Critique of *Nature* Perspective Article on Google-Sponsored Pd-D and Ni-H Experiments

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Editors' Note: On May 27, 2019, the journal *Nature* published a "Perspective" research article (#570, pp. 45-51) based on Google-sponsored experiments conducted at four institutions in North America. The authors of "Revisiting the Cold Case of Cold Fusion" are Curtis P. Berlinguette (University of British Columbia and Canadian Institute for Advanced Research), Yet-Ming Chiang (Massachusetts Institute of Technology), Jeremy N. Munday (University of Maryland), Thomas Schenkel (Lawrence Berkeley National Laboratory), David K. Fork (Google LLC), Ross Koningstein (Google LLC) and Matthew D. Trevithick (Google LLC).

In the opening the authors describe the research effort: "We came together in 2015 to determine how to produce reliable and accessible experimental data to better inform the polarizing debate about cold fusion that has simmered for three decades...A key objective...was to define quantitative bounds for the observation of any anomalous thermal or nuclear effects." They report that the project included about 30 researchers (staff scientists, grad students and postdoc researchers) who worked for over four years. It appears that research will continue.

While the authors report having found "no anomalous effects claimed by proponents of cold fusion that cannot be explained prosaically," they note that their work "illuminates the difficulties of producing the conditions under which cold fusion is hypothesized to exist." They note that this "leaves open the possibility that the debunking of cold fusion in 1989 was perhaps premature" and state that whether cold fusion is "real" is "itself an open question." Importantly, they note: "We believe that there is exciting new science to be done within the parameter space of cold fusion experiments, and that this is an area worthy of engagement from the broader scientific community..."

Dr. Michael C.H. McKubre, retired from Stanford Research Institute (SRI), has written a critique and observation about the publication and the experiments. He was involved with the research effort in its early stages. McKubre has a more optimistic view of the project and its publication in *Nature* than some in the cold fusion community. *Infinite Energy* welcomes and hopes to receive Letters to the Editor or other submissions from members of the cold fusion community, as well as other scientists and readers, highlighting their perspective on the Google research.

God bless Google! I am certain that I have never said this before and am unlikely to again, but in the context of my title I am delighted with the effort and the results of their four-year activity. This is vaguely self-praise and therefore slightly biased commentary since I was directly involved with Google and the team at the start of this activity in 2014 and 2015. But I have had no direct involvement since.

Is the *Nature* Perspective article perfect? No, nothing is. But my grumbles are few and I will dispose of them before enumerating what I feel are four startling positives. The team wanted to maintain separation from the CMNS (Condensed Matter Nuclear Science) community—a clean-sheet approach—so their vision and conclusions would be seen to be impartial and their sponsor's involvement concealed. Because of this disconnect the authors' perspectives did not fully reflect current thinking in the CMNS community.

The Perspective features "cold fusion" almost as if it were really possible under conditions where the Fleischmann Pons Heat Effect (FPHE) has been observed. To be sure, there are historical reasons to do this, but this is a straw man easily defeated. To a broad swath of nuclear physicists, "fusion" is a word reserved for a specific and very small set of reactions in which individual light nuclei interact in pairs by overcoming their mutual electrical repulsion (the "Coulomb barrier") and thus create one or more "fused-mass" objects with a mass deficit that is converted to energy. Such a process is invoked when the authors write, "It was therefore proposed that D + D → ^{4}He + 24 MeV was the dominant pathway for cold fusion, with essentially all of the energy transferred to the host metal lattice as heat, and helium."

The authors are correct that this reaction was proposed—or written down. But very few in 1989, and even fewer today, imagine that the interaction of deuterons (D) to produce helium-4 (^{4}He) can, does or did occur in such a simple scheme without many more moving parts. That reaction must be read as D + D → [a complex intermediate state involving many, potentially millions of atoms and nuclei in catalytic processes] → ^{4}He + 24 MeV. This is how chemists think about processes and reactions, with only the initial and final states identified together with the energy difference between them. What is the difference? The reaction in the preceding paragraph cannot and does not occur in condensed matter nuclear reactions—and would take no advantage from the condensed matter state if they did. The reaction extended in this paragraph may indeed occur as Julian Schwinger suggested[1] by taking catalytic advantage of the

embedding or subtending lattice. [When asked to report to Edward Teller at the Hoover Institute early in the cold fusion era, Teller concluded an extended discussion by stating that, on the basis of what I had described to him he was not sure that a novel nuclear effect was indeed taking place in the SRI experiments. But if it were, he said the explanation would turn out to be "nuclear catalysis at an interface."]

So my principal complaint is that this straw man is the totality of nuclear discussion in the Perspective and its possibility or occurrence is argued to be "remote." I agree, as written. But the CMNS community has evolved far beyond this point, including changing the name of the community and major conferences from "cold fusion" to "condensed matter nuclear science." This change was intended precisely to reflect more accurately the potentially broader and evolving implications of the Fleischmann and Pons' experimental observations[2] that nuclear reactions may take place in condensed matter by means, at rates, and with product branching ratios, different from those reactions in free space.

The principal endeavor of the CMNS community now is to find out *precisely how* the lattice involves itself to make heat and ^{4}He correlating in amounts more or less exactly as both forms of the equation predict. I would have been far happier with the Perspective article if it had included a sentence noting that there were multiple reports confirming the correlation of heat and helium production, and the reported energy value appears consistent with the values from fusion if deuterium is the fuel and heat and helium are the major products.

What is so good about the article? So good that the value, at this time, far overweighs my two objections above: mercilessly beating an already long-dead horse and failing to note or report observed heat-helium correlation? I have itemized four monumental (in the sense that history will record them) good things that this Perspective brings to us. There are more—but minor compared with the following:

1. Vision and action. Two of the authors of the Perspective article, Ross Koningstein and David Fork, senior engineers at Google, previously wrote an article[3] in which they analyze dispassionately earth's energy situation. In their vision, the known renewable energy sources and any conceivable, in their most optimistic projection, cannot supply the energy needs of our planet's growing and advancing population. One of their conclusions is that "new zero-carbon primary energy sources" must be developed. This article appeared in *IEEE Spectrum* in November 2014. Importantly, and before that, rather than congratulating themselves on their analysis and conclusions, the authors set out with Google's support to address that perceived need. The result is what we are discussing today, with the extension enumerated below. Google saw a problem, saw a potential solution, enlisted support and set out to do something about it.

What qualifies as a "new zero-carbon primary energy source"? The *IEEE Spectrum* article specifies low cost as a requirement, so that markets, not legislation, motivate technology conversion. If we add intrinsically safe, environmentally benign (independent of "carbon") and source-unconstrained by natural availability or geographic location, then few potential technologies are known to exist. Based simply on source energy density considerations, for me it is clear that the technological answer to this challenge almost certainly will be nuclear and I know of only two options that are viable and meet all criteria: conventional fission—preferably generation IV or beyond, perhaps employing thorium as a fuel; and cold fusion/LENR/CMNS, by whatever name we choose to call it. Koningstein and Fork saw that too. They and their company, colleagues and collaborators are making a genuine effort to solve what they foresaw as mankind's probably most pressing and universal long-range problem—our future energy supply. Congratulations to them and to all who participated with them.

Is "cold fusion" industrially or commercially viable, or potentially so? I do not know. The *Nature* article and the Google-supported research reported so far have not helped much with that question. Yet there is hope. Many experiments have been performed by highly capable individuals in highly respected institutions. What the CMNS world is crying out for is data. The field is small, generally underfunded and academically repressed (see next point). This Perspective is supported by nine peer reviewed technical papers and three arXiv posts. That body of work is embedded in the references. As the CMNS community and the world dig through these, with access to the authors and potentially to raw data, we are certain to learn something that will help answer this question and teach "how." I have worked in the CMNS field for 30 years and on the deuterium-palladium system for ten years before that. [Coincidently to develop technology to improve safety in conventional fission reactors.] As originally claimed by Fleischmann and Pons in 1989[2] there is quite apparently a nuclear-level anomalous heat effect in the deuterium-palladium system that can be accessed, with difficulty, but under relatively well-determined conditions.[4] We need help in elaborating those conditions. (See Point 3 herein.)

If it should turn out that the "excess heat" reported from CMNS experiments is real, as seems likely from the results of a large body of experimental results with which I am familiar, the cause nuclear and the effect technologically accessible, when should we expect to see our first practical CMNS generator of heat or electricity? Again, I do not know, but I will say that the principal authors of this Perspective—Berlinguette, Trevithick and the rest of the team—have advanced this timing and probability considerably. Thank you, gentlemen and Google.

2. Publication. The existence of this publication is of immeasurable importance—just the fact that it exists and exists in *Nature*. Since their early rejection of "cold fusion," many erstwhile practitioners have attempted, but none have passed the gates of *Nature*. I have written before that probably the most effective disincentive to research and researchers in the CMNS field is the perceived embargo of mainstream publication. That embargo is herewith lifted. The barrier is down. The door has not been opened fully and entrance broadly welcomed, but the nose of the camel is under the tent. Academics will be "allowed" to pursue their interests in the CMNS world, and many with high and relevant aptitude already have expressed interest in uncovering the secrets of nuclear processes in condensed matter. They will even be encouraged to enter, since groups with the "pulling power" of Google are now seen to have weighed in, joined by several other groups of significant stature with similar motivations, both scientific and environmental. If

Koningstein, Fork and Trevithick *et al.* at Google are correct that "a new zero-carbon primary energy source" is needed for the planet, and I am correct that this *will* be nuclear, and Gen IV nuclear fission and "cold fusion" are presently the only potentially viable candidates, then how can any scientist with relevant aptitude not seek to work on this?

3. Confirmation. A major technical recognition in the Perspective article is the literature association of the FPHE with a threshold loading of deuterium into palladium. They state there (citing me[5] but also simultaneously reported by Kunimatsu[6]) that one is able to "observe excess heat only when the palladium cathode was loaded with hydrogen beyond a threshold of PdH_x where $x > 0.875$." There are qualifiers that I would add to that statement, but it is close enough for this purpose. All the work put in by the Google team so far supports or at least does not contradict the generality of this inequality. [One electrode of rather special construction was reported to load into the range where excess heat might have been possible according to my understanding, if other conditions (discussed below) were also present. Due to the circumstances of this experiment no calorimetry was attempted, but apparently no obvious thermal excursion apparently was observed either. It is probably more accurate to state that what was reported in the *Nature* Perspective neither supports nor controverts the "necessity of high loading." No excess heat was reported—but the bounds and circumstances of the null heat results are yet to be reported. Likewise, while loading is discussed and the need recognized "to produce and sustain highly hydrided palladium," it is not yet clear how many samples were loaded with, for example, deuterium, and to what loading levels in what geometries.]

The experiments performed to this point by that team should not, by my understanding, have produced excess heat at calorimetrically detectable levels—and did not. With further elaboration, the experiments referenced in the *Nature* article may thus become a valuable set of "nulls" (not the same as a "null set"). We can potentially learn a very great deal more about the "circumstances of cold fusion" from a comprehensive analysis of how these experiments were performed. It is worth noting that a more nearly complete descriptor of the conditions under which excess heat might be expected (Equation 1 in Reference 4) includes two other threshold criteria and one linear effect: high loading must be maintained for a considerable time (several weeks for bulk cathodes); current density must exceed quite a high threshold value (~100 mA cm^{-2}); and the flux of deuterium through the cathode surface must be large (equivalent to ~10 mA cm^{-2}). It is not clear to what extent the research supporting the Perspective article achieved or failed to achieve comparable values of these additional parameters, but I and the entire CMNS community are keen to learn.

Personally, therefore, I am both disappointed (albeit not surprised) that excess heat was not seen by the Google-sponsored team in their first clean-sheet outing, and delighted that they have provided independent experimental support for the "McKubre-Kunimatsu" threshold loading observation/conjecture/hypothesis.[5,6] Perhaps the first is not so bad. In my experience experimenters and their backers in the CMNS field with strong positive results are very reticent to publish or even discuss or disclose their results in public. *Nature* so far has not published any positive result. I draw no conclusions and am very pleased to see this article. To paraphrase Martin Fleischmann's comments in his keynote lecture at ICCF7 (Vancouver, 1998): "one of the more notable products of the continuing LENR saga may well be what it teaches about the way that science is done and publication undertaken in modern times."

4. Youth involvement. I have saved the best for last. This single point elevates the designers and creators of the program behind the Perspective article to "heroic" level in the CMNS community. Our field is dying. Our average age increases nearly one year per year. I was 40 when we started in 1989 and near the peak of my career. Now I am 70 and retired. The problem is not just age and inactivity, it is unwillingness and inability to learn or change. We need fresh new ideas and perspectives and to incorporate technically modern concepts. We need to attract young people into our field!

Google has done that, deliberately, by program design. Not only is the student involvement large, the engaged academics are young—most not yet anywhere near the peak of their career capability. They will all be with us working for a long time. These academics were hand-picked to be able, agile and good teachers. This project has trained and motivated a new set of minds and hands to teach, lead and nurture the next generation, and the next.

Quoting from the *Nature* article, "Early results from these ongoing studies have confirmed that we can produce and detect neutrons from D-D fusion at discharge voltages corresponding to 1.2-keV ion energies in the centre-of-mass frame." This observation clearly relates to CMNS and stands in direct conflict with the premise of many early assertions that "cold fusion is theoretically denied." I know from personal experience that once you are bitten by the "cold fusion

bug" you can never completely give up. To see with your own eyes excess heat at nuclear levels where there should be none, or nuclear emissions or products issue from the gentle stimulation of a few hundred volts or °C, is the closest thing to a "Holy Grail" that any physical scientist or physicist or engineer can ever hope to experience. According to one of the principal investigators on the Google-sponsored team,[7] "We are not finished—in many ways this is just the beginning—and we want others to join the effort to look into the materials science, electrochemistry and physics surrounding this topic."

I wrote the following in 2009:[4] "How do we make progress? We make progress through theory: quantitative predictive fundamental physics descriptions. We will continue to make progress best by using the scientific method. To do so we are going to have to engage the broader scientific community. We simply can't sit here secure behind our walls and talk in closed groups; we need to invoke enthusiasm in the broader scientific community." Ten years later it looks like this enthusiasm has been invoked and ignited to a very significant degree. Google has helped to secure our future. To end with the theme of my beginning: we are born again.

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