Department of Energy
Office of Scientific and Technical Information
Post Office Box 62
Oak Ridge, Tennessee 37831

August 10, 2016

Re: OSTI-2016-01064-F

Dear Mr. Ravnitzky:
This is in final response to the request for information you sent to the Department of Energy (DOE), Office of Scientific and Technical Information (OSTI) under the Freedom of Information Act (FOIA), 5 U.S.C. 552 on June 22, 2016.

You requested a "copy of records, electronic, or otherwise, of each letter TO and FROM universities, companies, and organizations, from the OSTI 'cold fusion' documents collection." On July 11, 2016, you were emailed an interim response letter informing you of the need for OSTI to obtain release authorization from the Department of Energy. OSTI received notification to release the letters to you in their entirety on August 8, 2016. As a result, OSTI is releasing 72 cold fusion letters in this mailing on a CD-ROM because of the volume and file size of the PDFs.

In addition, there are approximately 13 letters that are currently being reviewed by the DOE's General Counsel Office (GC) for release or redaction. Upon receipt of guidance from GC, OSTI will release in whole or in part.

This decision, as well as the adequacy of the search, may be appealed within **90** calendar days from your receipt of this letter pursuant to 10 C.F.R. § 1004.8. Appeals should be addressed to Director, Office of Hearings and Appeals, HG-1, L'Enfant Plaza, U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, D.C. 20585-1615. The written appeal, including the envelope, must clearly indicate that a FOIA appeal is being made. You may also submit your appeal to OHA.filings@hq.doe.gov, including the phrase "Freedom of Information Appeal" in the subject line. The appeal must contain all of the elements required by 10 C.F.R. § 1004.8, including a copy of the determination letter. Thereafter, judicial review will be available to you in the Federal District Court either: 1) in the district where you reside; 2) where you have your principal place of business; 3) where DOE's records are situated; or 4) in the District of Columbia.

You may contact OSTI's FOIA Public Liaison, Charlene Luther, Office of Preservation and Technology at 865.576.1138 or by mail at the Department of Energy, Office of Scientific and Technical Information, 1 Science.gov Way, Oak Ridge, TN 37830 for any further assistance and to discuss any aspect of your request. Additionally, you may contact the Office of Government Information Services (OGIS) at the National Archives and Records Administration to inquire about the FOIA mediation services they offer.

The contact information for OGIS is as follows: Office of Government Information Services, National Archives and Records Administration, 8601 Adelphi Road-OGIS, College Park, Maryland 20740-6001, e-mail at ogis@nara.gov; telephone at 202-741-5770; toll free at 1-877-684-6448; or facsimile at 202-741-5769.

If you have any questions about the processing of the request or about this letter, please contact Madelyn M. Wilson at

Sincerely,

Madelyn M. Wilson
FOIA Officer
DOE OSTI
1 Science.gov Way
Oak Ridge, TN 37830

Fib- Cold Fusion

BRIGHAM YOUNG
UNIVERSITY

THE GLORY OF GOD
IS INTELLIGENCE

June 12, 1991

TO: Colleagues researching anomalous nuclear effects in deuterium-charged solids

RE: Proceedings of Provo Conference and Future Meetings

Dear Colleague,

The proceedings of our international workshop on "Anomalous Nuclear Effects in Deuterium/Solid Systems" will be published by the American Institute of Physics soon. The original schedule was for publication in May, but due largely to the unusual length of our proceedings (nearly 1000 pages, representing enthusiastic response to our meeting), publication has been slowed somewhat. Shipment is planned for June 27. If you have already paid the $55 conference-rate for the proceedings, it will be sent directly to you by the AIP. Please recall that the proceedings was not included in the conference registration fee. Until June 26, books can still be ordered at the $55 rate (check payable to S&J Scientific Co.); after that, a higher rate will be charged by the American Institute of Physics. For reference purposes, the following is provided:

> †S E Jones, F Scaramuzzi and D H Worledge *Proceedings of Anomalous Nuclear Effects in Deuterium/Solid Systems* Workshop held 22-24 Oct 1990 Provo, UT (American Institute of Physics, NY, number 228)

A review of our meeting by V. Tsarev and D. Worledge is enclosed; a shorter review will be published in Fusion Technology in July.

At the Provo meeting, a proposal was generated by a committee to hold another meeting on "Nuclear Effects" in about one year and the consensus of the community assembled seemed very favorable to this proposal. Italy, the Soviet Union, China, India and Japan were mentioned as possible locations with October 1991 as a target date, to give sufficient time for research before the next meeting.

There are now at least two meetings which interfere with our plans. ICENES '91 (International Conf. Emerging Nuclear Systems), June 16-21, Monterey, California sponsored by Lawrence Livermore Lab. and numerous research organizations worldwide is a meeting held every two years with a strong interest in catalyzed fusion topics (including muon-catalyzed fusion and "cold" fusion). Proceedings will be published in Fusion Technology

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(editor Prof. G. Miley is one of the ICENES '91 organizers). Shortly after this meeting, the "II Annual Conference on Cold Fusion" is planned for Lake Como, Italy to cover topics of "excess heat, nuclear debris," etc. Various members of the nuclear effects research community will attend one or the other of these meetings; I will attend the ICENES '91 meeting. Still, I hope that we will not lose sight of the decision to re-assemble, expressed by Dr. Scaramuzzi in a widely-transmitted letter in December 1990:

"Those of you who were present at the [Provo] Workshop quoted in the address will remember that in our meeting during the last lunch intermission, on October 24, we reached unanimously the conclusion that the Workshop had been a success, for participation, results and discussion, and that many interesting developments were to be expected in the near future. As a consequence, we all agreed that a second meeting of the same kind was strongly advisable ..." (Franco Scaramuzzi letter, Dec. 17, 1990)
Let us not abandon this plan.

At the Provo meeting, the crucial need to publish solid results in major journals was agreed upon (in addition to Fusion Technology). For example, the BYU/LANL collaboration accepted the invitation given at the meeting by Professor Yoji Totsuka of the University of Tokyo to conduct experiments in the giant Kamiokande detector. These experiments will extend into July 1991 (at least). Others are likewise engaged in crucial experiments that should be published in major scientific journals. Perhaps this should be our first goal, to sufficiently refine our research to merit significant, peer-reviewed journal publication. After this, we should perhaps consider another international research meeting of the kind held in Provo in October 1990.

With best wishes for your research efforts--and publication:

Steven E. Jones

Steven E. Jones
Professor of Physics

Enclosures

BRIGHAM YOUNG
UNIVERSITY

THE GLORY OF GOD
IS INTELLIGENCE

June 7, 1991

Prof. Giuliano Preparata
U. Milano

Dear Giuliano,

I returned recently from further experiments in Japan and found your letter. Thank you.

With regard to the Lake Como meeting later this month, I think that the best service I can give to the nuclear-effects community at this time is to check the effect in the Kamiokande detector then publish the results, whatever they are, in a major journal rather than to attend your meeting. Data will be taken in the giant Kamiokande detector into July at least, with detailed analysis following. I will miss my colleagues there (including yourself). My best regards to all. (I believe that these and other salient reasons have previously been given to you and Dr. Scaramuzzi.)

Please note that Drs. Pons, Fleischmann, and Bockris did not participate in the Provo meeting. I suspect that the two meetings will be quite different. Best wishes for a meeting that helps bring forth the scientific facts of the matter or, from my viewpoint, unrelated matters (heat and nuclear effects).

I sincerely wish that the significance of difficult low-level nuclear measurements not be diminished in the highly-charged atmosphere of "excess heat" claims.

Let us turn to the scienfific question of energy transfer from d-d fusion reactions to a metal lattice. Thank you for responding to my arguments challenging the notion of d+d --> helium-4 + heat to lattice. To summarize my arguments briefly: suppose d-d fusion occurs in a lattice cell, then distance 'a' to lattice constituents is of the order of a few Angstroms. Then $\Delta t \sim a/c \sim 10^{-18}$ sec by the requirement that the speed of light not be exceeded. Then the Heisenberg principle $\Delta E \Delta t \sim h$ allows only a limited amount of energy to be transferred to the lattice without production of real particles such as neutrons or gammas. Using $\Delta t \sim 10^{-18}$ sec deduced above, Heisenberg says only $\Delta E \sim$ KeV can be transferred without realizing particles, orders of magnitude smaller than the energy released by fusion or other nuclear reactions.

You state in your letter: "Let me first acknowledge that if no coherent-collective dynamics is at work in the metal matrix your argument is perfectly sound... However... if the deuterons are in a collective, supperradiant state and are electromagnetically

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coupled to a collective, superradiant state of the d-electrons of Pd, the picture changes drastically. Firstly one cannot say any more where is the fusion process taking place, much in the same way one cannot tell which slit the electron is going through in the classic two-slit experiment. One must add in phase all the possible "fusion paths" and then square the amplitude... To try to dispel somewhat your incredulity I shall mention that similar behaviours are present in well known phenomena such as the Moessbauer effect."

I object, although my 'card' says I am an experimentalist rather than a theorist. Deuterons are heavy and (in this context certainly) slow. Therefore, they are localized: the DeBroglie wavelength $h/\sqrt{2mE_K}$ for ~ 1 eV deuterons is a fraction of an Angstrom. To this extent, we CAN say "where the fusion process is taking place", localized in the lattice where the spacing is a few Angstroms (in Pd, the nearest-neighbor distance is 2.74 Å). On the other hand, a ~ 1 eV electron has $\lambda \sim 10$ Å. Thus, an attempted analogy between deuterons reacting in a lattice and the double-slit experiment for electrons is clearly stretching far.

Can we draw a valid analogy between putative "lattice-heating" nuclear reactions in a lattice and the Mössbauer effect? I think not. First, typical gammas in the Mössbauer effect are of order of a few keV, not MeV, putting us back in the regime of my earlier arguments. (Fe-57* emits a 14.4 keV gamma, for instance.) Second, the excited state of the nucleus emitting the gamma is relatively long-lived: Fe-57* has a finite lifetime of 6.9×10^{-8} seconds. The lifetime of the excited helium-4 nucleus is many orders of magnitude less, and intermediate metastable states of helium-4 are lacking so the energy cannot come out piecemeal. One is dealing here (theoretically) with nuclear interactions (e.g. fusion) with exceedingly short time scales and short distances. Finally, in the Mössbauer effect, "there is no energy transfer to or from the lattice vibrations" (H. J. Lipkin, Annals Physics 9 (1960) 332 -- a very interesting paper to review: "Some simple features of the Mössbauer effect.") By contrast, your superradiance model, as I understand it, allows tens of MeV of energy transfer to the lattice, without production of either primary or secondary gammas or x-rays or other detectable particles. Quite a different picture indeed!

I am enjoying reading your paper: "Theories of 'cold' nuclear fusion: a review."

Ciao and best regards,

Steven E. Jones

Steven E. Jones

cc: Drs. Scaramuzzi, Srinivasan, Will, Close, Bergesen, Menlove, Bertin y Vitale, perhaps a few others

Analysis by graduate Student Guy Larson
June 14th

In lattice-catalyzed low-temperature fusion, there has been "much ado" about the delocalization of the deutrons in the lattice. A number of qualitative analogies have been made to known behaviour of electrons, often completely overlooking the enormous quantitative differences between what might be qualitatively similar electron versus deutron systems - due of course mainly to the almost four orders of magnitude greater mass of the deuteron compared to the electron.

To get a quantitative estimate of the delocalization of the deutron, we first consider its delocalization in D_2 gas, and then find an approximate upper bound for its delocalization in the potential of the lattice.

The Born-Oppenheimer effective internuclear potential for the H_2 molecule is independent of the masses (and thus independent of the isotope(s)) of the hydrogen nuclei. Our results will involve the harmonic oscillator approximation's force constant K, which depends only on the potential (specifically it is the curvature of the potential at its minimum) and is therefore also independent of the isotope(s) of the nuclei.

We can calculate K from the equation

$$2\pi\nu_e = \sqrt{\frac{k}{\mu}} \qquad (1)$$

where μ is the reduced mass of the nuclei and $\frac{1}{2}h\nu_e$ is the harmonic oscillator approximation to the ground state vibrational energy.

Expanding the vibrational energy levels of a diatomic molecu in powers of $(n+\frac{1}{2})$ gives

$$E_n = h\nu_e - h(\nu_e(n+\tfrac{1}{2}) - x_e\nu_e(n+\tfrac{1}{2})^2 + \ldots) \quad (2)$$

For the standard "light" hydrogen (i.e. protonium) molecule,

$$\nu_e = c\cdot(4395.2\,cm^{-1}) = 3.187239\times10^{-3}\,\frac{m_e e^4}{\hbar^3} \quad (3a)$$

and

$$\nu_e x_e = c\cdot(117.90 cm^{-1}) \quad (3b)$$

(D.A. McQuarrie, Quantum Chemistry, University Science Books: Mill Valley, CA 1983. p.454 Table 10-4.)

This gives us a force constant

$$K = (2\pi\nu_e)^2\mu_{p-p} = (2\pi\nu_e)^2(\tfrac{1}{2}m_p) = 0.3681866\,\frac{e^2}{a_o^3} \quad (4)$$

Note that the anharmonic coefficient, $\nu_e x_e$ is very small compared to ν_e:

$$\frac{\nu_e x_e}{\nu_e} = 2.68\cdot10^{-2} \quad (5)$$

This suggests that for small n in the harmonic oscillator approximation

$$E_n \approx h\nu_e(n+\tfrac{1}{2}) \quad (6)$$

for protonium is a good one. (For deuterium it should be even better, because the vibrational energy levels will be even deeper in the potential well, where the potential is more harmonic.)

For the harmonic oscillator wave function

$$\varphi_n(R) = N_2 H_n(\xi) e^{-\frac{\xi^2}{2}} \quad (7)$$

($H_n(\xi)$ is a Hermite polynomial, $\xi = \left(\frac{K\mu}{\hbar^2}\right)^{\frac{1}{4}} x$, and N_n is a normalization constant), the standard deviation σ is [illegible] and

to be (c.f. Ibid, last equation p. 183)

$$\sigma_n \equiv \sqrt{\langle (R-R_e)^2 \rangle} = \left(\frac{\hbar^2 (n+\frac{1}{2})^2}{\mu K} \right)^{\frac{1}{4}} = \sigma_0 \sqrt{2n+1} \tag{8}$$

for D_2 we have

$$\mu = \mu_{d-d} = \frac{1}{2} m_d \doteq m_p \tag{9}$$

which gives us

$$\sigma_0 = 0.13867\, a_0 \tag{10}$$

Even for $n=3$ we still only have

$$\sigma_3 = 0.36689\, a_0 = 0.19415 \text{ Å} \tag{11}$$

which is much smaller than the equilibrium d-d separation in D_2 (i.e. the bond length) of $1.4006\, a_0$ (see e.g. G. Herzberg, J. Mol. Spectroscopy 33, 147 (1970)).

It is simple to show that at room temperature, the vibrational states above $n=3$ will be totally unoccupied for the size of samples used in the experiments that are being performed. (Actually, the total population of all states above $n=0$ will be extremely tiny.)

Statistical mechanics tells us that the fractional population P_m for the state m of a harmonic oscillator is (see ref 1. p. 444 or any statistical mechanics text)

$$P_m = \frac{e^{-\frac{mh\nu}{k_B T}}}{\sum_{j=0}^{\infty} e^{-\frac{jh\nu}{k_B T}}} \tag{12}$$

Summing equation (12) from $m=n+1$ to ∞ gives

$$P(m>n) \equiv \sum_{m=n+1}^{\infty} P_m = \frac{\sum_{m=n+1}^{\infty} e^{-\frac{mh\nu}{k_B T}}}{\sum_{j=0}^{\infty} e^{-\frac{jh\nu}{k_B T}}} = e^{-\frac{(n+1)h\nu}{k_B T}} \quad (13)$$

Substituting $n=3$, $T = 298°K$, and

$$\nu = \nu_{d\text{-}d} = \frac{1}{2\pi}\sqrt{\frac{k}{\mu_{d\text{-}d}}} \quad (14)$$

gives

$$P(m>3) = e^{-60.02} = 8.6 \times 10^{-27}$$
$$= 5.2 \times 10^{-3} \text{ atoms per mole of sample !}$$

– G. Larsen
(BYU)

Los Angeles Times
LOS ANGELES, CALIF.
CIRC 1,400,693

MAY 12 1991
BUSINESS

Perpetual Motion It Isn't

TOO HOT TO HANDLE
The Race for Cold Fusion
By Frank Close
(Princeton University Press: $24.95; xxi pp.) 92-30A

Reviewed by Stephen S. Hall

From the very beginning, cold fusion sounded too good to be true. In March of 1989, two chemists at the University of Utah announced that they had achieved the energy equivalent of alchemy. By running a current through a beaker full of what is known as heavy water, they claimed to have created a physical cell that generated more energy than it consumed.

The announcement was hailed as the discovery of the century, as a triumph of "small science" over big. It promised a cheap and clean source for global energy needs, relief for a polluted planet—even respite from the geopolitical chore of liberating dubious democracies to assure supplies of foreign oil. Reporters chased the scientists as if they were rock stars; patents were hastily filed, and the state of Utah promptly ponied up $4.5 million toward a National Cold Fusion Institute. All they had to do was to confirm the initial claims.

The unraveling of those claims is the heart of "Too Hot to Handle" by Frank Close, a respected theoretical physicist at Oak Ridge National Laboratory in Tennessee and the author of several books about physics. It is a fascinating tale of scientific misadventure that produced what the author calls "the most bizarre 500 days in the history of modern science." In Close's telling, cold fusion was indeed too good to be true.

The allure of fusion, hot or cold, has a long and distinguished history, attracting such certified intellects as Edward Teller and Andrei Sakharov. The idea, simply put, is to force two atoms together, usually hydrogen's "heavy" cousin deuterium, so that the two atomic nuclei fuse. In the process, energy in the form of heat is generated.

Uncontrolled fusion results in a thermonuclear explosion, but if the reaction can be controlled, it promises a sustained source of energy. In one form or another, fusion accounts for the heat of the sun, the destructiveness of nuclear arsenals and multimillion-dollar budgets given to laboratories trying to achieve "hot fusion," in which temperatures as high as 250 million degrees are created in the laboratory to force those reluctant atoms to fuse. Word that fusion could occur at room temperature sparked justifiable frenzy throughout the world.

At the center of the drama were two chemists, Martin Fleischmann of the University of Southampton in England (who consented to an interview with Close) and B. Stanley Pons of the University of Utah (who apparently did not). Fleischmann comes across as a witty and erudite scientist of rootless cosmopolitan, a member of Britain's Royal Society. Pons took a rather more unorthodox route to his 15 minutes of academic fame. Born in North Carolina, he attended graduate school in chemistry at the University of Michigan, but dropped out before completing his Ph.D., and then worked as the manager of a family restaurant for about seven years before returning to academia, where he ultimately became chairman of the chemistry department at the University of Utah.

Both Pons and Fleischmann enjoyed reputations as careful and creative scientists, so when they announced that they had achieved cold fusion, most members of the scientific community presumed they had done their homework and performed the requisite checks. The record unearthed by Close shows they had not.

They had dabbled in cold-fusion experiments without conspicuous success until 1988, when they began to detect a curious excess of heat. At roughly the same time, Pons and Fleischmann became aware that Steven Jones, a physicist at Brigham Young University, had discovered very slight nuclear evidence of cold fusion.

In the best tradition of scientific openness, Jones offered to share information with his Utah colleagues. Pons and Fleischmann, however, accused him of stealing their idea, and then University of Utah officials elbowed in, urging Jones to cancel an invited talk about his cold-fusion results and brokering an awkward truce in which both teams of scientists would meet at the Federal Express office in Salt Lake City on March 24, 1989, and send their manuscripts together to the journal Nature. Without warning Jones ahead of time, the University of Utah then pressured Pons and Fleischmann to hold a press conference on March 23 to obtain patent priority.

With the press conference, the work hit the global airwaves before it had received the most cursory vetting. As "Too Hot to Handle" makes clear, the scientific press conference can also become a form of scientific self-entrapment. Pons and Fleischmann became enamored of the fame, wedded to a shaky thesis, blind to weaknesses in their argument. The ensuing furor brought discredit upon the university, the researchers, cold fusion and science in general.

The flaws were easy to find. Chemical and nuclear reactions, like financial ledgers, must have balanced energy books, and when so momentous a claim as cold fusion was announced, scientific accountants throughout the world immediately began to audit the Utah experiment. If heat is created by fusion, for example, physical laws demand certain amounts of neutrons, tritium and helium to turn up as well. Even as Pons and Fleischmann were lionized at meetings, the initial audits failed to find these other traces in the right amounts. True, researchers at Texas A&M, Georgia Tech and the University of Washington initially reported evidence of cold fusion, but most researchers had difficulty balancing accounts.

When another scientist later asked the Utah researchers if they had performed a simple (and crucial) control experiment with ordinary water, Fleischmann replied, "I'm not prepared to answer that question." Shockingly evasive, that response sent a chill through the entire scientific community.

And still the story grew curiouser and curiouser. Pons and Fleischmann refused to disclose details about the experiment, so resourceful scientists at Caltech and MIT re-created cold-fusion cells on the basis of TV images and diagrams published in newspapers. They found nothing. Texas A&M, Georgia Tech and Washington recanted their confirmations. Nature asked Pons and Fleischmann to revise their manuscript; Pons' latest reply was that he was too busy.

Meanwhile, scientists throughout the world monitored and gossiped about the unfolding drama on an electronic bulletin board, a kind of postmodern Greek chorus commenting upon the impending fall of the two protagonists. Occasional news reports resurrect the idea, but the cold-fusion claims of Pons and Fleischmann, Close concludes, were "based more on enthusiasm than on well-controlled science."

It is a riveting, complex and important story. Close does a workmanlike job of recounting how the saga unfolded, and where the protagonists fouled up. But one never feels the touch of a master storyteller at work, nor of language rising to the occasion of a terrific tale.

There is a disjointed feel to the narrative, with its some repetitions (we are told three times that Caltech's Kellogg lab is named after the cereal magnate). The story is marked by banal scientific explanations, but would have benefited even more from better organization, sharper reporting and more psychological insight.

Close relies on Who's Who for personal details about Pons and Fleischmann. We never really get a sense of who they are, and why they behaved so contrarily to the well-established mores of their profession.

With the recent travails of David Baltimore and colleagues coming on the heels of cold fusion, the public might easily view science as a better refuge than politics for scoundrels. The underlying message of "Too Hot to Handle," however, is quite the opposite. From the March 23 press conference, when Pons and Fleischmann stunned the world, to the May 1 meeting of the American Physical Society, when critics poked large and ultimately fatal holes in the cold-fusion story, it took a mere five or six weeks to get to the bottom of the affair. (If politicians were similarly dedicated to the hasty resolution of important disputes, we would have read April Glaspie's memo from Baghdad months ago).

But truth came at considerable cost to the community: Tremendous expense and countless man-hours were lost debunking work flawed in ways that would be obvious to any well-trained graduate students. As Close reveals, Pons and Fleischmann didn't know the literature; didn't consult more knowledgeable colleagues before going public; and, when the story began to collapse, responded with a defensiveness that can only be termed perverse.

Caltech chemist Nathan Lewis remarked at one point in this sorry affair that the only universities to confirm cold fusion were ones that had winning football teams. Even that claim doesn't hold up: Caltech had a winning record in 1989. Lewis took a lot of flack for the remark, but the NIH, NSF, DOE and other government funding agencies could do worse than adopt the same kind of sanctions that the NCAA doles out to football teams.

If scientific teams announced results at press conferences before the results have undergone the refereeing process of a journal, or if they faced serious peer scrutiny, and those results turned out to be false, funding levels could be cut, scholarships curtailed and no TV crews allowed on campus to report the latest breakthrough that sounds too good to be true. We would have very few sequels, I suspect, to cold fusion. ■

Hall is the author of "Intrusive Frontiers: The Race to Synthesize a Human Gene" (Tempus).

New Results on Cold Nuclear Fusion
(Review of the Conference "Anomalous Nuclear Effects in Deuterium/Solid Systems), Provo, October 1990

V.A. Tsarev* and D.H. Worledge+

***Lebedev Physical Institute of the Academy of Sciences of the U.S.S.R.**
Moscow, USSR
+Electric Power Research Institute, California, USA

A conference entitled "Anomalous Nuclear Effects in Deuterium/Solid Systems", organized by the Electric Power Research Institute (EPRI), the U.S. Department of Energy, and Brigham Young University (BYU) was held from October 22-24, 1990 at Brigham Young University (Provo, Utah, USA).

It was not by accident that BYU was chosen as the venue for the conference on cold nuclear fusion (CNF). It was there that a year and a half earlier that S. Jones' group was the first (independently of M. Fleishmann and S. Pons) to discover neutron emission following the loading of crystal lattices of the transition metals palladium and titanium with deuterium. Thus started the "cold nuclear fusion era".

The Provo conference subtitle "Review of International Progress" was reflected in its participants. Slightly more than 150 participants from 18 countries of America, Europe and Asia were somewhat too large a group for an effective workshop. The conference aroused a great deal of interest and surpassed the expectations of the organizers, who had planned to conduct the conference within only three days. As a result, the conference program, which comprised more than 70 reports, a dozen short communications and a visit to the BYU laboratories, proved to be overcharged. Though the sessions started at 8 AM and finished at 8-10 PM, the conference participants clearly did not have enough time for discussions and meetings.

The main attention at the conference was on experimental work on CNF (more than 50 papers, including 6 reports on geophysical aspects of CNF and 7 on techniques). As distinct from several previous conferences on CNF that had passed in an atmosphere of agitation and exaltation, the conference in Provo was thankfully notable for its calm and efficiency. No reporters or TV staff, so characteristic of earlier CNF conferences, were present.

The conference summed up results of a year and a half of the "cold fusion era" that passed after the first reports in March 1989 which excited the whole world. During that time, CNF survived a period of unbelieveable popularity, associated with hopes

Neutron Detection Experiments

We start with the reports which were most numerous, those dealing with neutron detection.

The group from the Los Alamos National Laboratory (LANL) [3] and Brigham Young University (BYU) [4] continued their research in loading Ti with deuterium from the gas phase. Since April 1990 the experiments were conducted with modified instrumentation and an improved procedure for sample preparation. Use was made of a detector, consisting of two separate rings with 9 and 42 ^{3}He-filled neutron counters, having a total efficiency of about 44% for ^{252}Cf 2.3 Mev neutrons. Background monitoring was conducted by three additional detectors. To reduce the background from radioactive impurities, ^{3}He tubes of stainless steel were used in some experiments. Preamps, directly coupled to the base of the ^{3}He tubes were sealed with desiccant and thoroughly screened against electrical pickup. The measurements were performed on samples of titanium, titanium-based alloys and sponge titanium of total mass up to 300 g monitored for several weeks with multiple cryo-temperature cycles.

In 7 of 9 bottles with D_2/metal samples there was a neutron excess of 3 to 9σ over the background, from frequent small bursts (2-10 neutrons per 128 μs). In an older experimental series [5] of five bottles, three had given a positive result, 2-4 bursts of neutrons with multiplicity of 20-30. Figure 1(a) shows the distribution of bursts versus multiplicity for the earlier measurements with D_2, and Figure 1(b) presents a similar distribution in control experiments with H_2. Of the recent nine bottles 8 gave results above 3σ significance, defined by summing up the measurements of minor bursts (2-10 neutrons) over 24-hour measurement periods. Four of the 9 recent samples were counted with two different detectors which gave closely similar results all above 4σ significance, Fig 2.

The authors point out that, as a rule, the large bursts arrived in the process of warming the samples at a temperature of about -30°C (Fig 3), but this thermal correlation was not strongly apparent in the recent 9 tests with smaller multiplicities, and higher levels of deuteriding.

A few measurements made after the Provo meeting are shown to have produced up to 900 coincidence neutrons, once again in correlation with warming during the cryocycle, this time in an underground tunnel at LANL. These high statistics events gave the correct ratios of counts in the inner and outer detector rings.

S. Jones presented the results of measurements performed by a group [4] from BYU, LANL and Colorado Mountain College in the Black Cloud lead mine of Leadville (Colorado) at a depth of 600 m. Slow neutrons from Pd electrolysis were detected by a set of 16 proportional ^{3}He counters placed into a polyethylene moderator and

of a solution to the problems confronting humanity. Later on, the earlier enthusiasm changed to skepticism, irritation and disbelief not only in energetics, but also in the reality of the phenomenon itself. The reason for this was an overwhelming flow of negative results obtained by different groups and the irreproducibility of almost all the results that became a real curse for experiments on CNF. An additional rather important reason for disbelief in CNF was the absence of any clear understanding of a possible mechanism for this phenomenon. It did not fit the conceptual framework of standard nuclear and solid-state physics.

Both authors have already written of the controversial and dramatic situation with CNF that had arisen by the beginning of 1990 [1,2]. What is the situation now, after the conference in Provo?

The most important conclusion following the conference presentations is that there is now a larger body of quality evidence suggesting the reality of some kind of CNF phenomena. However, the debate is no longer on the initial hope for implementation of a continuous "stationary" process of cold fusion by way of "pumping" hydrogen isotopes through a crystal lattice. The issue is rather one of unusual phenomena, which are sporadic and which, evidently, have little to do with "nuclear fusion" in a classical understanding of this term. This change in the viewpoint was reflected in the conference name which does not contain the usual word-combination "cold nuclear fusion". Confidence in the existence of CNF was felt to be somewhat more solid after the reproducibility of results had been greatly improved in a number of experiments. In some experimental series the reproducibility of positive results was as high as 70-100%.

This success was due to the following factors: a) experiments were conducted with large samples of Pd and Ti having mass up to several hundreds of grams and surface area up to several hundreds of cm^2, which resulted in either a larger total signal or a more frequent signal; b) a higher efficiency of detectors (from 10^{-6} to 10^{-2} in the initial experiments to 30-45% in later ones) allowed the detection of very weak signals and rare events; c) thorough analysis and suppression of background due to the use of materials free from radioactive impurities, employment of both passive and active protection from external noise, work in underground low-background laboratories, (even in a submarine in experiments by Argentine physicists); d) confidence in the positive results is enhanced by the fact that many of the data have been reproduced under different conditions and with the use of quite different techniques; e) some success of the latest experiments was due to the use of different methods for CNF stimulation (effect of pulse current, thermo- and cryo-shocks, "explosive desorption", etc.).

Following are the most interesting experimental results submitted to the conference, considered in greater detail. Theoretical papers, worthy of special discussion, will be mentioned briefly.

separated into four autonomous groups and two separate rings. The general construction and electrical screening closely resembled the Menlove detector. The detector total efficiency was about 34%. Measurements conducted for seven weeks showed that the singles background (conditioned mainly by radioactive decays in the counter walls) remained stable and was about $2.10^{-2}\ s^{-1}$. The background for correlated events was very low; in three weeks only one background event was detected that contained two counts within 128 μs. In the BYU lab the correlated rate is a factor of 70 higher. In the mine, the cells gave periods of neutron activity from 1.5-40 hours in duration. During three weeks of measurements there were five bursts in the time gate of 128 μs with neutron number up to 300. An example of a burst with a high multiplicity is shown in Fig 4.

The 300 neutron burst was produced during manual fracturing of partially deuterided YBaCuO superconductor during warming from liquid nitrogen temperature. Another of the 5 bursts contained 71 neutrons produced during warming of 35 g of Ti662 alloy from liquid nitrogen temperature. More recent data included in the paper show bursts of 4, 6 and 10 neutrons in 10 second bins using a similar detector in the Kamioka mine in Japan, also from YBaCuO cryoshattering. Only a $5X10^{-4}$ probability exists of these multiplicities resulting from the measured Poisson background. There was no sign that the overall neutron burst rate from active samples (about 2 bursts in 150 hours), or multiplicity, differs between surface measurements and those in deep mines.

Jones also reported electrolytic measurements of neutron bursts (multiplicities 35, 121 and 135) from Pd electrolytic cells with 1M Li_2SO4 in D_2O electrolyte in his own laboratory at BYU, during a 3 week run. A neutron singles rate of 0.08/s (source) was also quoted from these cells in one 3-hour period, equal to 28 times the background or 90σ above background, Fig 5. Similar singles emissions from electrolytic cells run by Wolf in the Black Cloud Mine (reported below) and from TiDx samples of Menlove were noted.

In the above experiments background checks and controls were emphasized. For example, the segmented detector was shown to be highly resistant to electronic, acoustic and microphonic pickup. Even ingress of humidity or enormous mechanical shocks gave relations between totals and correlated counts that were in inverse relation to the signature for real neutron bursts. Equivalence between the 4 segments and a correct 2:1 ratio between inner and outer rings were also demanded. Backgrounds were checked to be Poissonian with the correct theoretical and measured inner to outer ratio of 1.3:1. In the electrolytic experiments two 4-week controls were run (H_2O vs. D_2O cell and a D_2O cell with Pd electrode outside) as well as recording concurrent backgrounds using two additional neutron detectors of diverse types.

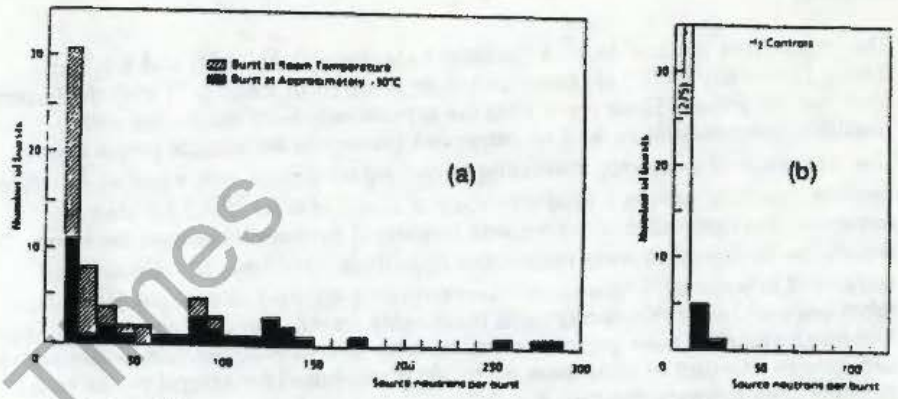

Fig. 1 Number of neutron bursts versus multiplicity, (a) deuterium runs from Ref 5; (b) hydrogen controls

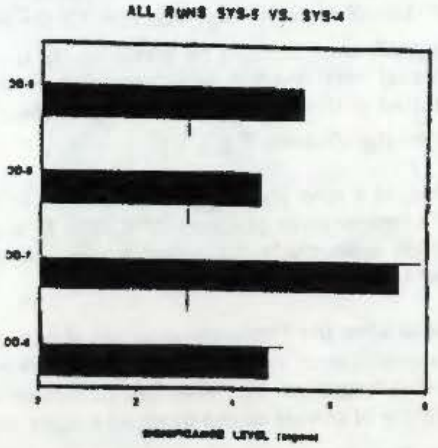

Fig. 2 Significance levels for 4 samples each run with 2 detectors. Ref 3

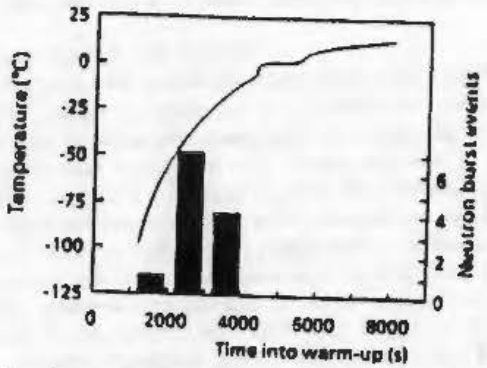

Fig. 3 Number of neutron bursts versus time and temperature. Ref 3

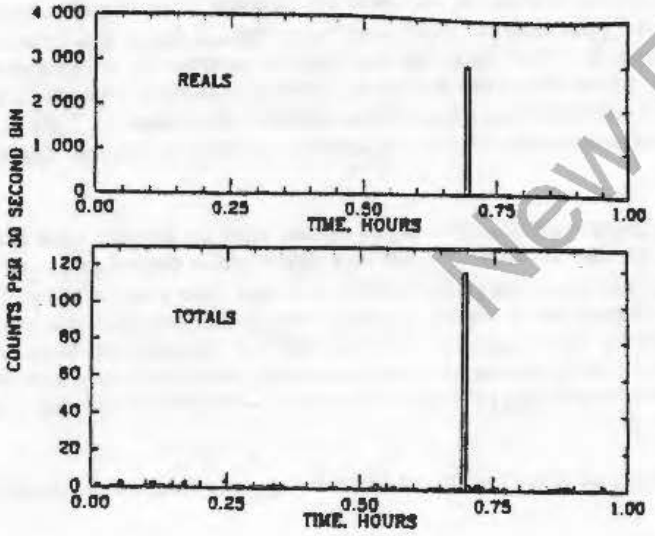

Fig. 4 A high multiplicity neutron burst at BYU. Ref 4.

The authors underlined, that the use of these measures in combination with suppression of the cosmic ray background allowed them to substantially improve the reliability of measurements.

K. Wolf of the Texas A&M University Cyclotron Institute [6] reported neutron emission from Pd electrolytic cells in an expanded effort, following his earlier report [7] of up to 0.8n/sec (source), Fig 6, from one sample of Pd of 20, in three different cells. That electrode was a rod only 0.03 cm^3 in volume. Five new cells each with about 0.6 cm^3 volume, together produced singles neutrons on several occasions at 3-4 times the background (about 7σ) for periods of about 3 hours, both an hour or two after starting loading at ~20ma/cm^2 and also an hour or two after current density increases by a factor of two after appreciable loading with deuterium, Fig 7. The singles (source) rate was 0.5 n/sec. The detection system for the above consisted of a proton recoil detector using two types of pulse shape discrimination simultaneously, plastic cosmic veto detectors set to reject electronic noise pickup as well as the charged cosmic component, and a noise rejection antenna at the electronics racks. A second identical detector under the same cosmic shield with a dummy cell using the same amount of Pd and D_2O, and correlated event by event with the active cell detector, produced simultaneous background measurements. In each case the energy spectrum was analyzed, the active cell giving a peak as expected for 2.5 MeV neutrons but with no such structure in the background.
Similar results were obtained in the Black Cloud Mine using a Menlove-type thermal neutron detector with just 3 of the 5 cells, giving a result of 4-5σ significance. In this situation the cosmic contribution was essentially eliminated as described previously, the neutron signal appeared approximately as predicted in time, and endured for about the same period as previous emissions from these cells.

Verification of the earlier results with the totally diverse Menlove detector, in a different laboratory far underground, adds considerably to the confidence in these measurements. Wolf also points out that his results are similar to those of Arata [8] where the electrode was large, charged at low current density, gave neutrons early in the charging (as also results from BARC), and with signal regeneration after cleaning of the electrode surface. Experiments on signal enhancements, triggering and scaling are continuing.

A program of studies on CNF is underway at the Bhabha Atomic Research Center, India (BARC). During 1989 and 1990, 12 independent groups had conducted experiments with electrolytic and gaseous loading of Pd and Ti [9, 10, 11]. Because new results were reported on tritium (see later) brief mention is made below of the previous neutron results from these groups so that their reports of anomalous tritium to neutron ratios can be seen in perspective. Although little processing was done on the neutron signals, the high signal to background ratios, and semi-quantitative agreement between different types of detectors run concurrently in

some experiments, made these results important during the early part of the CNF era.

In 11 different electrolytic experiments with cathodes of 0.1-300 cm^2 area, strong bursts of neutrons were observed. Some of these are shown in Fig 8a through 8c. Fig 8a shows correlation between two different types of detector; Figs 8b and 8c show correlation between neutrons and tritium. The first bursts of neutrons (and tritium) were observed, as a rule, after a charge of several ampere-hours (from 0.6 - 3.2 A.hour/cm^2) had passed across a cell. Emissions of neutrons were also detected in experiments with loading D_2 from the gas phase and with subsequent thermal cycling.

The characteristic number of neutrons detected in various experiments was in the range of 10^6 to 10^7 . In most cases neutrons were emitted for each of the targets in the form of a single high burst with intensity exceeding the background by 30-1000 times. After some time the neutron emission became attenuated and stopped. It seems that, irrespective of the sample form, the integral neutron yield per unit area of the sample surface was approximately the same and in the range of 10^4 to 10^5 /cm^2 .The total fraction of "successful" experiments on detecting neutrons in the BARC work is about 70%. Their results are presented in Table 1.

Soon after the first electrolytic experiments on CNF were carried out in the USA, experiments were conducted in Frascati, Italy, under the direction of F Scaramuzzi, with the first use of the gas loading technique in CNF [12]. In that work strong neutron bursts were detected for the first time. Such techniques have been widely practiced in later experiments on CNF, as described above.

To address the lack of reproducibility in these experiments, Fig 9, (as in all the others), the Scaramuzzi group performed a thorough review of their experiments of the "first generation" to make sure the effects revealed by them were valid. The results of this analysis and the detector performance data of the "second generation" experiment with an improved Menlove-style, segmented detector for detecting neutrons (and with analysis for tritium) were presented at the conference [13]. The authors' main conclusions were as follows: a) a critical check of the data from the initial measurements confirmed their reasonableness; b) in new experiments with the well detector rare multiplicities as high as 30 were seen in the sea level background (as noted by Menlove), but in the Gran Sasso tunnel, with lower residual activity ^3He tubes, the background totals count, integrated to 25 MeV, is 1000 times lower than at the surface.

Neutron bursts were also detected by a group from the China Institute of Atomic Energy (Beijing) [14], who conducted some of their measurements in an underground laboratory at a depth of 580m. Their experiments used a ^3He well detector with 18 tubes (20% efficiency) and a well-designed experiment sequence to attempt to verify Menlove's results. The group initially found noise coincidence

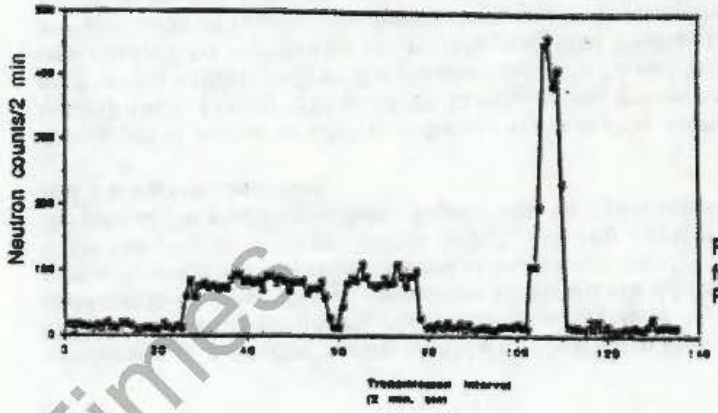

Fig. 5 90 σ neutron signa from a Pd electrolytic cell. Ref 4

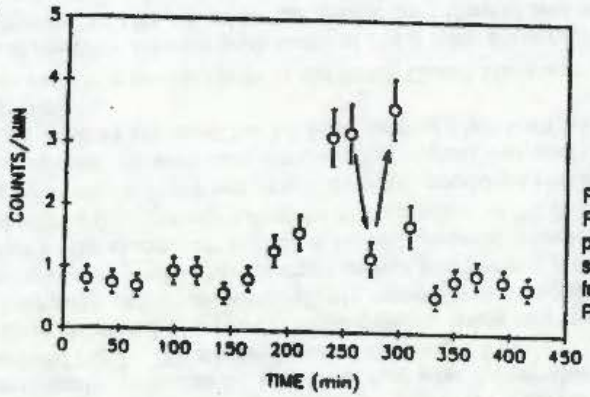

Fig. 6 Neutrons from Wolf's Pd cell at Texas A&M using proton recoil detector. Arrow shows effect of moving cell aw from detector and back again. Ref 7

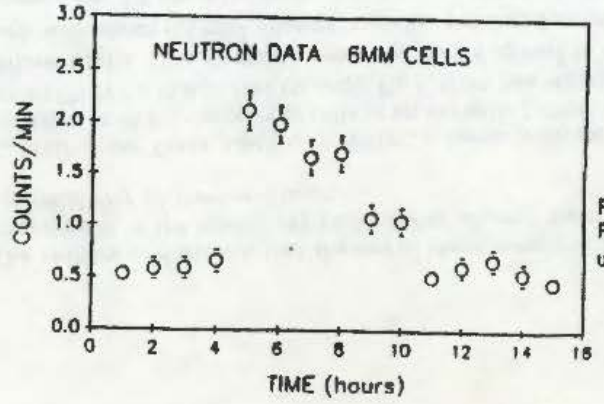

Fig. 7 Neutrons from Wolf's Pd cells in Black Cloud mine using ^3He well detector. Ref 6

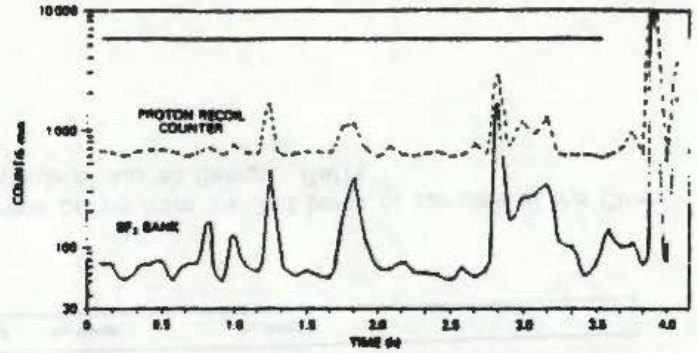

Fig. 8a Correlation between two different detectors at BARC. Ref 9

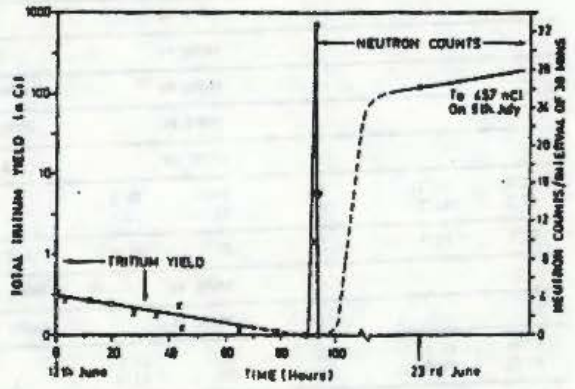

Fig. 8b Increase in tritium yield after neutron emission during Pd electrolysis

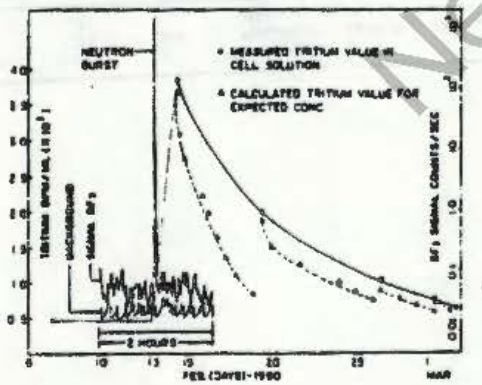

Fig. 8c Increase in tritium yield after neutron emission during Pd electrolysis

TABLE I : SUMMARY OF ELECTROLYSIS EXPERIMENTS WITH NEUTRON AND TRITIUM GENERATION

Sr. No.	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
Division	DD/ BWD NiPD	NiPD/ BWD	NiPD/ BWD	DD/ BWD NiPD	BWD/ NiPD	AsCD	ROMG	ROMG	AsCD	AsCD	IGCAR
Cell (Name)	Ti-SS	MR-1	MR-2	6 Module	Par. Plate	PDC-1	RCS-11	RCS-10	Nafion-1	Nafion-2	RCP-II
Date	1989 21 May	1989 21 April	1989 12-16 Jun	1989 5 May	1990 15 March	1989 21 April	1989 June-Aug	1990 Jan-Apr.	1989 July	1990 Feb	1989 Dec
Cathode: Material	Ti Rod	Pd-Ag Tubes	Pd-Ag Tubes	Pd-Ag Discs (6)	Pd Plate	Pd Hollow Cyl.	Pd Cube	Pd Pellets	Pd Ring	Pd Coil	Pd Bottom
Geometry	22 φ x 150 Long	- 3 x 4 x - 200 M		115 φ x 0.1 thk	40 x 50 x 1 thk	-	1 cm³	11 φ x 11.2 ht.	250 x 10 ht x 1 thk	1 φ x 140 long	-
Dimension (in mm)	104			78	20	5.8	6	6.7	15	4	6
Area (Cm²)		300	200								
Anode	S.S. Pipe	Ni-Pipe	Ni-Pipe	Porous-Ni	Ti Plate	Pt Mesh	Pt Mesh	Pt Mesh	Pt Mesh	Pt Mesh	Pt Mesh
Electrolyte	NaOD (5M) 250	NaOD (5M) 250	NaOD (5M) 250	NaOD (5M) 1000	NaOD (5M) 200	LiOD (0.1 M) 45	LiOD (0.1 M) 150	LiOD (0.1 M) 120	LiOD (0.1 M) 250	Li_2SO_4 (0.1 M) 140	LiOD (0.1 M) -
Volume (ml)	125										
Current Density (mA/cm²)	5400	~300	~300	~800	~200	5340	~100	~700	~60	~60	<100
Switching On: Charge ($\frac{A-hrs}{cm^2}$)	1.2	0.6	–	3.2	0.8	3.0	2.5	650	34	0.15	36.7
Time (hrs)	3	6	0.5	4	4	8	24	930	330	3	300
Active Life	Few hrs	~3.5 hrs	~2 hrs	53 mins	<1 min	~6 hrs	~5 d	~100 sec	~40 hrs	~5 d	8 hrs
Neutron Yield: No. of Bursts	Continuous	8	1	1	1	3	17	1	Many	Many	2
Total n/cm²	$3x10^7$ $2.8x10^8$	$4x10^7$ $1.7x10^9$	$9x10^7$ $1.3x10^{10}$	$5x10^8$ $1.3x10^{10}$	$1x10^8$ $5x10^8$	$3x10^4$ $5x10^4$	$1.6x10^6$ $2.3x10^6$	$3x10^4$ $5.2x10^4$	$5.8x10^8$ 10^7	$5.8x10^8$ $1.3x10^9$	$2.4x10^{10}$ $3x10^{10}$
Tritium Yield: Total (Bq)	$2.6x10^6$	$1.5x10^7$	$3.8x10^6$	$7x10^6$	–	$1.42x10^5$	$1.3x10^5$	$7.7x10^5$	225	22.5	$6.3x10^6$
Total (Atoms)	$1.6x10^{16}$	$8x10^{16}$	$1.9x10^{16}$	$4x10^{16}$	–	$7.2x10^{13}$	$6.7x10^{13}$	$4x10^{13}$	$1.8x10^{16}$	$1.8x10^{16}$	$3.5x10^{17}$
t/cm²	$1.3x10^{-23}$	$2.7x10^{-22}$	$6x10^{-23}$	10^{-22}	–	$1.2x10^{-23}$	$1.1x10^{-23}$	$5.2x10^{-23}$	$1x10^{-22}$	$4x10^{-23}$	$4.6x10^{-23}$
(n/t) Ratio	$2x10^{-7}$	$0.5x10^{-6}$	$0.5x10^{-6}$	$1.2x10^{-6}$	–	$4x10^{-6}$	$1.7x10^{-6}$	10^{-6}	10^{-6}	$3.2x10^{-6}$	$7x10^{-7}$

NUMBER OF BOTTLES: 3
MATERIAL: TAI TURNING
TOTAL AMOUNT: 270 GRAMS
PRESSURE: 30 ATM

BEGINING DATE M/D/Y	TIME	NUMBER OF CYCLE	RUN TIME (h)	E+A	NUMBER OF NEUTRON (n)	(n+b)/h	n/σ_n
4/4/90-4/10/90		background		no burst			
4/10/90	15:54	1	1.31 2.36	49 1123	34 221	2.82 12.96	6.71 44.13
4/11/90	9:10	2	0.14 3.47	583 2191	144 386	9.58 24.15	24.80 58.26
4/11/90	18:04	E_a Dummy		no burst			
4/12/90	9:30	E_a Dummy		no burst			
4/12/90	18:00	3	4.58	18	15	1.84	3.11
4/13/90	9:30	4	1.53 2.92	51 1948	51 482	3.78 27.84	6.00 74.36
4/13/90	18:00	5		no burst			
4/14/90	8:50	E_a Dummy		no burst			
4/14/90	15.40	E_a Dummy		no burst			
4/15/90	9:40	6		no burst			
4/15/90	18:00	7		no burst			
4/16/90	9:40	8		no burst			
4/16/90	18:00	E_a Dummy		no burst			
4/17/90	9:15	E_a Dummy		no burst			

Table 2 Neutron bursts from the 2nd batch of samples at the China Institute of Atomic Energy. Ref14

counts from humid air but not from microphonic pickup. Fast preamps, directly coupled to the ^{3}He tubes and fully screened against electronic pickup were used. Desiccant in the battery-powered HV compartments, and room temperature and humidity controls reduced the humidity so that 11 runs with H_2 dummy cells, mostly interspersed between cryocycles of D_2 runs gave no bursts at all. Backgrounds were run for at least two days for each batch of material prepared.

In 7 of 10 cylinders, filled with a mixture of Ti and D_2, neutron bursts occurred at temperatures from -100°C to room temperature. In the first four cryocycles of a typical batch of material 7 bursts were observed with neutron number from 15 to 482, which exceeded the background level (based on 1000 sec) by 3 to 75 times (background was $5X10^{-3}$ coincidences/s at the surface but essentially zero at depth), Table 2. The total number of bursts was 23 from 4 batches described in detail, with from 15-536 neutrons per burst. As with Menlove's results, a sample would become inactive on repeated cryocycles after producing bursts in the first few cycles. Reactivation (degassing and reprocessing of chips) gave diminished frequency and intensity of bursts. This pattern of results from an independent investigation constitutes a verification of the LANL results. The same group failed to detect neutrons from Pd electrolytic cells.

A rate increase using ^{3}He-detectors was also registered by a group [15] from the University "La Sapienza", Rome, in electrolysis with a palladium electrode, although, the authors believe this could be due to electronic pickup or some false effects (for example, due to mechanoemission [1]).

Registration of bursts of γ-quanta by the group from Frascati, who conducted electrolytic saturation of Pd and Ti with deuterium in the underground Gran Sasso laboratory, was reported by F. Celani [16]. The same report contained new data on the search for neutron emission following gaseous loading of high-temperature superconducting materials of $Y_1Ba_2Cu_3O_{7-x}$ type with deuterium. Samples of 6-8 g mass were subjected to a complex series of cryo and pressure cycles. The group used ^{3}He-type detectors with efficiency only 0.6%. During the first thermal cycle (~1 hour) there was a rise in neutron emission to about 10 counts (with background about 1 c/hour i.e., signal of 1666 n/h with the background 166n/h. In the subsequent cycles the excess emission decreased and completely vanished after the tenth cycle.

Granada and his team from the Argentine National Atomic Energy Commission reported [17] small neutron enhancements (less than two times background) as well as many negative results during current cycling Pd electrolytic cells, observed with a 22% efficient detector (18 ^{3}He tubes connected in 3 groups with "only 1 of 3" anticoincidence logic in a 2μs gate). Precautions were taken against electronic and microphonic noise and humidity. Backgrounds were run with H_2O, but not simultaneously with D_2O runs. Integrated average counts over 68 additional runs

on three cells, conducted at 50m depth in a conventional submarine, yielded a 40% (3σ) increase over background. The enhancements always seemed to be associated with high D loading and high concentration gradients in the cathodes. The authors state that the deuterium diffusion length over the cycle time of ~90 seconds would indicate only a small effective volume for nuclear reaction rate calculations.

Another interesting observation was made by a group from Weber State University [18]. In two experiments with deuterium gas loaded Pd two neutron bursts were registered in the first experiment. A rise in the neutron emission level occurred for almost 10 days in the second. No increased activity was found in a long experiment using hydrogen, nor in separate background runs. The bursts were highly non-Poissonian. An increase in the sample resistance was observed, as well as a pressure increase, coinciding with one of the high neutron bursts ~3000 n/hr (source), Fig 10. The possibility of such changes in conductivity, connected with the formation of unstable hydride phases, has been predicted by the LPI-LMI group [1].

Results were reported by Takahashi [19] from the University of Osaka, who also detected neutrons in pulsed electrolysis using an NE213 liquid-scintillation spectrometer with pulse shape discrimination between neutrons and gammas, as well as a ^{3}He detector. In addition to 2.45 MeV neutrons there appeared groups in the range 3 to 7 MeV, Fig 11. Maximum count rates were two to three times the backgrounds measured using a Pd cell with no electrolysis and a cell with no Pd.

An indication of a possible initiation of CNF reactions in chemical reactions was first obtained in experiments conducted [20] at the Institute of Nuclear Physics of the Academy of Sciences of the USSR, Novosibirsk. A brief communication to that effect was delivered by M. Danos who had visited the Institute shortly before the conference. In dissolving crystals of LiD in D_2O accompanied by heating up to 70 to 80^{0}C, the neutron count rate was found to increase to 1.70± 0.14 times the background. A similar effect was discovered in exothermic interactions of deuterated complex salts of Pd and Pt with zinc. Although the appearance of neutrons from a chemical reaction is astonishing, the experiment used a Menlove-style screened detector in a low-background subterranean laboratory. The results were fairly reproducible, Fig 12.

Vysotski and Kuz'min of Kiev and Moscow State Universities reported [21] neutron emission from Ti and Pd electrolytic cells using two neutron detectors (Zn S(Ag) scintillation type and ^{3}He tubes) with overall efficiencies 1 to 10%. Care was taken to measure backgrounds before and after each run using the same detector, and also continuously during the runs with a similar detection 10m away. Controls with H_2O and without any water agreed with the background although the latter could vary by a factor of two from day to day. Large plate electrodes gave neutron enhancements of up to 4 times background in about a dozen runs, the signals appearing soon after the start of electrolysis and often being correlated with warming or cooling of the electrolyte, Fig 13a. In one run involving both H and D, a

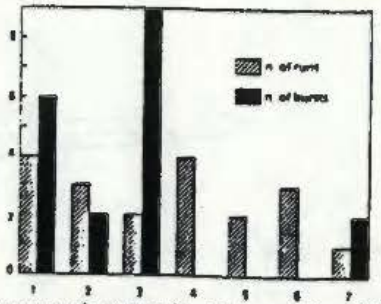

Fig. 9a Number of runs and neutron bursts in a series of Frascatti experiments. Ref 13

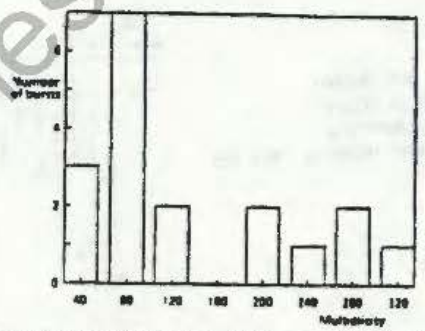

Fig. 9b Number of bursts versus neutron multiplicity in Frascatti experiments

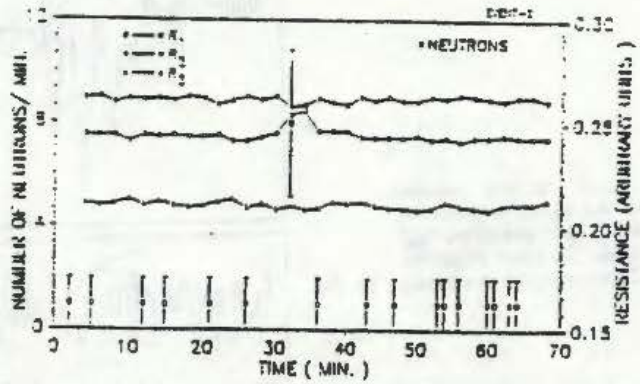

Fig. 10 Neutron count rate and resistance in second neutron burst at Weber State. Ref18

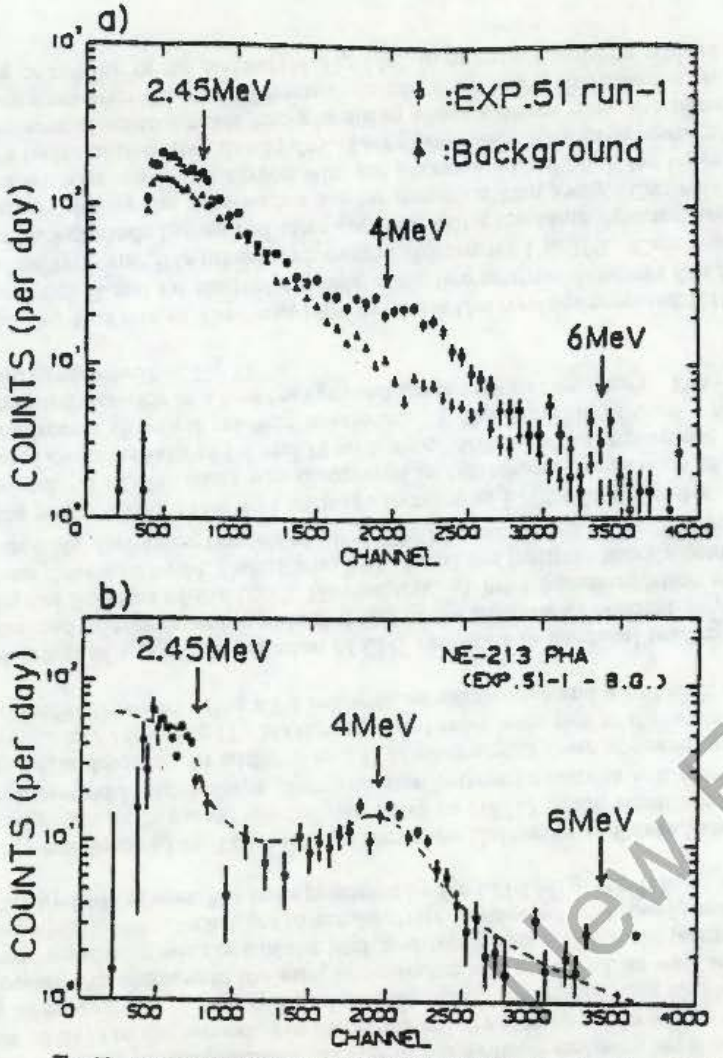

Fig. 11 Recoil proton spectra by NE213 detector, for Exp.51-run1; Ref 19
(a) comparison of raw pulse height spectra between foreground and background runs.
(b) recoil proton spectrum for excess neutron counts.

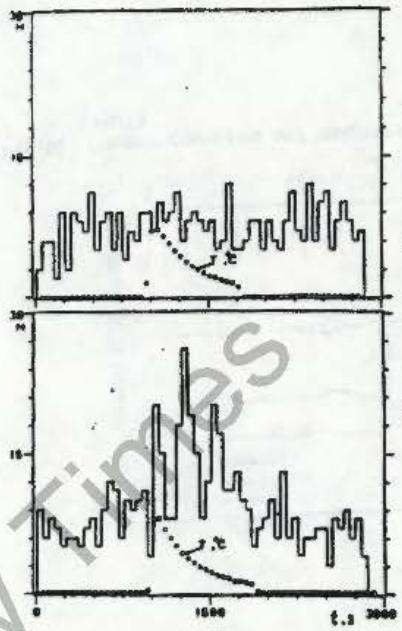

Fig. 12 Neutron count rate during Redox reactions using (A), hydrogen salts, (B), deuterium salts. Elevated temperature marks the period of reaction. Ref 20.

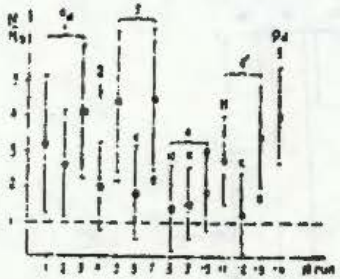

Fig 13a Neutron count ratio to background for Pd cells (runs 1-3,14) and Ti cells (runs 4-13). H stands for heating (to 90C), K for boiling, and O for current.off. Ref 21.

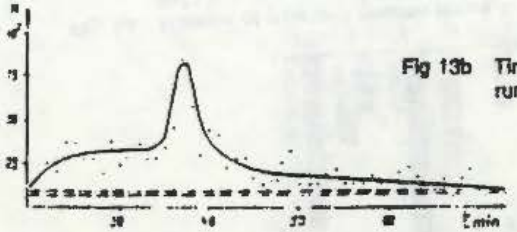

Fig 13b Time trace of neutron count rate in one run.

peak intensity of 7.5 times background was found, Fig 13b. Most of the neutron emissions lasted 10 to 20 minutes.

A group from the University of Manitoba, headed by McKee, reported [22] possibly anomalous emission of neutrons from Pd and Ti targets during implantation to very high loadings (~2×10^{31} m^{-3}) with 60KeV D^+ and 30KeV D_2^+. Whether the neutrons observed were due to normal hot fusion was not resolved.

Work of the LPI-LMI-LSU group [23] is mainly reported under the section dealing with correlation experiments, but their neutron results are mentioned here. During the first six hours of electrolysis ($Pd/LiClO_4$ cells with 13g cathode), a series of 6 small neutron bursts was observed, each containing 10 to 100 neutrons (about 100 times background), and each lasting about one minute . Fast and slow neutron coincidences were required (within 10 to 100 μs). Backgrounds were run with the same materials but no current, with a nickel cathode in the same electrolyte, and nickel with H_2O-based electrolyte. Other low statistic events were reported (below), involving triple and ternary coincidences between neutrons, protons, acoustic and electromagnetic signals. In the Baksan underground neutrino observatory, a doubling of the neutron count rate was experienced 5 hours after the start of electrolysis [24], somewhat similar to Jone's and Wolf's results. 42 neutron counts were recorded in delayed coincidence with acoustic start pulses. Fig 14 shows moderating time distributions as evidence of real neutrons coming from the central cell.

It should be noted that in the experiments conducted by the LPI-LMI-LSU group, as well as by the group from the University of Osaka , by the Argentine group from the Central Atomico Bariloche, and by the Italian group from the University La Sapienza, a correlation effect with time-dependent electrolysis current, predicted earlier by the LPI-LMI group [1], was observed.

Along with reports containing positive results, there were four communications on experiments that failed to observe any neutron emission at all.

R. Anderson (LANL) reported [25] the results of measurements of integral neutron yield, spectroscopic measurements and a search for neutron bursts. Neutron excess was not found either in experiments with electrolysis or with gaseous loading. A thorough comparison of neutron background performed by the authors both at ground level and in an underground room (at 15 m depth), with empty detectors and with those having different fillings, gave results similar to the effects associated with CNF signals. In particular, in the integral neutron spectrum fluctuations were detected at the level of 3σ to 7σ. In the background neutron spectrum a weak peak was observed at energy ~2.5 MeV. Additionally, some events were observed with a high neutron multiplicity (mostly <30n, but also 22 events >30n at the surface with a lead brick in the detector, compared to only one event underground) due to the cosmic ray background, Fig 15. An important lesson of this work is the necessity of a thorough check of detector operation and background level in experiments on CNF.

A group from Oregon State University (USA) [26], in the process of a 40-weeks' electrolysis of heavy water, observed 7 instances of temperature rise not accompanied by a rise of neutron intensity, γ-quanta or tritium concentration. The authors stated that the thermal effects were caused merely by electrochemical effects.

No positive results were obtained also by a group from Eötvös University (Hungary) [27] who had attempted to detect excess neutrons and γ-quanta during electrolytic deuteration of the amorphous alloy $Fe_{90}Zr_{10}$, since this alloy possesses a high hydrogen adsorptivity and had not been used previously in experiments on CNF.

Mention should also be made of negative results on neutron detection in electrolytic and gaseous charging of Pd and Ti obtained by a group from the Joint Institute for Nuclear Research (JINR), Dubna [28] which, however, were not reported owing to the absence of the authors.

Charged Particle Detection

As is well known, detection of energetic charged products of nuclear fusion (p, t, ^3He) in experiments on CNF is greatly hindered by the very short particle paths in both samples and detectors. That is why until recently there were only a handful of papers on the search for charged products of CNF, mostly containing negative results [1,2]. In contrast, at the conference in Provo surprisingly many papers (7) were presented which contained positive results on charged particles, mainly protons.

Mention should first be made of the work of Cecil at the Colorado School of Mines [29] (USA), who, for the first time, had observed a whole series of intense bursts of charged particles (up to 10^3 s^{-1}) emitted from deuterated foils of Ti662 alloy. During 56 days of measurements 24 bursts were detected in 12 samples out of 26. The activity was initiated during thermal cycling in the range of -180°C to room temperature, Fig 16. Measurements performed with the use of silicon surface-barrier detectors and thin aluminium degrading foils made it possible to infer that the particles were most likely tritons or ^3He with a maximum energy of ~10 MeV. In eight foils saturated with hydrogen, analogous bursts were not observed in seven days of measurements. Since October 1990, however, Cecil has been unable to reproduce the particle bursts.

Cecil's work was inspired by earlier reports from Chambers of the Naval Research Laboratory, that ion implantation of ~350 ev to 1Kev deuterons into Ti produced rare bursts of intense charged particles. Chambers reported [30] that bursts of what appeared to be 5 MeV tritons had appeared 4 times in 9 experiments, at rates of order 10-30 events/second for two to five minutes, Fig 18. The spectra showed a distinct

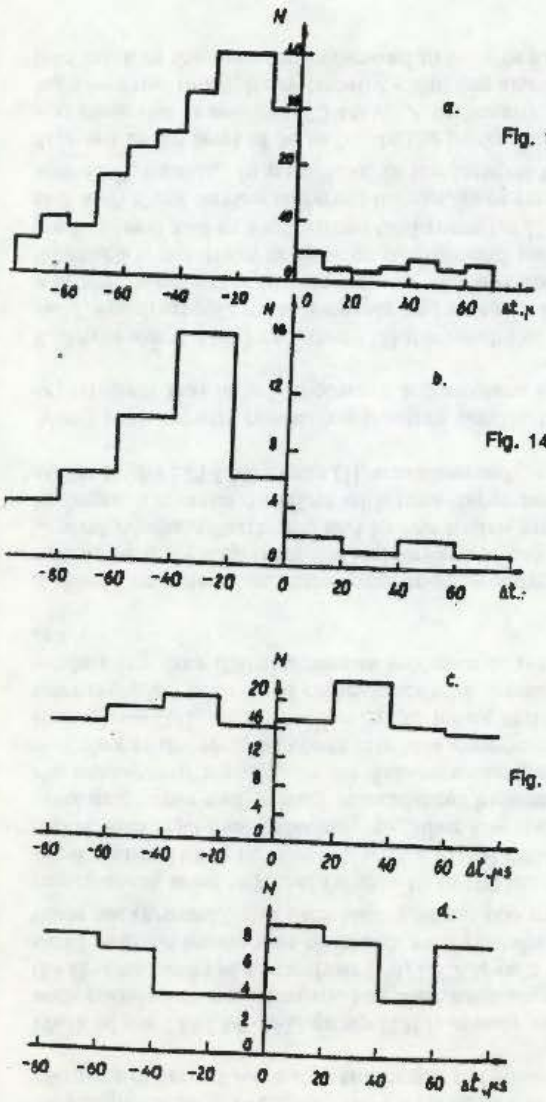

Fig. 14a Neutron moderation times for ^{252}Cf using proton recoil start signal. Ref 24.

Fig. 14b Neutron moderation times with Pd electrode and delayed acoustic start signal.

Fig. 14c Data of Fig.14b with start signal generated by ^{252}Cf neutrons.

Fig. 14d Data of Fig.14b with start signal generated by "hand".

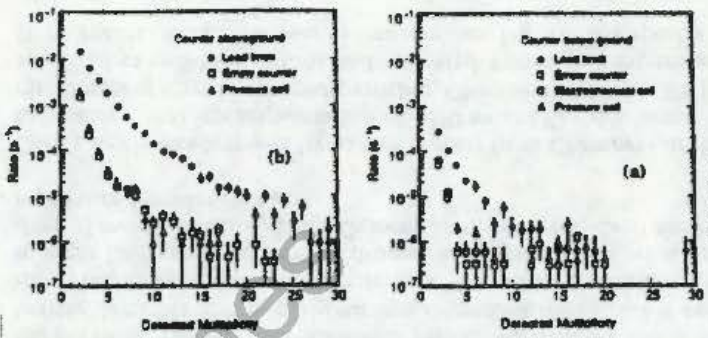

Fig. 15 High multiplicity neutron events from Ref 25; (a) below ground, (b) above ground.

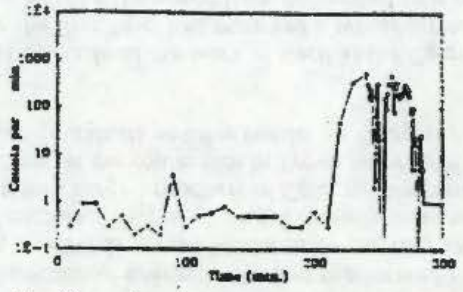

Fig. 16 Charged particle activity over time from Ref 29.

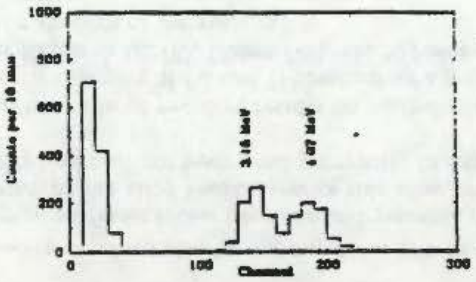

Fig. 17 Energy spectrum of charged particle burst with energy degrading foil over part of detector aperture. Ref 29.

energy for each burst, with well shaped pulses and energy peaks. One experiment with poor statistics showed a split energy peak after an energy-degrading foil was inserted to cover part of the detector aperture, with the energy loss consistent with tritons.

Cecil's experiments showed similar results with higher peak rates, and an apparent correlation, or triggering, using cryocooling and warming cycles, accounting perhaps, for a larger number of shorter experiments and more particle bursts. It is interesting to note that all bursts observed in Cecil's work when using the part-aperture degrading foil technique (15 bursts), produced double energy peaks, Fig 17. The sudden appearance and cessation of the particles in both group's work, and the good energy definition (~ 600 Kev) for each burst, suggest a very small local site for the nuclear reactions that produced them, and therefore reaction rates several orders of magnitude larger than the neutron emission rate published by Jones.

Chambers and Cecil pointed out that these two sets of experiments were not at all definitive, and, moreover, claim emission of particles at energies that can not be accounted for at all by conventional d + d reactions. Contrary evidence was presented by Wolf of Texas A&M University. In his experiment Wolf deuterated titanium foils specifically to imitate Cecil's procedure. The foils were placed in a high vacuum and cooled down to liquid nitrogen temperature. This was followed by a warming cycle for 24 hours. In each series two samples of about 300 mm^2 area were used. They were viewed by silicon semiconductor detectors constituting an active, high efficiency, particle identification system. In many samples, each subjected to thermal cycling four times, no emission of single-charged particles was observed. The background was defined mainly by α- particles from radioactive decays.

Jones described [31] a new large area particle detector consisting of a thin plastic scintillator bonded to a thick glass scintillator. The detector could be run in conjunction with a neutron spectrometer using a fast waveform digitizer and event storage for off-line analysis. After elimination of cosmic (anticoincidence with neutron detector) and radon decay backgrounds, and using deuterium-charged Pd foils, several episodes of charged particle emission were detected at rates similar to the Jones' neutron rate, and at energies in the range of 2.3 - 3.0 MeV if they were protons, to 4 MeV if d or t, and to 8 MeV if alphas. The spectra show clear peaks, Fig 19, relatively free of background (signal to noise ratio was ~35). Having 1% neutron efficiency in relation to 50% particle efficiency (2π) meant that any coincident neutrons could not be seen against the background at sea level. No enhancements were seen with equivalent exposures of hydrated foils, nor with TiDx foils.

In the experiments of three other groups: LPI-LMI (Golubnichi) [23], Osaka University (Takahashi) [19], and Tsinghua University (Li) [32], searches were made for correlation between proton emission and electromagnetic radiation. The groups

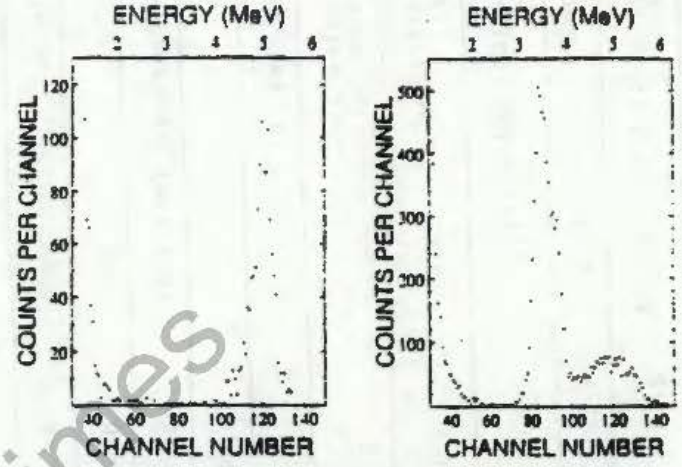

Fig. 18 Spectra acquired after 40 minutes of 350 eV deuterium bombardment of a 1-μm thick titanium film evaporated onto 500 nm gold on a 3.8 μm thick nickel foil. The spectral peak, centered at 5 MeV, occurred during two approximately minute long bursts and consists of over 1100 counts. (b). Spectra acquired after 5 minutes of 350 eV deuterium bombardment of a 1-μm thick titanium film evaporated onto a 3.8 μm thick nickel foil, during a five minute long burst. The double peaks are due to the changing of detector bias voltage form -200 volts to zero and back to -200 volts again during the reaction. The spectrum consists of over 8000 counts. Ref 30.

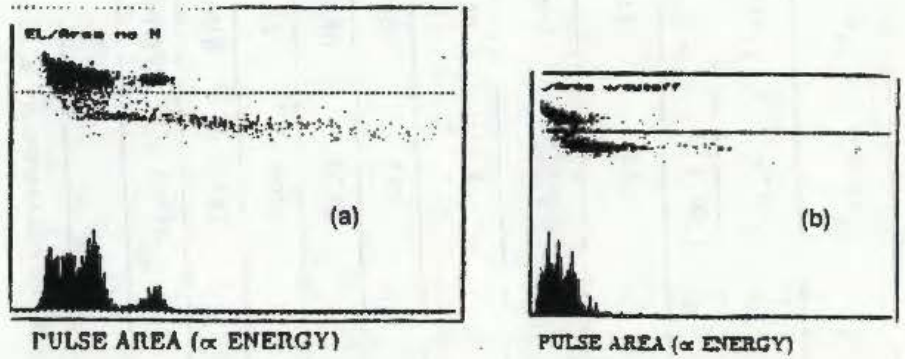

Fig. 19 Charged particle energy spectra from Ref 31. showing peak in test sample (a) not appearing in the background.(b).

Table 3 Detection of tritium during electrolysis in the Bhabha Atomic Research Centre

xperiment No.	1	2	3	4	5	6	7	8	9	10	11
ıthode material	Pd-Ag	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	
ırface area (cm^2)	113	113	19	14.5	6.37	6.37	6.37	2.75	0.57	0.126	4
lectrolyte volume (ml)	150	150	150	65	60	100	80	80	20	3	1.5
ırrent density (mA/cm^2)	350	350	105	160	350 pulse	470 pulse	350 pulse	800	100	278	7.5
lectrolysis time	12 h	30 h	13 d	7.4 d	366 h	183 h	5.8 d	40 d	190 d	17 days	80 days
ritium measurements: ıitial concentration (Bk/ml)	1.44	3.33	3.6	2.7	2.81	2.77	2.70	2.68	1.6	2.0	2.5
ax. concentration (Bk/ml)	225.7	18.5	-	$0.9 \cdot 10^4$	$5.9 \cdot 10^4$	4.6	-	-	72	65	23
ınal/initial concentration ratio	167	5.6	3.36	3425	21	1.66	2.5	1.9	15.7	32.5	9.16
ıtal excess (Bk)	$3.3 \cdot 10^4$	$2.3 \cdot 10^3$	$2.7 \cdot 10^3$	$6 \cdot 10^5$	$2.1 \cdot 10^6$	$3 \cdot 10^3$	$6.3 \cdot 10^2$	$1.1 \cdot 10^3$			
(Atoms)	$1.76 \cdot 10^{13}$	$1.2 \cdot 10^{12}$	$1.44 \cdot 10^{12}$	$3.2 \cdot 10^{14}$	$1.1 \cdot 10^{15}$	$1.56 \cdot 10^{12}$	$3.96 \cdot 10^{11}$	$5.8 \cdot 10^{11}$	10^{12}	10^{11}	$2 \cdot 10^{10}$
eld of T/cm^2	$1.6 \cdot 10^{11}$	$1.1 \cdot 10^{10}$	$0.8 \cdot 10^{11}$	$2.2 \cdot 10^{13}$	$1.7 \cdot 10^{14}$	$2.4 \cdot 10^{11}$	$6.2 \cdot 10^{10}$	$2.1 \cdot 10^{11}$	$1.8 \cdot 10^{12}$	$0.8 \cdot 10^{12}$	$0.5 \cdot 10^{10}$

Table 4 Tritium production during gas saturation of Pd with deuterium in the BARC

:periment No.	1	2	3	4	5
ımple material	Pd	Pd-Ag	Pd-Ag	Pd-Ag	Pd-Ag
ıas (g)	20	0.96	10.9	10.6	0.43
·lume of absorbed D_2(ml)	1325	34.5	516.4	222	20.2
'Pd ratio	0.63	0.46	0.45	0.20	0.45
ıuilibrium time (h)	16	16	240	40	240
·lume of water used r extraction (ml)	50	6	50	50	5
·itium activity of ter (Bk/ml)	8.1	5.9	8.5	12.5	32.6
·itium absolute activity (Bk)	111	37	429	718	159
D ratio on Pd	$32 \cdot 10^{-11}$	$1.1 \cdot 10^{-11}$	$0.87 \cdot 10^{-11}$	$3.4 \cdot 10^{-11}$	$8.3 \cdot 10^{-11}$
tal number of tritium oms in Pd	$2.3 \cdot 10^{11}$	$2 \cdot 10^{10}$	$2.4 \cdot 10^{11}$	$4.1 \cdot 10^{11}$	$9 \cdot 10^{10}$
ıber of tritium atoms r gram of Pd	$1.2 \cdot 10^{10}$	$2.1 \cdot 10^{10}$	$2.2 \cdot 10^{10}$	$3.8 \cdot 10^{10}$	$20.8 \cdot 10^{10}$

Table 5 Tritium production in Ti during gas saturation with deuterium in the Bhabha Atomic Research Centre

Experiment No.	1	2	3
Sample mass (g)	0.98	0.206	0.2
Mass of absorbed D_2 (mg)	0.42	0.07	0.29
Activity from count of β-radiation quanta (Bk)	290	1330	$5.5 \cdot 10^6$
Number of tritium atoms	$1.5 \cdot 10^{11}$	$6.5 \cdot 10^{11}$	$3 \cdot 10^{11}$
T/D ratio	$1.2 \cdot 10^{-9}$	$3.2 \cdot 10^{-8}$	$7.1 \cdot 10^{-9}$

from LPI-LMI used time-varied electrolysis current to stimulate the CNF reactions. All three groups recorded emission of charged particles.

Analysis for Tritium

Much attention at the conference was paid to experiments on the search for tritium production. The matter of tritium generation via the channel $D + D \rightarrow T + p$ in CNF is one of the most acute and disputable. While in many experiments some tritium yield was discovered and usually exceeded the neutron yield, when measured, by several orders of magnitude, in numerous other experiments no tritium excess was found. The conference in Provo strengthened the position of those supporting the prevalence of the tritium channel over the neutron channel ($D + D \rightarrow n + {}^3He$), but did not give a final answer to this question.

The most extensive results on tritium were obtained by groups lead by M. Srinivasan [10] at the Bhabha Atomic Research Centre (BARC) using Pd and Ti by electrolysis, by gaseous loading, and in experiments using a plasma focus device. The tritium level in the near-surface layer of the samples was measured by different methods: by direct counting of β activity using gas proportional counters, by NaI and Ge detectors used for detection of 4.9 KeV X-rays from excitation of Ti atoms, and by a radiographic technique using X-ray films. In all 22 experiments with electrolytic cells tritium excess was found in quantities of 10^{10} to 10^{16} atoms. An indication was obtained of a simultaneous production of neutrons and tritium in about half of the experiments, e.g., Fig 8b and c. The integral tritium yield is in the range of 4.10^9 to $1.7.10^{14}$ per cm^2 of the sample surface. In 10 out of 22 cells it is in the range of 10^{12} to 10^{14} cm^{-2}, whereas in the others from 10^{10} to 10^{12} cm^{-2}. Just as regards neutrons, the total share of "successful" experiments with tritium detection in the BARC work was ~70%. The most striking feature is a large value of the tritium-to-neutron yield ratio which is typically 10^6 to 10^9 and only seldom 10^3 to 10^4, the latter sometimes when the tritium assay was known to be incomplete.

An interesting result recently obtained by BARC is connected with the use of a plasma focus facility using deuterium fill gas [33]. Following a run with 80 discharges, 10^{16} tritium atoms were found in the surface layer of the central electrode. The authors suggest a stimulating role of high-frequency heating in generating tritium in Ti.

Table 1 and Tables 3 through 5 summarize the main data from previous experiments at the BARC on the search for tritium. The questions aimed by critics concerning the role of ambient tritium contamination at BARC can only be answered by further experiments with careful controls.

Positive results on the search for tritium were also presented by groups from the University of Autonoma de Madrid [34], Los Alamos National Laboratory [35], the University La Sapienza [15], and LPI-LMI-LSU [23]. The last two groups had used

time-variable current in the electrolyzer to attempt stimulation of tritium production.

Claytor (LANL) [34] reported production of small amounts of tritium from deuterium absorbed into a device consisting of alternate thin discs of Pd and Si, made from compressed powders. The passage of a pulsed electric current (up to 2500V, 100 Hz, unipolar, 150 μs width) for periods up to 500 hours (typically 100 hours) gave yields of up to 7×10^{12} atoms of tritium, and one yield of 4×10^{15} atoms. Positive results were obtained in 8 cells of 23, Table 6, (excepting cells that shorted early and hydrogen controls). There were indications that the oxide layer on the metal particles affected the tritium yield.

The group from the University of Autonoma de Madrid [35], in the process of long (1000 hour) electrolysis of heavy water (+ Li_2SO_4) with Ti electrodes, obtained several indications of tritium production. In two cases, 4-fold and 8-fold increases in electrolyte tritium scintillation counts were obtained within a few hours of the start of electrolysis, falling smoothly over the next 1200 hours to the asymptotic limit expected for open cells (~twice the initial concentration). In another case, Fig 20, the asymptotic limit was reached after about 500 hours, but at 800 hours an additional smooth increase in tritium concentration occurred that lasted at least 400 hours, roughly linear to 50% beyond the asymptotic limit. Contamination from ambient sources would have had to have been remarkably constant, in just one cell of many, over 20 days to give this result. Conceivably, cations promoting a tritium to deuterium separation factor larger than two could have begun to plate out on the electrode.

Along with these positive results on tritium, Wolf from Texas A&M University (USA) presented negative results which denied previous data which had pointed to significant formation of tritium during Pd electrolysis. Other measurements conducted on more than 100 electrolytic cells exhibited no tritium production. More than 100 samples of stock Pd gave two indications of tritium that could definitely not be considered due to CNF. According to the author the tritium excesses observed in his earlier work was most likely due to contamination in the electrode metal and perhaps in the electrolyte.

In discussion on this paper and in some other subsequent communications, Wolf's point of view was criticized. Cedzynska from the National Cold Fusion Institute , NCFI (Salt Lake City), informed the conference [36] of work conducted especially to check the supposition of impurities in Pd as a possible source of excess tritium. In the NCFI tritium assay method catalytic oxidation and distillation steps were included in a closed analysis system. This eliminated traces of metals that were believed responsible for high tritium counts in some samples that did not contain tritium. Their check of 45 palladium samples with different metallurgical history and of variable size, produced by three different companies, showed no signs of tritium impurities even with the open analysis system. Within the limits of experimental error (± 1 decays/min/ml) those samples gave a tritium count at the

Sample No.	Tritium Total in curves	Hours Run	Cell Type	Fill Gas and Pressure	Notes on Cell
1	Not Analyzed	3	4 Pd layers 12 g	D1, 7.5 atm	Sample shorted out
2	170 nCi	96	4 Pd layers 12 g	D1, 7.5 atm	5% Hydrogen added to cell on 4-26
3	Not Analyzed	20	4 Pd layers 12 g	H1, 7.5 atm	Hydrogen control
4	Not Analyzed	< 1	4 Pd layers 12 g	D1, 7.5 atm	Leaky seal
5	Not Analyzed	< 1	4 Pd layers 12 g	D1, 7.5 atm	Leaky seal
6	No	17	4 Pd layers 12 g	D1, 7.4 atm	Sample shorted out
7	68 nCi	99	4 Pd layers 12 g	D1, 7.2 atm	Repeat of sample 2
8	less than 2 nCi	142	Pd mixed layers 11.6	D2, 13.6 atm	Palladium and silicon powders mixed together
9	less than 2 nCi	43	3 Pd mixed layers 11 g	D1, 8.8 atm	Same as 8, but outgassed at 110 C
10	320 nCi	77	4 Pd layers 12 g	D2, 17 atm	Repeat of sample 2
11	15 nCi	182	4 Pd layers 12 g	D3, 17 atm	Leaky seal
12	44 ± 3 nCi	62	6 Pd layers 18 g	D3, 17 atm	Cell shorted after 62 hours
13	less than 2 nCi	169	6 Pd layers 18 g	D3, 20.4 atm	Repeat of 12 but no oxide on palladium
14	10 nCi	110	6 Pd layers 18 g	D3, 20.4 atm	Repeat of 12
15	4 nCi	106	6 Pd layers 18 g	D3, 40.8 atm	Repeat of 12
16	less than 1 nCi	22.2	7 Pd layers 12 g	D3, 34 atm	Sample shorted out
17	12 ± 3 nCi	112	6 Pd layers 18 g	D3, 40.8 atm	Repeat of 12 but higher fill pressure
18	less than 1 nCi	86	6 Pd layers 18 g	D3, 40.8 atm	Repeat of 12 but with sulfur surface treatment
19	56 nCi	124	8 Pd layers 15 g	D3, 54.4 atm	Si with dow binder and Pd heated to 350 C
20	214 nCi	356	11 Pd layers 19.5 g	D3, 54.4 atm	Si with dow binder and Pd heated to 350 C
21	75 nCi	85	8 Pd layers 14 g	D3, 54.4 atm	Si with dow binder and Pd heated to 350 C
22	11 nCi	49	8 Pd layers 14 g	H3, 54.4 atm	Si with dow binder and Pd heated to 350 C
23	< 6	13	13 Pd layers 18 g	D4, 54.4 atm	Sample shorted out ..Material treatment same as 19
24	13 nCi	522	7 Pd foils, Si wafers	D4, 54.4 atm	7 -10 mil foils plus two powder end caps, 21.6 g total
25	6 nCi	113	8 Pd foils, Si wafers	D4, 54.4 atm	8-10 mil foils plus two powder end caps, 24.3 g total
26	10 nCi	190	10 Pd layers 14.4 g	D4, 54.4 atm	Same as 19 but native oxide and PVA binder
27	1.5 nCi	65	10 Pd foils, Si wafers	D4, 54.4 atm	10-10 mil foils plus two powder end caps, 29 g , PVA
28	11 nCi	182	11 Pd layers 15.6 g	D4, 54.4 atm	Same as 20 but native oxide
29	4 nCi	66	10 Pd foils, Si powder	D4, 54.4 atm	26.4 g total Pd, Si powder with dow
30	20 nCi	61	7 Pd layers 13.4 g	D5, 9.5 atm	Repeat of 19 but shorted after 61 hours
31	8 nCi	15	10 Pd foils, Si powder	D5, 43.8 atm	29.6 g total Pd, shorted after 15 hours
32	4 nCi	198	7 Pd foils, Si wafers	D5, 13.6 atm	16.9 g total Pd.
Tritium in Deuterium bottles			(in micro curies per meter cubed)		
D1	119				
D2	28				
D3	28				
D4	68				
D5	17				

Table 6 Data on tritium content of Claytor's Pd/Si device. Ref 35

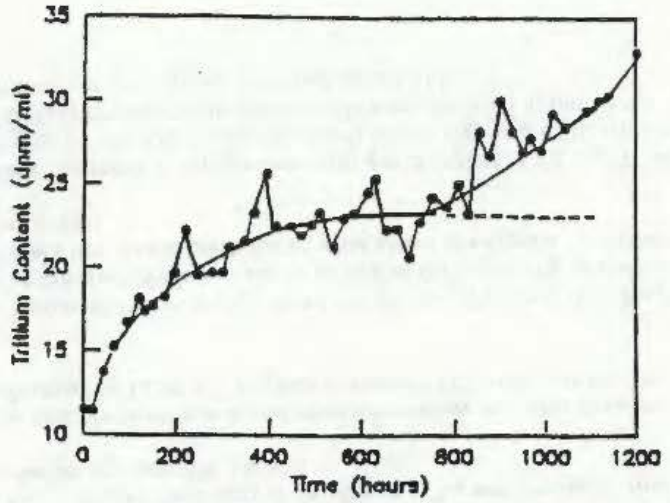

Fig. 20 Tritium concentration of electrolytic cell in Ref 34

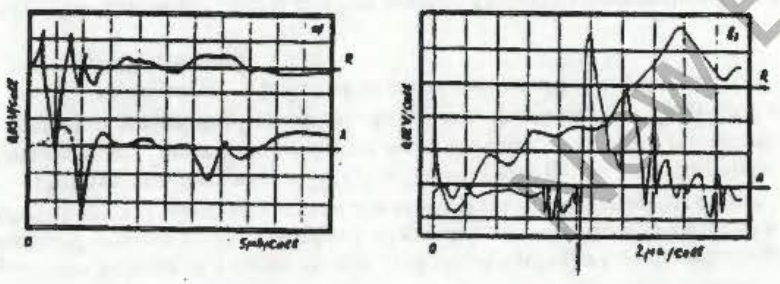

Fig. 21 Oscillogramms of events demonstrating the time correlations of the proton. acoustic (A) and radio (R) emissions from palladium target. The oscilloscope was triggered by the CsI scintillation detector signals. (a) the event of 23.12.89: (b) the event of 29.12.89: Ref 24

background level (26 decays/min/ml). A further 90 samples from 2 manufacturers (including Wolf's source) all gave tritium assays from the closed system at the background of 27 ± 1 decays/min/ml. The authors point out, that the use of open electrolyzers could lead to unreliable results provided no special precautions are taken.

Correlation Experiments

The experiments considered above, where metal lattices are deuterided in various ways and specific nuclear fusion products (neutrons, protons, γ - quanta, tritium) are registered, could be classified as traditional. Along with these, the results of first experiments of a new kind were presented, so-called "correlation" experiments, where simultaneous detection was made of both nuclear reaction products and possible signals from "accompanying" phenomena [1].

A series of experiments conducted by LPI-LMI-LSU capitalized on the experience of the Golubnichi group (LMI) in studies on radiation acoustics and mechanoemission [23, 24]. They searched for time correlations between pulses of nuclear (proton), electromagnetic and acoustic emission in electrolytic saturation of palladium foils with deuterium, where the Pd was part of the cell wall. The following transducers/instrumentation channels were positioned close to the samples: a) nuclear: CsI scintillator viewed by a photomultiplier, b) acoustic: piezoceramic chip soldered to the Pd electrode, and c) electromagnetic: toroidal coil with an amplifier having amplification factor ~10^4 and passband ~1 Mhz. Average backgrounds in the channels were respectively, ~10^{-3}/s, 400/s, and ~0.03/s. The starting pulse was produced by the CsI scintillator. Acoustic pulses had a 10 μs delay that made it possible to register an acoustic signal that preceded a nuclear pulse. Triple correlations were searched for in a time interval of 10 μs. During 15 hours of reference measurements with electrolysis of H_2O not a single triple coincidence was registered.

During three experiments with electrolysis of D_2O with total duration 11.5 h two events with triple coincidences were detected [23]. Their oscillograms are presented schematically in Fig. 21. In both cases the acoustic pulse was initiated 2 to 3 μs earlier than the proton starting pulse, which is expected from the viewpoint of the 'accelerating mechanism' theory [1]. The expected number of chance coincidences during the time of measurements was ~ 10^{-7}. One more correlation of a proton burst and acoustic emission was registered during the thermal desorption of deuterium while heating the deuterided Pd foil.

Unfortunately, this experiment has some disadvantages: a) the number of events detected was very small, b) there is a possibility triggering the detector with X-ray quanta accompanying the cracking of palladium hydride, although the control experiment with H_2O would exclude this factor for good statistics; c) a contribution

is possible from correlated background, induced by the interaction of cosmic ray particles, which can produce fast nucleons, and which might simultaneously cause cracking in stressed material of a hydride.

To eliminate these disadvantages, the group from the LPI-LMI-LSU performed a further experiment in a well-screened, low-background laboratory at the Baksan underground neutrino observatory of the Nuclear Research Institute of the Academy of Sciences of the USSR [24]. Use was made of a chamber constructed for studying double β-decay at a depth of 1000 m of water equivalent, with utilization of low-background materials. The chamber background was considerably reduced as compared with typical laboratory conditions at sea level, for instance, for muons as much as ~10^4 times, and for γ-quanta (of 0.2 to 3.0 MeV energy) by approximately 10^3 times. Unfortunately, these fine conditions were not fully used, since the neutron detector contained radioactive impurities. As a result, they had $N_\gamma \sim N_{\gamma\ lab}/200$ and $N_n \sim N_{n\ lab}/30$ which gave ~ 4.10^{-3} slow neutrons per second in the detector (10 ^{3}He tubes in paraffin, 10% efficient).

In auxiliary experiments the central block of paraffin moderator was replaced by a fast neutron detector and a ^{252}Cf source to obtain the neutron moderation time distribution for the experimental geometry, presented in Fig. 14a. Typical moderation times were several tens of μs. In the main series of four-hours of measurements coincidences between slow neutrons and acoustic pulses were detected; to stimulate the effect they used current cycling and sample cyro-cooling. With a 100 μs time gate, 42 coincidence events were detected from neutrons and acoustics (only during the thermal cycling), with ~5 expected random coincidences. The good agreement between the shape and timing of the neutron moderation curve, Fig 14a, and the distribution of relative arrival times between neutrons and acoustics, Fig. 14b, confirms the origin of the signals. The authors stated that control experiments excluded artefacts, Fig 14c and d.

Proton emission and electromagnetic radiation correlation was also observed in the experiment performed by Li, from Tsinghua University [32], with gas loading of Pd samples.

Taniguchi and Yamamoto from the University of Osaka [37] found high-frequency current signals at the electrolytic cell anode arising at the beginning of electrolysis. However, they were not able to establish to what extent the signals correlated with proton emission events.

Signals of acoustic emission in experiments with gas charging of Pd and Ti were detected by the group from Los Alamos National Laboratory and BYU, who used them to detect sample cracking, but these signals were reported to not be in coincidence with the neutron spikes described earlier [3,4].

Experimental Techniques

An important aspect of work on CNF is the improvement of detecting instruments and in the techniques for conducting experiments. Much of the conference material was concerned with this field.

Conceptually, the neutron detection techniques underwent no substantial changes. To detect fast neutrons, solid and liquid scintillators are used, with pulse shape discrimination systems for γ/n separation. Slow neutrons are detected with ^{3}He- and BF_3-proportional counters. At the same time efficiency (up to ~45%) and noise immunity of detectors have improved considerably. In some facilities the operation of separate detector segments is checked, to exclude interference and faulty operation. A reliable technique is neutron detection both before and after moderation, first used for CNF by Jones's group and then employed in experiments at the LPI-LMI, and some others.

Unlike experiments on CNF conducted during the initial period, much attention is now being paid to suppressing the background. In a number of measurements use was made of low-background underground laboratories

Three Italian groups conducted work in the neutrino laboratory of Gran Sasso, the Soviet group from the LPI-LMI-INR utilized a low-background chamber of the Baksan underground neutrino observatory, the Chinese group from the China Institute of Atomic Energy (Beijing) performed measurements in the Mentou laboratory at a depth of 580 m, and Jones, Menlove and Wolf performed some key experiments in a lead mine in Colorado. Menlove and Claytor are now routinely working in a tunnel at Los Alamos. This has made it possible to reduce the background contributed by cosmic rays by 3 to 6 orders of magnitude. Under such conditions the greatest background is contributed by radioactive impurities in materials of the instruments and in surrounding rocks. In the Baksan low-background chamber, the latter background source is also substantially suppressed. Special low-background materials are therefore beginning to be used for constructing detectors for CNF. Particularly suitable for underground use is the type of fast neutron scintillation detector used by Wolf and others, which has a low intrinsic background.

An extremely interesting prospect for experiments on CNF is the use of the underground Cherenkov detector at Kamioka proposed in the report by Y. Totsuka [38] from the University of Tokyo. It was proposed to place an active CNF sample into a nickel cylinder to detect γ-rays from the neutron capture reaction ^{A}Ni (n, γ) $^{A+1}$Ni. The isotopes ^{58,60,62}Ni, making up 68%, 26%, and 3.7% of natural Ni, will produce γ-rays with energy 9.0, 7.8, and 6.8 MeV, respectively, which will be detected with ~10% efficiency. Taking into consideration the very low background rate, it is possible to obtain a neutron sensitivity (at 90% confidence level) of 4.10^{-5} neutron/s (1.10^{-5} neutrons/s), at a γ threshold energy of 7 MeV (8 MeV), which exceeds the

existing level by at least three orders of magnitude. It is also possible to detect γ-quanta from the reaction $p + D \rightarrow {}^3He + \gamma$ under practically backgroundless conditions. At the time of writing, experiments have been started at Kamioka, in collaboration with Jones, Menlove and Wolf.

Frequently, charged particles are detected using surface barrier detectors, which make it possible not only to detect the particles and find their energy, but, with the use of ΔE/E telescopes, to identify the particles in real time.

To detect tritium, various techniques are used, including direct counting of β-activity by liquid or solid scintillators, active detection of X-rays, radiography, etc. Utilization of different techniques makes it possible to increase data reliability, although assay preparation was itself a hot topic at the meeting.

Correlation measurements have already been mentioned in the previous section. These are of interest not only from the viewpoint of explanation of the nature of CNF but, should the existence of correlations be confirmed by subsequent studies, this technique can become a convenient and effective way of suppressing background and discriminating weak signals.

In earlier work at LPI-LMI [1] a hypothesis was put forward of possible triggering of CNF by means of various external effects: ultrasonics, thermo-, cryo-, and current-cycling, mechanical strains, etc. At the current time some of these means are widely used and, evidently, lead to CNF intensification. Thus, thermal cycling, used for the first time by Scaramuzzi's group, is now widely used in experiments on metal charging with deuterium from the gas phase. In papers by the groups from Osaka University (Japan) [19], Centro Atomico Bariloche (Argentine) [17], LPI-LMI (USSR) [23, 24], University La Sapienza (Italy) [15] and others, there was information on the triggering effect of pulsating or step-wise, time-variable current on CNF during electrolysis.

A curious observation was made by M. Srinivasan from BARC, who claimed tritium formation was stimulated by high-frequency heating of deuterided Ti samples.

Yamaguchi and Nishioka from NTT Basic Research, Japan, reported a new technique for stimulating CNF processes [39]. A plate of palladium deuteride 1 mm thick, was coated on one side with a 100nm-film of gold preventing deuterium atom escape, and on the other side with a MnO film, 10 nm thick, and having a deuterium diffusion coefficient smaller than that of Pd. This layer served as a surface barrier for controlling the rate of deuterium atom escape from the metal. Three such samples were placed in vacuum. Three hours later the following simultaneous phenomena were found: neutron emission, $\sim 10^6$n (analogue indicator) continuing for 2 to 3 s, "explosive" emanation of gas, surface temperature rise to ~700°C and biaxial deformation of the samples due to uniform expansion on the side coated with the MnO film. At subsequent pumping-outs the same samples gave two more neutron bursts about as powerful. The next 20 pumping-outs gave no new signals. As the authors underline, their procedure leads to creation, in the vicinity of the surface coated with a MnO film, of a thin Pd layer (< 40 μm) with a higher deuterium concentration. Several other papers reported neutron emission coinciding with desorbtion of deuterium from previously loaded lattices.

Along with traditional sample saturation methods there was information on successful use of a plasma-focus facility (BARC) [33], of an electrolizer with solid electrolyte (Jorne, University of Rochester, USA) [40], and of a molten salt electrolyte operating at 400°C (Liaw and Liebert, University of Hawaii) [41].

Besides Pd and Ti, a search for new materials as deuterium "accumulators" is going on. Often these were alloys of Ti and Pd but there were also reports of experiments with amorphous $Fe_{90}Zr_{10}$ [27] and high-temperature superconductors $Y_1Ba_2Cu_3O_{7-x}$ [16], first suggested by Rabinowitz.

Reports presented at the conference contained many interesting "technology" details connected with preparation of samples, choice of conditions for electrolysis and gas charging, as well as with results of structural analyses (by electron microscopy, neutron diffractometry, X-ray diffraction) and studies on cracking and deformation of samples in the process of hydrogenation.

In particular, the groups from Los Alamos and BYU have achieved much improved reproducibility with gas charging of Ti by careful degreasing of samples using methylene chloride, methanol and water. The group from Frascati points to the fact that no positive results were obtained, if Pd and Ti electrodes had not been degassed initially, or if electrodes were made of superpure Ti.

CNF and Geology

An intriguing aspect of the CNF problem was discussed at a special session of the conference on geochemical and geophysical studies. Some of the reports contained assumptions on the role that could be played by CNF processes in the life of our planet, in particular, in the abundance of certain isotopes and even, possibly, in its energy balance.

The report by P. Palmer [42] from BYU contained the following arguments which could give evidence of CNF processes going on in the Earth's interior.

a) The concentration of ^3He in the atmosphere is too high, unless one assumes the existence of a constantly acting source of this element.

b) In volcanic gases, liquids and lavas an unexpectedly high ratio of $^3He/^4He$ is observed.

c) Tritium, an unstable element with a half-life of 12.4 years, is present both in volcanic gases and in water of hot springs.

d) Volcanic heat, associated with subduction of cold, water-bearing sedimentary rocks proves to be too high, if it is to be explained only by frictional heat generated by gravitational potential energy and by heat of surrounding rocks.

e) While ordinary radioactivity, due to U, Th and K, is not associated with hot points of the Earth but exists in cold continents, nuclear fusion products, on the contrary, are detected in hot points.

f) Lastly, recent estimates of the Earth's radiogenic heat source point to insufficiency of U, Th, and K for explaining the heat balance of our planet and the high temperature of its core.

P. Britton from the Riess Foundation (South Hamilton, USA) reported [43] the analysis of samples taken during deep drilling in the shear zone of the state of Massachusetts. It was found that the concentration of tritium and ^{3}He increases approximately linearly with depth, pointing to the presence of a single source of these elements or a constantly occurring process with both these isotopes involved.

An anomalously high tritium content in the lavas of the Mount St. Helens volcano was found by a group from LANL, USA [44]. The studies have shown that a considerable amount of atmospheric moisture is cycling through the cracking lava. Tritium accumulation is possible both due to natural processes (CNF) and as a result of contamination connected with nuclear weapon tests.

In the report by G. McMurtry (University of Hawaii) [45] there is data on a large anomalous increase in tritium content in the atmosphere detected by the Mauna Loa tritium monitoring station on the Hawaii Islands in February-March 1978. The data analysis points to a possible correlation with the concurrent eruption of the Mauna Ulu volcano situated 40 km from the station and the occurrence of suitable winds at the time, whereas a relation with the test of a Soviet hydrogen bomb five months before the observations is scarcely probable. These and other similar data suggest the necessity of more thorough investigation into the possible role of CNF processes as a source of some light isotopes and maybe, heat in the Earth.

CNF Models

At the conference no unique, universally recognized point of view was formulated on the mechanism of CNF. It is not possible in this brief review to consider in detail the various theoretical models and physical concepts contained in a score of reports presented in the theoretical sessions. Therefore, we confine ourselves only to brief remarks on some directions that are being followed in the search for an answer to the nature of this phenomenon.

A long standing idea has been that of an "accelerating" or "fracto-acceleration mechanism" (FAM) [46]. In FAM, fusion is not actually "cold" (as in μ- catalysis), but "micro-hot". The energy required to overcome the Coulomb barrier is imparted to the ions by acceleration in cracks arising in the process of metal loading with hydrogen isotopes [1]. The strongest evidence in favor of FAM are the results of correlation experiments. It was also shown in the report by the LPI-LMI group [23,24], that many other predictions formulated earlier on the basis of FAM have some experimental evidence (surface-volumetric nature, stochasticity, quasi-periodicity, nonequilibrium of the metal/deuterium system, possibility of external effects, for example increase of electrical resistance in the "activity" period). At the same time, in FAM there is a number of problems connected with the necessity for rather strong fields in cracks and with the characteristic times of different concurrent processes [46]. Additionally, if the prevalence of the tritium channel over the neutron channel is eventually demonstrated, FAM would need to be modified to account for the inequality. Some possibilities in this respect were discussed by Y. Kim (Purdue University, USA) [47] in connection with the Efimov effect (an infinite number of levels in a three-body system in the presence of a zero-energy level in a two-particle system). The difference between D(D,p)T and D(D,n)^{3}He could be a consequence of the interaction in the final state.

In connection with the problem of "strong fields", the report by G. Preparata (NCFI, USA) [48] contained the idea of a possible unification of FAM and an approach considering coherent electrodynamic effects in a condensed medium.

Another possibility was pointed out by M. Danos (National Institute of Standards & Technology, USA) and V.B. Belyaev (JINR, Dubna) [49] of enhancing the probability of deuterium nuclear fusion by virtual interactions in the Coulomb field of lattice ions. This effect might also explain the prevalence of the tritium channel.

In some papers the authors turned to exotic particles for an explanation of CNF. Thus, in reports by J. Rafelski (University of Arizona, Tucson) [50] and G. Shaw (University of California, Irvine) [51] by analogy with μ-catalysis, a scenario is suggested where CNF arises due to catalysis initiated by heavy particles (integrally charged hadrons or fractionally-charged, free, stable antidiquarks). A supposition on the emission of new light particles in CNF processes was introduced in the report by M. Matsumoto (Hokkaido University, Japan) [52]. Similar models possess very interesting properties, but have the disadvantage that to explain one strange phenomenon they involve other, still more hypothetical, effects.

A considerable number of reports was dedicated to specific features in the process of nuclear fusion due to collective effects arising in the crystal lattice (reports by P. Hagelstein, MIT, USA [53]; E. Tabet, INFN, Rome [54]; H. Takahashi, Brookhaven National Laboratory, USA [55]; S and T Chubb [56]; M Jandel, Royal Institute of Technology, Sweden [57], R. Bush, CalPoly [58], and others).

V. M. Vysotski from Kiev State University and R. N. Kuz'min from Moscow State University discussed [21] conditions under which deuterons trapped in micro-defects in crystals could participate in "thresholdless fusion" brought about by strong overlapping of their wave functions.

G. Cerafolini, (EniChem, San Donato, Italy) [59] hypothesised the production of metastable exotic "binuclear atoms", $(D^+ + D^+)\ 2e^-$, preceding the process of fusion.

Other work obtained limits on the nuclear fusion cross-section at very small energies. W. Zakowics and J. Rafelski (University of Arizona) [60] have shown that the data available at present on cross-sections of DD and PT-reactions at low energies substantially limit the effect of possible nuclear resonances and exclude an explanation of CNF on that basis. Another limitation on the DD-cross-section was obtained by M. Gajda (University of Arizona) [61] from estimating the planet Jupiter's excess heat. Conclusions based on Jovian energy balance are approximately nine orders of magnitude less sensitive than are the laboratory experiments at providing information on CNF. Finally, M. Vaselli, C.N.R., Pisa, Italy [62], confirmed results obtained earlier concerning the insufficiency of screening effects in Pd crystals for giving agreement with CNF results.

M Rabinowitz [63] of the Electric Power Research Institute suggested an important role for heavy ions of the projectile in explaining anomalously high fusion rates using $(D_2O)_n$ cluster ions and deuterated targets [64].

Making a summary of the conference in his final speech, [65] one of us (DW) underlined the following items:

- the phenomena observed are not "normal" DD-fusion,
- theory is not yet sufficiently oriented by experiment,
- the quality of many experiments had improved considerably,
- there are many very different experiments, but results seem to be broadly similar,
- the research field under development has every right to its existence and deserves support.

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