# Low energy nuclear reaction research – Global scenario

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*This article reviews highlights of low energy nuclear reaction research, part of the field of condensed matter nuclear science. The field evolved from the so-called cold fusion discovery of two electrochemists, Martin Fleischmann and Stanley Pons at the University of Utah. Since the announcement of their discovery in 1989, more than 200 researchers in 13 nations have confirmed and expanded the set of experimental evidence that provides the validation for this new field of science.*

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AT a press conference on 23 March 1989, at the University of Utah, USA, two electrochemists, Martin Fleischmann and Stanley Pons announced that they had produced a sustained nuclear fusion reaction. Pons had been Chairman of the Department of Chemistry, and Fleischmann was one of the world's top electrochemists.

The surprising announcement by Fleischmann and Pons introduced a possible third – and environmentally friendly – route to use nuclear energy. The first route, nuclear fission, has been well-understood and cost-effective in many countries, though it is not without its problems. The second route, thermonuclear fusion, thought to be the process that powers the sun and the stars, has been well-understood for many decades, but it has never worked as a source of energy. Researchers hope to create a miniature sun on earth, without destroying its own container; however, this engineering feat remains elusive.

The discovery by Fleischmann and Pons was labelled 'cold fusion' by the press. However, as the field matured, researchers identified 'low energy nuclear reaction' (LENR) as more appropriate for research and 'condensed matter nuclear science' to identify the field.

LENR research is potentially of great significance because of the following key characteristics: LENR does not produce greenhouse gases, strong prompt radiation or long-lived radioactive wastes. The fuel is deuterium or hydrogen, which is abundantly available in ocean water. The dominant reaction product is He-4, which is harmless.

Fleischmann and Pons reported that they observed unusually large excess heat production from their experiment; yet it was clear to them and the world that the commensurate radiation that normally would come with any thermonuclear fusion was missing. It was also clear that the circumstances of thermonuclear fusion – complex containers enabling temperatures in the millions of degrees – were not those of the Fleischmann–Pons experiment, which was a test-tube experiment performed at room temperature. If it was fusion, it was not fusion as we then, or now know it. Thus was born a fissure in the scientific community: people reluctant to accept that Fleischmann and Pons had, in fact, obtained the Holy Grail of energy, and others willing to consider that there was something real, but not understood.

In less than six weeks after the press conference, public opinion shifted to the view that the Fleischmann–Pons claim had no merit. The US Department of Energy cold fusion review panel provided the official stamp in the fall of 1989, that the discovery was not as claimed. However, a different track emerged simultaneously, but quietly.

The first hard evidence to support the claim that Fleischmann and Pons had created a nuclear reaction by chemical means was the discovery of tritium. Unlike excess heat that vanishes as soon as it is created, tritium is not nearly as ephemeral. And its presence in concentrations above background is an unambiguous sign of a nuclear reaction.

One of the first teams to witness tritium evolution from a cold fusion cell was that of P. K. Iyengar and M. Srinivasan at the Bhabha Atomic Research Centre (BARC), Trombay, India. They witnessed a burst on 21 April 1989, and reported[1] it to the scientific community in July 1989.

Halfway around the world, at Texas A&M University, USA, a group led by world-renowned electrochemist John O'Mara Bockris was startled to notice extremely high concentrations of tritium in cold fusion cells on 24 April 1989. The Bockris group published a paper[2] in October 1989.

But there were some problems. Fleischmann and Pons were mistaken about their theory; they were mistaken about their gamma spectrum. Yet in the larger picture, these were relatively insignificant factors. Their rushed preliminary note, published in April 1989, left much to be desired[3]. Its shortcomings, however, were more than

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compensated for in their seminal paper[4], published in July 1990. Several challengers scrutinized this paper, and, to this day, the excess heat they claimed has not been refuted in the scientific literature. The first replication of excess heat reported in the press was by the Stanford University team, USA, led by Robert Huggins, on 19 April 1989. The credit for the first published replication of excess heat[5] goes to Richard Oriani, professor emeritus from the University of Minnesota, USA in December 1990.

Nineteen years later, excess heat has been reported in hundreds of papers using a variety of experimental methods, with high certainty in the precision of the calorimeters, lasting many hours in duration and, recently[6], on the order of 1–2 W.

Numerous examples have been reported in which the measured energy is at least 1000 times greater than any known chemical reaction, eliminating many arguments, including that of stored and released chemical energy. In a report to the Pentagon[7], Garwin's assessment of an SRI international experiment stated, 'A chemical reaction involving the Pd at perhaps 1.5 eV per atom would correspond to about 3.5 kJ of heat; this is to be compared with the 3 Mj of excess heat observed, so such an excess could not possibly be of chemical origin'. A few researchers like Focardi and Piantelli, also have reported excess energy with hydrogen and nickel systems[8].

The original Fleischmann–Pons experiment used a heavy-water electrochemical cell. Other configurations have used pressurized deuterium gas, gas-electric field discharge, gas diffusion, plasma electrolysis, ion bombardment, acoustic and mechanically induced cavitation, nanostructured or finely divided palladium, and even biological organisms.

One of the most fascinating reports was that of Fralick *et al*. (NASA Lewis Research Center, USA) in December 1989. They pumped deuterium and hydrogen gas (individually) through a palladium filter in a search for neutrons, as one might expect in thermonuclear fusion. They found no significant neutron signal, but they were perplexed about the 'source of the heating which occurs when $D_2$ and not $H_2$ is removed from the Pd'[9].

Many of the early failures to confirm the Fleischmann–Pons excess experiment were the result of experimenters' impatience in their search for excess heat; as well, many of them were looking in the wrong direction – for high-energy neutrons[10]. In some cases, the successful early replicators knew Fleischmann personally and, as a result, were convinced that making a more concerted effort was worthwhile. Other successful replicators had either prior experience with the Pd/D or Pd/H environment or expertise in metallurgy.

In the early 1990s, Melvin Miles, at the US Navy's China Lake facility, working with analysts Ben Bush and J. J. Lagowski at the University of Texas, Austin, USA, observed that He-4 is a dominant nuclear ash from LENR experiments[11], as did other researchers in later years.

A variety of anomalous physical effects on the cathodes have been observed, such as the melting and vapourization of palladium in experiments. These effects cannot be the result of Joule heating because the energy inputs are too low[4,12]. Other changes to the cathodes include unusual morphological deformations[13], craters[12,14] and 'hot spots'[15].

Radiations observed in LENR cells are emitted at very low intensities and thus are difficult to measure; however, some X-ray[16,17], gamma ray[18], and energetic particles (ions and electrons)[19,20] have been detected and reported.

Low energy nuclear transmutations are among the most intriguing aspects of the field. Several rigorous sets of experiments have been performed by Iwamura at Mitsubishi Heavy Industries. A multilayered substrate is built containing layers of palladium and calcium oxide. Atoms from the source element are placed on the surface. Deuterium gas is passed through the substrate.

Iwamura reported, 'When Cs was added on the surface of a Pd complex, Pr emerged on the surface while Cs decreased after the Pd complex was subjected to $D_2$ gas permeation. When Sr was added to the surface, Mo emerged while the Sr decreased after $D_2$ gas permeation. The isotopic composition of the detected Mo was different from the natural abundance. . . . The detected Pr was confirmed by various methods such as TOF-SIMS, XANES, X-ray Fluorescence Spectrometry and ICP-MS'.

Analysis was performed *in situ* and later at the Japanese Spring-8 Synchrotron. This research has been published in the *Japanese Journal of Applied Physics* as well as in conference proceedings[21,22]. A related replication was performed at Osaka University[23].

George Miley, University of Illinois, USA, has compiled a worldwide summary of LENR transmutation experiments in a paper that is part of a 16-paper compendium to be published by Oxford University Press in August. Of particular interest in this paper is the review of anomalous isotopic distributions seen in some LENR experiments[24,25]. In 2005, Miley, working with Sheldon Landsberger at the University of Texas, published a paper that used both NAA and SIMS analysis to show anomalous isotopic shifts[26].

Repeatability by originators, and reproducibility by replicators, has been and remains one of the greatest limitations of this field of research. The transmutation experiments have shown very high repeatability and reproducibility; the excess heat experiments have been the most challenging. Michael McKubre, SRI International, makes clear a subtle but important point about excess heat repeatability. McKubre notes that achieving excess heat is not difficult, but achieving the required prerequisite conditions for it is. In the early 1990s, McKubre identified three threshold parameters that are required: a minimum deuterium to palladium loading ratio, a minimum current density through the cathode surface, and the need for a dynamic trigger[27]. The failure to achieve a minimum loading of 0.90 D/Pd was perhaps the most significant reason for the failure to replicate the excess heat effect by many prominent laboratories in 1989.

SRI International's knowledge of these parameters, use of a proprietary triggering waveform by Energetics Technologies LLC, New Jersey, and of proprietary metallurgical preparations developed by researchers at the Italian National Agency for New Technologies Energy and the Environment (Frascati) and the University of Rome, enabled them to obtain from 10 to 300% excess heat in 12 of 23 experiments, recently.

Some researchers choose to detect and identify the He-4 evolution from LENR experiments using elemental analysis, that is, using a high-resolution mass spectrometer. Other researchers have chosen to seek this evidence as the emission of charged alpha particles, using solid-state nuclear track detectors, also known as CR-39 track detectors or by the observation of tracks on X-ray films[28].

Some of the most significant *in situ* particle detections have been observed in experiments and replications of work originating from the US Navy's Space and Naval Warfare Systems Command Center in San Diego[29,30]. The unique aspect of the SPAWAR experiment is the co-deposition process, wherein atoms of palladium and deuterium are deposited, atom by atom, onto a host metal. This method appears to provide the conditions required to create LENR effects repeatably and reproducibly. Many years ago, the researchers reported observing excess heat with the co-deposition method. Recently, they have searched for, and found, strong signs of charged particles and, most surprisingly, small fluxes of relatively low-energy neutrons. It has been known that neutrons are not the dominant emission from LENR experiments for a long time; hence this recent evidence is intriguing.

Lawrence Forsley, JWK Technologies, Virginia, a collaborator of SPAWAR, used a device (Track Analysis Systems Ltd.) to map the patterns of tracks on CR-39 detectors from these experiments. Forsley has shown a direct spatial correlation between the cathode, believed to be the source of the emissions, with tracks on the side of the CR-39 that faces the cathode, as well as tracks on the side of the CR-39 that faces away from the cathode. No other logical (or illogical!) explanation has been suggested about the conditions of this experiment that explains the correlated tracks from anything else than proton recoil effects from neutron emissions[31].

Researchers at SRI International reproduced the SPAWAR experiment and observed similar tracks. The identification of alpha and proton tracks remains ambiguous. However, SRI reported a 'neutron count above background suggested in at least three experiments' through the use of a $BF_3$ ionizing neutron detector that has worked reliably for many years.

In one of these experiments, coincident with the increase in neutron count, the researchers saw a sudden change, an inflection in the cell potential. A possible interpretation of the inflection is that the electrolyte heated up, which increased the conductivity.

Francis Tanzella, SRI stated, 'This is a very unsupported suggestion that we might be seeing some sort of thermal effect during the increase in neutron count. I should point out that this is simply a count as measured on the meter. We don't have any independent evidence that those neutrons had been measured separately'.

Their presentation provides additional caveats and context[32].

Two of the CR-39 detectors from the SRI International SPAWAR replications were measured and analysed independently, using a sequential etching method by researchers at the Russian Academy of Sciences.

They reported that 'a weak, but statistically significant emission of fast neutrons has been observed in SRI's #7 and #5 runs replicating the SPAWAR Pd-codeposition experiment'.

They displayed a plot of track density vs track depth[33], converted to MeV, which shows a plot that is consistent with neutron emissions from Cf-252.

The theoretical side to LENR has been coming along slowly. One theorist, for example, Peter Hagelstein at MIT, USA, has tried more than 100 models to explain the LENR effect as a fusion process. One perspective that he emphasizes is that thermonuclear fusion, as explained in nuclear physics textbooks, was all based on nuclear reactions in a plasma, whereas LENR reactions occur in a solid, the metal lattice.

An alternate idea that has been proposed recently by Allan Widom, Northeastern University, USA and Lewis Larsen, Lattice Energy LLC, is that of 'ultra low momentum neutron catalysed nuclear reactions'. They believe that the LENR anomalies result not from a fusion reaction, which would involve the strong force, but from other low energy nuclear reactions that involve weak interactions, namely neutron formation from electrons and protons/deuterons, followed by local neutron absorption and subsequent beta-decay processes[34,35].

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