New data on low-temperature fusion (based on materials of the conference in Provo, Utah, USA; October 22–24, 1990)

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A conference on "Anomalous Nuclear Effects in Deuterium/Solid State Systems," organized by the Research Institute of the Power Industry, the U.S. Department of Energy, and Brigham Young University, was held at Brigham Young University (Provo, Utah USA).

The choice of Brigham Young University as the site of this conference, devoted to the problems of low-temperature (or cold) fusion (LTF), was not by accident. It was here a year and a half ago that the emission of neutrons was first observed by the S. Jones group (independently of M. Fleishman and S. Pons) from the transition metals palladium and titanium with deuterium-saturated crystal lattices, marking the beginning of the "race for cold fusion".

The subtitle of the conference: "Review of international progress" was quite well reflected in its content. Despite the relatively small number of participants (not many more than 150 persons), 18 countries of the American European and Asian continents were represented.

The conference gave rise to very great interest which, to all appearances, exceeded the expectations of the organizers, who provided a total of only three days for its work. As a result, the program of the conference, including more than 70 papers, a dozen brief reports, and a visit to the laboratories of Brigham Young University, proved to be extremely overloaded. Despite the fact that the meetings began at 8 a.m. and ended at 9 or 10 p.m., the time for discussions and meeting the conference participants turned out to be clearly inadequate.

Major attention at the conference was directed at experimental work on LTF (more than 50 papers, including 6 dealing with geophysical aspects of LTF and 7 dealing with methods).

The conference summed up the one and a half years of the "era of cold fusion" that have elapsed since the first reports in March 1989 which rocked the world. During this time cold fusion survived a period of improbable popularity, caused by the hopes that it would solve the energy problems facing mankind. Later, scepticism, irritation, and disbelief not only with regard to power generation but also with regard to the reality of the phenomenon itself replaced the euphoria. A stream of negative results, obtained by various groups, and the nonreproducibility of their results, giving rise to absolute damnation of experiments on LTF, were the cause of this. Another reason of no small importance for the disbelief in LTF was the absence of any clear understanding of a possible mechanism for this phenomenon. It did not fit within the customary framework of the notions of nuclear physics and solid-state physics.

The contradictory and dramatic situation with LTF, summed up to the beginning of 1990, has already been described in the journal "Uspekhi" (see V. A. Tsarev, Usp. Fiz. Nauk **160**, No. 11, 3 (1990) [Sov. Phys. Usp. **33**, (1990)]. How does the situation look now, after the conference in Provo?

It appears that the most important result coming from the materials of the conference consists of indisputable proof of the reality of the LTF phenomenon. Now, however, the subject is no longer the initial hopes for the existence of a continuous steady-state low-temperature fusion process when hydrogen isotopes are pumped through a crystal lattice. Instead, we must speak of phenomena that are rare, sporadic and, apparently, have no relationship to "cold" fusion of nuclei in the classical understanding of this term. (This change in viewpoint also was apparently reflected in the name of the conference, which did not contain the now-familiar phrase "cold fusion".) Confidence could be placed in the existence of low-temperature fusion after the basic difficulty associated with nonreproducibility was overcome in a number of experiments. In some experimental series the repeatability of positive results has reached a level of 70–100%.

Success was achieved because of the following factors:

a) Working with large Pd or Ti samples (with a mass of several hundred grams and a surface area up to several hundred cm^2) made it possible to obtain a large total useful signal;

b) Increasing the efficiency of the recording equipment (from 10^{-6}–10^{-2} in the initial experiments to 30–45% in later ones) made it possible to detect very weak signals and rare events;

c) A careful analysis and suppression of background through the use of materials in the equipment free from radioactive impurities, the use of passive and active protection against outside interference, working in underground low-background laboratories and even a submarine (in an experiment by Argentine physicists) made it possible to create favorable conditions for the experiments;

d) Confidence in the positive results is strengthened by the fact that many of them have been obtained under different conditions and by means of a completely different set of methods;

e) The use of different methods of inducing LTF (the action of a pulsing current, thermal and cryo-shocks, "explosive desorption," etc.) have also played an important role in the successes of recent experiments.

The results of correlation measurements, conducted by Soviet physicists at the P. N. Lebedev Physics Institute, Academy of Sciences of the USSR (FIAN), the Luganskiĭ Mechanical Engineering Institute (LMI) and the Institute of Nuclear Research (IYaI), Academy of Sciences of the USSR, who were the first to observe a correlation of the emission of fusion products (neutrons and protons) with acoustic and radio emission, can also be considered as another important summary of studies presented at the conference. These correlations, predicted earlier by the FIAN-LMI group, indicate a relationship between LTF and the acceleration of particles in local electric fields in crystals and it may be a key for understanding the mechanism of the LTF phenomenon.

Let us now consider in greater detail the most interesting experimental results presented at the conference. Theoretical work, deserving a separate discussion, will be mentioned only very briefly here.

EXPERIMENTS WITH THE DETECTION OF NEUTRONS

Let us begin with the largest group of papers devoted to the detection of neutrons.

A group from Los Alamos National Laboratory and Brigham Young University have continued their studies involving a saturation of Ti with deuterium from the gas phase. Starting in April 1990 the work was carried out with more sophisticated equipment and an improved procedure for preparing the samples. A detector was used that consists of two independent rings with 9 and 41 ^{3}He neutron counters having a total efficiency of $\eta \approx 44\%$. The background was monitored with three additional detectors. In order to reduce the background from radioactive impurities special gas bottles of stainless steel were used. The measurements were made with samples of titanium, titanium alloys and spongy titanium with a total mass up to 300 g over a period of several weeks with many temperature cycles.

An excess of neutrons of from 3σ to 12σ over the background, frequent small bursts (2–10 neutrons in a time of $\lesssim 50\,\mu$s), and much less frequent bursts with a large multiplicity (up to 300 neutrons) were recorded in 11 of the 13 bottles with samples that were used. The distribution of bursts in terms of multiplicity in measurements with D_2 is shown in Fig. 1a, and the analogous distribution in control experiments with H_2 is shown in Fig. 1b. In the first series of 5 bottles 3 gave a positive result of 2-4 bursts of neutrons with a multiplicity of 20–30. The other 8 bottles gave a positive result, established by summing the measurements of small bursts (2 to 10 neutrons each).

The authors point out that as a rule the bursts appeared during warming of the samples at a temperature of − 30 °C (Fig. 2).

S. Jones presented the results of measurements performed by a group from Brigham Young University, Los Alamos and the Colorado School of Mines in a lead mine in Leadville, Colorado at a depth of 600 m. Slow neutrons generated during electrolysis were recorded by a set of 16 ^{3}He proportional counters, placed in a polyethylene moderator and separated into four independent groups. The total efficiency of the detector was $\eta \approx 34\%$. Measurements over a period of 7 weeks showed that the background (caused primarily by radioactive decays in the walls of the counters) remained stable at $\approx 2 \times 10^{-2}$ sec^{-1}.

Periods of activity lasting from 1.5 to 40 hours were recorded. After 3 weeks of operating measurements 5 bursts had been found with neutrons numbering up to 300 in an interval of 128 μs. An example of a burst with a large multiplicity is shown in Fig. 3. The background for the correlated events was very small: only one background event, containing two readings during 128 μs, was recorded during 3 weeks. The authors emphasize that the use of a segmented detector in combination with suppression of the cosmic ray background makes it possible to increase the measurement reliability significantly.

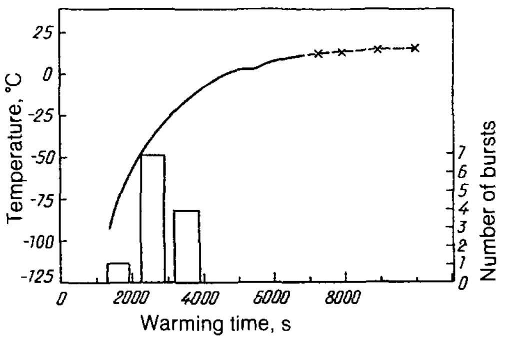


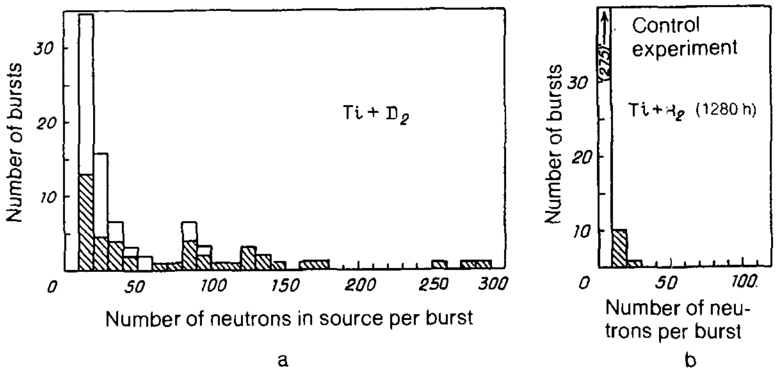
FIG. 2. Los Alamos National Laboratory-Brigham Young University experiment. The number of neutron bursts as a function of time and warming temperature for two Ti + D_2 samples.

A comprehensive program of research on LTF is being implemented at the Bhabha Center of Atomic Research (India). Twelve independent groups are performing experiments here with electrolytic and gas saturation of Pd and Ti.

Large neutron bursts have been observed in 11 different electrolytic experiments with cathodes having areas from 0.1 to 300 cm^2. Some of these bursts are plotted in Fig. 4. It is important to point out that the first neutron (and tritium) emission bursts were observed, as a rule, during the initial period of the electrolysis (see our review in "Uspekhi"), after a charge of several ampere-hours (from 0.6 to 3.2 amp·h/cm^2) had passed through the cell.

Multiple neutron emission was also observed in experiments with saturation from the gas phase followed by thermal cycling.

The typical number of neutrons recorded in the various experiments is $10^6 - 10^7$. In most cases the neutrons are emitted for each of the targets in the form of one large burst with an intensity many times greater than the background. After some time has elapsed, the neutron emission dies down and ceases. It appears that except for a dependence on the



a

b

FIG. 1. Los Alamos National Laboratory-Brigham Young University experiment: a–number of neutron bursts as a function of the number of neutrons in source per burst in active Ti + D_2 samples; b–number of events as a function of the number of neutrons in source per burst, recorded during 1280 hours of a control experiment with Ti + H_2.

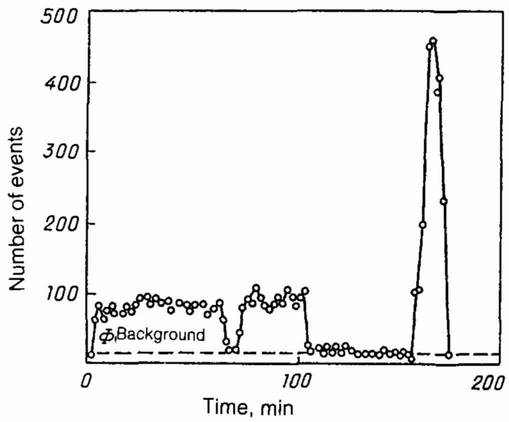


FIG. 3. Neutron burst with large multiplicity, recorded by the Brigham Young University-Los Alamos National Laboratory-Colorado School of Mines group.

shape of the samples the integrated neutron yield per unit surface area of the sample is approximately the same and lies within the limits 10^4–10^5 cm^{-2}.

The total fraction of "successful" experiments with respect to the recording of neutron amounts to $\approx 70\%$ at the Bhabha Center. Their results are presented in Table I.

New results were presented by three Italian groups.

As is known, soon after the first electrolytic experiments on LTF, conducted in the USA, experiments were performed in Italy at Frascati under the direction of F. Scaramuzzi using a different technique: saturation of Ti from the gas phase and a variation in the thermodynamic parameters (pressure, temperature). Strong neutron bursts were observed for the first time in this work. Subsequently, a similar technique has come into widespread use in experiments on LTF.

The lack of reproducibility of these experiments on LTF (as with all others) forced the Scaramuzzi group to carry out a careful analysis of their "first-generation" experiments in order to prove the authenticity of the effects they had observed. The results of this analysis and preliminary data of a "second-generation" experiment with improved equipment for neutron recording (and tritium analysis) were presented at the conference. The main conclusions of the authors were as follows:

a) A critical check of the results of the first measurements confirmed their authenticity;

b) Neutron bursts have been found in the new experiments in Ti + D_2 systems (Fig. 5) and have not been found in measurements with Ti + H_2.

An increase in the counting rate of burst-type ^{3}He detectors has also been recorded by a group from the University La Sapienza (Rome, Italy) for electrolysis with a palladium electrode although, as the authors presume, this may be partially caused by some false effects (for example, mechanoemission, see Ref. cited above).

F. Celani reported on the detection of high-intensity gamma-ray bursts by the Frascati group, who were carrying out an electrolytic saturation of Pd and Ti with deuterium in the Gran Sasso underground laboratory (see review in "Uspekhi"). New results on searches for neutron emission for gas saturation of samples of high-temperature superconducting materials of the $Y_1Ba_2Cu_3O_{7-x}$ type were presented in this same paper. Samples having a weight of 6–8 g were placed in a stainless steel bottle, into which D_2 was admitted at a pressure of 35 bar and a temperature of 300 K. Then the bottle plus sample was heated to 371 K. After absorption of the D_2 resulted in a pressure drop, the temperature was lowerered to 358 K and the system was held in this condition for 3 hours. Then it was cooled to 300 K over a period of a few minutes and the pressure of the D_2 was again raised to 36 bar. Then thermocycling was carried out: cooling to 77 K

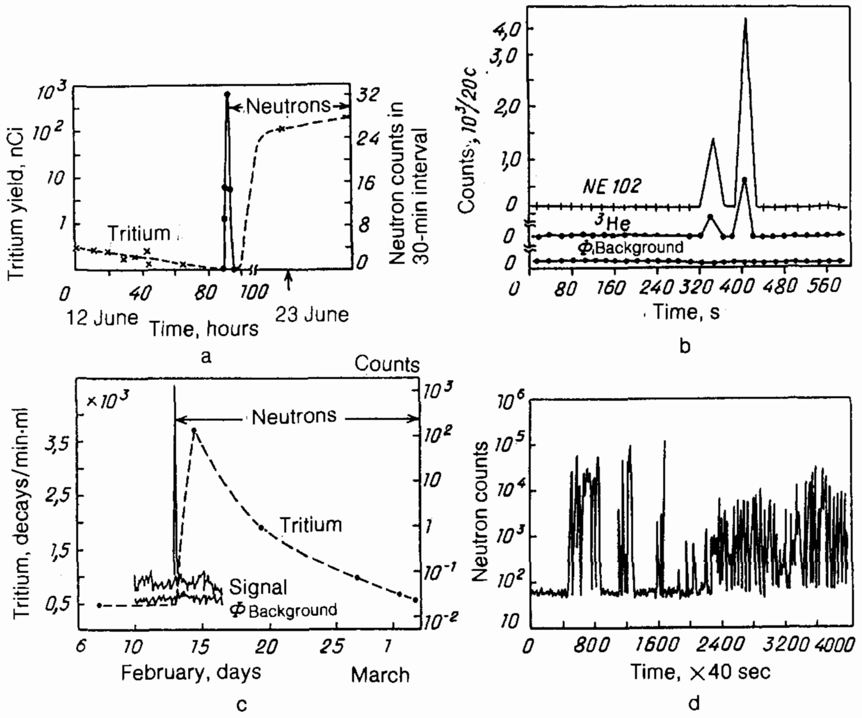


FIG. 4. Neutron bursts and formation of tritium in Bhabha Center of Atomic Research experiments (a–d).

TABLE I. Recording of neutrons and tritium during electrolysis at the Bhabha Center of Atomic Research.

Experiment number	1	2	3	4	5	6	7	8	9	10	11
Cathode:											
Material	Ti	Pd—Ag	Pd—Ag	Pd—Ag	Pd	Pd	Pd	Pd	Pd	Pd	Pd
Surface area	104	300	300	78	20	5,9	6	5,7	18	4,4	8
Current density, A/cm^2	400	300	300	800	200	340	100	700	60	50	100
Charging:											
Charge, A·h/cm^2	1,2	0,6	—	3,2	0,8	3,0	2,5	650	3,4	0,15	36,7
Time, h	3	5	0,5	4	4	9	24	930	560	3	300
Active time	several hours	3.5 h	2 h	3 min	1 min	5 h	5 days	100 sec	40 h	5 days	8 h
Neutron yield:											
Number of bursts	continuously	9	1	1	1	3	17	1	Many	Many	2
Total number of neutrons	$3\cdot10^{7}$	$4\cdot10^{7}$	$9\cdot10^{7}$	$5\cdot10^{6}$	$1\cdot10^{6}$	$3\cdot10^{6}$	$1,4\cdot10^{6}$	$3\cdot10^{6}$	$1,8\cdot10^{8}$	$5,8\cdot10^{6}$	$2,4\cdot10^{6}$
Neutrons/cm^2	$2,9\cdot10^{5}$	$1,7\cdot10^{5}$	$1,3\cdot10^{4}$	$1,3\cdot10^{4}$	$5\cdot10^{4}$	$5\cdot10^{5}$	$2,3\cdot10^{5}$	$5,2\cdot10^{5}$	10^{7}	$1,3\cdot10^{6}$	$3\cdot10^{5}$
Tritium yield:											
Total, Bq	$2,6\cdot10^{5}$	$1,5\cdot10^{7}$	$3,8\cdot10^{6}$	$7\cdot10^{6}$	—	$1,4\cdot10^{5}$	$1,3\cdot10^{3}$	$7,7\cdot10^{3}$	325	32,5	$6,3\cdot10^{3}$
Total, atoms	$1,4\cdot10^{14}$	$8\cdot10^{15}$	$1,9\cdot10^{15}$	$4\cdot10^{15}$	—	$7,2\cdot10^{13}$	$6,7\cdot10^{11}$	$4\cdot10^{12}$	$1,8\cdot10^{11}$	$1,8\cdot10^{10}$	$3,5\cdot10^{12}$
T/cm^2	$1,3\cdot10^{12}$	$2,7\cdot10^{13}$	$6\cdot10^{12}$	10^{13}	—	$1,2\cdot10^{13}$	$1,1\cdot10^{11}$	$5,2\cdot10^{13}$	$1\cdot10^{10}$	$4\cdot10^{9}$	$4,4\cdot10^{11}$
N/T ratio	$2\cdot10^{-7}$	$0,5\cdot10^{-8}$	$0,5\cdot10^{-8}$	$1,2\cdot10^{-9}$	—	$4\cdot10^{-8}$	$1,7\cdot10^{-6}$	10^{-6}	10^{-3}	$3,2\cdot10^{-4}$	$7\cdot10^{-7}$

and heating to 300 K in 1 hour. A rise in the neutron emission level was recorded during the first thermal cycle to ≈ 10 h^{-1} (for a background of ≈ 1 h^{-1}). During subsequent cycles the excess emission level decreased and completely disappeared after the 10th cycle.

The FIAN-LMI-LGU (State University, Lvov) group reported the recording, during the first 6 hours of electrolysis, of a sequence of 6 neutron bursts, each containing $\sim 10^2$ neutrons (signal/background rate $\gtrsim 10$), with a duration of < 1 min (Fig. 6). Three giant neutron bursts with $\sim 10^6$ neutrons in an interval $\lesssim 1$ sec have been recorded by Japanese physicists from the Fundamental Research Laboratory (Tokyo) through the use of a special "explosive desorption" technique (see below).

Bursts have also been detected by a group from the Chinese Institute of Atomic Energy (Beijing), with some of their measurements being performed in an underground laboratory at a depth of 580 m. Bursts appeared at a temperature from -100 °C to room temperature in 6 of 8 cylinders with a $Ti + D_2$ mixture. Bursts with 15 to 500 neutrons, which exceeded the background level by a factor of 3–75, were observed in the first four series. No bursts were observed in a control experiment with $Ti + H_2$.

During the course of an 800-h electrolysis of heavy water with a titanium cathode a Spanish group from the University of Madrid recorded 25 periods of an appreciable increase in the level of neutron emission. The intensity of the neutron emission during the bursts fluctuated from 6.4 to ~40,000 counts/h and exceeded the background (1–2 counts/h) by a considerable amount. The duration of the bursts ranged from 0.4 to 11.2 hours. A signal of gamma rays with energies in the 2.15–2.30 MeV interval, appearing every time the neutron detector had a neutron counting rate reading greater than ~50 counts/h, was also recorded. (One can easily understand this last circumstance, considering the origin of gamma quanta from the capture of neutrons in a moderator and the efficiency with which they are detected by an NaI(Tl) detector.) Examples of the bursts in the neutron and gamma-ray channels are shown in Fig. 7.

Let us point out that in the experiments of the FIAN-LMI-LGU Soviet group, as well as the Japanese group at the University of Osaka, the Argentine group at the Atomic Center in Bariloche, and the Italian group from La Sapienza University the stimulating effect on LTF by an electrolysis current varying in time, which had been predicted earlier by the FIAN-LMI group (see review in "Uspekhi"), was demonstrated. The Argentine group found a difference in the neutron emission level during the current rise and fall, depending on the conditions of its preliminary saturation with deuterium.

Another interesting observation was made by a group

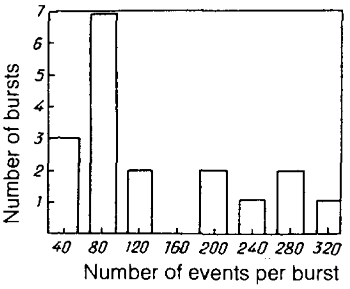


FIG. 5. Frascati experiment. Number of neutron bursts as a function of the number of neutrons in source per burst.

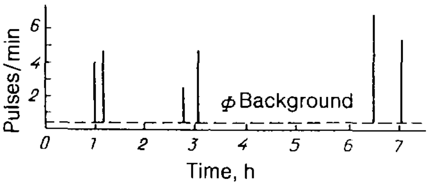


FIG. 6. Sequence of 6 neutron bursts, recorded at onset of electrolysis by the FIAN-LMI-LGU group.

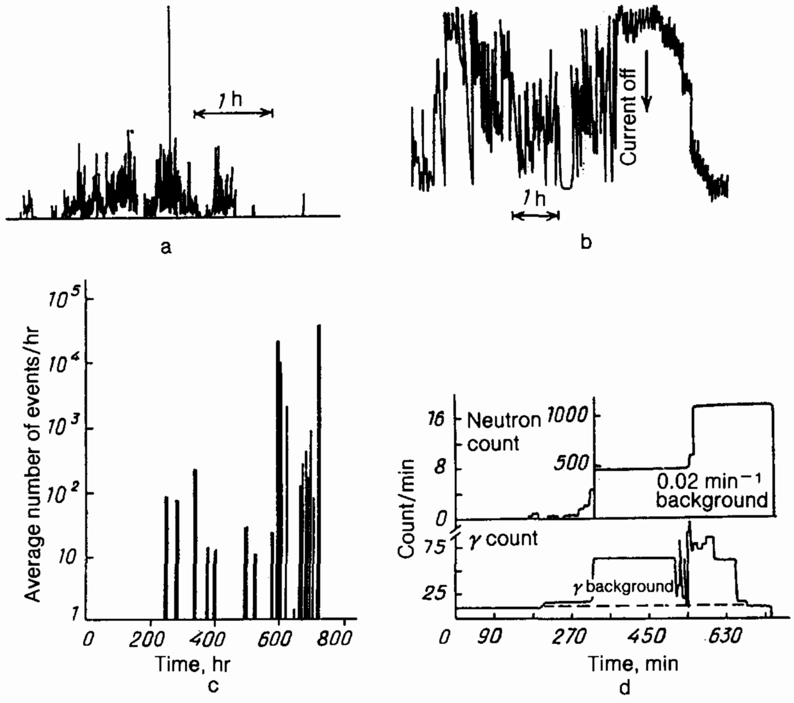


FIG. 7. Neutron and γ-quanta bursts, recorded by the University of Madrid group: a–typical burst, b–most powerful burst, containing $\sim 3\times10^5$ neutrons; c–average intensity during different periods of activity; d–development of neutron and γ-ray signals during most powerful burst.

from Weber State College. In an experiment with gas saturation of Pd with deuterium, where several neutron bursts were recorded together with an overall increase in the neutron emission level, lasting for about 10 days, drastic variations were found in the sample resistance, coinciding with one of the large neutron bursts (Fig. 8). Let us point out that the possibility for such changes in conductivity, associated with the formation of unstable hybrid phases, was predicted earlier by the FIAN-LMI group (see review in "Uspekhi").

A result that has not yet been explained was reported by the group from the University of Osaka, who recorded neutrons during electrolysis by means of an NE213 liquid scintillator neutron spectrometer with a separation of the neutron and gamma-ray signals. Besides the expected neutrons with an energy of 2.45 MeV, they found signals from neutrons with an energy of 3–7 MeV, the origin of which is not yet understood.

An indication of the possible initiation of low-temperature fusion reactions in chemical reactions was first obtained in experiments performed at the Institute of Nuclear Physics, Siberian Branch, Academy of Sciences of the USSR. A brief report on this matter was made by M. Danos, who had visited this Institute not long before the conference. When LiD crystals were dissolved in D_2O, which was then heated to 70–80 °C, an increase in the count rate by a factor of 1.70 ± 0.14 in a neutron detector was observed relative to the background. A similar effect had been detected during the interaction with zinc of complex salts of Pd and Pt, containing deuterium.

In addition to the papers containing positive results, three papers were presented at the conference describing experiments in which attempts to observe neutron emission were unsuccessful.

A paper by R. Anderson from the Los Alamos National Laboratory presented the results of measurements of the integrated neutron yield, spectrometric measurements, and a search for neutron bursts. No neutron excess was found in an experiment with electrolysis or with gas saturation. A careful study of the neutron background, performed by the authors both on the surface and also in a basement room (at a depth of 15 m) with empty detectors and with the same detectors with various contents, gave results resembling the effects which are associated with the signals of LTF. In particular, fluctuations at a level of 3–7σ were observed in the integrated neutron spectrum. A weak peak at an energy of ≈ 2.5 MeV was detected over the background neutron spectrum. Finally, events having a large neutron multiplicity, caused by the background of cosmic rays, were observed. An important lesson that follows from this work is the necessity for a careful monitoring of equipment operation and the background level in LTF experiments.

A group from the University of Oregon (USA) recorded in the course of a 40-week electrolysis of heavy water 7 cases of a temperature rise, not accompanied by a rise in the intensity of the emission of neutrons or gamma rays, nor in

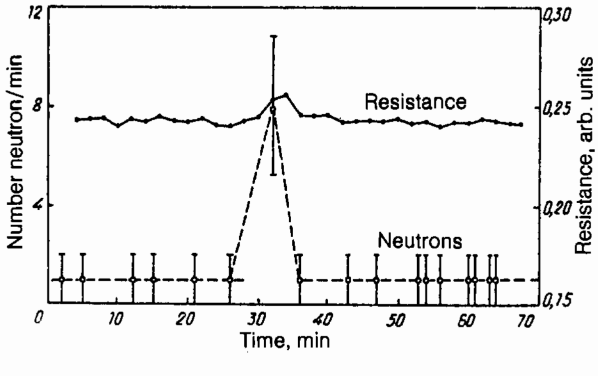


FIG. 8. Correlation of neutron bursts and change in sample resistance in the experiment of the Weber State College group.

the concentration of tritium, and apparently caused by purely electrochemical effects. The attempts of a group from Eötvös University (Hungary) to detect excess neutrons or gamma rays during electrolytic saturation of the amorphous substance $Fe_{90}Zr_{10}$ with deuterium, which up until now has not been used in LTF experiments and has a high capacity for the absorption of hydrogen, did not lead to a positive result either.

Mention should also be made of the negative results of a search for neutron emission during the electrolytic and gas saturation of Pd and Ti, which were described by a group from the Joint Institute of Nuclear Research (Dubna); however, because of the absence of the authors these were not reported at the conference.

DETECTION OF CHARGED PARTICLES

As is known, the detection of the charged products of nuclear fusion (p, T, ^{3}He) in experiments on LTF is very difficult since the paths of these particles in the material of the samples and equipment are short. For this reason only a few papers have been published until recently on the search for the charged products of LTF, with most of them recording negative results (see review in "Uspekhi").

A remarkable number of papers (7), in which positive results were reported with regard to charged particles (primarily protons), were presented at the conference in Provo.

Above all, mention must be made of the group from the Colorado School of Mines (USA), in which high-intensity bursts of charged particles (up to 10^5 s^{-1}) from deuterated titanium alloy foils were observed. After 56 days of measurements a total of 24 bursts were recorded in 12 out of 26 samples. The activity increased during thermocycling in the interval from -180 °C to room temperature. Measurements made by means of silicon surface-barrier detectors made it possible to establish that tritons are also present among the charged particles in addition to protons. No similar flashes were observed during 7 days of measurements in 8 foils saturated with hydrogen.

In an experiment by a group from 6 California institutes (a paper by E. Lopez) a thin palladium film (3400 Å thick with a 1 cm^2 surface area) was deposited onto the surface of a semiconductor detector and ion-implanted by a beam of D_2^+ ions having an energy of 80 keV. After the film was saturated and the source shut off a charged-particle emission signal was recorded.

The ion implantation method was also used to saturate titanium foils with deuterons having an energy of 0.3–1 keV in an experiment conducted at the Naval Research Laboratory in Washington, D. C. (USA) and also by a group of Canadian physicists from the University of Manitoba.

Experiments to find correlations of the emission of protons and electromagnetic radiation have been conducted by three groups: FIAN-LMI, University of Osaka (Japan), and Qing Hua University (China). The FIAN-LMI and Osaka groups used a time-varying electrolysis current to induce LTF reactions. Emission of charged particles was recorded in all three experiments.

In addition to these positive experiments, negative results were presented by a group from the University of Texas (USA). In this experiment deuterated titanium foils were placed in a high vacuum and cooled to the temperature of liquid nitrogen. Then they were warmed over a period of 24 hours. Two samples with an area of about 300 mm^2, which were monitored by silicon semiconductor detectors, were used in each series. One of these ($\Delta E/E$) with an area of 100 mm^2 consisted of two layers having thicknesses of 16 and 300 μm while the other with an area of 450 mm^2 had a thickness of 300 μm. The piece-wise detection of events made it possible to obtain an unequivocal identification of the particles with a high detection efficiency. In the samples, each of which was subjected to four thermocycles, no emission of singly charged particles was observed. The background was caused primarily by α-particles from radioactive decays.

TRITIUM ANALYSIS

Considerable interest at the conference was directed at experiments to find the formation of tritium. The question of

TABLE II. Recording of tritium during electrolysis at Bhabha Center of Atomic Research.

Number of experiment	1	2	3	4	5	6	7	8	9	10	11
Cathode Material	Pd—Ag	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd
Surface, cm^2	113	113	19	14,5	6,37	6,37	6,37	2,75	0,57	0,126	4
Electrolit volume, ml	150	150	150	65	60	100	80	80	28	3	1,5
Current density, μA/cm^2	350	350	105	160	< 350 pulse	< 470 pulse	< 350 pulse	800	100	278	7,5
Time of electrolysis	12 h	30 h	13 days	7,4 days	366 h	183 h	5,8 days	40 days	190 days	17 days	80 days
Measurement of tritim:											
Initial concentration, Bk/ml	1,44	3,33	3,6	2,7	2,81	2,77	2,70	2,68	4,6	2,0	2,5
Maximum concentration, Bk/ml	225,7	18,5	—	$0{,}9\cdot10^4$	$5{,}9\cdot10^4$	4,6	—	—	72	65	23
ratio of the end and initial concentration	167	5,6	3,36	3425	21	1,66	2,5	1,9	15,7	32,5	9,16
complete excess, Bk	$3{,}3\cdot10^4$	$2{,}3\cdot10^3$	$2{,}7\cdot10^3$	$6\cdot10^5$	$2{,}1\cdot10^6$	$3\cdot10^3$	$6{,}3\cdot10^2$	$1{,}1\cdot10^3$			
of atoms	$1{,}76\cdot10^{13}$	$1{,}2\cdot10^{12}$	$1{,}44\cdot10^{12}$	$3{,}2\cdot10^{14}$	$1{,}1\cdot10^{15}$	$1{,}56\cdot10^{12}$	$3{,}96\cdot10^{11}$	$5{,}8\cdot10^{11}$	10^{12}	10^{11}	$2\cdot10^{10}$
Output, T/cm^2	$1{,}6\cdot10^{11}$	$1{,}1\cdot10^{10}$	$0{,}8\cdot10^{11}$	$2{,}2\cdot10^{13}$	$1{,}7\cdot10^{14}$	$2{,}4\cdot10^{11}$	$6{,}2\cdot10^{10}$	$2{,}1\cdot10^{11}$	$1{,}8\cdot10^{12}$	$0{,}8\cdot10^{12}$	$0{,}5\cdot10^{10}$

TABLE III. Formation of tritium during gas saturation of Pd with deuterium at Bhabha Center of Atomic Research.

Experiment number	1	2	3	4	5
Sample material	Pd	Pd—Ag	Pd—Ag	Pd—Ag	Pd—Ag
Mass, g	20	0,96	10,9	10,6	0,43
Volume of absorbed D_2, ml	1325	34,5	516,4	222	20,2
D/Pd ratio	0,63	0,46	0,45	0,20	0,45
Time to arrive at equilibrium, h	16	16	240	40	240
Volume of water used for extraction, ml	50	6	50	50	5
Tritium activity of water, Bq/ml	8,1	5,9	8,5	12,5	32,6
T/D ratio in Pd	$32\cdot10^{-11}$	$1,1\cdot10^{-11}$	$0,87\cdot10^{-11}$	$3,4\cdot10^{-11}$	$8,3\cdot10^{-11}$
Absolute tritium activity, Bq	411	37	429	718	159
Total number of tritium atoms in Pd	$23\cdot10^{11}$	$2\cdot10^{10}$	$2,4\cdot10^{11}$	$4,1\cdot10^{11}$	$9\cdot10^{10}$
Number of tritium atoms/g of Pd	$1,2\cdot10^{10}$	$2,1\cdot10^{10}$	$2,2\cdot10^{10}$	$3,8\cdot10^{10}$	$20,8\cdot10^{10}$

the generation of tritium in accordance with the $D + D \rightarrow T + p$ channel in LTF is one of the most critical and controversial. Whereas a tritium yield was observed in a whole series of experiments, generally exceeding, moreover, the yield of neutrons by several orders of magnitude, in many other experiments no excess of tritium was found. The conference at Provo, although it supported the predominance of the "tritium channel" over the "neutron channel" ($D + D \rightarrow n + {}^3He$), gave no final answer to this question.

The most comprehensive and impressive results on tritium were obtained at the Bhabha Atomic Research Center in experiments on electrolysis and gas saturation and in experiments with a plasma focus apparatus. The tritium level in the near-surface layer of the samples was measured by various methods: by a direct counting of β activity with gas-filled proportional counters, by detecting the 4.9-keV x rays from the excitation of Ti atoms with NaI and Ge detectors, and by radiography using x-ray films. In all 22 experiments with electrolytic cells an excess of tritium to the extent of 10^{10} to 10^{16} atoms was found. An indication of a relatively simultaneous formation of neutrons and tritium was obtained (in about half the experiments (see, for example, Figs. 4a and 4c). The integrated density of the tritium yield was between 4×10^9 and 1.7×10^{14} per cm^2 of sample surface. In 10 of the 22 cells it was between 10^{12}–10^{14} cm^{-2}, whereas in the rest it was 10^{10}–10^{12} cm^{-2}. Just as in the neutron case, the total fraction of "successful" series with respect to the detection of tritium at the Bhabha Center was $\approx 70\%$.

The most striking aspect is the large ratio of the tritium to neutron yields, typically amounting to 10^6–10^9 and only rarely 10^3–10^4.

An interesting result obtained at the Bhabha Center recently is associated with the use of the plasma focus apparatus with deuterium filling. After a session with 80 discharges, 10^{16} tritium atoms were found in the surface layer of the central electrode of the apparatus. The authors suggest that the rf heating plays the role of a stimulus with respect to the generation of tritium in Ti.

Tables I–IV contain the principal results of the Bhabha Center experiments on the search for tritium.

Positive results in the search for tritium were also presented by the Frascati group (Italy), the University of Madrid group (Spain), the Institute of Nuclear Energy group (China), the University La Sapienza group (Italy) and the FIAN-LMI-LGU group. The last three groups listed here used a time-varying current in an electrolyzer to induce LTF.

During a lengthy 800-hour electrolysis of heavy water with a titanium electrode the University of Madrid group obtained an indication of two regimes of tritium formation. In the first 500 hours several periods of increased tritium content were observed, which correlated with neutron and gamma bursts. (Fig. 9). The delay (~ 10 hours) between the T and n, γ bursts can be explained by the diffusion time T from cathode to electrolyte. After ≈ 500 hours the tritium concentration exhibited an "oscillating" behavior, during which the neutron and gamma bursts were accompanied not by a rise but by a fall in the tritium content (see Figs. 9e and 9f). In the opinion of the authors, the two observed regimes may correspond to the $D + D \rightarrow T + p({}^3He + n)$ and $D + T \rightarrow {}^4He + n$ reactions (in the latter case the neutron would have an energy of 14.1 MeV rather than 2.45 MeV).

In addition to the positive results with respect to tri-

TABLE IV. Formation of tritium in Ti during gas saturation with deuterium at Bhabha Center of Atomic Research.

Experiment number	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 in terms of x ray count, Bq	290	1300	$5,5\cdot10^6$
Number of tritium atoms	$1,5\cdot10^{11}$	$6,5\cdot10^{11}$	$3\cdot10^{11}$
T/D ratio	$1,2\cdot10^{-9}$	$3,2\cdot10^{-8}$	$7,1\cdot10^{-5}$

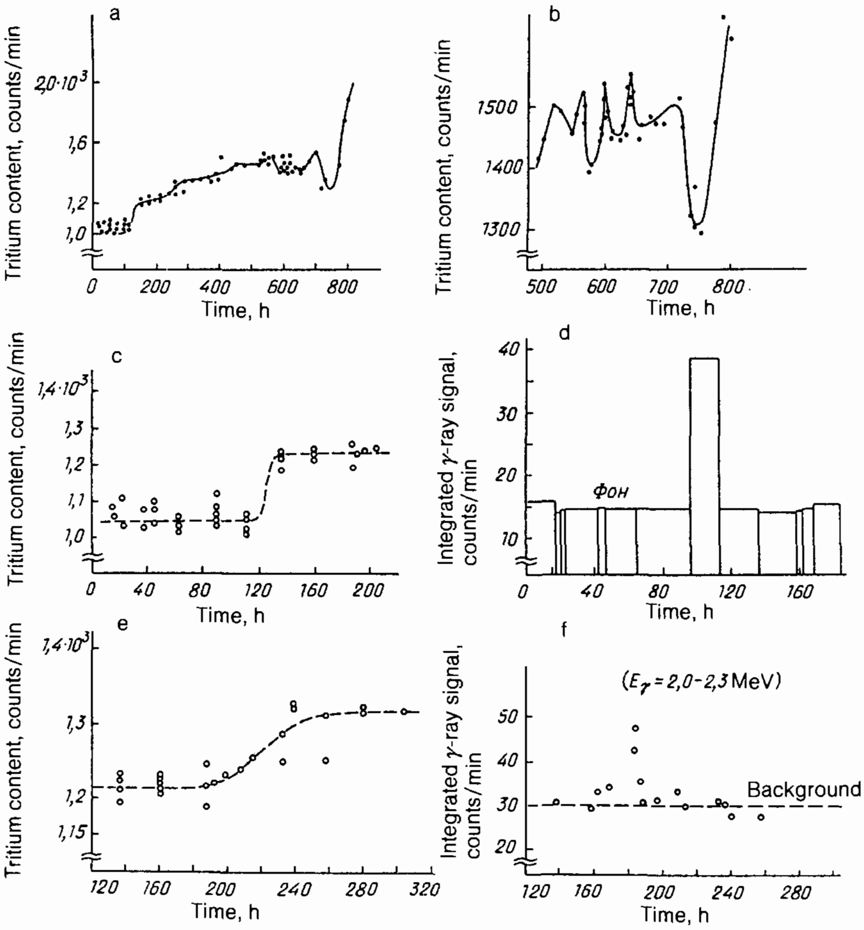


FIG. 9. Concentration of tritium in electrolyte in experiment of the University of Madrid group: a–tritium content in electrolyte in the first 800 hours; b–tritium content in electrolyte during the period from 500 to 800 hours; c–tritium content in electrolyte in the first 200 hours; d–integrated γ-ray signal during the first 200 hours; e–tritium content in electrolyte in the measurement period from 120 to 320 hours; f–integrated γ-ray signal in the period from 120 to 320 hours.

tium, the University of Texas group discarded their early data, indicating an abundant formation of tritium during electrolysis, and presented negative results. In the new measurements no tritium formation that could be related to LTF reactions was observed in any of more than 100 electrolytic cells. In the opinion of the authors, the tritium excess they had observed was caused by impurities contained in the electrode metal and in the electrolyte.

In a discussion of this paper and some subsequent reports this point of view was subjected to a critique. Thus, the group from the National Institute of Cold Fusion (Salt Lake City, Utah) reported on work especially carried out by them to test the suggestion of impurities in Pd as a possible source of excess tritium. They used open electrolyzers, like those used in the experiments where tritium formation had been found earlier. A total of 45 palladium samples, produced by three different companies and having different dimensions and metallurgical history, were tested. No signs of tritium impurities were found: within the limits of the experimental error (± 3 decays/min·ml) all samples gave a tritium count at the background level (26 decays/min·ml). The authors point out that the use of open electrolyzers can lead to unreliable results if special safeguards are not provided. In this respect, systems with a closed electrolysis cycle are preferable.

CORRELATION EXPERIMENTS

The experiments considered above, in which one or another product of nuclear fusion (neutrons, protons, gamma rays, tritium) is recorded for different methods of deuterium saturation of the lattice of metals, can be relegated to the category of traditional experiments. In addition to these, the results of the first experiments of a new type, so-called "correlation" experiments, in which the products of nuclear reactions and possible signals from accompanying phenomena were recorded simultaneously, were presented at the conference (see review in "Uspekhi").

The abundant experience with investigations of radiation acoustics and mechanoemission, accumulated by the P. I. Golubnich group (LMI), was utilized in an experiment performed by the FIAN-LMI group. A search was made for time correlations between pulses of nuclear (proton), electromagnetic, and acoustic emissions during electrolytic saturation of palladium targets with deuterium. The sensors of the recording channels were placed in the immediate vicinity of the target: a) A nuclear sensor in the form of a CsI scintillator monitored by a photomultiplier; b) An acoustic sensor in the form of an ITS-19 piezo-ceramic washer, soldered to the Pd target; c) An electromagnetic sensor in the form of a toroidal coil with an amplifier having a gain of $\sim 10^4$ and a bandwidth of ~ 1 MHz. The loads on these channels were $\sim 10^{-3}$ Hz, ~ 400 Hz and ~ 0.03 Hz, respectively. The starting pulse was produced by the CsI scintillator. A delay of 10 μs was introduced into the acoustic pulse, making it possible to record acoustic signals preceding the nuclear pulse. Triple correlations were looked for within the limits of a 10-μs time interval. For the stated conditions the probability of random triple coincidences was $\sim 3 \times 10^{-12}$ s^{-1}. Not

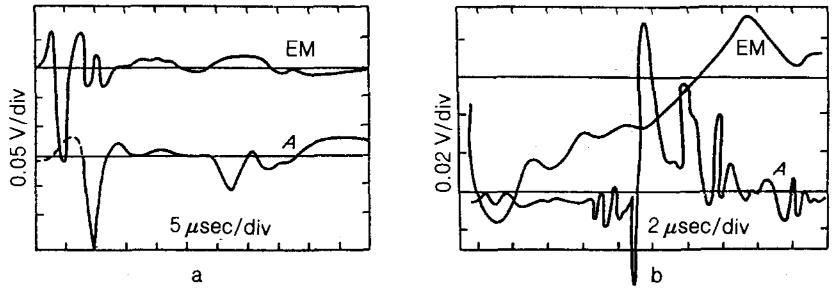


FIG. 10. Oscillogram of two events (a, b), recorded by the FIAN-LMI group, demonstrating time correlation between pulses of nuclear, acoustic (A) and electromagnetic (EM) emissions from palladium target. Oscilloscope sweep was triggered by signal of scintillation detector.

one triple coincidence was recorded during 15 hours of control measurements with the electrolysis of H_2O.

During three working series with the electrolysis of for a total measurement duration of ~ 11.5 hours, two events were detected with triple coincidences, the oscillograms of which are depicted schematically in Fig. 10. The amplitudes of the acoustic and radio signals were also measured. In both cases the acoustic pulse began to develop 2–3 μs earlier than the starting pulse; this is a natural result from the viewpoint of an acceleration mechanism (see "Uspekhi" review). The expected number of random triple coincidences during the time of the measurements was $\sim 10^{-7}$. One other correlation of a proton burst and acoustic emission was recorded during the thermal desorption of deuterium when the deuterium-saturated Pd target was heated.

Unfortunately, this experiment had certain drawbacks: a) The number of recorded events was very small; b) There was the possibility of a signal of mechanoemission nature from the CsI (photons or x rays accompanying cracking of the Pd hydride) although the control experiment with H_2O eliminates this factor to a considerable degree; c) A contribution of a special kind of correlation noise is possible, induced by the interaction of cosmic ray particles, which can form fast nucleons and simultaneously cause a cracking in the stressed hydride material.

In order to eliminate these drawbacks, the FIAN-LMI-IYaI group conducted a special experiment in the low-background laboratory of the Baksan Underground Neutrino Observatory of the Institute of Nuclear Research of the Academy of Sciences of the USSR. A low-background chamber, constructed for investigations of double β-decay at a depth of 1000 m of water equivalent using low-background materials, was used. The background in the chamber was reduced significantly compared with typical laboratory conditions at sea level, for example, by a factor of about 10^4 with respect to muons and by a factor of about 10^3 with respect to γ rays (having an energy of 0.5–2.5 MeV) and neutrons. Unfortunately, these excellent background conditions could not be exploited to the fullest since the standard equipment used in the measurements contained considerable radioactive impurities. As a result there were $N^{\gamma} \sim N^{\gamma}_{\rm lab}/200$ and $N^{n} \sim N^{n}_{\rm lab}/30 \sim 5\times 10^{-3}$ slow neutrons/s in the detector.

In a special auxiliary series the central block of paraffin moderator was replaced by a fast neutrino detector and a ^{252}Cf radioactive source. By means of this modification a curve of the distribution of the neutron slowing times, shown in Fig. 11, was obtained for the geometrical conditions of the experiment. Typical slowing times amounted to several tens of μs. In the primary series of measurements lasting for 4 hours slow neutrons and acoustic pulses were recorded at coincidence and a pulsing current and cooling of the sample were used to induce LTF. A total of 42 events were recorded with a correlation of the neutron and acoustic signals within the limits of a 100-μs time interval during cooling; the number of random coincidences was ~ 5. The good agreement between the shape of the slowing curve and the curve of the distribution in terms of the arrival time difference of the neutron and acoustic signals (see Fig. 11) confirms the correctness of the results obtained. Control experiments made it possible to exclude possible spurious equipment effects.

The presence of proton emission and electromagnetic radiation was also confirmed in an experiment by the group from the University of Qing Hua when Pd was saturated with deuterium from the gaseous phase.

The group from Osaka University recorded high-frequency signals at the anode of their electrolytic cell, which appeared at the beginning of electrolysis. However, it could not be established to what degree they correlate with proton emission events.

Acoustic emission signals were recorded in experiments with the gaseous saturation of Pd and Ti by the Los Alamos and Brigham Young University group and were used for monitoring the sample cracking stage.

In concluding this section, let us emphasize again that the correlation experiments are important mainly because if they establish a relationship between LTF and cracking processes of the hydrides they may indicate possible mechanisms that are initiating this phenomenon.

DEVELOPMENT OF METHODS

An important aspect of the work on LTF is the refinement of measuring equipment and the methods for conduct-

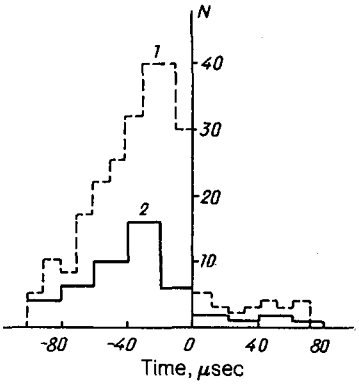


FIG. 11. Correlated FIAN-LMI-IYaI experiment: 1–time distribution of neutron slowing in control experiment, 2–distribution in terms of difference in arrival time of acoustic and neutron signals in working experiment.

ing experiments. Let us discuss of the results of the conference in this area.

1. In their basic aspects the methods for recording neutrons have not undergone any significant changes. Solid and liquid scintillators, generally supplemented by systems for γ/n separation, are used for the most part for the detection of fast neutrons. Slow neutrons are detected by means of ^{3}He and BF$_3$ proportional counters. Moreover, the efficiency has been increased appreciably (to $\simeq 45\%$ in the best detectors), as has the noise immunity of the recording equipment. In some facilities the operation of the individual elements is monitored, thereby eliminating pickup and spurious responses. Recording neutrons before and after slowing is the most reliable method, and it was first used by the Jones group, followed by its use in the experiments of the FIAN-LMI, the Bhabha Center and a number of other groups.

Semiconductor detectors are generally used for the recording of charged particles; by the use of these devices one can not only detect the particles and determine their energy but also, through the use of $\Delta E/E$ sandwiches, determine the kind of particles.

Diverse methods are used for detecting tritium, including direct counting of the β-activity with liquid or solid scintillators, recording of x rays, radiography, etc. The use of different methods makes it possible to increase the reliability of the results.

2. In contrast to the experiments on LTF conducted in the early period, at the present time considerable attention is being focused on questions of background suppression. It is sufficient to say that low-background underground laboratories have been used in a whole series of measurements (Fig. 12). Three Italian groups have worked in the Gran Sasso neutrino laboratory, the FIAN-LMI-IYaI Soviet group has used the low-background chamber of the Baksan underground neutrino observatory, the Chinese group from the Institute of Atomic Energy (Beijing) have made measurements in the underground Mentow laboratory at a depth of 580 m, and the S. Jones group has worked in a lead mine in Colorado. This has made it possible to reduce the background from cosmic rays by 3–6 orders of magnitude. Under these conditions the radioactive impurities contained in the materials of the instruments and the surrounding rocks become the most important background source. In the Baksan low-background chamber, constructed for experiments on double β-decay, this last background source has also been suppressed significantly. Special low-background materials have also come into use for the fabrication of experimental equipment for LTF.

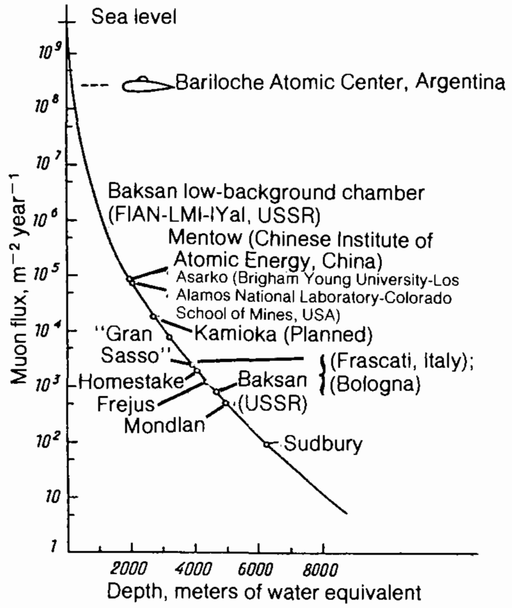


FIG. 12. Variation of cosmic muon flux with depth of underground laboratories. The groups conducting LTF experiments in these laboratories are enclosed inside parentheses.

The use of the underground Kamiokande Cerenkov detector, proposed in the paper of I. Totsuka from Tokyo University (Japan), opens up extremely interesting prospects for experiments on LTF. It is proposed to place an electrolytic cell inside a nickel cylinder and to record the gamma rays from the neutron capture reaction Ni(n, γ)Ni. The isotopes ^{58}Ni, ^{60}Ni and ^{62}Ni, comprising 68%, 26% and $\approx 3.7\%$ of natural Ni, give γ rays with energies of 9.0, 7.8 and 6.8 MeV, respectively, which will be recorded by a detector with an efficiency of $\simeq 10\%$. Taking into consideration the very low background loads, one can ensure a neutron sensitivity limit (at the 90% confidence level) of 4×10^{-5} neutrons/s (or 1×10^{-5} neutrons/s) for a background γ-quantum energy of 7 MeV (or 8 MeV), which is at least three orders of magnitude better than the existing level. For conditions of no background it is actually also possible to record the γ rays from the $p + D \rightarrow {}^3He + \gamma$ reaction.

3. In the previous section we have already mentioned correlation measurements. They are of interest not only from the viewpoint of explaining the nature of LTF but they can be a convenient and effective method for suppressing background and isolating weak signals (if the presence of correlations is confirmed by subsequent investigations).

4. Even in the earliest work of the FIAN-LMI group (April 1989; see the "Uspekhi" review) it was assumed that LTF processes could be stimulated by means of various outside influences: ultrasound, thermo-, cryo- and current-cycling, mechanical deformations, etc. At the present time some of these methods are widely used and they actually do lead to an intensification of the LTF. Thus, thermocycling, first used by the F. Scaramuzzi group, is now being widely used in all experiments on the saturation of metals with deuterium from the gas phase. The groups from the University of Osaka, the Atomic Center at Bariloche, FIAN-LMI, La Sapienza University, and others have all reported on the experimental observation of the enhancement of LTF caused by a time-varying (pulsing or stepped) current during electrolysis (Fig. 13).

An interesting observation was made by Indian scientists from the Bhabha Center, who observed an enhancement of the formation of tritium, caused by high-frequency heating of the deuterated sample.

The group from the Tokyo Laboratory of Fundamental Research have reported on a new effective technique for inducing the LTF processes. A plate of palladium deuteride (α-phase) 1 mm thick was covered on one side with a 100-nm gold film, preventing escape of deuterium atoms, and on the other side by an MnO film with a thickness of $\lesssim 10$ nm, in which the deuterium atoms have a diffusion constant that is less than in Pd. This layer served as a surface barrier for regulating the rate of escape of deuterium atoms from the

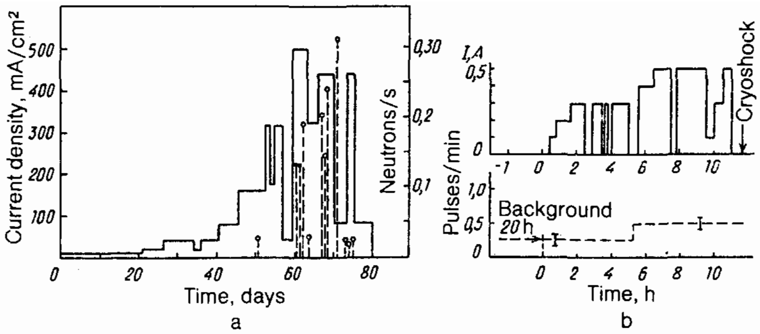


FIG. 13. Variation of electrolysis current for LTF stimulation: a–experiment of University of La Sapienza group. Neutron bursts are shown by dashed line. b–FIAN-LMI-IYaI experiment. Upper part of the figure shows current variation, lower part the neutron emission level.

hydride. Three such samples were placed in a vacuum chamber. After three hours the following effects were observed, occurring essentially simultaneously: emission of neutrons ($\sim 10^6$), lasting 2–3 sec, an "explosive" evolution of gas, an increase in the surface temperature $\gtrsim 700$ °C, and a biaxial deformation of the samples because of a uniform expansion on the side coated with the MnO film. Upon subsequent pumpdowns these same samples gave two more neutron bursts of about the same power. A subsequent 20 pumpdowns did not lead to any new signals. As the authors stress, this procedure leads to the formation of a thin Pd layer ($\lesssim 40\,\mu$m) with an increased concentration of deuterium near the surface coated with the MnO film.

5. In addition to the traditional methods for saturating samples (electrolysis, D_2 gas, ion implantation) for LTF experiments, in the papers presented at the conference there were reports on the successful use of a plasma-focus apparatus (Bhabha Center) and an electrolyzer with a solid electrolyte (University of Rochester, USA). Let us point out that the use of a solid electrolyte opens up interesting prospects for varying the temperature during the electrolysis process.

Besides using the traditional Pd and Ti, a search is underway for new materials—deuterium "accumlators"; generally these are various alloys of Pd and Ti. Experiments have also been reported with amorphous $Fe_{90}Zr_{10}$ and the high-temperature superconductors $Y_1Ba_2Cu_3O_{7-x}$.

6. Many interesting "technological" details were presented in the papers at the conference, associated with the preparation of samples, choice of electrolysis and gas saturation regime, as well as with the results of structural studies (by electron microscopy, neutron diffraction, and x-ray diffraction methods) and studies of crack formation and deformations of samples during their hydrogen absorption process.

Let us mention in particular that the group from Los Alamos and Brigham Young University have achieved a high reproducibility of positive results for the gas saturation of Ti by carrying out a preliminary degreasing of the samples with methylene chloride, methanol, and water. The Frascati group points out that for electrolytic saturation they were unable to obtain positive results if the Pd and Ti(Al) electrodes were not degassed beforehand or if the electrodes were made from ultrapure Ti.

LTF AND GEOLOGY

An intriguing aspect of the LTF problem was discussed in a special section of the conference, devoted to geochemical and geophysical investigations. In a number of the papers, ideas were put forth concerning the role which LTF processes can play in the life of our planet, in particular, in the abundance of certain elements and even, possibly, in the energy balance of the Earth's interior.

The following arguments, which could indicate the occurrence of LTF processes in the interior of the Earth, were presented in a paper by P. Palmer from Brigham Young University.

a) The concentration of ^{3}He in the atmosphere is too high if the existence of a constantly acting or "initial" source of this element is not assumed.

b) An unexpectedly high value of the ^{3}He/^{4}He ratio is observed in volcanic gases, liquids and lavas.

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

d) The heat of volcanic activity, associated with the subduction of cold water-bearing sedimentary rocks, is too high to be accounted for only by frictional heat generated by the gravitational potential energy and by the heat of the surrounding rocks.

e) Whereas normal radioactivity, caused by U, Th and K, is not associated with the hot points of the earth, but exists on cold continents, the products of nuclear fusion, on the other hand, are found at hot spots.

f) Finally, estimates of the radiogenic sources of the Earth's heat indicate the inadequacy of U, Th and K for explaining the heat balance of our planet and the high temperature of the core.

P. Britton from the Reiss Foundation, South Hamilton, MA (USA) presented data from an analysis of samples taken during a deep bore hole in a fault zone in the state of Massachusetts. Here it was found that the concentration of tritium and ^{3}He increases with depth approximately linearly, indicating the presence of a single source of these elements or a gradually occurring process including both of these isotopes.

An anomalously high tritium content in the lavas of the volcano crater of Mount St. Helens was found by the Los Alamos National Laboratory group. Studies showed that an appreciable amount of atmospheric moisture cycles through cracked lava. An accumulation of tritium is possible both because of natural processes (LTF?) and also as a result of contaminations associated with nuclear weapon tests.

G. McMurtry from the University of Hawaii reported on an anomalous increase of the tritium content in the atmosphere, measured by tritium monitoring stations in the Hawaiian Islands in February–March 1978. An analysis of the data indicates a possible correlation with an eruption of the volcano Mauna Ulu, located 40 km from the station, whereas any connection with the testing of a Soviet hydrogen bomb 5 months before the observations is not very likely. These and other similar data prompt the need for a closer study of the possible role of LTF processes as the source of certain isotopes (and, possibly, heat) in the Earth although the results of laboratory experiments on LTF have yet to give any fairly reliable bases for this.

LTF MODELS

Just as before, no common generally accepted point of view on the mechanism of LTF was formulated at the conference. In this brief review it is impossible to consider in any detail the various theoretical models and physical considerations contained in the twenty papers in the theoretical sections and in many of the experimental papers presented at the conference. Therefore, we will restrict ourselves to only brief comments on some directions in which the search is proceeding for an answer to the question of the nature of this phenomenon.

If one is speaking of the most popular idea, then this would be the idea of an "accelerating" or "crack-acceleration" mechanism (ACM) of LTF, which was mentioned in many of the papers. In the ACM fusion is actually not "cold" (as in μ-catalysis), but is "microscopically hot". The energy necessary to overcome the Coulomb barrier is imparted to the ions by acceleration in the cracks that are formed in the process of saturating the metals with hydrogen isotopes (see review in "Uspekhi"). The most significant evidence in favor of ACM comes from the results of correlation experiments. Moreover, as shown in a paper by the FIAN-LMI group (see the Uspekhi article), all other predictions previously formed on the basis of ACM also apparently obtain experimental confirmation (surface-volume character, stochasticity, possible "quasiperiodicity", nonequilibrium of the metal/deuterium system, "microhot" fusion, the possibility of outside influences, an increase in the electrical resistance during "activity" periods). However, there are a number of problems in the ACM, associated in particular with the need to assume the presence of sufficiently strong fields in cracks and with the characteristic times of the various competing processes (see review in "Uspekhi"). Moreover, if the predominance of the tritium channel over the neutron channel is finally established, this will require introducing into the ACM some modifications in the nuclear interaction cross section, taking into consideration the nonequivalences of these channels. Certain possibilities in this regard were discussed by Y. Kim from Purdue University in connection with the Efimov effect (an infinite number of levels in a three-body system in the presence of a level with zero energy in a two-particle system); the difference of D(D, p)T and D(D, n)^{3}He may be a consequence of an interaction in the final state.

In conjunction with the "strong field" problem J. Preparata from the National Institute of Cold Fusion (USA) put forth the idea of a possible combining of the ACM and an approach that takes account of coherent electrodynamic effects in a condensed medium.

Another possibility may be associated with the enhancement of the probability of fusion of deuterium nuclei in the Coulomb field of the lattice ions, suggested by M. Danos (National Institute of Standards and Technologies, USA) and V. B. Belyaev (Joint Institute for Nuclear Research, Dubna). This effect may also make it possible to explain the predominance of the tritium channel.

In a number of papers the authors have turned to exotic particles to explain LTF. Thus, in papers by J. Rafelski from the University of Arizona and L. Shaw from the University of California, Irvine, scenarios are suggested, by analogy with μ-catalysis, in which LTF occurs because of catalysis by new heavy particles (integer-charged hadrons or fractionally charged free stable anti-diquarks). A suggestion of the emission of new light particles in LTF processes was also introduced in a paper by T. Matsumoto from Hokkaido University (Japan). Such models have very interesting properties; however, they have the disadvantage that in order to explain one phenomenon that is not understood another even more hypothetical phenomenon is introduced.

A considerable number of the papers were devoted to features appearing in the nuclear fusion process due to collective effects caused by the crystal lattice (papers by P. Hagelstein from the Massachusetts Institute of Technology (USA), S. Chubb from the Corporation of Research Systems (USA), A. Tenenbaum from La Sapienza University (Italy), G. Takahashi from the Brookhaven Nation Laboratory (USA), and others).

V. M. Vysottskiĭ from the State University of Kiev and R. N. Kuz'min from the State University of Moscow discussed the conditions for which deuterons located near microdefects in crystals could take part in "non-threshold fusion", caused by strong overlapping of the wave functions.

In a paper by J. Cerofolini from the Materials Technology Laboratory (San Danato, Italy) a suggestion is made concerning the formation of metastable exotic "two-nuclei atoms" $(D^+ + D^+)2e^-$, preceding their fusion process.

Let us also mention a number of papers in which constraints are obtained on the fusion cross section at very low energies. V. Zakowicz and J. Rafelski from the University of Arizona showed that data on the cross sections of the DD and pT reactions at low energies at the present time impose serious constraints on the influence of possible nuclear resonances and prevent explaining LTF experiments on the basis of them. Another constraint on the DD cross section was obtained by M. Gajda from the University of Arizona based on estimates of the excess heat of Jupiter. It is about 9 orders of magnitude smaller than is required to explain LTF data. Finally, M. Vaselli from the Institute of Atomic and Molecular Physics (Pisa, Italy) confirmed the previously obtained results of the relative inadequacy of the screening effect in Pd crystals for agreement with LTF experiments.

Summarizing the conference, D. Worledge from the Electric Power Research Institute (USA) made the following points in his concluding address:

—the observed phenomena are not "normal" DD fusion;

—experiments thus far are inadequate to provide a guide for theory;

—the quality of many experiments has improved significantly;

—many very different experiments yield similar results;

—this area of research has every right to exist and must be supported.

On my part, concluding this review, I would like to evaluate the situation with LTF after the conference in Provo with the following words: "The stigma is removed, questions remain".

The author wishes to express his sincere gratitude to the organization committee of the conference for their hospitality and financial support, as well as D. Worledge for useful discussions.

Translated by Eugene R. Heath