Measurement of γ-rays from cold fusion

SIR—Petrasso *et al.*[1] have recently published a critique of the γ-ray spectrum given by three of us[2] as supporting evidence for the solid-state fusion of deuterons in palladium host lattices. The basis of this critique was the nature of a γ-ray spectrum displayed during a television broadcast. One of us (M.H.) denies the accuracy of ref. 6 of Petrasso *et al.*; M.H. did not state that the quoted television spectrum was made in these laboratories, as it most certainly was not. In view of this somewhat strange approach to the collection of scientific data and, as we cannot vouch for the authenticity of the spectrum transmitted (we have now confirmed that the "curious structure" in the television 'data' given by Petrasso *et al.* — their Fig. 1*b* and legend[1] — is simply the trace of a screen cursor on the multi-channel analyser visual display unit!), we give in the first place one of the complete set of spectra recorded at that time (Fig. 1).

In the work reported by us[2], γ-ray spectra were measured principally to check on the safety of our operations and, as we have repeatedly pointed out, we are well aware of the deficiencies of these spectra. Figure 1 gives the background spectrum ('sink'; solid line) taken over a sink containing identical shielding materials but at a distance of 5 m from the tank containing the experimental cell. This cell contained a 0.4 × 10 cm palladium electrode polarized at a current density of 64 mA cm^{-2}; during the period of the measurement it was generating excess heat at the rate of 1.7–1.8 W (over and above that due to the electrode reactions).

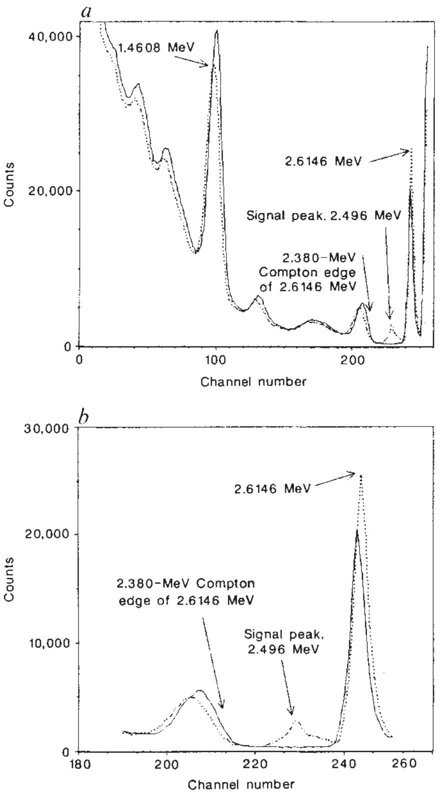

FIG. 1 The γ-ray spectrum accumulated over the water bath containing the electrolytic cells ('tank'; dotted line) and over a sink 5 m away ('sink'; solid line). Detector is a 3 × 3 in. NaI right circular cylinder. Spectral accumulation times: 50 h. *b* is an expanded version of the most relevant region of *a*.

The 'peak' under discussion is centred at 2.496 MeV, and it can be seen in Fig. 1*a* that all the peaks in the background spectrum on the low-energy side of 2.496 MeV are displaced to higher energies whereas that on the high-energy side (due to ^{208}Tl) is displaced to a lower energy. (Scaling of the spectrum made near the electrolytic cell with a quadratic interpolation formula generated the spectrum we reported: this scaling produced a shift and narrowing of the 2.496-MeV peak.) The observed shifts are due to a combination of zero shift in the analyser and a gain shift of the NaI detector resulting from drift of the pre-amplifier. Over the long data-acquisition times, the shifts are of little importance. The spectra do indicate, however, that the nature of the background radiation in the two areas of the laboratory is essentially the same. The only significant difference between the spectra is the signal peak. This is very convincing evidence that the signal peak is not due to products of radon decay.

It can be seen, however, that there is another unexplained feature in these spectra: there is a rising tail at the end of the spectra. This is due to pulse pile-up in the last few channels as a result of a peak at slightly higher energy than the 2.6146-MeV peak (Fig. 2). Figure 2 represents a background spectrum that was acquired with a slightly reduced gain so that the energy window could be extended.

The exact interpretation of the 2.496-MeV peak is in doubt; certainly, the peak from the reaction $^{1}\mathrm{H} + \mathrm{n} \rightarrow {}^{2}\mathrm{D} + \gamma$ (2.22 MeV) would be expected to lie to the left of the Compton peak that arises from the thorium decay chain. The search for this peak does not seem to be feasible using NaI detectors. In spite of the problems underlying the interpretation of these spectra, we consider that the measurements show the emission of γ-rays from the cell environment: removal of the cells leads to the removal of the signal peak. A possible interpretation is that the signal peak is a single- or double-escape peak from 3.01- or 3.52-MeV peaks, or from summing of other unidentified peaks at lower energies. The unusual shape of the signal peak suggests that it may be a combination of such peaks. The size and energy of the signal peak imply that any associated Compton edge or escape peak will be lost beneath the rest of the spectrum.

Petrasso *et al.*[1] have also commented on the integrated peak intensity of the γ-ray spectrum reported by us and imply that we sought to relate this to the neutron count observed close to a similar cell operated in the open air. We point out that we made no such comparison but instead sought to relate the neutron count rate to the tritium production which we and others have observed. Clearly, further work on the γ-ray spectra should include the characterization at high resolution with solid-state intrinsic germanium detectors of the γ-ray emissions in the energy region above 2 MeV.

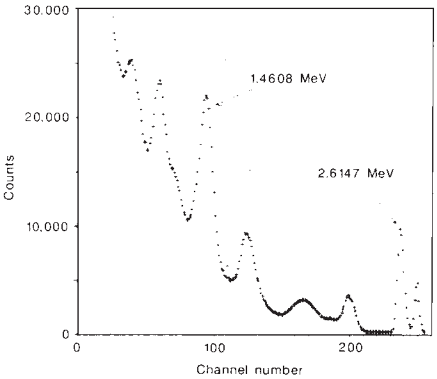

FIG. 2 The γ-ray spectrum accumulated in a similar manner to those in Fig. 1 in a remote laboratory at reduced gain.

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PETRASSO *ET AL.* REPLY—Our criticism[1] of the published 2.22-MeV neutron-capture-on-hydrogen γ-ray line of Fleischmann *et al.*[2], claimed by them as compelling evidence of neutron production in their electrochemical cells (Fig. 1*a* of erratum of ref. 2; Fig. 2 of ref. 1; our Fig. 1 here), raised two fundamental points: Fleischmann *et al.*'s γ-ray line first is a factor of two narrower than their instrumental resolution would allow, and, second, lacks a Compton edge, which should be distinctly evident at 1.99 MeV (Fig. 1). We therefore concluded that their γ-ray signal line was an instrumental artefact, and we argued that the energy position of their signal line was unlikely to be at 2.22 MeV as they claimed. We suggested that the energy of the signal line could easily be verified by publication of their full γ-ray spectrum, because prominent, naturally occurring background lines from ^{40}K (1.46 MeV) and ^{208}Tl (2.61 MeV) calibrate their spectra absolutely[1,3,4].

In their response above, Fleischmann

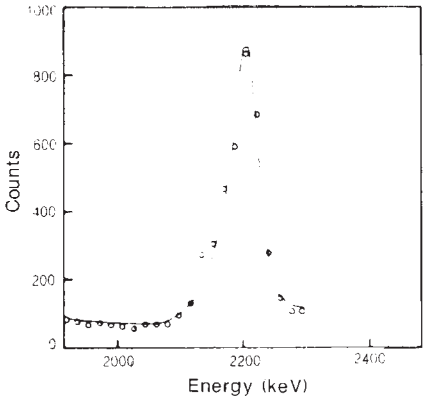

FIG. 1 A reproduction of the purported 2.22-MeV neutron-capture-on-hydrogen γ-ray line of Fleischmann *et al.* (Fig. 1*a* of ref. 2, erratum). As we discuss in ref. 1, the resolution of their NaI spectrometer would be about 2.5% based on this linewidth. With such resolution, one would expect to see a clearly defined Compton edge at 1.99 MeV. No edge is evident. Also, a resolution of 2.5% is inconsistent with their spectral resolution (Table 1*b* of ref. 1). Because of these inconsistencies, we argue that this signal is an instrumental artefact[1]. In this figure, Fleischmann *et al.* show the peak energy to be at 2.22 MeV. In their response above, they indicate that their γ-ray signal line has an energy of 2.496 MeV (see peak 7 of Fig. 2*a* and text).

et al. fail to address our key criticisms concerning their published 2.22-MeV γ-ray line. They further claim, erroneously, that their televised γ-ray spectrum[1] was the basis of our analysis. (Our quantitative analysis is based on their published signal line (Fig. 1), their instrumental resolution (Table 1*b* of ref. 1), a controlled neutron experiment (Fig. 3 of ref. 1) and the well-known properties of NaI scintillation detectors[5,6].) Fleischmann *et al.* do, however, show their full γ-ray spectra (our Fig. 2*a*), in which they identify a signal line to have an energy not of 2.22 MeV, but now of 2.496 MeV. (No explanation is given for their original identification of 2.22 MeV (Fig. 1).) They contend nonetheless that this signal line is proof of true γ-ray emissions from their heat-producing cell, although unrelated to the 2.22-MeV neutron-capture γ-ray. Unfortunately they are unable to identify the nuclear process that generates this 2.496-MeV γ-ray, or to account for its distinctly unphysical lineshape. We again suggest that their signal line is an instrumental artefact unrelated to a γ-ray interaction — this holds both for their signal line in the errata of ref. 2 and for that in their response above (peak 7 of our Fig. 2*a*).

In regard to their γ-ray spectra (Fig. 2*a*), we argue that Fleischmann *et al.* have misidentified the ^{208}Tl peak and therefore that their energy calibration and interpretations are correspondingly suspect. We have numbered the peaks in their spectra so as to best match our energy identifications[1,3,4], and we show beneath their γ-ray spectra one obtained at MIT with a 3 × 3 in. NaI(Tl) crystal (Fig. 2*b*)[1,7]. (See refs 1 and 2 for a discussion of the 3 × 3 in. NaI detector used by Fleischmann *et al.*[2].) The energy scales in Fig. 2 have been scaled and aligned so that the ^{40}K and (true) ^{208}Tl peaks (peaks 3 and 6, respectively) coincide for both spectra. There is a clear correspondence between the Fleischmann *et al.* and MIT spectra for all energies below the (true) ^{208}Tl peak at 2.61 MeV. To further test our energy identifications for the Fleischmann *et al.* spectrum, we plot in Fig. 3 their channel number against our line-energy identifications. The relationship is approximately linear, as it should be if our identifications are sensible. (For the weaker 'peaks' (1, 2, 4 and 5) the precise centroid of energy is a function of the local terrestrial radiation environment[4].) Based on this calibration curve (Fig. 3), their purported γ-ray signal line resides at about 2.8 MeV, not at 2.496 MeV.

The next issue is to identify the other features in the spectra of Fleischmann *et al.* (peaks 7, 8 and 9 in Fig. 2*a*) above the (true) ^{208}Tl line (peak 6). Peak 8, very prominent in both background (sink; solid line) and the cell (tank; dashed line) experiments, and identified by Fleischmann *et al.* as the ^{208}Tl peak, is unphysical, as its linewidth is more than two times smaller than their instrumental resolution would allow (based on the ^{40}K linewidth in Fig. 2*a*; see also refs 1, 6, 7). This is exactly the same objection that we raised in regard to their purported 2.22-MeV γ-ray line (Fig. 1). This observation especially reinforces our contention that peak 6, rather than 8, is to be identified with the ^{208}Tl line. A similar criticism of the linewidth can be made of peak 9 (see Fig. 2 of Fleischmann *et al.* above). The unphysical shape of peak 7, their signal line, also argues against its identification as a real γ-ray line. Thus we conclude that all 'γ-ray signals' above the (true) ^{208}Tl peak (6) are instrumental artefacts. We further point out that in our background spectra (Fig. 2*b*) and in the standard works on γ-ray background radiation[3,4], there is no evidence for any strong lines above the (true) ^{208}Tl peak. Therefore, Fleischmann *et al.*'s present claim of having observed γ-ray emissions from their cell is unfounded.

Another important issue is whether 2.22-MeV neutron-capture γ-rays actually emanate from the water bath surrounding their heat-producing cell which, according to ref. 2, generates 1.7–1.8 W. Using our energy calibration for their spectral data (Fig. 3), and looking in the vicinity of peak 5 of Fig. 2*a* (which is close to 2.22 MeV), we find no evidence for even a small change in the background spectrum relative to that of their heat-producing cell. Quantitatively, from our controlled neutron experiment in a water bath[1,7] and the spectral data of Fig. 2*a*, we can estimate an upper limit on the neutron production rate of about 4×10^2 neutrons s^{-1}. This bound is a factor of 100 smaller than the rate Fleischmann *et al.* claim to have actually observed with their neutron detector[2]. (Fleischmann *et al.* purport above that NaI scintillation detection is inadequate to detect 2.22-MeV neutron-capture γ-rays. This view is erroneous[1,5,6].)

In conclusion, Fleischmann *et al.* fail to answer our key criticisms[1] of their published γ-ray spectrum[2], in particular the spurious nature of their purported 2.22-MeV neutron-capture γ-ray line (our Fig. 1). Although they inexplicably no longer claim to have observed the 2.22-MeV neutron-capture γ-ray, they now

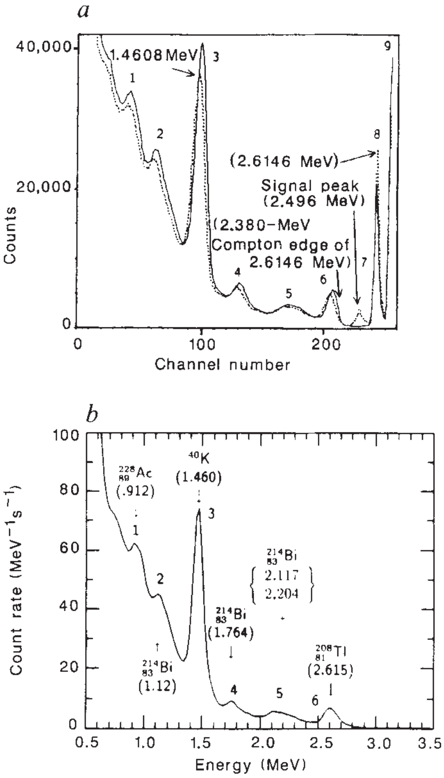

FIG. 2 The γ-ray spectra from *a*, the Fleischmann *et al.* experiments (solid and dotted lines are for 'sink' and 'tank', respectively), and *b*, the MIT γ-ray background measurements. In these two figures, the various peaks have been identified with numbers. (Peaks 1, 2, 4 and 5 are actually blendings of many lines[3,4] of which we have identified the main contributors.) In *a*, Fleischmann *et al.* have identified the ^{208}Tl line with peak 8; we believe that it should instead be peak 6. Consequently we have placed in parentheses their energy identifications and remarks which we believe are in error, and we have accordingly recalibrated their data. With this recalibration, *a* and *b* have been drawn on the same energy scale. Fleischmann *et al.* identify peak 7 as their γ-ray signal line, that is, as the indicator of actual nuclear γ-rays emanating from their heat-producing cell. They now identify its energy as 2.496 MeV, not 2.22 MeV as in their earlier work[2]. (See also Fig. 1.) Using our energy calibration (Fig. 3), peak 7 corresponds to an energy of about 2.8 MeV. We argue that the Fleischmann *et al* peaks of 7, 8 and 9 are instrumental artefacts; see text.

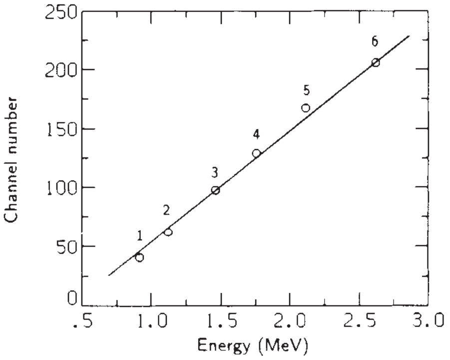

FIG. 3 The energy calibration for the γ-ray spectrum of Fleischmann *et al.* (tank spectrum, dotted line of Fig. 2*a*) using the energy identifications of Fig. 2*b*. Note that we have identified the ^{208}Tl line (2.61 MeV) with peak 6, not 8 as Fleischmann *et al.* did. The straight line is drawn through the ^{40}K (1.46 MeV) and the ^{208}Tl (2.61 MeV) points, which are the most prominent background lines[3,4].

contend that their γ-ray signal line is a true γ-ray of energy 2.496 MeV and, most importantly, that this signal is evidence for nuclear reactions in their cell. They make this claim despite their inability to identify the nuclear process associated with their purported 2.496-MeV γ-ray or to account for its distinctly unphysical lineshape. Furthermore, after correcting their spectral data for a miscalibration in energy, we argue that their signal line (with a correct energy of 2.8 MeV rather than 2.496 MeV) as well as all lines above their (true) ^{208}Tl peak (2.61 MeV; peak 6) are instrumental artefacts in the upper channels of their spectrum analyser. Finally, using our calibration for their γ-ray spectra (Fig. 3), we find no evidence for the emission of 2.22-MeV neutron-capture-on-hydrogen γ-rays from the water bath surrounding their heat-producing cell. Quantitatively this can be interpreted as imposing an upper bound of 4×10^2 neutrons s^{-1} for the production of neutrons. This limit is a factor of 100 times smaller than the neutron rate Fleischmann *et al.* claim to have actually observed[2].

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Fast pulsations in supernova 1987A

SIR—The extremely fast pulsations reported in the 2-year-old supernova SN1987A in the Large Magellanic Cloud[1] will pose serious problems if the pulsations are caused by stellar rotation[2]. I would like to suggest an alternative model where the fundamental mode of stellar radial vibrations is responsible for the short period.

In a supernova explosion some of the matter near the centre which was ejected earlier but with less than the escape velocity should fall back to the star. I assume that such accretion of the infalling ejecta is taking place near the Eddington limit and that the inner region of the accretion flow is in the two-temperature phase with the corresponding equipartition magnetic field, B, of about 10^7–10^8 gauss[3].

In magnetized accretion flows of this type electron cyclotron radiation is emitted[3]; because the cyclotron optical depth for the fundamental and higher mode harmonics is larger than one, these photons are self-absorbed up to the critical frequency where the optical depth becomes one[3]. The flux of this self-absorbed cyclotron emission can be calculated from the equation derived in ref. 3.

Adopting as the typical physical parameters the accretion rate $\dot{M} = 10^{-8}\ M_\odot$ per year, the stellar mass $M = 1.4\ M_\odot$, the electron temperature $T_e = 2 \times 10^9$ kelvin, and $B = 10^7$ gauss in the inner part of the accretion flow at a distance of 10 × the stellar radius, we found the total cyclotron flux emitted over the optical region to be $F_c = 8.4 \times 10^{18}$ erg cm^{-2} s^{-1}. The corresponding total luminosity is 2.7×10^{35} erg s^{-1}, which agrees with the observed optical pulsar radiation.

The flux depends sensitively on the magnetic field strength, B, and very small periodic variations of B near the surface caused by the stellar radial vibrations can, through shocks, produce observed periodic variations in F_c. The light-travel time at a distance of 10 stellar radii, where most optical pulsar radiation is emitted, is less than the pulsar period, and thus the pulsed radiation will not be washed out. The sharp pulses can be maintained as the infalling clouds are expected to be highly inhomogeneous. A decrease of B by a factor of only 2 will reduce the total luminosity to 2×10^{33} erg s^{-1}, fainter than 20 mag. Therefore, in my model, the reported disappearance of the pulsar to below 20 mag can be explained by a small decrease of B.

My model is fundamentally different from the vibration-cyclotron model proposed by Wang *et al.*[2] in the following senses. First, whereas I assume the accretion near the Eddington limit is the energy source, Wang *et al.* assume the energy source is the residual vibration. Second, I adopt a weak field model whereas Wang *et al.* require B to be about 10^{12} gauss. Finally, for Wang *et al.* the optical pulsed emission is caused by the ion cyclotron fundamental mode emitted right on the surface, while in my model it results from the self-absorbed electron cyclotron higher harmonics emitted within the accretion flow, near to, but above, the surface.

Observational tests should be able to distinguish between the two models. If, within a few years, the GINGA X-ray satellite detects X-rays directly emanating from the hot neutron star accreting near the Eddington limit, this should support our model and exclude that of Wang *et al.*. Also, if slower rotation-powered pulsed radiation is detected in SN1987A, the exact value of the period should distinguish between the models.

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Taxonomy debate signing off

SIR—In response to A.S. Clare and D. Rittschof (*Nature* **338**, 627; 1989) I would like to point out that trinomia are already used in taxonomy, but that the name in brackets is reserved for the subgenus.

Also, the equals sign means synonymy, but a species being moved from one genus to another does not mean that the previous genus is synonymized unless the species happens to be the type species. To be correct, it should be *Semibalanus balanoides* (= *Balanus balanoides*), assuming that the species has not been split up during transfer.

Clare and Rittschof might consider quoting the species name in full by adding its author and date. If the species has been transferred then the original author and date go in parenthesis as is the norm and, borrowing from botany, the name and date of the latest revisor can be added after the original author. The taxonomic history of the species should now be traceable.

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This correspondence is now closed — Editor, *Nature*.