Subj: cold fusion constraints

Here is a LATEX file of a brief note discussing the rates of palladium coulomb excitation gamma rays expected from fusion processes producing fast charged particles. The observation (or lack thereof) can be used to constrain proposed cold fusion mechanisms. There is also a brief discussion of the well known radon daughter gamma ray at 2.204~MeV which is consistent with the line Pons andFleischmann observe. Feel free to circulate this. Does anybody have any coherent written reports on any of the reported confirmations? We are now using our MARK IV version cell and haven't seen anything. David Bailey (Physics Dept., University of Toronto)

Title **Gammas from Cold Nuclear Fusion**

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Date April 20, 1989
University of Toronto Physics UTPT-89-15
Submitted to Phys. Rev.

Abstract

The absence of both neutrons and gamma rays can be used to constrain possible cold fusion processes in deuterium-metal systems. In particular, milliwatt cold fusion processes producing fast protons, tritium, helium-3 or helium-4 nuclei would also usually produce easily observable numbers of Coulomb excitation palladium gamma rays.

Two groups have recently reported evidence of cold nuclear fusion of deuterons electrolytically infused into metal (**Pons & Jones**). One group (**Pons**) reports large amounts of fusion heat from a palladium-deuterium cell but with only small amounts of associated radiation.

Any search for radiation from cold fusion should cover a wide range of gamma energies. In addition to gammas from capture of neutrons from $d + d \rightarrow n + He^3 + 3.27\,MeV$ or $d + t \rightarrow n + He^4 + 17.6\,MeV$ reactions, there are possible direct gammas from $d + d \rightarrow He^4 + \gamma + 23.8\,MeV$ or $p + d \rightarrow He^3 + \gamma + 5.49\,MeV$. Some exotic processes such as $p + d \rightarrow He^3 + e^+e^- + 4.5\,MeV$ (**Horowitz**) would produce an intense broad spectrum of bremsstrahlung radiation and a sharp positron annihilation line at 0.511 MeV. Other processes involving only heavy charged particles would also produce indirect gamma rays and neutrons.

For example, the reaction $d + d \rightarrow p + t + 4.03\,MeV$ produces a proton with an energy of 3.0 MeV. Some of these protons will produce gamma radiation via interactions with palladium nuclei. Measurements of 2.9 MeV protons being absorbed in thick palladium targets show that gamma ray yields from Coulomb excitations of palladium nuclei and from proton bremsstrahlung are about 10^{-7} gammas per proton (**Coulomb**). In particular, gamma rays are expected at 0.3738, 0.4339, 0.5119 (**Footnote 2**) and 0.5558 MeV (**Isotab**) with yields of 1.32×10^5, 2.29×10^5, 1.14×10^5 and 0.255×10^5 gamma rays per microcoulomb of protons(**Coulomb**). These gamma lines are, respectively, the lowest $2^+ \rightarrow 0^+$ transitions in Pd^{110}, Pd^{108}, Pd^{106} and Pd^{104}. In terms of gamma rays per proton, the yields are 2.1×10^{-8}, 3.7×10^{-8}, 1.8×10^{-8} and 0.41×10^{-8} gamma rays per 2.9 MeV proton being absorbed in palladium. The gamma yields increase with the proton energy (**Coulrev**), so the yield would be slightly higher for the 3.0 Mev protons from $d + d \rightarrow t + p$ fusion - the extrapolated yields are 2.5×10^{-8}, 4.5×10^{-8}, 2.3×10^{-8} and 0.52×10^{-8} gamma rays per 3.0 MeV proton absorbed in palladium. These yields are extrapolated from the data in Ref.(**Coulomb**) using the formulas of sections II C.1, II C.2 and III B.2 of Ref.(**Coulrev**). (The accuracy of the measured 2.9 MeV proton gamma yields is 10 to 20%.)

One watt of power from $d + d \rightarrow t + p$ fusion corresponds to 1.55×10^{12} fusions per second. The expected gamma yields from this process for each of the above four Coulomb excitation lines are thus 3.9×10^{4}, 6.9×10^{4}, 3.5×10^{4} and 0.8×10^{4} gammas per second per watt of fusion power (i.e. gammas/joule). Hence typical gamma detectors are easily sensitive to milliwatts of fusion power. Coulomb excitation gammas due to protons produced by unexpected reactions such as $d + He^{3} \rightarrow He^{4} + p + 18.3\ MeV$ would also be easily observed - the expected yields would be 1.6×10^{6}, 3.2×10^{6}, 2.5×10^{6} and 0.6×10^{6} gammas/joule.

Another possible process of interest is $d + Li^{6} \rightarrow He^{4} + He^{4} + 22.4\ MeV$. This reaction does not produce any direct gammas or neutrons, but indirect neutrons are expected from $He^{4} + Pd$ interactions. The yield of neutrons from interactions of 11 MeV He^{4} nuclei being absorbed in palladium is 4×10^{-8} neutrons per incident He^{++} (**Alphan**). Such a flux is consistent with that reported by Fleischmann and Pons(**Pons**). If such processes were occurring, however, the yield of palladium Coulomb excitation gamma rays (from $He^{4} + Pd$ collisions(**Footnote 2**)) would be even larger than in the case for $d + d \rightarrow t + p$ fusion discussed above and very easily detected; the expected yields of the 0.3738, 0.4339, 0.5119 and 0.5558 palladium Coulomb excitation lines would be 3.9×10^{5}, 8.3×10^{5}, 5.6×10^{5} and 1.5×10^{5} gammas/joule of fusion energy. The accuracy of the extrapolation of yields from 3 MeV protons to ~10 MeV alpha particles was confirmed to ~15% using Cd^{114}, Te^{126}, Te^{128} and Te^{130} data(**Extest**).

A third, more hypothetical, fusion process could be $d + d + Pd \rightarrow He^{4} + Pd + 23.8\ MeV$, where the palladium nucleus balances momentum for the process. The He^{4} nucleus would have an energy of 22.9 MeV if it recoils against a single Pd nucleus, or 23.8 MeV if it is recoiling against the entire palladium metal lattice. In either case, very large rates of Coulomb excitation gamma rays should be observed. For 23.8 MeV He^{4} production, the four Coulomb excitation line yields would be 1.8×10^{6}, 4.3×10^{6}, 3.2×10^{6} and 0.9×10^{6} gammas/joule.

One useful indirect fusion gamma line is produced by neutron capture on protons producing a 2.224 MeV gamma ray. Observation of a gamma line at 2.2 MeV has been used (**Pons**) as evidence for neutron production by cold fusion. This method is, however, subject to a well known strong background from the 2.204 MeV gamma ray produced by $Bi^{214} \rightarrow Po^{214}$ decay. Bi^{214} is a radon daughter produced via $Rn^{222} \rightarrow Po^{218} \rightarrow Pb^{214} \rightarrow Bi^{214}$. The 2.204 MeV gamma is produced in 5% of all Bi^{214} decays. Radon levels vary by large amounts depending on location and local ventilation (**Nero**). The typical resolution of NaI(Tl) counters is such that careful calibration is necessary to distinguish a np capture line at 2.224 MeV from a Bi^{214} background line at 2.204 MeV. Using a single crystal coaxial germanium detector the two lines can be readily distinguished. A 5.4% germanium detector at the University of Toronto typically detects the Bi^{214} line at a rate of $0.003 s^{-1}$. This corresponds roughly to an expected count rate for a typical 3 by 3 inch NaI(Tl) detector of about $0.06 s^{-1}$, comparable to the $0.1 s^{-1}$ reported(**Pons**) for a 2.2 MeV neutron capture line. Such a line cannot be identified as a neutron capture line without very careful consideration of the background from the ubiquitous 2.204 MeV line.(**Footnote 1**) The reported line is actually observed to peak at

2.204 Mev, not 2.224 Mev,according to the energy scale of Fig. 1A in Ref. (**Pons**) A good test is to monitor the other gamma lines produced by Bi^{214} decays(**Isotab**); for example, a line at 1.764 MeV should be observed with about 3 times the intensity of the 2.204 MeV line.

It is very difficult not to produce detectable radiation for any known fusion process, even those with only charged particles in the final state. If fusion can occur without such radiations being detected, the energy is not being transferred by the normally expected processes of scattering and absorption of nuclear particles - the energy must be directly coupled to low energy excitations of the metal-deuteride system in some unknown manner.

Footnote 1. I would like to thank Steve Errede for many useful comments and for pointing out that the reported (**Pons**) 2.2 MeV gamma ray actually peaks at 2.204 MeV.

Footnote 2. I would like to thank Richard Bailey, Dale Pitman and Jim Prentice for helpful discussions.

This work is supported in part by the Natural Sciences and Engineering Research Council of Canada.

PONS M. Fleischmann, S. Pons, and M. Hawkins, J. Electroanal. Chem. 261 (1989) 301, plus errata.
JONES S.E. Jones, *etal.*, submitted to Nature.
HOROWITZ Charles J. Horowitz, submitted to Phys. Rev. C.
COULOMB P.H. Stelson and F.K. McGowan Phys. Rev. 99 (1955) 112.
ISOTAB Table of the Isotopes, 7th Edition, eds: C.M. Lederer and V.S. Shirley, John Wiley (1978).
COULREV K. Alder et al., Rev. Mod. Phys. 28 (1956) 432.
ALPHAN P.H. Stelson and F.K. McGowan Phys. Rev. 133 (1964) B911.
EXTEST P.H. Stelson and F.K. McGowan Phys. Rev. 110 (1958) 489.
NERO Anthony Nero, Physics Today 42, No. 4 (April 1989) 32, and references therein.