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To: rlg2@yktvmv.BITNET
Subject: draft FUSION PRODUCTS chapter
X-ANJE-To: GARWIN,SCHIFFER

four sides

4.7

Dear Dick

Enclosed the latest draft of the 'FUSION PRODUCTS' CHAPTER. I am to send a draft chapter to DOE for distribution this coming Monday the 9th. If I do not hear from you I will send the enclosed draft (with possible minor changes that I may get from others in the next few days).

Hz

About the draft: The material you sent me has been trimmed in various ways -- please check that it still makes sense.

1) I put the section on neutron detection into an appendix -- is that OK? Or should this be omitted? I have no strong feelings about it.

2) Several references need to be added, some of them may already be on the list at the end.

3) It is not clear to me that having the Fleischman & Pons gamma spectrum as a figure adds much, except that it rubs in the fact that they do not understand gamma detection. It seems to me to be beating a dead horse.

4) Likewise about the Frascati figure that you indicated.

5) I felt that you had somewhat overdone the Menlove business -- as I think I mentioned in an earlier note, several things you said (e.g. H2O control runs, separating counters) Menlove told me he had checked. I changed it but you should check and rewrite as you see fit.

6) I thought that too much was made of the BARC report in your writeup, giving it a lot of weight and leaving the reader up in the air. I cut it back -- feel free to change it.

7) I did leave the tables from the BARC report in as as appendix -- I think we should probably remove them (as well as the Bockris tables) if you agree.

8) I put in a table of neutron rates -- normalized to the published Jones rate. Could you please check this? Huizenga is worried that Jones quoted a slightly lower rate to us at the visit to BYU. But this was only in a hand drawn figure of comparisons, and I would prefer to stick with the published number -- otherwise people will be very confused.

9) Any other changes would be appreciated.

PLEASE NOTE THAT I WILL NOT BE ABLE TO COME TO THE MEETING AT CHICAGO. SO IT WOULD BE GOOD IF WE COULD TALK BEFORE THEN.

Regards, John Schiffer

Draft -- October 4, 1989

FUSION PRODUCTS

I. INTRODUCTION

The nuclear fusion of deuterium has been studied intensively for over 40 years. The reaction between two low energy deuterium nuclei can proceed in three ways:

(a) D + D --> 3He + n + 3.269 MeV

(b) D + D --> 3H + p + 4.037 MeV

(c) D + D --> 4He + gamma(23.847 MeV)

The reactions (a) and (b) have been studied down to deuteron energies of a few keV and the cross sections found to be equal to within 10%. In the interaction of deuteron beams with heavy ice or metal deuteride targets, almost one 2.45 MeV neutron is produced (with an accompanying 3He) for every triton (with an accompanying proton). This near-equality of neutron and proton branches of the D + D reaction, shown in figure 1, is a reflection of the basic symmetry of nuclear forces between proton and neutron, disturbed only slightly at the MeV energies of the emerging particles by the Coulomb interaction which is not symmetrical between proton and neutron. The cross sections for reaction (c) are very small -- on the order of 10**7 lower than the first two.

All nuclear reactions at low energies between two deuterons are retarded by the Coulomb repulsion between the positively charged nuclei -- the penetration of the repulsive Coulomb barrier changes exponentially with bombarding energy: for instance the measured cross section for reaction (b) changes from 0.2 microbarns at 2.7 keV to 35 millibarns at 100 keV. But the _r_a_t_i_o_s for the three reactions appear to be constant below 100 keV.

Any fusion between deuterium nuclei _m_u_s_t lead to detectable fusion products. For reaction (a) neutrons are the most easily detected product, by direct counting. For (b) the protons or tritons can be detected by direct counting, and the accumulated tritium could also be identified by its radioactivity, albeit with lower sensitivity. Neutron counting perhaps the most useful technique here, since neutrons must be produced by the energetic tritons interacting with other deuterons in the material at the rate of 1 neutron for every 10000 to 50000 tritons. reaction (c) leads to readily detectable high energy gamma rays, and 4He may be identified by mass spectroscopic measurements, but the sensitivity is low -- though the 10**17 levels implied by the 1 watt of heat should be readily observable.

In the following we wish to summarize the experimental evidence on these fusion products. First we discuss the plausibility of reactions at room temperature and the issue whether the constancy of the three reaction modes is a reasonable extrapolation to very low energies. Then the data on neutrons, charged particles, gamma rays and tritium are summarized. Finally, some comments are included on the more exotic explanations.

II. THE REACTION PROCESS.

Fusion reactions can occur only if, during a nuclear collision, the Coulomb barrier is surmounted or, at low energies, penmetrated and the nuclei approach each other within about 10**-12 cm, some 10000 times smaller than the typical separations in ordinary matter. Fusion is generally enhanced by a well-understood quantum mechanical phenomenon called tunneling that allows fusion to occur in collisions far less violent than might be required otherwise.

In the thermonuclear fusion that occurs in stars and in laboratory "hot fusion" experiments, very high temperatures provide the violent collisions required to produce fusion. However, in the so-called cold fusion experiments, it is claimed that the penetration of the barrier through quanum mechanical tunneling has somehow become so effective as to allow fusion to occur even at room temperatures. Further, some of the experimenters claim that the nuclear process is changed by some unspecified mechanism so as to alter dramatically the nature of the reaction products. These claims must be understood as separate and equally surprising.

Some simple calculations serve to illustrate how remarkable the claim of fusion at room temperatures really is. The fusion rate for the two deuterium nuclei in a deuterium molecule (where they are even closer than they are when embedded in a metal) results in one fusion per year in a solar mass of deuterium. Further, the fusion of protons and deuterons is 10**9 times faster than the D + D reaction claimed to have been observed (although it is still extraordinarily slow). There is no known mechanism by which these rates _c_o_u_l_d be enhanced by the 40-50 orders of magnitude required to agree with the reported observations.

One commonly invoked mechanism for enhancing cold fusion rates is screening by "heavy" electrons. It is true that endowing the electron with a hypothetical mass some 5-10 times larger than it actually has would enhance fusion rates sufficiently to agree with most cold fusion claims [Ko]. It is also true that there are "heavy fermion" materials whose thermodynamic properties at very low temperatures are characteristic of quasiparticles with masses many times those of a free electron. However, this phenomenon is understood as involving long-wavelength excitations in which strong correlations "dress" electrons near the fermi surface. As such, heavy fermions extend over many lattice sites. Because the tunnelling in nuclear fusion occurs at distances smaller than one lattice site, only the short-wavelength "bare" electron excitations are relevant for screening, and cannot enhance the fusion rate significantly.

IIa. The D + D Branching Ratios.

The relative rates of reactions (a), (b), and (c) are called the branching ratios and are a crucial issue in the discussion of some cold fusion claims. These reactions have been studied in laboratory experiments using accelerators for deuteron energies above a few keV [Kr]; the smallness of both cross sections prevents reliable measurements at lower energies. The ratio between the two rates exhibits a weak energy dependence and is near 1.0 at the lowest energies. Data from muon-catalyzed D + D fusion [muon], which probes the energy range around 3 keV is still consistent with equal rates.

A branching ratio of more than one million would be required to explain experiments that claim to observe high fusion rates (either through heat or tritium production) without a corresponding high neutron flux. As "cold fusion" is thought to occur at energies on the order of eV, this is not directly ruled out by the data discussed above. However, there is no known mechanism for inducing such a rapid energy-dependence in the branching ratio. The Oppenheimer-Phillips process involving the Coulomb break-up of the deuteron has been invoked in this regard [??].
However,
this mechanism requires the deuteron size (some 5 fm) to be large relative to the spatial scale (the Bohr radius) of the internuclear Coulomb wave-function. As this latter is some 25 fm for D + D, the Oppenheimer-Phillips

process cannot give rise to the large effects required.

IIb. The Gamma Branch.

Some researchers have hypothesized that the D + D -> 4He + gamma (23.847 MeV) reaction, which is ordinarily some 10**7 times weaker than reactions (a) and (b) in which two fragments are produced, somehow dominates in cold fusion situations. To be consistent with the lack of neutrons, a very large enhancement of the gamma branch by a factor somewhere in excess of 10**13 would be required. We know of no way whereby the atomic or chemical environment can effect such an enhancement, as this ratio is set by phenomena on a length scale some 10**4 times smaller than the atomic scale.

Even if there were such an enhancement, the absence of observed high-energy electromagnetic radiation (photons, positrons, or fast electrons) rules out such a mechanism. While direct coupling to the lattice through unspecified mechanisms has been invoked to supress such radiation, any such coupling must occur through the electromagnetic field and would result in some observable high-energy radiation.

IIc. It has been suggested an alternative fusion process, could be the reaction

p + D --> 3He + gamma (5.49 MeV)

for which the penetration factors are still overwhelmingly small at room temperature, but somewhat less so than for the D + D process. This reaction must produce a readily observable gamma ray. If it is to account for 1 watt of heat, then it should also produce 3He in observable concentrations.

IId. Estimate of Secondary Yields from Fusion Products.

i) ___Neutrons from tritium.___ The tritons produced in reaction (b) are produced with an energy of 1.01 MeV. This energy must be lost in the immediately surrounding material, which in the case of an electrolytic cell is either the Pd electrode saturated with deuterium, or heavy water. The tritons will therefore bombard the deuterium in the surrounding material. The t+d reaction is a rich source of neutrons, with a cross section that reaches 5 barns at 0.12 MeV, then falls to about 0.7 barns at 0.5 MeV, and reaches slightly below 0.3 barns at 1 MeV. For the 1.01 MeV tritons from the D + D reaction one may assume an average cross section of about 1.2 barns. For tritons that are stopped in PdD this translates into a neutron yield between 0.15 and 0.2x10**-4 neutrons per triton; for tritons stopping in heavy water there are about 0.9x10**-4 per triton.

ii) ___Coulomb excitation of Pd by protons___. The even Pd isotopes (104,106, 108,110) with abundances of 11,27,26,12 % have first-excited 2+ states at 555,512,434,374 keV and B(E2) values between 0.5 and 0.8 barns. The cross sections for Coulomb excitation are in the vicinity of 20 to 50 mb and thus the yields expected are 2 to 5 10**-6 per proton. In palladium the half thickness for absorption of these gamma rays is about 4 mm, in water it is several cm.

In terms of power, there must be about 10**8/sec secondary neutrons per watt of fusion, even if direct neutron production is completely suppressed and all the reaction goes into tritium production.

Under these conditions there must also be slighly under 10**7 secondary photons per second in the 500 keV range.

III. NEUTRONS.

IIIa. Detection.

As discussed above neutrons are a major product of D + D fusion. Neutrons are very convenient particles to detect, since they interact only with the nuclei of atoms and so can emerge from reaction vessels of substantial size unscathed and without having lost any energy. Similarly, large counters can be used without the problem of thin entrance windows, since neutrons enter into the mass of the counter without difficulty. Neutron detection is summarized in Appendix A.

IIIb. Selection of Data.

In what follows, we have tried to use published material, where available, or material prepared for publication and presented at formal meetings or as preprints distributed without restriction as to citation. It is important to include not only _p_o_s_i_t_i_v_e results, that claim the detection of neutrons, but also the _n_e_g_a_t_i_v_e ones, that have attempted to replicate the experimental procedure of the former and failed to detect neutrons at a level of sensitivity substantially better than the positive results.

IIIc. Initial claims.

The University of Utah (UU) group in its i_n_i_t_i_a_l publication [Fle] claimed the detection of neutrons from D + D by virtue of the gamma ray emitted by the capture of the moderated neutron in the water bath surrounding the electrolytic cells. A very narrow peak in the pulse-height spectrum from the NaI scintillator was shown in the paper, and is reproduced in figure 2
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at the expected energy of 2.2 MeV. The text, however, claimed that the expected energy was 2.5 MeV 2.45
RLG check
and so narrow a window of the overall scintillation spectrum was shown that the reader could make no judgment as to the reality of the peak.

These very questions were taken up by a group at MIT, [Pe] who showed that the photo peak at 2.2 MeV obtained at MIT from Cf spontaneous fission neutrons moderated in water and radiatively captured on protons is accompanied by other peaks from natural background that enable one to calibrate the energy, and successive interchange between UU and MIT groups in the scientific literature ~~have~~ demonstrated with high probability that the claimed detection of neutrons by the proton capture gamma ray at UU has been an artifact of the experimental apparatus.

The original publication from Brigham Young University (BYU) [Jo] presented the detection of neutrons as the sole experimental evidence for the existence of cold nuclear fusion. The neutrons were detected in a two-stage neutron counter -- first by the proton recoil in organic scintillator, followed within a few tens of microseconds by a signal from the capture of the moderated neutron on boron viewed by the same photomultipliers. This double detection of a single neutron serves substantially to reduce the ambient background due to gamma rays, although

there remains background in the experiment due to gamma rays and to real neutrons from cosmic rays* and other sources. The group at BYU has chosen to attempt to vary the experimental conditions in order to obtain a greater rate of D + D fusion, and so has not presented much more data than the original paper on the detection of neutrons with that counter. In fact, BYU has been working in collaboration with other groups, notably at LANL [??], [Mel], and also with ~~a group at Yale University.~~ [??] The original claim of neutron detection five standard deviations above the background is somewhat reduced in statistical strength if one considers the degrees of freedom that are fixed by the presentation of a peak in one of a number of experiments and at a particular energy, and also the possible fluctuation in the cosmic-ray neutron background. Ordinarily, however, such a significant result can be brought up from the background by using different counting or detection equipment or by reducing background through improved shielding or by moving to underground site.

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*(footnote) Additional care is needed as the rate of cosmic ray neutrons can fluctuate by 20% or more with variations in barometric pressure as well as with solar activity.

Typical of the latter is work presented by the group at Sandia National Laboratory, [Sa] **RLG cite** in which a site was found with substantially less background and results presented as follows for the neutrons produced in electrolytic fusion. [Jo] **RLG cite** ???Should we also cite Frejus results presented at Santa Fe???

Many claims have been made for the production and detection of neutrons produced in electrochemical cells, but these claims have almost all been withdrawn or moderated by the discovery of difficulties with the counter -- particularly with the BF3 counters used. In some cases, the counters are sensitive to humidity; in others to microphonic noise (vibration); or to other afflictions. A summary of some of the limits on neutron fluxes reported, compared to the flux reported by the BYU group, is shown in Table I.

IIId. Dry Fusion.

Results presented in April 1989 by a group at Frascati [DeN] opened an entirely new opportunity for the observation of D + D cold nuclear fusion. In this work, deuterium gas at 60 atmospheres pressure (60 bar) was allowed to contact titanium lathe turnings in a stainless steel reaction vessel. That allowed the temperature of the sample to be varied either by heating or by cooling. No neutrons were observed from the hydriding reaction at room temperature or at elevated temperature, when viewed by a nearby BF3 counter. However, after cycling to nitrogen temperature, _b_u_r_s_t_s of counts were obtained from the counter -- typically on the order of 20 counts per burst emerging over a period of 60 microseconds. One set of data was presented on counts obtained by cycling to nitrogen temperature, showing neutrons essentially only in these bursts.

A totally different type of neutron emission was also claimed by

the Frascati group [DeN] following warming from nitrogen temperature over one weekend. A bell-shaped curve rising to a peak of 300 neutrons per ten-minute counting interval is reproduced in figure 3.
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This, of course, is an important experimental result, and provoked great effort toward verification both at Frascati and elsewhere. It is understood from private communication from M. Martone at Frascati that there has been no confirmation of either the burst results or of the continuous neutron emission from the D-Ti system or from any other dry fusion activity at Frascati. In addition, electrochemical cells operated without producing observable numbers of neutrons, and their operation was terminated during the month of July.

A group at LANL [Me] has conducted dry fusion work with Ti and Pd, and has presented results both at the Santa Fe meeting and in a preprint. This group at LANL uses high-efficiency systems that moderate any fast neutrons emitted from experimental cells, detecting the moderated thermal neutrons in 3He gas counters.
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Bursts of neutron counts are sometimes observed 3000-5000 seconds after the sample is removed from liquid nitrogen, at a time when the sample temperature is typically -30 C. These bursts, consisting of about 100 neutrons at most, are seen in about 30% of the samples tested. An attempt to reproduce this effect at Sandia National Laboratory yielded entirely negative results.
[??]

At the Santa Fe workshop, Moshe Gai of Yale presented results obtained in collaboration with Brookhaven National Laboratory, in which no neutrons were detected from electrolytic cells.

Finally, a conference report from the Bhabha Atomic Research Center (BARC), [Iy] provides text and tabulated results from several groups at BARC. Fig. 1 of the BARC report shows counts from neutron detectors observing a large electrolytic cells, with an estimated 2x10**7 neutrons in the 5 minutes following an overpower trip of the electrolyzer. Fig. 2 of the BARC report shows dry fusion 3He counter output during gradual rise of temperature of 20 g of Ti while deuterium gas was being pumped off. It is also commented that samples could be loaded with deuterium gas at 1 bar and 900 C, and that "one such disc shaped button loaded on Friday 16th June began emitting neutrons on its own, almost 50 hours after loading. It produced (about) 10**6 neutrons over a 85-minute active phase. The background neutron counter did not show any increase in counts over this time."

IIIe. Secondary Neutron Production.

There are severe problems of consistency between the number of tritium atoms found in some of the experiments discussed above and the number of neutrons detected. The BARC abstract reads, "The total quantity of tritium generated corresponds to about 10**16 atoms suggesting a neutron to tritium branching ratio less than 10**-8 in cold fusion."

But, as discussed above there _m_u_s_t be at least one neutron per 100,000 tritons if the observed tritium were is originating from fusion, _1_0_0_0 times more than was observed!

IV. CHARGED PARTICLES AND GAMMAS.

A few experiments [Po,Pr,Re,Su] to measure the 3 MeV protons and/or the 1 MeV tritons produced in the reaction, D + D --> 3H + p, have been reported; they are summarized in Table II below. A variety of different methods has been used, but the lowest limit on charged-particle production appears to be that set by Price using plastic track detectors. Their setup was designed so that the light water control cell matched the heavy water cell as closely as possible. Electrolysis was performed for 13 days, and the cathode stochiometry was determined to be Pd(H,D)0.8. Both cells showed track production rates which agreed and were consistent with the alpha-particle emission rate for native Pd foils due to trace (ppm) impurities of the natural 238U and 232Th decay chains; however, no tracks due to protons with energies between 0.2 and 3 MeV or tritons with energies between 0.2 and 1 MeV were found. From these data Price [Pr] set limits on the fusion rate of less than 0.002 per cm3 per second. This value results in an upper limit of 8.3x10**-26 fusions per dd pair per second. This is about an order of magnitude lower than the limits obtained using Si surface barrier (SSB) techniques.

A limit on the fusion rate of 0.028 per cm3 per second or 1.2 x 10**-24 fusions per dd pair per second was obtained by Ziegler [Zi] using a SSB technique. Porter [Po] used a SSB detector to view the back of a 76 micron thick Pd foil cathode ina heavy water electrolysis cell. They obtained a limit of less than 6x10**-25 protons per dd pair per sec at the 2 sigma level; chemical analysis of their electrolytes showed no evidence for anomalous increases in tritium concentrations. Sundqvist et al. [Su] also used a SSB technique to detect protons. The detector was placed close to Pd foil cathodes which were thin enough to allow all the protons produced to escape from the foil. All of their runs gave a result of 0 within the statistical errors, resulting in a fusion rate of -2.1 (+/-2.2) x10**-24, if a bulk process is assumed.

Recently, Rehm [Re] has reported using a proportional counter to search for charged particles from electrolytic cells with Pd and Pt electrodes in 0.1 M LiOD in D2O. They obtained an upper limit of 4 x 10**-23 fusions per dd pair per second, not as low as the limits using the other methods.

In summary, a variety of experimental techniques has been used in searches for charged particles; all of them set very low limits on fusion occuring via the D + D --> 3H + p. Most of these results set limits on fusion via this channel that are considerably less than Jones' [Jo] value of 1.00 (+/-0.82) x 10**-23 fusions per dd pair per second for the D + D --> 3He + n channel obtained from neutron measurements. (The uncertainty was calculated by [Su]).

The upper limit of Price [Pr] of 8x10**-26 fusions per dd pair per second is much below the average low rate inferred from the neutron measurements of Jones or even those of Menlove [Me]. The extremely low limits which the searches for charged particles (either protons or tritons) place on their production is clearly inconsistent with the reported production of tritium via the cold fusion reaction.

IVa. GAMMA-RAY SEARCHES

As was mentioned above, a ~~small~~ rare branch of the D + D reaction proceeds through capture, in which a 23 MeV gamma-ray is emitted. Similarly, the p + D reaction is associated with a 5.49 MeV gamma ray.

Several searches have been published in which no gamma rays that would be associated with the D + D or p + D capture reactions were seen. They include a report by Henderson [He] who cites limits around 10**-23/sec 23-MeV gamma rays emitted per deuteron in various cells. Porter [Po] reports no 5.5 MeV gamma rays -- though no absolute limit is quoted. They also comment on the absence of Pd K X-ray production. Greenwood [Gr] also report limits of 10**-23 for gamma rays above 1.9 MeV. Other negative results are quoted in the Santa Fe abstracts without quantitative detail.

V. TRITIUM.

As discussed above, one branch of the D + D reaction produces tritons and protons. As was also discussed, searches involving the direct detection of charged particles have yielded rather stringent negative results. A number of searches have also been made for the tritium accumulated during the electrolysis of D2O with palladium cathodes, determining tritium content by detecting the radioactive decay of tritium. In such experiments it is important to determine the initial tritium content of the heavy water and to take cognizance of the fact that the electrolysis of the heavy water will enrich the naturally occurring tritium in the heavy water.

The detection of tritium by measurement of its beta decay is inherently a less sensitive probe of the D + D reaction than the direct measurement of neutron production or charged particle production. About 10**7 tritium atoms give 1 decay by beta emission per minute. The tritium content of normal water is about 10**-18 relative to hydrogen but, as discussed in Appendix C the normal manufacturing of heavy water also enriches in tritium and thus heavy water currently being sold gives between 120 and 180 disintegrations per minute (dpm) from tritium decay.

Va. Null Experiments.

Most of the work reported to date on the search for excess tritium produced in electrolytic cells can be accounted for by the electrolytic enrichment process. This includes the original report by Fleischmann and Pons [Fle], and experiments at ANL, Gre,Red BNL, Da,McB,Wi2 Cal Tech, Le2 CRNL, Sc INEL, Lo LLNL, Al NRL, Er ORNL, Fu,Sc Sandia, Na SRL, Ra Texas A & M, Ma and Utah. Wad

Vb. Tritium Bursts.

A small number of experimenters report occasional irreproducible amounts of excess tritium in their D2O samples taken from their electrolytic cells after days of operation. This includes observations by Storms St at Los Alamos, and Fuller [Fu] and Scott Sc at ORNL. The ORNL experiments show single cases of an excess of tritium which is of short duration, after which a cell returns to background level. Storms reports excess tritium, 100 times background, in two cells out of fifty.

Vc. Closed Cells - Correlation with Excess Heat.

Four different groups [McB,McC,Sc,Ma] have now looked for tritium production in closed electrolytic cells. These experiments detect all the tritium from the electrolytic process with the exception of that which may be contained in the Pd cathode. In general, the deuterium inventory in the cathode is negligible compared with the D2O. Only that tritium formed within the cathode and which remains there because of slow diffusion is unaccounted for. There is no electrolytic enrichment of the tritium in the

make up D2O. In these experiments the total amount of excess tritium found in the total D2O is less than 10**4 T atoms/sec. If this tritium is produced by the D + D reaction, then the maximum amount of excess power (cold fusion power) is 10**-5 milliwatts. In one experiment [Wad] in an open cell there was a heat burst of 35 watts for 90 minutes (187,000 joules). The tritium was measured after the burst and no excess above the electrolytic enrichment was found. Clearly the heat burst does not come from the D + D reaction.

Vd. High Levels of Tritium.

Two groups [Pa,Iny] find tritium at levels of 10**12 to 10**14 T atoms/ml D2O after periods of electrolysis of the order of hours. This amount of tritium cannot be produced by electrochemical enrichment with the D2O volume reductions reported. The results of the Bockris [Pa] group at Texas A & M for cells in which excess tritium was found are given in Table 1 of their paper, reproduced in Appendix B. Excess tritium is not found in all of their cells. A listing of cells in which no excess tritium was found is given in their Table 4 (also in Appendix B). The Bockris cells are 0.1 M in LiOD and have nickel anodes. They precipitate nickel oxide during the electrolysis; some nickel is also electroplated out on the palladium cathode. In one experiment, A8, the specific activity of the D2 gas produced by the electrolysis was measured. It is 100 times that of the electrolyte.

D2(gas) containing tracer amounts of tritium and in equilibrium with D2O(liquid) has a specific activity that is lower by 0.6 than the D2O (liquid). If the tritium is formed during electrolysis, this result suggests that it is formed in the chemical species DT and that the tritium in the liquid D2O is the result of hot atom processes or slow isotopic exchange of the DT(gas) with D2O(liquid) [Bi2].

Wolf [Wo] at Texas A & M have looked for neutron production in Bockris type cells. An upper limit to their neutron production rate is 1 neutron/second, which is 10**-10 times that of the tritium production rates reported with similar cells by Packham et al. [Pa] This is a large discrepancy from the equal production rates for neutrons and tritons required by the branching ratio in the fusion reaction, discussed in section II, and is inconsistent, by a factor of 10,000 to 100,000, even with the secondary neutrons that _m_u_s_t accompany the tritons produced from nuclear fusion. One is strongly inclined to conclude that the excess tritium found in the electrochemical cells cannnot be the result of nuclear fusion in the cell.

The most extensive and systematic search for tritium in the electrolysis of D2O with Pd cathodes has been carried out by Martin [Ma] at Texas A & M. He has used both open and closed cells. His cathodes come from either Johnson & Mathey, a major supplier, or Hoover and Strong, who supplied the cathodes to the Bockris [Pa] group. He has operated cells with Pt, Ni wire and Ni gauze (obtained from Bockris) anodes. In none of his cells does he find any excess tritium beyond that expected from electrolytic enrichment. Nor does he find any neutrons. Two of his cells produced excess heat but no tritium. In short, he has been unable to reproduce the results of the Bockris group.

The BARC [Iy] group have found amounts of tritium comparable to the Bockris group in the D2O electrolyte from cells in which electrolysis was carried out for a few days with currents varying between 1 to 100 amperes. As was already mentioned above, here there is again a factor of 1000 internal inconsistency between their measured neutron yields and the

neutrons that have to be there if this tritium was indeed produced by fusion -- even if one assumes the very unlikely drastic modification of the branching ratio in the D + D reaction.

The experiments carried out to date include the large number of null experiments. There are a few experiments in which excess tritium is found, and which other groups have not been able to reproduce. These measurements also contain a serious internal inconsistency, in that the ratio of measured neutrons to tritium is smaller by orders of magnitude than what is consistent with a fusion process being their source. Additional investigations are desirable to clarify the origin of the excess tritium which is occasionally observed.

VI. EXOTIC EXPLANATIONS.

The data on fusion products, even where positive results are reported, give rates far below those that would be expected from the levels of heat reported in some electrolysis experiments. There have been some attempts to propose mechanisms where the reaction heat from the D + D --> 4He process would go entirely into lattice heat, rather than a photon [Wal,Ha]. Analogies have been made with the internal conversion process, and with the Mossbauer effect. Neither of these analogies is applicable to 4He.

Internal conversion allows an atomic electron of an excited nucleus to carry off the reaction instead of a photon. This process is understood quantitatively -- it is dominant in heavy atoms with tightly bound inner electrons and for low energy (less than 1 MeV) photons. In helium the atomic electrons are loosely bound and the photon is 23.8 MeV -- there can not be any appreciable coupling between the photon and the atomic electrons, and internal conversion or any related process cannot take place at anywhere near the rate that would be required.

In the Mossbauer effect the _m_o_m_e_n_t_u_m of a very low energy (below 100 keV) photon is taken up by the entire lattice in a coherent mode, but _n_o_t its energy. The process cannnot be relevant to the present process.

Considering experimental evidence more generally, there have been careful studies of a very large number of reactions analogous to the D + D fusion process, in which gamma rays of comparable energy emitted from low-energy nuclear reactions (thermal-neutron capture gamma rays) and the cross sections for cpature have been studied very carefully and quantitatively. Their knowledge is essential to the operation of fission reactors. If there were any anomalous processes in which the energy of a capture gamma ray were converted into lattice heat, this would have almost certainly been noticed as a discrepancy in cross sections with major implications on the operation of reactors. After four decades of extensive study of the processes relevant to the operation of fission reactors the possibility is extemely remote that an entirely new process, that could dominate these nuclear reactions, would have remained hidden.

VII. SEARCH FOR PRODUCTS OF COLD-FUSION IN THE EARTH

Products of low-level cold fusion have been inferred to be produced by natural geologic processes [Jo, Jo1]. The 3He:4He ratio is anomalously high in volatiles from deep-source volcanoes such as Hawaii, Iceland, and Yellowstone [Cr,Ku,Mam]; anomalous 3H is also suggested by fragmentary data [Om,Jo2], and production of other radiogenic products such as 36Cl have

been predicted [Pk]. Although the high 3He values have previously been considered relict from early earth processes, presence of anomalous 3H or 36Cl (beyond that due to bomb tests) would be definitive evidence of natural cold fusion at depth within the earth. Implications would be major for geophysical problems such as heat-flow modelling, element-distribution with depth, and composition of the Earth's core.

Although some knowledgeable isotope geochemists see no evidence for naturally occurring cold fusion [Cr1], several government and university labs are searching for evidence of such fusion processes as recorded by volcanic volatiles [Jo2,Ky,Go,Loc,Qu]. Even if laboratory experiments for cold fusion are discredited, such geologic studies could add much to understanding of the behavior of volcanic volatiles. No rigorous results are yet available, but experiments proposed or underway at Brigham Young, Los Alamos, Lawrence Livermore, New Mexico Tech, and the U.S. Geological Survey (Denver) should yield data within 6 months to 1 year.

VIII. SUMMARY.

A number of careful experiments have been carried out to search for the expected products of cold fusion. _N_o_n_e have seen these products at anywhere near the level that would be expected from the heat production reported in electrolysis, by many orders of magnitude. Some experiments report neutrons or tritium at a much lower level -- however, the rates of these two fusion products (measured in the same experiments) are inconsistent with each other, again by large factors.

The neutron bursts reported in some experiments also suffer from not being reproducible by other experimenters. While it is conceivable that some mechanism might produce very small bursts of hot fusion (e.g. high voltage internal sparks associated with fracture of the material at certain temperatures) at the present time the experimental evidence is not redily reproducible, and if real, the phenomenon does not appear to be related to 'cold fusion' as postulated in the heat production experiments.

If there _w_e_r_e such a process as room temperature fusion, it would require not only

(a) the circumvention of fundamental quantum mechanical principles, that have been carefully tested against numerous measurements of barrier penetration (such as the systematics of spontaneous fission and alpha radioactivity lifetimes and those of nuclear cross sections), but also
(b) drastic modifications of branching ratios in the D + D reaction, _a_n_d
(c) the invention of an entirely new nuclear reaction process.

'Alice laughed. "There's no use trying," she said: "one can't believe impossible things."

"I daresay you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."'

from 'Through the Looking Glass'

TABLE I. SOME COLD FUSION NEUTRON RATES

Authors	Reference	Neutrons per DD pair per sec (Volume Yield)	Normalized Neutron Yield (Energy Yield)
Yield corresponding to 1 watt of heat production	[Fle]	3x10**-11	3x10**12
Yield corresponding to neutron yield of Jones et al	[Jo]	10**-23	1
Gai et al	[Ga]	< 2x10**-25	< 0.02
Kashy et al	[Ka]	< 10**-25	< 0.01
Lewis et al	[Le]	< 1.5x10**-24	< .15
Williams et al	[Wi]		< 0.2
Alber et al	[Alb]	< 5x10**-25	< 0.05
Broer et al	[Br]	< 2.2x10**-24	< 0.2
Schriber et al	[Schr]		< 0.02
De Clais et al	[DeCl]		< 0.01 < 0.001

TABLE II. SOME COLD FUSION FAST CHARGED PARTICLE RATES

Authors	Reference	Protons per DD pair per sec	Yield Normalized to Jones et al. neutrons
Yield corresponding to 1 watt of heat production	[Fle]	3x10**-12	3x10**12
Jones et al.	[Jo]	1x10**-23	1.0
Porter et al.	[Po]	< 6.7x10**-25	< 0.07
Price et al.	[Pr]	< 8.3x10**-26	< 0.008
Ziegler et al.	[Zi]	< 1.2x10**-24	< 0.12 [a]
Rehm et al.	[Reh]	< 4x10**-23	< 4
Sundquist et al.	[Su]	< 2x10**-24	< 0.2

Schrieder et al.	[Schr]	< 3.1x10**-24	< 0.31 [a]

[a] 6. Rehm et al comment that the choice of the low-energy cutoff (e.g. 1 MeV in Ref. [Zi]) restricts the emission angle of the protons with respect to the foil to a small cone representing only a few of the total solid angle. This effect seems to hve been neglected in the efficiency calculations for the limits quoted by these authors.

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APPENDIX A

Neutrons can be detected either at their initial energy in the MeV range ("fast"), or after they have lost energy by successive collision with light material -- particularly hydrogen ("moderation.") The detection of fast neutrons can be achieved by photomultiplier tubes viewing the proton recoil in plastic or liquid scintillation material. _S_l_o_w neutrons (those that have lost almost all their kinetic energy and are in thermal equilibrium at room temperature) are conventionally detected by the charged particles produced when the neutron is captured with high probability in the nucleus of an atom of 10B (producing an alpha particle), or in a 3He nucleus, producing a recoil proton. A noble gas, 3He is used in the form of a proportional counter, while boron can be used either in the form of BF3 proportional counters or in the solid form, with the boron immersed in plastic or inorganic scintillator viewed by photomultiplier.

Additionally, neutrons can be detected after moderation by their capture in some material of very high capture cross section (such as

cadmium Cd), which produces several gamma rays that may, in turn, be detected by a photomultiplier viewing a scintillation detector. Similarly, neutrons moderated in water are almost entirely captured on the protons ("radiative capture"), giving rise to a deuteron plus a gamma ray of energy for the threshold of photodisintegration of the deuteron-2.2 MeV.

Finally, moderated neutrons may be captured in a trace element in the moderator (silver is a detector of choice) to produce a radioactive material that can be transported away from the experimental apparatus and counted separately with high efficiency at low background. The emitted radiation is typically a beta ray (negative electron), or a characteristic gamma ray following the beta decay. Of course, the world has enormous experience since the 1930s in detecting neutrons and in detecting neutrons from the D + D fusion reaction.

APPENDIX B

Garwin: "Yes"

????COULD WE DO WITHOUT THIS????

Reproduce BARC tables

Reproduce Bockris tables

APPENDIX C Considerations in tritium concentrations.

Tritium is produced in the atmosphere by cosmic ray bombardment. Most of the cosmic ray produced tritium ends up in the oceans and in rivers. The "natural" abundance of tritium varies widely and was greatly increased by atmospheric testing of thermonuclear weapons in the '50s and in the early '60s. The order of magnitude of tritium in ordinary water is T/H - 10**-18 (1 TU). Sources vary from 1 to 200 TU. The production of heavy water from ordinary water is even more efficient in the enrichment of tritium than deuterium from the feed material. Most of the heavy water currently available is produced by the H2S - H2O dual temperature exchange process (GS process). The tritium content of fresh heavy water produced by the GS process is 68 dpm/ml D2O/TU feed. Processes which are more efficient than the GS process in heavy isotope enrichment will have a minimum tritium specific activity of 50 dpm/ml D2O/TU feed. Heavy water currently being sold on the open market has a specific activity in the range 120 - 180 dpm/ml D2O. There are sources with a specific activity as high as 10**4 dpm/ml

Most of the work done to date on the search for tritium produced in the electrolysis of D2O in cells with palladium cathodes has been done in open cells. The measurements are frequently limited to assays of the specific activities of the starting D2O and the electrolyte after electrolysis. In general, there have been periodic additions of D2O to replace the D2O decomposed to form palladium hydride and D2(g). To determine how much tritium, if any, has been produced requires a complete inventory of the tritium at the beginning and end of the experiment. From the data on the current and duration of the electrolysis it is possible to estimate the amount of D2O which has been electrolyzed. Electrolysis will enrich the tritium in the D2O of an electrolytic cell. The amount of enrichment is primarily a function of the amount of water electrolyzed for a given type of cathode. It can reach a factor of 5 when 95% of the initial charge of water is electrolyzed. Thus a careful analysis of an electrolytic experiment must be carried out if one is to interpret tritium specific activities after electrolysis below 1000 dpm/ml D2O as anything other than electrolytic enrichment Bi.