Summary

Nuclear Products in Cold Fusion Experiments Comments and remarks after ICCF–6

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1 Introduction

From the first beginning two major problems have affected the scientific development of the Cold Fusion and related phenomena. They are:

- the lack of reproducibility of most of the experimental observations (in particular the Excess Power in given conditions)
- the lack of a substantial amount of nuclear ashes that could validate the hypothesis that the sometimes observed Excess Power could be the result of nuclear reactions occurring in the metal lattice. Nuclear origin was inferred in an indirect way. by the observation that the sometimes measured Excess Powers were at least three orders of magnitude greater than those produced by any known chemical reaction.

I think that. by the time of ICCF–6. one of these two problems has been solved in a positive way. following the accepted cryterion of the scientific methodology. that is SEVERAL INDEPENDENT CONFIRMATIONS BY DIFFERENT GROUPS AT DIFFERENT LABORATORIES. The nuclear product which is observed to be emitted in correlation with the Excess Power and in quantity of the expected order of magnitude is ^{4}He.

One could ask himself why so much time elapsed before reaching such a conclusion. The main reason. to my opinion. is the experimental difficulty. coupled to the well known general discredit in which Cold Fusion was put by the majority of the scientific establishment. This circumstance discouraged a substantial part of the Groups to follow the ^{4}He detection approach.

I remind that Fleischmann. Hawkins and Pons [1] from the first beginning. noticed that the neutron and ^{3}H production in their cells. even if measured with rudimentary tools. was lower by 10^8 to 10^{10} orders of magnitude than what expected by the measurement of the Excess Heat. in the hypothesis that it was of nuclear origin. following the fusion of two deuterons. In the Pd lattice the $d + d$ fusion reaction had to proceed in a way substantially different than in free space, in which case the $(n + ^3He)$ and $(p + ^3H)$ channels almost equally probable. are the well known final products. It must also be noticed that. from the first beginning. the channel with ^{4}He in the final state. known to occur with a frequency lower by a factor 10^{-6} with respect to

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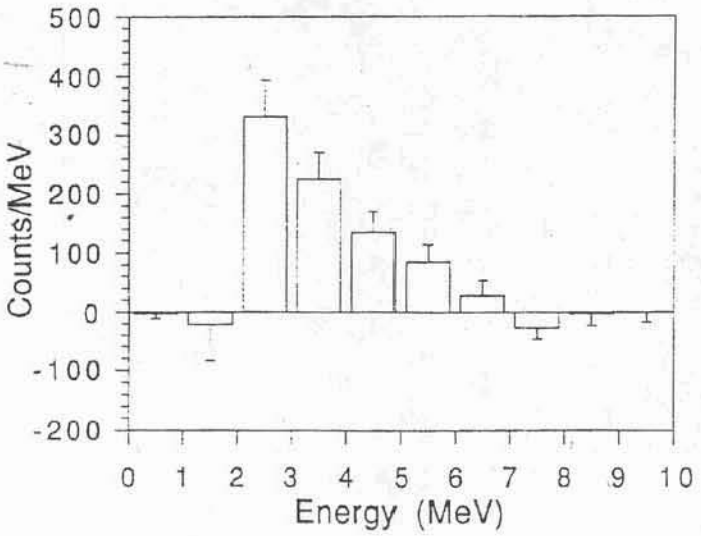

Figure 1: Neutron spectrum observed from a Ti/D_2 system, loaded in gas phase [3].

the $(n +^3 He)$ and $(p +^3 H)$ ones in free space, was supposed to be the most important one in $(d + d)$ fusions in a metal lattice by some authors [2].

Notwithstanding these facts, tens of experimental Groups in many Laboratories in the world started to set up in a hurry neutron detection systems, more or less sophisticated, and also, in a reduced number, ^3H detection devices. Why such a big experimental effort, in spite of the lack of observation of substantial amounts of neutron and ^3H by Fleischmann, Hawkins and Pons? The reason is quite simple. Many groups knew the techniques of neutron detection and had at home more or less complete apparatuses. Their hope was that of observing in a clear–cut way even a few neutrons (at 2.5 MeV), that were the simpler signature for ascertaining that "something nuclear" occurred in a Cold Fusion cell. The problem of the discrepancy of the orders of magnitude (10^8!) was left over, implicitely assuming that some other reaction, not producing neutrons, was responsible of the Excess Heat.

Now, after several years of experiments (more than 100) on neutrons and ^3H detection from Cold Fusion cells, quite general conclusions can be drawn. There is a weak emission of neutrons, completely unable to explain the amount of Excess Heat, with a statistical significance exceeding hardly a few standard deviations. Fig.1 shows, as an example, a neutron spectrum observed from a Ti/D_2 system, loaded in gas phase [3]. The neutron detector was constructed ad hoc for Cold Fusion experiments, not recuperated from scratch, and is rather sophisticated in controlling background and environmental effects. It is in fact based on the time–of–flight, double scattering method and incorporates the state–of–art techniques of electronics and data acquisition. The statistical significance of the signal reaches at best 5 standard deviations.

The low statistics prevented also to observe in a convincing way correlations between the weak neutron emission and the occurrence of Excess Heat. However, in some cases, correlations were reported: last examples were discussed at this Conference by Okamoto [4] and Sanchez [5].

2 Measurements of ^{4}He from Cold Fusion Cells

I said in the introduction that experiments on ^{4}He detection were started rather late. Fig.2 shows the evolution with time of dedicated experiments on ^{4}He production; in abscissa

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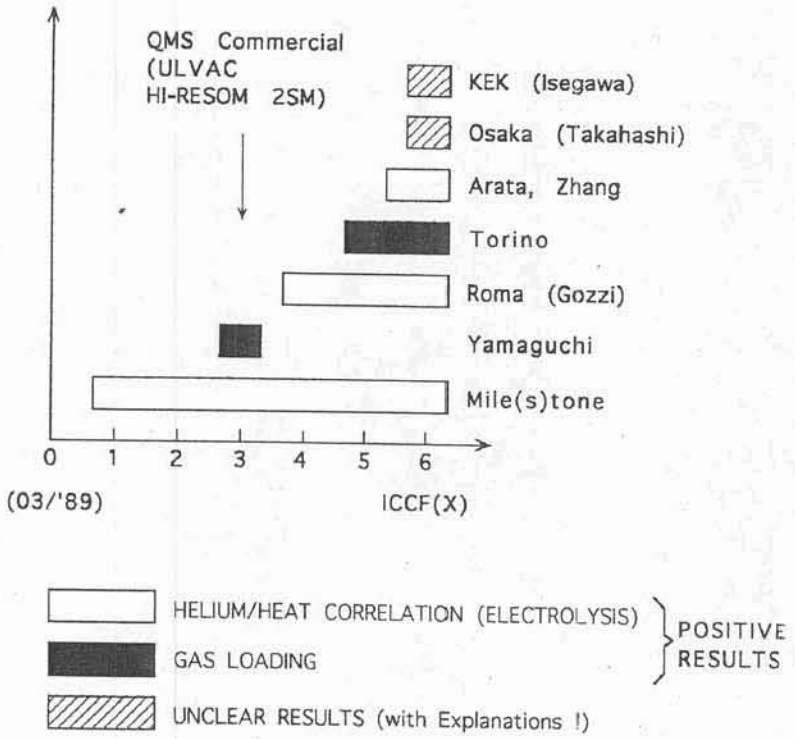

Figure 2: Evolution of dedicated experiments on ^{4}He production; the abscissa scale indicates the edition of the subsequent ICCF's held until now.

I used the time at which subsequent ICCF's were held. The time interval between each ICCF is, in average, fifteen months. At ICCF–1 (Salt Lake City, March 28–31, 1990) no dedicated experiments on ^{4}He were presented. However it is quite instructive to notice that a qualitative test at ETEC/Rockwell showed anomalous ^{4}He presence in Pd samples previously electrolysed and having produced a weak Heat Excess [6].

At ICCF–2 (Como, June 29–July 4, 1991), the first dedicated experiment on ^{4}He production was presented and discussed by Miles et al. [7]. They used open isoperibolic calorimetric cells with Pd rod cathodes in D_2O solutions. Effluent gas samples were collected in flasks and sent to the University of Texas for analysis by mass spectrometry. The results were striking. ^{4}He was observed in large quantities in experiments in which Excess Heat was measured. No ^{4}He was observed in experiments without Excess Heat or with H_2O solutions (blank). From ICCF–2 to ICCF–6 Miles et al. continued their impressive series of measurements, carried out in a sometimes hostile scientific environment, producing at the end a final report [8] which summarizes six years of experiments. Their main conclusions are: 30 of 33 experiments showed a correlation between either Excess Power and ^{4}He production or no Excess Power and no ^{4}He. The ^{4}He production rate is (10^{11}–10^{12}) He atoms/sec per watt of Excess Power, which is the correct magnitude for $d + d$ reaction that yield ^{4}He as a final product. The probability that these observations are the results of random correlations is $\sim 10^{-6}$.

At ICCF–3 (Nagoya, October 21–25, 1992) an advanced set–up for the detection of ^{4}He released from a heterostructure of Pd deuterated in gas phase was presented by Yamaguchi and Nishioka [9]. The apparatus was completely built in stainless steel pieces, avoiding glass or other materials that could induce the suspicion of contamination from atmospheric ^{4}He, and a high resolution electric quadrupole mass (Q–mass) spectrometer allowed the separation of the peaks due to $^4He^+$ and D_2^+. The measurements showed a close correlation between the production of ^{4}He and the Heat Excess released by the Pd sample (a few watt for 10^3 seconds).

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and the amount of detected ^{4}He was in the order of magnitude of that expected. Unfortunately Yamaguchi and Nishioka did not continue their experiments beyond ICCF-3. I notice that a quite important fact occurred at ICCF-3, that might explain the trend of the experiments on ^{4}He detection, as shown by Fig.2: the commercialization of a relatively simple high resolution Q-mass spectrometer (ULVAC HI-RESOM 2SM), rather largely used in the following by several Groups.

At ICCF-4 (Maui, December 6-9, 1993) first results on ^{4}He content of effluent gas from electrolytic cells were presented by Gozzi et al. [10]. They used open cells with different Pd electrodes. ^{4}He was measured not "in situ" but at a nearby Laboratory, equipped with a high resolution magnetic mass spectrometer. They found a quite nice correlation between ^{4}He and Heat production, but control measurements of the $^{20}Ne^{2+}$ content in the samples, indicator of a possible contamination from atmosphere, were somehow puzzling. They continued their improvements on the apparatus, by the use of a Q-mass spectrometer directly coupled to the apparatus (ICCF-5), and results were presented at ICCF-6 [11]. I am personally very impressed by the completeness of the apparatus and the cleverness of the data handling. During the years, the apparatus of Gozzi et al. was continuously improved, adding time-by-time new detectors of nuclear ashes and new controls. At present, it is the most complete of all Cold Fusion experiments, featuring simultaneously: calorimetry, neutron, ^{3}H, ^{4}He and X-rays on-line detection. ^{4}He detection also for melted electrolysed cathodes, complete control of all possible sources of contamination (atmospheric He). Owing to this unique potentiality, Gozzi et al. tried to obtain not only a Yes/No correlation between ^{4}He and Excess Heat, which is quite good in their experiments, but also a time correlation between the evolution of these two quantities. This goal required a lot of experimental efforts and the preliminary results show an indication of a time correlation, even though not yet completely established. Incidentally, I notice that at ICCF-6 Gozzi et al. reported a very convincing measurement of hard X-ray emission, a clear-cut proof that a nuclear phenomenon is at work.

At ICCF-5 (Monte Carlo, April 9-13, 1995) a new experiment (Botta et al. [12]) entered in the arena of ^{4}He apparatuses. The set-up is dedicated to the on-line measurement of ^{4}He from Pd, loaded with D_2 in gas phase. The loading ratio is enhanced by electromigration: measured values of α up to 0.83 were reported. The entire apparatus is made of stainless steel to avoid atmospheric contamination, with on-line careful controls at all the stages of the experiment. Evidence for ^{4}He production was reported, but the results were affected by a quite large value of background. In the following year the set-up was improved, in particular the gas sampling could be performed by the Q-mass spectrometer in static vacuum conditions instead of with the turbomolecular pump on, and at ICCF-6 a quite impressive result was reported (see Fig.3) [13]. A peak corresponding to $^4He^+$ is clearly observed after several days of D_2 loading, enhanced by electromigration. The amount of produced ^{4}He is large: $(5.3\pm0.2)\times10^{18}$ atoms. Unfortunately no correlated calorimetric measurement was done.

At ICCF-6 (Toya, Hokkaido, 13-18 October, 1996) three new groups using ^{4}He detection by Q-mass spectrometer reported their results. The experiment of Arata and Zhang is really impressive for cleverness and completeness [14]. They use closed electrolytic cells with special cathodes (Pd fine powder). Considerable amounts of Excess Heat are measured by careful calorimetry and several runs with D_2O and H_2O (blanks) were performed. The produced ^{4}He, which was supposed to reside in the Pd cathodes, was thermally desorbed at high temperatures (1300 K) in a sealed-off apparatus including two Q-mass spectrometers, reference samples for ^{4}He and D^+ and getter pumps to lower the D_2 percentage of the gas composition. The two Q-mass spectrometers were set around the masses 3 and 4 respectively in order to determine the time evolution of the $^4He^+$ and D_2^+ and HD^+ ions, the last two lowered by the getter pump

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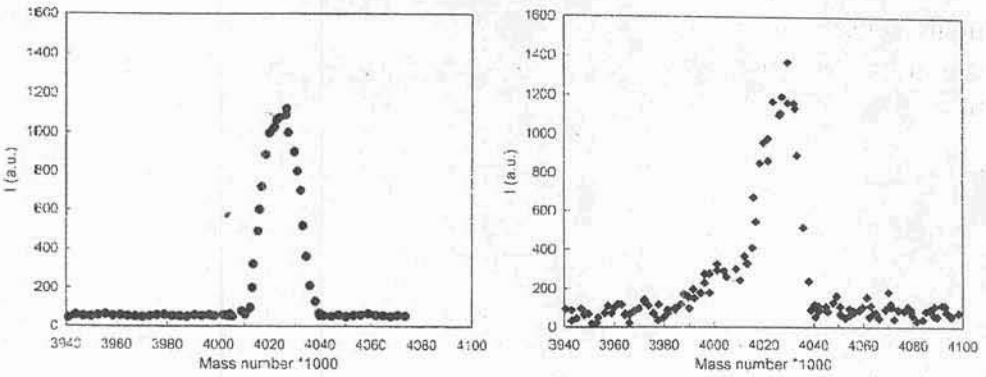

Figure 3: Spectra of "mass 4" gases as measured by the Q–mass. Left: spectrum at the beginning of the experiment: only the peak corresponding to D_2^+ is visible. Right: spectrum at the end of the experiment: a second peak. corresponding to $^4He^+$ is clearly visible.

action. This control was very effective in obtaining the certitude that $^4He^+$ was really desorbed by the electrolysed Pd. No $^4He^+$ was measured in blank runs.

Yasuda et al. [15] presented at ICCF–6 a quite complete set–up. They use closed electrolytic cells. with on–line measurement of Heat Excess. loading ratio of the cathodes and neutron emission. Production of ^3H and ^4He is measured off–line. by sampling. Correlation of ^4He production with Excess Heat was not clearly ascertained. but the authors underlined some calibration problems of their spectrometer. operative since a short time.

Isagawa et al. [16] too presented a quite complete set–up. They use open type cells: Heat Excess, neutron. ^3H and ^4He emission were measured. A large amount of ^4He was detected with a Pd sample heated above 1000°C. The authors cannot avoid however that it is due to permeation from air.

3 Conclusions and Perspectives

Production of large amounts of ^4He. whose order of magnitude is compatible with that expected in the hypothesis of Excess Heat due to $(d + d)$ fusion was measured by at least five different experimental Groups. Four of them report also a convincing evidence of the correlation of ^4He production with the Excess Power. All the Groups working on ^4He production are well experienced in Cold Fusion experimental research. being active from the first beginning. The different settings are quite complete and expensive (from 0.5 to 1 Million of U.S. $): apparently those Groups did not suffer from severe budgetary cuts from the funding agencies. A further remark concerns the order of magnitude of ^4He production. Since the ^4He detection device (Q–mass spectrometer) works on a minimun ionization current. not on single particle counting like neutron and ^3H detection. it is clear that a current signal. when observed. corresponds to a large amount of ^4He atoms. Therefore in judging the quality of the results. it is important to evaluate the signal/noise ratio. It appears to be from 10 to 100 in the different experiments.

THESE EXPERIMENTAL FACTS SEEM TO ME LARGELY ENOUGH TO CONCLUDE THAT THE EXCESS POWER RELEASED IN COLD FUSION CELLS IS OF NUCLEAR ORIGIN ($d + d \rightarrow {}^4He$ + heat).

A related conclusion is that the claims of Fleischmann. Hawkins and Pons in 1989 were substantially correct. Starting from these considerations it is important to continue vigorously

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the experimental effort on ^{4}He detection with Q–mass spectrometers. To that purpose it is necessary to start a coordinated work for normalizing the procedures of operation with these devices, still quite difficult. In particular it would be necessary to agree protocols on:

- operation with dynamic or static vacuum:
- effect of getter pumps;
- precise determination of the detection sensitivity:
- precise determination of residual gases pressures
- other items.

In parallel it will be necessary to continue the experimental work necessary to solve still some open problems like. for example:

- the precise relation between ^{4}He amount and Excess Power (at present it is determined only as order of magnitude !)
- the determination of the percentage of ^{4}He directly desorbed from the electrodes during the Cold Fusion occurrence with respect to that remained in the metal.

The solution of these problems will probably convince all the Groups working on Cold Fusion to use ^{4}He detection as a standard tool in all experiments, as a sort of microcalorimetry.

I am grateful to Prof. F. Iazzi and Dr. E. Botta for their useful discussions and comments.

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