of apparent enhanced (≈10%) neutron flux have been recorded in a single Ti-D_2 experiment; however, additional experiments, including continuous background monitoring, are needed to obtain meaningful data at these levels.

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June 15, 1989

Dr. David Goodwin
Special Assistant to the
Associate Director
Office of High Energy Nuclear Physics
ER-20.1, GTN
U.S. Department of Energy
Washington, DC 20585

Reference: Letter, June 5, 1989, William L. Woodard to Dr. William R. Wiley.

Dear Dr. Goodwin:

Subject: Summary of PNL Cold Fusion Research Activities

Enclosed is a summary of PNL's research activities in cold fusion as per Dr. Woodward's request dated June 5, 1989. This summary covers our research activities as of March 23, 1989, and includes our current experimental activity and collaborations.

Our current level of activity includes 6 scientists/engineers working at about a 2 manyear/yr. level of effort. We're pleased to participate with other DOE laboratories in assessing cold fusion phenomena. If you need further technical information, please contact Dr. Russell H. Jones at (509) 376-4276.

Very truly yours,

W. R. Wiley
Director

WRW:sw

cc: PM Pak - DOE-RL
JJ Sutey - DOE-RL
WL Woodard

Attachments

RESEARCH ON "COLD FUSION" PHENOMENA AT PACIFIC NORTHWEST LABORATORY

R. H. Jones, R. P. Allen, R. L. Brodzinski, M. D. Merz,
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Pacific Northwest Laboratory
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Research on cold fusion has been in progress at PNL since the March 23, 1989 announcement by Pons and Fleischmann. Early experiments emphasized nuclear counting for neutrons, gammas and x-ray. Experimental changes were made as more information regarding the conditions used by Pons and Fleischmann became available. An integrated experiment to measure heat and nuclear products in closed electrolysis cells is in progress. Other activities include a gas charging experiment and collaboration with Texas A&M and the University of Utah in tritium measurement of their D_2O.

SUMMARY OF PHASE I EXPERIMENTS

Experiments have been run to verify the claim of Pons-Fleischmann that "cold" fusion occurs in the Pd-deuterium system. Pd cathodes were electrochemically charged with deuterium from a 0.1M LiOD electrolyte. The Pd was 99.9% pure and consisted of 3 to 5 mm wide strips cut from a 25 by 25 mm wide by 1 mm thick foil piece. A Pt lead was spot-welded onto each Pd strip. Pt wire (0.68mm diameter) was used as the anode in most experiments. The LiOD solution was made by dissolving either ^7Li metal or $^6Li_2O$ in 99.8% D_2O. Cells were run at constant current, with current densities on the Pd ranging from 16 to 320 mA/cm^2, both cell voltages and currents were periodically measured, however, no temperature measurements were made. In one experimental setup, an electrochemical cell was placed inside a high sensitivity neutron counter and neutron counts were taken at 10 min intervals. In addition, temporal multiplicity events, characteristic of bursts postulated to be produced by muon catalysis, were measured by connecting the output of the neutron counter to a multiplicity counter. In a second setup, a cell was placed inside a germanium gamma-ray spectrometer to measure Pd x-rays generated by high energy fusion products (e.g., protons) and secondary gammas produced by (n,γ) reactions on a Cd foil placed around the electrolysis cell. Gamma-ray spectra were collected over 1 to 2 day intervals.

Approximately 13 experiments were run, with the longest continuous charging time being 20 days. No positive results have been observed; upper limits to the D-D fusion reaction rate are $\sim 2x10^{-21}$ and $\sim 3x10^{-18}$ fusions/sec per D-D pair for neutron and x-ray measurements, respectively.

SUMMARY OF INTEGRATED EXPERIMENT

Several pertinent factors became apparent following our early experiments. These factors are: 1) the need to perform the calorimetric experiments in a closed system, 2) the observation of high tritium in the Texas A&M cells and 3) the difficulty of obtaining D/Pd ratios greater than about 0.8. Therefore, an integrated experiment in which nuclear products and heat are assessed in a closed system was undertaken. Also, an emphasis is being placed on obtaining a D/Pd ratio greater than 0.8.

Internal D_2 and O_2 recombiners will be used to maintain a closed system. These cells will use 5 mm diameter by 5 cm long Pd rods which have been arc-melted and annealed at 1000°C in D_2 gas. Internal cooling coils will be used to maintain isothermal conditions and the temperature difference of the inlet and outlet coolant used to calculate the heat output of the cells. The input heat will be determined from the integrated electrical energy input to the cells. Since the cells are closed, all energy associated with D_2 and O_2 production is returned to the cells. The data is continuously monitored with data logging system and D_2O will be removed periodically for tritium analysis. ^3He and ^4He analysis will be conducted on the Pd rods following the experiments. Neutron and gamma counting will be conducted. Goals for this research are twofold: 1) measure the tritium concentration in the D_2O of a closed electrolysis cell and correlate these results with thermal and neutron/gamma measurements and 2) to evaluate the same parameters in an electrochemical cell with a D/Pd ratio >1. Recombination poisons and other surface alterations will be used to maximize the D/Pd ratio.

SUMMARY OF OTHER ACTIVITIES

PNL has conducted one gas charging experiment similar to those conducted at Frascati and at LANL. A palladium rod was heated while inside a high pressure gas cell filled with deuterium gas. The cell was then counted using a moderated BF_3 tube neutron detector which had been calibrated with an NBS traceable PuBe neutron source. The cell was cooled to liquid nitrogen temperature and allowed to slowly warm back up to room temperature while neutron counts were taken. Each count lasted 10 minutes, and data were recorded for about 70 hours. No neutrons above the background level were detected coming from the gas cell.

PNL's tritium analysis capabilities have been made available to other laboratories. Tritium analysis has been performed on D_2O obtained from Bockris' group at Texas A&M and from Milt Wadsworth at the University of Utah. Our results from the Texas A&M samples are as follows:

Sample	dpm/ml
Electrolysis Cell	1.96×10^6
Electrolysis Cell	1.17×10^8
Blank-D_2O	140
Blank-D_2O+0.1MLiOD	127
Standard	8.08×10^5

We recently analyzed the D_2O from a cell operated by Professor M. Wadsworth at the University of Utah. This cell operated for several days at an increased temperature following a significant temperature increase which lasted a short period. Tritium analysis was performed on the starting electrolyte and samples removed immediately following the large temperature rise and after the cell operated at the elevated output for several days. A small increase in tritium was noted for the electrolysis samples relative to the blank, but the increase was only about 36% which is within that expected from the difference in electrolysis of D_2O and T_2O.

PNL has been approached by the University of Utah to assist them in the analysis of palladium electrodes from several Pons and Fleischmann electrolysis cells. Our role will be to act as an intermediary between the University of Utah and laboratories performing the analysis. We have also offered to perform surface, microstructural and chemical analysis of the electrodes.

PRINCETON PLASMA PHYSICS LABORATORY

Date: June 15, 1989

To: Energy Research Advisory Board
US DOE 1000 Independence Ave., SW
Washington, DC, 20585

Subject: Summary Report of PPPL Cold Fusion Experiments to the ERAB, pursuant to W. L. Woodard to H. F. Furth, 5 June 1989, pursuant to Watkins to Schoettler, 24 April 1989

Filed by: D. M. Manos, Head, PPPL Ad-hoc Task Group on Cold Fusion

Motivated by press releases on cold fusion, PPPL, in association with Electron Transfer Technologies, Inc. of Princeton, NJ, undertook a modest experimental program to investigate certain claims. At PPPL, two apparatus were set up, one to count neutrons, one to count gamma rays.

APPARATUS

A schematic drawing of the neutron counting apparatus is shown in Figure 1 and a block diagram of the counting circuitry employed for this apparatus is shown in Figure 2. Not shown in Figure 1 is an interior lid of cadmium absorber material which was present on top of the inner steel drum. The apparatus is capable of displaying the neutron energy spectrum in addition to the counts which fall within a selected range of energies accumulated during adjustable periods of time. The range was adjusted so that only events corresponding to the deposition of 2 to 3 MeV in the BF_3 detectors would register on the counter. The device was calibrated frequently using a ^{252}Cf source. The background neutron rate was highly variable, ranging from 3 to 30 counts/hr. The neutron efficiency was 2% for experiments using the central test cell, 0.3% for most experiments using the outer test cell, and 0.1% for certain few experiments which used the outer test cell and a modified arrangement of shielding materials. Figure 3 shows a comparison of a background spectrum and the spectrum of the ^{252}Cf source. We claim that our apparatus can continuously resolve a neutron source strength of 1 n/s.

Figure 4 shows a schematic, including a block diagram of the counting equipment, for the gamma ray counting apparatus. The counter, borrowed from the Colorado school of Mines, consists of a 4" dia. by 4" long, cylindrical NaI crystal, surrounded by a 4 inch i.d. , 12" o.d. by 8" long, annular NaI crystal. The interior crystal is fitted with a single photomultiplier, the annular crystal is fitted with 6 photomultipliers. The geometric arrangement is shown in Figure 4. When a gamma ray transits the annular NaI crystal the resulting signal from one of the 6 outer photomultipliers is used to gate the counting electronics so as not to count the signal from the interior photomultiplier should that gamma ray also transit the interior crystal. This provides a very effective discrimination against the cosmic ray background. This apparatus also permits display of the energy spectrum aong with the total counts within a selected energy range during an adjustable counting time interval. The energy range selected was 5-6 MeV, in an attempt to observe the 5.4 MeV gamma production associated with the p-D fusion reaction. The detection efficiency for the apparatus is 0.3 %. The observed background count rate with the anti-coincidence veto active was 10 to 25 counts/hr., the background with the veto off was 275 counts/hr. Figure 5 compares of backgrounds with the veto on and off, indicating the observed spectrum in our laboratory, and showing the selected energy window. We claim that this apparatus can continuously resolve a gamma source strength of 1.5 photons/s.

EXPERIMENTS

Using these counting apparatus we studied the following different types of "cold fusion" systems:

1. Electrochemical cell using Pd rods and spheres, metallurgically prepared both by casting and drawing using LiOD in D2O at current densities up to 0.6 amps/cm^2. A similar cell was studied at Electron Transfer Technologies to determine whether energy and power balance were achieved.

2. Electrochemical reactor using Pd wires and spheres, metallurgically prepared by casting and drawing using LiOH in 50% H2O/50% D2O. (In addition to the D-D reaction, the p-D reaction was chosen for careful study to test the hypothesis that fusion may occur by tunnelling through a coulomb barrier at low temperature, mediated by unknown effects from the crystal lattice. Such studies are made easier by the relatively rare occurrence of 5.4 MeV events in the cosmic ray background.)

3. Thermal and pressure cycling of Ti turnings as prescribed by workers at Frascati.

4. Thermal and pressure cycling of ultra-pure, 200 mesh Ti powder as prescribed by workers at Genoa.

5). Numerous variations of items 3 and 4 changing the schedule of variation of pressure and temperture with time.

6. Thermal and pressure cycling of Nb bar stock and Nb turnings using the pressure and temperature schedule of Frascati.

7. Thermal and pressure cycling of alumina, quartz, and feldspar mixtures (known to have large piezoelectric coefficients and/or to produce persistent high-energy exo-electron emission on fracture).

8). Tensile and compressive strain and fracture of Ti sheets loaded with D2 by glow discharge plasma bombardment.

9. Rapid compressive fracture (hammer blows) of Zr/Al/V pellets loaded with D2 by glow discharge plasma bombardment (after the method of Klyuev et al).

RESULTS

In every case we saw no neutrons or gamma rays above the measured background, as indicated in the following table:

Experiment	Claimed Level	Observed at PPL
Electrolysis D-D	4×10^4 n/sec	< 1 n/s
Electrolysis p-D	>4×10^4 photons/s Theoretical	< 3 photons/s
Pressure/Temperature Cycling (Frascati, Genoa)	5×10^3 n/s	< 1 n/s
Fracture studies	3 × background	no change from
(Klyuev and variants)	(0.4 n/shot)	background
Jones et al	0.4 n/s	not attempted

(special electrolyte)In the electrolytic cell experiments at Electron Transfer Technologies, performed by William Ayres, we found energy and power balance to within +/- 10% for currents up to 0.6 amps/cm^2. The uncertainties at low currents make the error bars larger than at high current. Figure 6 summarizes our energy balance experiments.

PRESENT STATUS

Based on our own results and those reported by other groups we feel that the proof of the existence of cold fusion now requires unequivocal demonstration to qualified observers by those who claim to be able to detect it. Therefore we have reduced our level of activity in this area.

We have returned the gamma ray detector to Colorado School of Mines and have suspended indefinitely, work on electrochemical cells. We have suspended attempts to reproduce pressure and thermal cycling results of the type claimed by Frascati and Genoa pending further reports from the group of Menlove et al, at Los Alamos. We are sustaining a low-priority effort related to further studies of X-rays, radio waves, and neutrons which may result from particle acceleration in electric fields associated with the fracture of deuterium-loaded non-conductors and metals. We intend these studies to be conducted in the surface physics branch by an incoming graduate student.

cc: E. C. Brolin
H. F. Furth
L. Ianello, DoE
D. Meade
Members Ad-Hoc Cold-Fusion Group
PPPL Division Heads

#89X0302

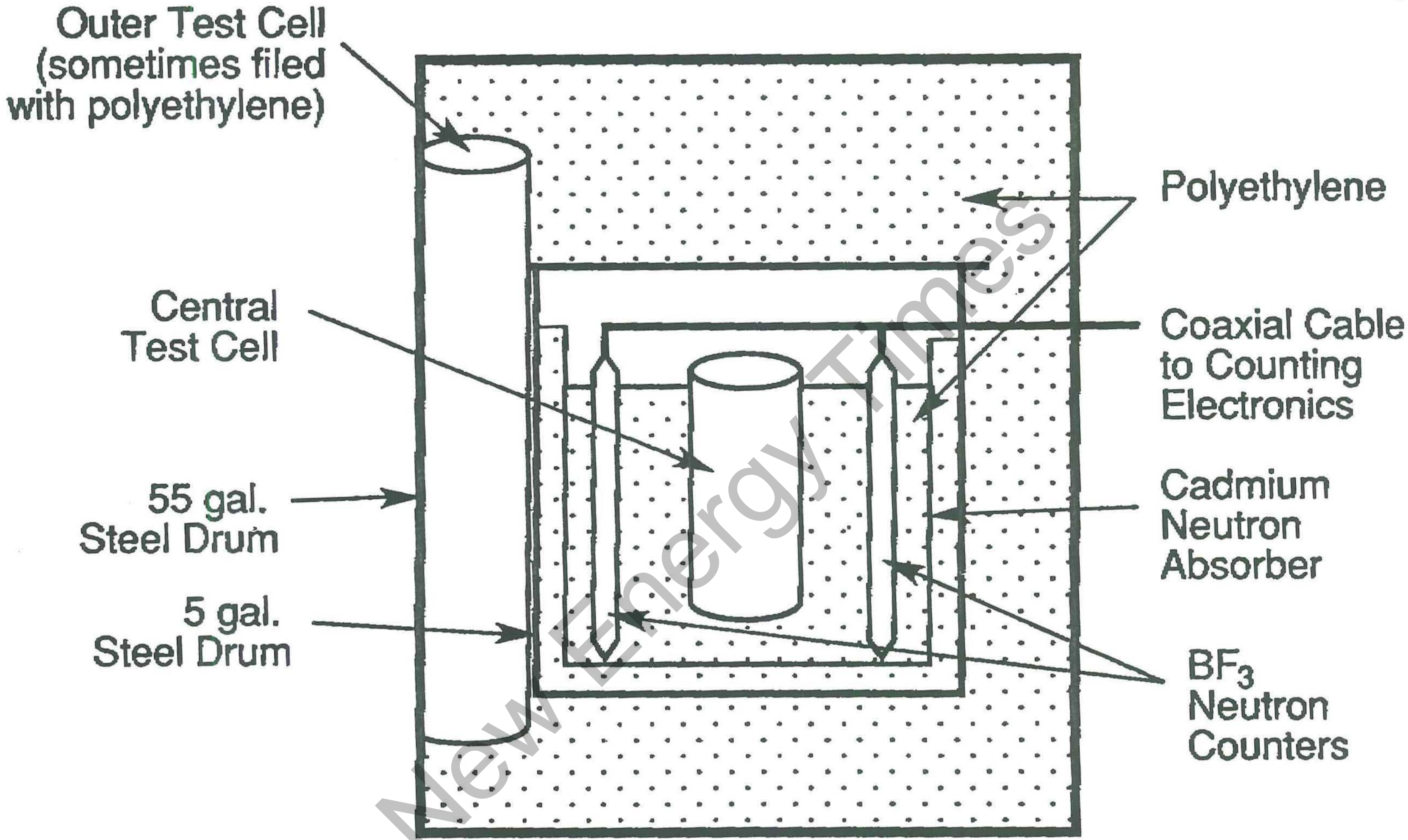


Figure 1

#89X0303

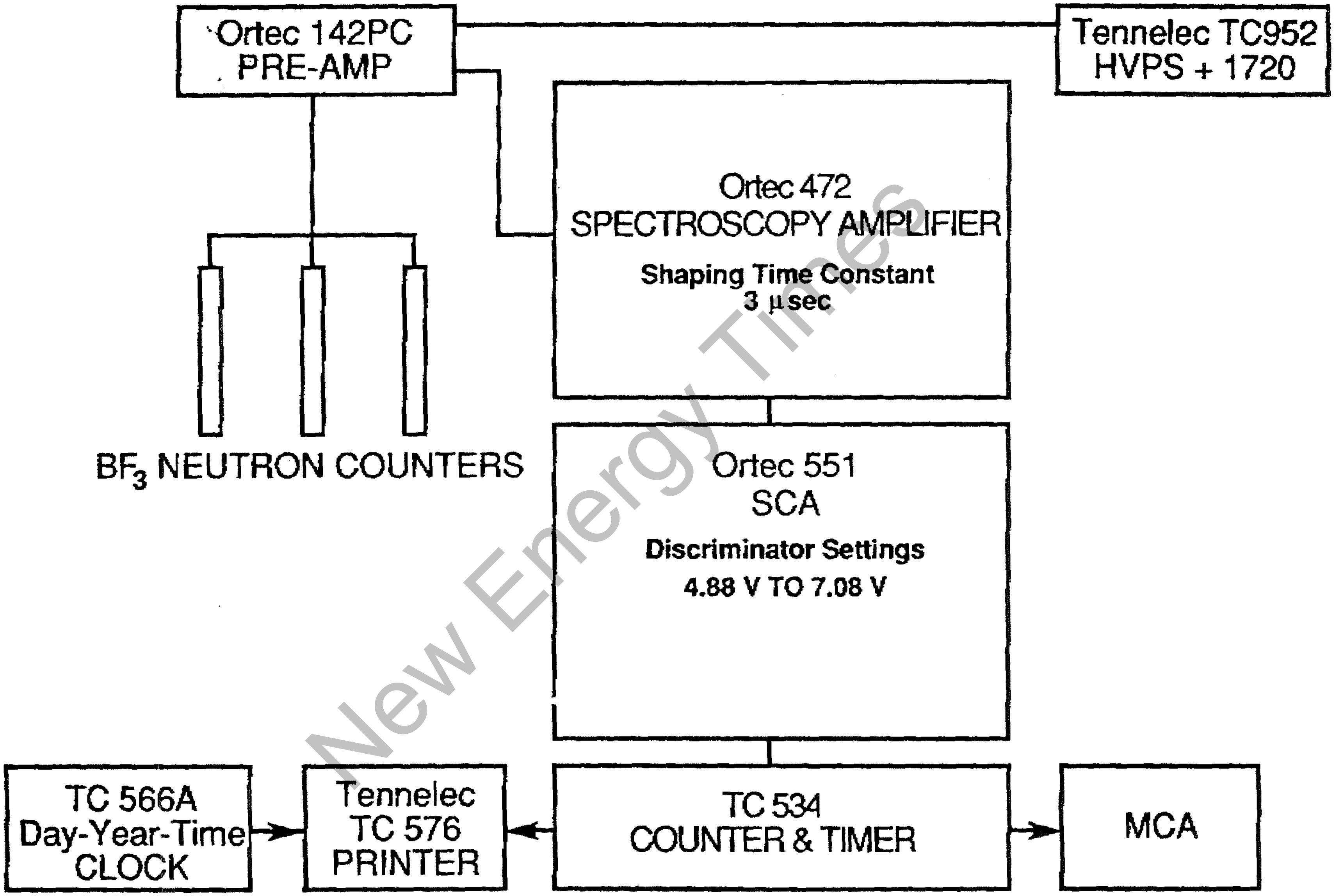


Figure 2

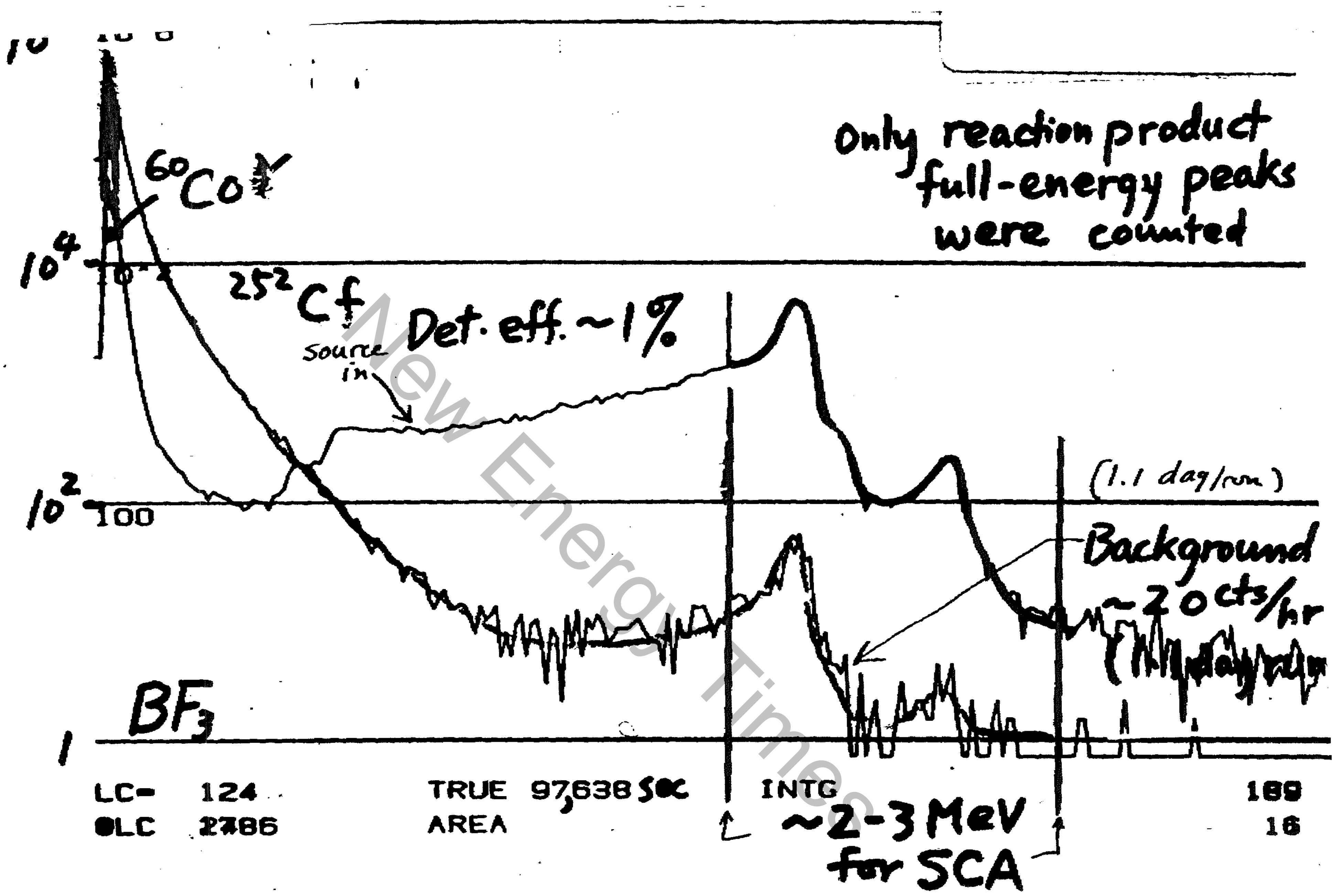

Only reaction product full-energy peaks were counted
^{60}Co γ
^{252}Cf
Det. eff. ~1%
Source in
10^4
10^2
100
1
(1.1 day/run)
Background ~20 cts/hr
BF_3
LC- 124
LC 2786
TRUE 97,638 SEC
AREA
INTG
189
16
~2-3 MeV for SCA

Figure 3

#89X0308

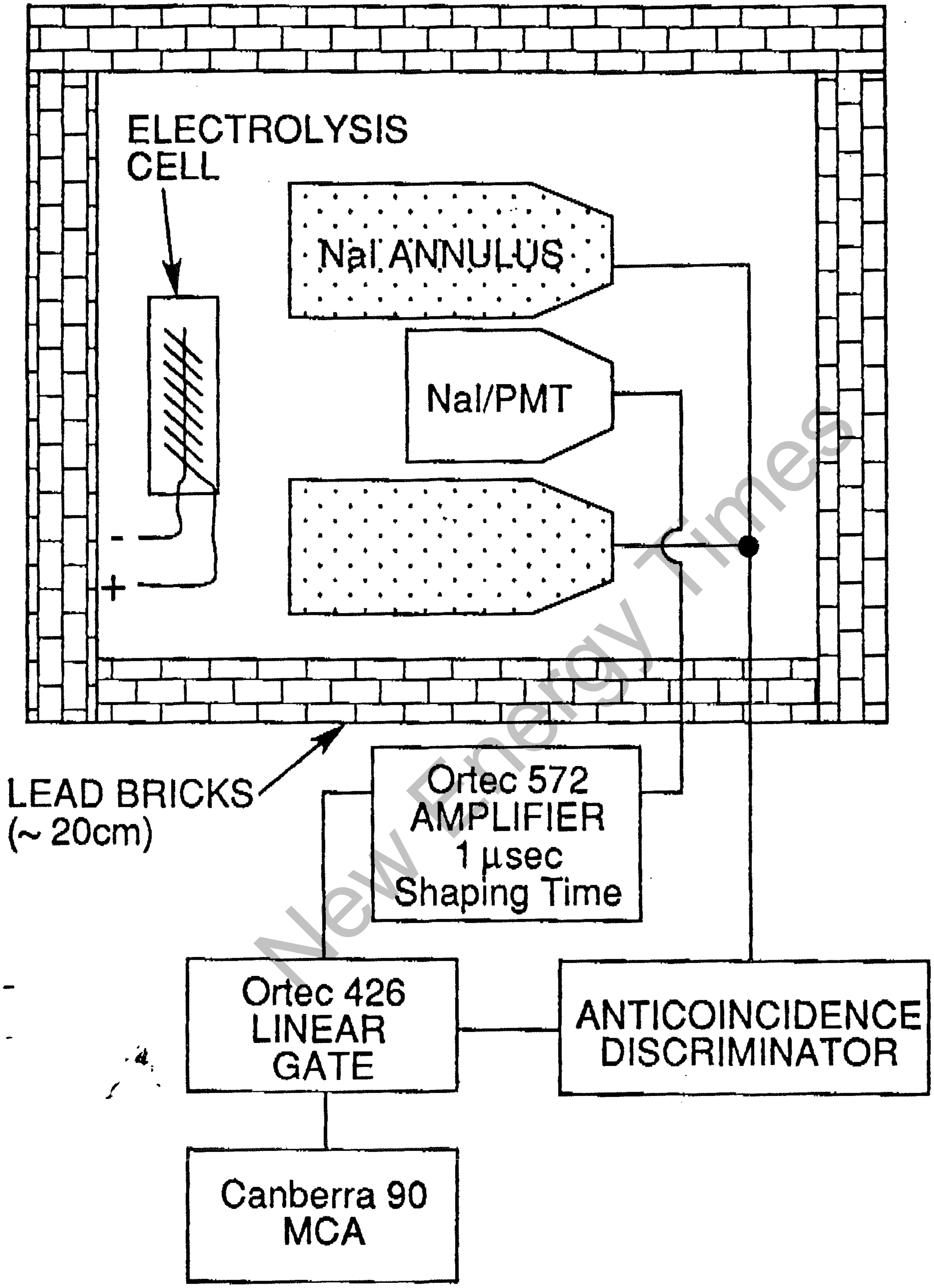
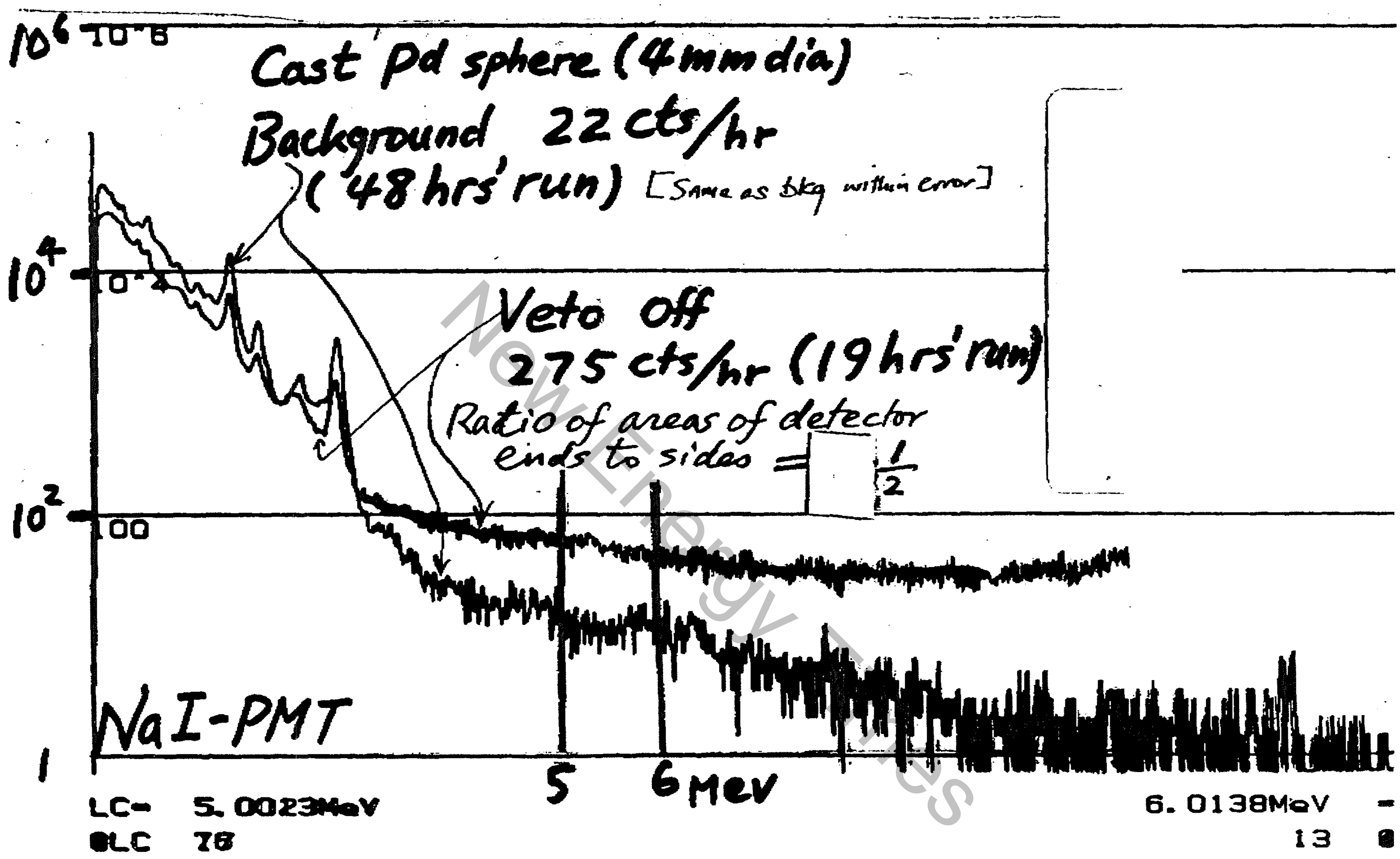
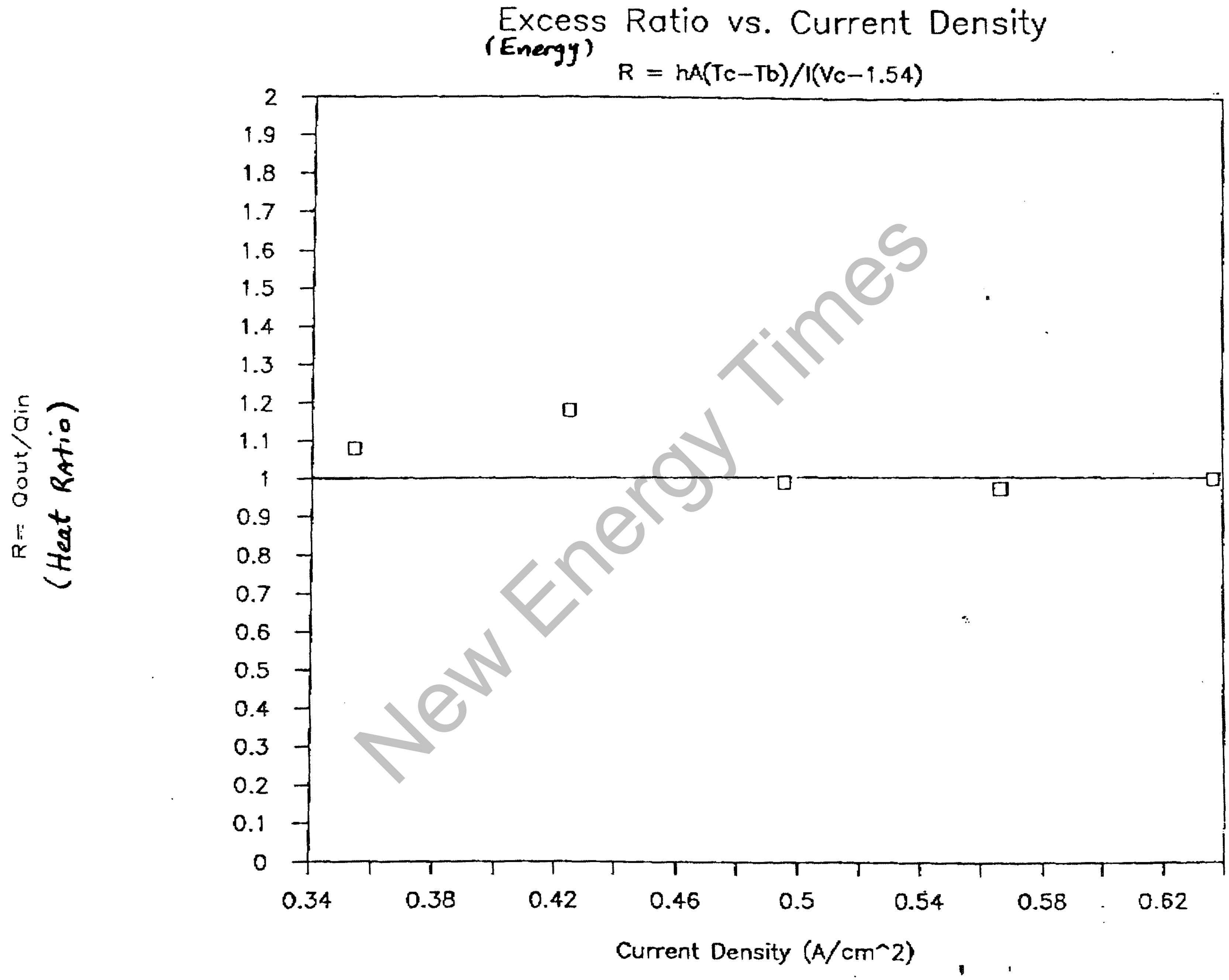


Figure 4



10^6
10^6
Cast Pd sphere (4mm dia)
Background 22 cts/hr
(48 hrs' run) [Same as bkg within error]
10^4
10^4
Veto off
275 cts/hr (19 hrs' run)
Ratio of areas of detector ends to sides = 1/2
10^2
100
NaI-PMT
1
5
6 Mev
LC= 5.0023MeV
6.0138MeV
13

Figure 5



Excess Ratio vs. Current Density
(Energy)
R = hA(Tc−Tb)/I(Vc−1.54)
R= Qout/Qin
(Heat Ratio)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.34
0.38
0.42
0.46
0.5
0.54
0.58
0.62
Current Density (A/cm^2)

Figure 6

SUMMARY OF COLD FUSION RESEARCH PROGRAM
Sandia National Laboratories
June 15, 1989

I. OVERVIEW

Since the announcement of cold fusion in late March by the University of Utah investigators we have carried out an extensive range of research activities at Sandia National Laboratories in an attempt to duplicate those experiments and also to gain evidence for the existence of this phenomenon. The program has focused on experiments of both the University of Utah type, where significant excess heat was reported, and on the Brigham Young University type, where a lower level of fusion reaction was reported. Approximately twenty members of technical staff have been involved, representing expertise in materials science, radiation physics, electrochemistry, solid state physics and metallurgy. We find no evidence for the existence of cold fusion. Remaining investigations are focused on our sensitive calorimetry experiment to search for the production of excess heat at longer operating times.

II. DETECTION SYSTEMS

Three special detection capabilities have been utilized in these studies. First we have set up a multi-detector neutron detection system of ^3He proportional counters and located it underground on Kirtland Air Force Base near our Albuquerque location. This has allowed us to carry out studies with both electrochemical cells and high pressure gas cells with the capability of detecting continuous neutron emissions corresponding to production levels as low as 100 neutrons/hr or bursts as low as 50 neutrons. Not only have these underground experiments allowed us to reduce background levels by three orders of magnitude from aboveground tests, but by correlating the signals from three independent detectors operating simultaneously we have found that we are able to essentially eliminate spurious artifacts which occasionally give false signals in one detector system but not in all three simultaneously. Single-detector artifacts were observed that closely mimic both continuous and burst emissions reported previously as being due to cold fusion.

A second special capability is a closed cycle Freon calorimeter system in which we are performing electrochemical cell experiments. This calorimeter has the advantage of being sensitive to the presence of small amounts of excess heat at high power levels (e.g., 1% at 20 W). Also, the total energy input is monitored from initiation of the experiment. We are presently conducting experiments with palladium electrode volumes >0.8 cm^3 and current densities above 300 mA/cm^2, while taking into account all experimental details proposed to be important by Pons and Fleischmann and by Huggins, but with a much more sensitive and accurate calorimetry system.

Finally we have utilized sensitive charged particle detection in conjunction with thin (25 μm) Pd foils where the foil forms one wall of the electrochemical cell. This approach allows the t+p branch of the D-D fusion reaction to be detected with essentially no background at very large detection efficiencies. The above three detection approaches have allowed us to exceed the sensitivity of the U. of Utah and the BYU experiments.

III. COLD FUSION EXPERIMENTS

A. Electrochemical Cells—(1) U. of Utah of Type: Electrochemical cells designed after the Pons and Fleischmann experiment have been carried out using a wide variety of electrode preparations, size, current densities, and times (up to 45 days). We have searched for the presence of radiation using neutron detectors, tritium by analyzing the electrolyte, and excess heat with our sensitive calorimetry system. We feel these experiments require another 10 to 15 days to exclude the possibility of excess heat generation, since our sensitive calorimetry under large sample volumes and high current densities has only been in operation for about two weeks. (2) BYU Type: Electrochemical cell experiments of the type reported by Jones et al. have been conducted using a wide variety of electrodes including Ti and Pd, immersed in LiOD or the Jones "mother earth" electrolytes. These were carried out under normal laboratory conditions as well as at the high neutron sensitivity underground location. (3) Thin Wall Cell Type: We have also utilized our thin wall cell configuration to obtain an order of magnitude higher sensitivity than in the Jones experiment (for bulk reaction rates within the Pd thin foils). These studies, as well as those of the BYU type, have been carried out for both steady-state and pulsed charging modes to look for cold fusion under highly non-equilibrium conditions.

B. Pressure/Temperature Cycling—We have carried out a wide variety of experiments in which pressure and temperature have been cycled between 1 atm and 4 kbar and between room temperature and 77 K. Materials included Pd powder, Ti powder, sintered Pd-Ti powder of the prescription given by Jones, TiD_2, Ti electrodes soaked in Jones electrolyte, and TiV and Zr shavings. The sensitive underground neutron detection system was used.

C. Plasma Loading—We have conducted experiments in which the atomic deuterium was introduced into Pd powder by plasma loading and the radiation measured by neutron and charged particle detectors. Experiments focused on understanding conditions for minimizing surface recombination and allowed loading ratios of about 0.9 D-Pd to be obtained.

D. Implantation Loading—Direct deuterium ion implantation into Pd and Zr at low substrate temperatures (40 K) were carried out to achieve superstoichiometric conditions. In the case of Pd, for example, we achieved loading ratios of D/Pd ≈1.6, with charged particle detectors used to monitor the t+p branch of the cold fusion reaction.

E. Chemical Assays for Fusion Products—We collaborated with Rockwell International (Canoga Park, CA, 91303) in the search for evidence of ^3He or ^4He fusion products in Pd electrodes from electrochemical cells provided by a number of U.S. laboratories. Measurements at Rockwell's Helium Assay Facility involve vaporizing samples under vacuum, passing all gases through multiple getter stages and measuring the helium concentrations using a precision mass spectrometer that had been calibrated with Pd samples implanted at various ^4He fluences by Sandia. The ultimate detection level is $\sim 1 \times 10^{10}$ helium (^3He or ^4He) atoms per gram of Pd and in no case (including samples from Texas A&M that were reported to exhibit either excess heat, neutron or tritium production) was there any helium product (^3He or ^4He) detected above system background.

In all the above experiments we were unable to find evidence for the presence of any radiation, radiation products, or excess heat which would have indicated the presence of cold fusion. We believe that we have faithfully reproduced the experimental conditions as best known and have a greater sensitivity for the presence of the phenomenon than that reported by the original investigators.

IV. SUPPORTING STUDIES

A. Loading Kinetics of Electrochemical Cells—Two experiments were conducted to better understand the actual loading kinetics of Pd electrodes, since it has been speculated that high D-to-metal loading ratios are important and there have been questions as to the loading times, cell operating conditions and electrolyte conditions under which proper loading may be achieved. In the first experiments thin wall cells were utilized in conjunction with an external ion beam for direct in situ analysis of the D concentration within the Pd metal. Loading dynamics as well as D/H poisoning kinetics were examined. In the second set of experiments the permeation through electrochemical cell thin foils examined the influence of palladium electrode surface preparation on the loading achieved.

B. Deuterium Atom Spacing—Molecular dynamics and total energy band structure calculations were carried out to examine the minimum D-D spacings which would be expected to be achieved. Theoretical consideration was also given to possible closer spacings on the surface of Pd. Even for superstoichiometric D:Pd ratios no evidence for D-D spacings closer than that for the D_2 molecule (about 0.7 Å) was found under the most favorable model conditions, and in all of these studies no evidence was found to predict a sufficiently close spacing as required by the proposed rates for cold fusion.

C. Power Balance Calculations—The assertion by Profs. Fleischmann and Pons of excess energy production is derived from a power balance calculation based ultimately on Newton's Law of Cooling which may not be directly applicable in their situation. They use a submerged resistor to heat the electrolyte solution and assume a constant heat transfer coefficient which in turn is used to calculate the energy loss rate, $k_T \Delta T$, to the surrounding environment. However, total heat loss (especially from evacuated Dewar cells) may be dominated by evaporation of electrolyte which increases exponentially with temperature. Calculations under the assumption of evaporation-dominated heat loss suggest that there is, in actuality, little or no excess energy produced.

V. SUMMARY

In summary we have investigated electrochemical loading, pressure and temperature cycling, and the direct formation of superstoichiometric metal hydrides by implantation for the production of cold fusion. We have found new ways to probe the kinetics of hydrogen isotope loading of electrochemical cells and we anticipate that these may bring research benefits outside cold fusion. We have carried out detailed neutron detection at extremely low rates underground with unexpected spurious continuous and burst signals in helium-3 detectors not previously appreciated. We find multiple detectors provide an excellent way to exclude spurious signals which might otherwise be interpreted as evidence for cold fusion. Finally, we find no evidence to support the existence of cold fusion in any of our studies or to suggest the appropriateness of initiating an extensive program of research in this area.