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Reasonable doubt

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No sooner had cold fusion surfaced than it was written off, and the idea that you could extract virtually limitless free energy from water quickly became taboo. Yet a small band of researchers at the US Office of Naval Research have come up with some puzzling observations that no conventional theory can explain. Some of them started out as sceptical as the rest, but they now believe they have evidence that cold fusion is worth pursuing. Bennett Daviss takes up the story

LAST YEAR, the US navy's Space and Naval Warfare Systems Center in San Diego released a two-volume report. Its soporific title, "Thermal and nuclear aspects of the Pd/D_2O system: a decade of research at navy laboratories", belies its contents. The report lays out the navy's evidence that cold fusion is real, a verifiable nuclear event that liberates more energy than it consumes.

If this claim were being made by almost anyone else, it probably would - and maybe should - be greeted with an embarrassed silence. But behind this research is the organisation that sponsored 50 Nobel prizes, produced radar, the laser, the Global Positioning System and thousands of other discoveries and products used every day around the world. After more than 200 experiments, conducted over 10 years at various navy laboratories, several of its researchers are willing to declare that these laboratories have played host to events that not only indicate that cold fusion is real, but that can't be explained in any other way.

"I had a bit of unease about putting my name to this," admits Frank Gordon, director of the San Diego centre's navigation and applied sciences department, who wrote and signed the report's introduction. "But our data is what it is and we stand by it."

Though the report has indeed been greeted by silence, the navy scientists are not embarrassed. They believe the experiments it describes could make a vital contribution to a hugely important scientific discipline. Indeed, Gordon is now calling for government agencies to begin funding cold fusion research again.

It's a brave gesture. Mainstream scientific opinion has stood against cold fusion since shortly after 23 March 1989. That's when Stanley Pons and Martin Fleischmann, working at the University of Utah, announced that they had created fusion in cells composed of a palladium electrode immersed in a bath of "heavy water", in which oxygen is combined with the hydrogen isotope deuterium.

In deuterium, each hydrogen atom, with its nucleus of a single proton, is replaced with the hydrogen isotope deuterium, which holds both a proton and a neutron at its core. Palladium readily absorbs deuterium atoms, but Pons and Fleischmann were claiming that deuterium nuclei were being packed into the palladium's molecular lattice in such a way that their nuclei were fusing together and releasing energy. However, overcoming the repulsion between two positively charged nuclei and bring them together requires an enormous amount of energy. It normally takes conditions of heat and pressure found in the Sun. Achieving fusion at room temperature, using a small piece of equipment sat on a lab bench, was widely believed to be impossible.

Within a few months, the Energy Research Advisory Board (ERAB), a panel of prestigious scientists appointed by the US Department of Energy to test the claim, pronounced to the contrary: Pons and Fleischmann were, to put it politely, mistaken. Since then, cold fusion has been as respectable in science as pornography in church.

Except, perhaps, in the US navy. According to David Edwards, assistant to the executive director of the Office of Naval Research (ONR), navy researchers rule nothing out until all avenues have been explored. "If we thought the underbelly of a dung beetle would make a better radar reflector than the material we're using now, we wouldn't hesitate to investigate that possibility as thoroughly as we needed to in order to make a judgement," he says.

And so, if researchers have time not claimed by assigned projects, they pretty much do what they want, using discretionary funds controlled by their department chiefs. "In 1986, when superconductivity became a hot topic, managers asked if anybody in our labs was working on it," says materials engineer and former navy officer David Nagel, who has since retired as a head of the division of condensed matter and radiation sciences at the Naval Research Laboratory (NRL) in Washington DC, and is now a research professor at George Washington University. "About 40 hands went up. With cold fusion, the same thing happened. It was unstoppable."

The prospect of cold fusion was irresistible to the navy. Calculations showed that a cubic kilometre of ordinary lake or ocean water contained enough deuterium to rival the combustion energy in all the world's known oil reserves. Then there were claims that some credible attempts to replicate Pons and Fleischmann's work had indeed seen something strange.

The navy's researchers were also influenced by personal contact with Fleischmann. A world-renowned electrochemist and Fellow of the Royal Society, he had long been a contract researcher and consultant for the navy, and several of its scientists had published papers with him. Many navy researchers were unwilling to accept he had gone off the rails. "We knew his abilities," says Pamela Mosier-Boss, an electrochemist at the San Diego centre. "I had to believe that he had something real going on there."

Boss's job, researching fuel cells and innovative propulsion systems, made it imperative for her to investigate the cold fusion claims if there was even the slightest chance they might hold up. So she and her colleague Stanislaw Szpak began to probe them. Both were well-established in the profession: Szpak had published more than four dozen papers in refereed journals, Boss more than two dozen. Both had made numerous presentations at professional meetings and had had their work included in volumes of proceedings. They felt confident that if anyone was well placed to make an objective assessment of cold fusion, they were.

Their first move was to make their own palladium electrode using a technique called co-deposition. They passed an electric current through a solution of palladium chloride in water that had been slightly enriched with deuterium. At the negative electrode, the cathode, which was made of copper in some experiments and silver in others, the current liberated palladium and deuterium gas, which were deposited together in spidery black filaments. In more than 100 such trials, Szpak and Boss saw something odd. After about 30 minutes, the temperature of the palladium-coated cathode rose about 3 °C above that of the surrounding liquid.

This takes some explaining. The bath's electrical resistance is greater than the cathode's. Resistance to current creates heat, so if the only heat source was the current flowing into the cell from the external battery, the electrolyte should have been warmer than the palladium. Because the reverse was true, the unaccountable energy had to be coming from the cathode: the metal had to be liberating energy. Spzak and Boss appeared to be witnessing a net energy gain.

While they were carrying out these experiments, Melvin Miles, an electrochemist long familiar with palladium-hydrogen interactions, was working not far away from them at the Naval Air Warfare Center at China Lake, California. A former college professor, Miles had been a NATO postdoctoral fellow in Munich and a visiting scientist at Brookhaven National Laboratory. By the time cold fusion came along, he had published 97 electrochemistry papers in professional journals and proceedings.

Miles had also been part of the process that had originally confined cold fusion to the trash pile. On hearing Pons and Fleischmann's announcement he tried to replicate their work. He built two cells using cathodes cut from a millimetre-thick piece of palladium wire that he found in the lab, but after a week or so he saw no unusual amounts of energy and no signs of nuclear reactions. He dutifully published his findings, and they were cited as evidence in the ERAB panel's negative report to the energy department.

But Miles wasn't satisfied by this, and continued his investigations. "I'm naturally sceptical of my own work, as any scientist should be," he says. Besides, colleagues he respected were reporting tantalising amounts of extra energy popping up in their own tests. So he ran a dozen experiments from March through to August 1989. Not one showed a glimmer of anything unusual.

But that September, everything changed. He was working with a new and much thicker piece of palladium from a manufacturer that Fleischmann had recommended. Miles set up two experiments side by side, using the 6-millimetre-thick rod. After a week or so, both began to deliver a sustained yield of between 20 and 30 per cent more energy as heat than they consumed as electricity. The cells' range of error was 0.02 watts, or 1 per cent. The excess energy measured was as high as 0.52 watts. "Enough to be beyond that range," Miles notes.

From September 1989 right through to July 1992, Miles ran eight separate experiments with the same cathodes made from the new palladium. "I didn't readily accept the finding of excess heat," he says. "I kept running the tests to see if the result was consistent." Each consistently delivered between 5 and 30 per cent excess energy. He also performed two other tests, using regular water in place of deuterium oxide, but using the same design, equipment and measuring devices. Those two experiments produced no excess heat. When he was convinced, he published the results in the *Journal of Electroanalytical Chemistry and Interfacial Electrochemistry*.

Then two things happened to give the navy's programme a boost. First, Michael Melich became intrigued by the work of colleague Wilford Hansen, a professor of physics and chemistry at Utah State University. Melich is a physicist, former branch head in the ONR, and now a research professor at the Naval Post-Graduate School. He came across a study in which Hansen had cross-checked Pons's and Fleischmann's raw data through a variety of mathematical analyses and found no flaws in their results.

Sponsored by an agency of the US defence department, Melich began to dig deeper into the negative cold fusion results reported by the Massachusetts Institute of Technology, the UK Atomic Energy Authority labs at Harwell, and the California Institute of Technology that formed the basis for ERAB's conclusion. With five colleagues, he visited CalTech to review the data. The group found a hostile reception and was denied access to lab notebooks and other key data. MIT officials told Melich that they had thrown away all the data and notebooks and had nothing for him to review. Visiting Harwell, Melich found that the researchers had made an earnest attempt but hadn't realised the complexity of what they'd taken on. Faced with a looming publication deadline for *Nature*, "they stopped the experiments at about the time they were beginning to learn how to do them", Melich says.

The second boost was that navy research officials decided to treat their scientists' cold fusion research a little more seriously. Up to this point the cold fusion work at the navy labs had been informal - experiments were carried out in researchers' "spare time", funded by their department chiefs' discretionary budgets. But after Miles, Szpak and Boss had been at their benches for three years, they had collected enough evidence to convince those higher up the ladder to formalise their efforts. Robert Nowak, an electrochemist and a programme manager in chemistry at the ONR, suggested to the executive director, Fred Saalfeld, that they give the programme a formal budget and coordinate the research. They decided that Boss and Szpak should pursue co-deposition and that Miles would test various forms of palladium electrodes made by Ashraf Imam, the NRL's metals wizard.

From the beginning, the idea was to keep things modest. "We put less than $1 million a year into the programme," Nowak says. "Above that level, the red flags go up." Saalfeld and Nowak never gave the programme its own line in the ONR's budget, but allotted money to it from miscellaneous funds. "We were to keep working and we were allowed to publish our results, but we weren't supposed to say a lot about it," Miles recalls. "Some people were worried that word would get out and it would jeopardise the navy labs' funding from Congress for other research. We didn't even call it 'cold fusion'. We called it 'anomalous effects in deuterated systems'."

That was still not enough to keep the sceptics off their backs. "Fairly prominent individuals within the physics community voiced threats," Nowak admits. "They said that they were aware that federal funds were going into cold fusion research and they were going to do what they could to stop it."

Saalfeld also had to defend his decision to other scientists and managers at the ONR, and several of them remained unpersuaded by the data and drafts of papers that were circulated in-house. "I told them that there is a phenomenon here that we don't understand, it might have relevance to naval science, and we're going to explore it," he says. The fusion researchers didn't soft-pedal their colleagues' criticism of their experiments. "I'd like to think that we did a good job of internal checks and criticism," Nagel says. "In our lab, there was a wide range of opinion, from open-minded interest to certainty that this wasn't worth our time. All of those opinions were expressed."

The initial results gave sceptics reason to doubt. In July 1992, Miles received Imam's first attempt at making a suitable electrode, a palladium-silver alloy. "It produced nothing," Miles recalls. "Energy in was equal to energy out." For almost two years, while Boss and Szpak logged success after success, Imam sent Miles a steady stream of palladium alloys, and even various forms of unalloyed palladium. None produced any excess heat at all.

Until, that is, the summer of 1994. That's when Imam alloyed samples of pure palladium with boron proportioned at 0.25, 0.5, and 0.75 per cent. When Miles tried the new materials, eight out of nine tests yielded a 30 to 40 per cent energy gain. It seemed that the more boron, the more excess energy.

But why didn't the ninth one work? When Imam examined the sample he found that unlike the others, which all had a flawless surface, this one had minute cracks that had appeared when it formed. A correlation between cracks and null results has been noted by many researchers, before and since.

So the researchers had evidence of excess heat. They had also seen telltale evidence of nuclear reactions in the form of tritium and otherwise inexplicably large amounts of helium (see "Search for the smoking gun"). But it wasn't enough: even Miles's success with Imam's palladium-boron samples was too little, and it came too late to save the programme. By 1995, after watching Miles trying and failing to wring excess energy from Imam's electrodes, Saalfeld and Nowak decided to stop giving the project any more money.

"For close to two years, we tried to create one definitive experiment that produced a result in one lab that you could reproduce in another," Saalfeld says. "We never could. What China Lake did, NRL couldn't reproduce. What NRL did, San Diego couldn't reproduce. We took very great care to do everything right. We tried and tried, but it never worked."

And so, Saalfeld says, they decided to declare failure and move on. Nagel regrets that it had to come to this. "I've looked at the data from the navy's work and elsewhere," he says. "I've seen reports of experiments where adequately skilled people - who didn't have their minds made up in advance - equipped themselves satisfactorily, did good calibrations and controlled experiments, had good signal-to-noise ratios, and met all of the other criteria, and reported anomalous energy. I've asked myself time and again: what's the probability that all of these experiments are wrong? I think it must be vanishingly small." But he also understands why Saalfeld made the decision he did. "Until we understand how it works and can reproduce it reliably, no one can be absolutely sure that cold fusion is real."

Neither of these criteria is close to being met. "In my experiments I'm still not able to control when the excess heat is large, small or even present," Miles admits. And, although there are various theories about the process and the by-products of cold fusion, most of them still contain gaping holes (see "Explaining the inexplicable"). There are certainly no compelling scientific arguments.

With the money gone, Szpak and Boss moved on to other projects. Miles wasn't so lucky. In 1996, Nowak left the ONR, robbing the navy's cold fusioneers of their front-line champion. Around the same time, Miles's boss left, and his replacement discontinued the discretionary funds that had been supporting the work. To make things worse, Miles couldn't find other work. "I couldn't get ONR funding for anything," he says. After failing to find new projects to take on, in 1997 Miles - with an international reputation and more than 100 publications to his credit by that time - was reassigned to work as a clerk in the stock room.

So what's the next step? There isn't one. The navy's report on 10 years of research into cold fusion might as well never have been written, for all the response it has generated. And Nowak says there is no point trying to take things forward. "To do the same experiments at the same level another 100 times wouldn't be compelling," he says. "We have reached the limit of accuracy and precision possible by doing that. But to expand into new tasks, which might well involve educating decision makers in Congress or setting up a programme and hiring 100 people, would have put cold fusion back on everyone's radar screen." People ideologically opposed to cold fusion "would have come out of the woodwork to kill it all over again", he says.

Those opponents are not short of ammunition: there are still more questions than answers. But Gordon thinks there is enough reason to start things up again. "What we have seen so far doesn't fit nicely into currently accepted theories, but that doesn't diminish the results from experiments by scientists throughout the world," he says. "It's time that this phenomenon be investigated so that we can reap whatever benefits accrue. It's time for government funding organisations to invest in this research."

And that may happen. "We haven't ruled out returning to this line of research," says John Pazik, director of physical sciences at the ONR. Public money may again go into this field whether or not the scientific establishment approves. "We're not at all embarrassed by this report," Pazik continues. "There is evidence of 'anomalous effects' in these systems." He won't use the f-word: no one has verified that a fusion process is taking place, he insists. Something is going on, though, and the navy may eventually see fit to investigate it further. "But there are budgetary constraints combined with funding and research priorities that will keep us from returning to it any time soon," he warns.

Miles is ready and waiting. He escaped from the stock room in 1997 when Japan's New Hydrogen Energy Program - its euphemism for cold fusion research - invited him to spend six months as one of its visiting scientists. During that time, he ran 11 experiments and three control tests. Of these 11 experiments, 10 yielded anomalous energy. These included tests that used Imam's palladium-boron blend, and three new tests of the co-deposition method. When he returned, Miles wrote papers detailing some of his results, which were published in 1999 in *Fusion Technology* and a year later in the *Journal of Electroanalytical Chemistry and Interfacial Electrochemistry*. He has now been invited to China to continue his research.

Boss is also ready get back on board if the work is funded. And though Szpak has now retired, he still comes in to the San Diego lab to work at refining the co-deposition technique, supported on a shoestring budget that Gordon, his department chief, supplies.

A modest revival would be best, Gordon believes. "If you put a bunch of money into this, you'd probably have the same result you had in 1989 - a lot of unqualified people would start working on it and we'd begin to convince ourselves again that this can't work." Melich agrees. "The worst thing that could happen to cold fusion is to make a big blip on the scientific radar screen again," he says. "It needs a modest amount of funding - a few million a year with a firm, multi-year commitment - run by people who aren't political and are more interested in the science than they are in building their resumés. The energies being reported are vastly too big to be chemical in origin. But that still leaves a huge question. Where the hell is all that energy coming from?"

Explaining the inexplicable

If cold fusion is real, how do the positively charged deuterium nuclei, or "deuterons", overcome their natural repulsion in order to join together? There is no consensus.

Many theorists are drawn to the notion of coherence. This is the idea that deuterons packed into a palladium lattice no longer behave as individuals but as parts of a whole, in the same way that coherent photons create a laser beam. Drawing on quantum field theory, they speculate that the interplay of the particles' wave functions somehow weakens the repulsive force separating the deuterons.

Others, such as nuclear engineer Akito Takahashi at Osaka University in Japan, have evolved elaborate mathematical models that support the idea of three, four or even eight deuterons fusing at geometric focal points within the palladium's lattice.

Then there are WIMPs (weakly interacting massive particles supposedly left over from the big bang) that some think appear somehow in a palladium lattice stuffed with deuterium and catalyse fusion. Scientists at Moscow State Technical University, for instance, have concocted an elaborately detailed theory of the "erzion", which they envision as a giant glob with a negative charge equal to that of 46 electrons, which overpowers deuterons' mutual repulsion and slams them together.

"The bottom line is that all of these theories are either incorrect or incomplete," says David Nagel, a research professor at George Washington University in Washington DC. "Some violate the results of well-established work in other areas of physics. None has been able to make numerical predictions that have been verified by experiment. We have no solid idea yet about where the phenomenon comes from."

Publish or be damned

The cold fusion controversy doesn't stop with experimenters' data. Many researchers allege that the storm of claims and counterclaims prevented the scientific process from working at all.

The issue, says Scott Chubb of the Naval Research Laboratory in Washington DC, is not that science should by now have decided whether cold fusion is real. The real question is whether the scientific process worked in a way that would let scientists pursue the answer, whatever it may be.

Chubb served as a guest editor of the October 2000 issue of the journal *Accountability in Research*, which conducted a post-mortem on the way cold fusion has been handled. It was "a scientific debacle", says Chubb

Pons and Fleischmann got the whole thing off to a bad start. Instead of testing their ideas informally at professional meetings, or announcing their findings in a peer-reviewed journal, they unveiled their ideas in a public press conference. The ensuing frenzy of competition, derision and hasty experiments led to some sloppy science. This poisoned the atmosphere surrounding the subject so thoroughly that by 1995 navy scientist Melvin Miles found most leading journals unwilling even to send his papers out for review. "I had published some of my cold fusion results in the *Journal of Physical Chemistry* - the top journal in physical chemistry," Miles notes. But when he submitted a paper reporting positive results from his early tests, the editor told him that they no longer wanted to accept papers in this field. Miles published this work in 2000 in the *Journal of Electroanalytical Chemistry and Interfacial Electrochemistry*.

The consensus that cold fusion must be nonsense resulted in "a breakdown in the process of unbiased, objective reporting of scientific information", Chubb wrote in the introduction to the issue he edited. "This conclusion holds regardless of whether the associated claims are valid."

Search for the smoking gun

Conventional wisdom expects the fusion reaction between two deuterium nuclei (each made up of a proton and a neutron) to yield either a tritium atom (a proton and two neutrons) plus a free proton, or an atom of helium-3 (two protons and a neutron) plus a free neutron. Finding such by-products would be crucial supporting evidence for cold fusion claims. So while the navy researchers examined their equipment for the unexplained sources of heat, they also looked for traces of nuclear radiation or "ash" - gamma rays, neutrons, tritium or helium isotopes.

Stanislaw Szpak and Pamela Manier-Boss at the Space and Naval Warfare Systems Center in San Diego, California, concentrated on hunting down tritium. The isotope is a common product of hot fusion, and is only created by nuclear reactions, so finding it would suggest that nuclear processes are going on.

From 1991 through to early 1994, they carried out more than a dozen tests to compare the amount of tritium coming from their cells with the amount present naturally in their environment.

Boss gave the data from five such experiments to a theoretical chemist, who determined that the cells' samples contained 14 per cent more tritium than their surroundings. Two of the tritium experiments were null - the matter present at the beginning and end balanced perfectly. "But in three there was evidence of excess material," Boss says. "The only way the chemist could account for the excess was to accept the idea that the cell had created tritium at the rate of 5,000 to 7,000 atoms per second."

Szpak and Boss published their results in *Physics Letters A* in 1994. Not only did no one challenge the results, but "the comments we got were quite favourable regarding the quality of our experiments", Szpak says.

Meanwhile, Melvin Miles at the Naval Air Warfare Center at China Lake was looking for helium-3 from his experiments. "There isn't much helium-3 in air," Miles says, "so it should have been easy to detect." He found none.

But he did find helium-4 in samples of gas from his experiments: an average of 7.93 parts per billion, with the highest registering 9.7, in those that yielded excess energy, compared with a maximum of 4.9 ppb and an average of only 4.5 ppb in cells that showed no unusual heat. Finding helium-3 would have been much more convincing because helium-4 is a much rarer by-product of fusion. Miles's reservations about the result caused him to look for explanations other than the idea that the cell was creating the isotope.

Miles gave samples from his cathode to Brian Oliver, a metallurgist with Rockwell International of Wisconsin, who specialises in measuring helium-4. Oliver calculated the amount of helium-4 impurity in the palladium was less than a thousandth of the amounts showing up in Miles's collected gas samples. Simple contamination from air was another possibility - helium-4 is normally present in air at 5.22 parts per million, and its molecules are so small that they slowly permeate most materials.

But Miles was careful to flush his cells with nitrogen to push out contaminants, and to use metal flasks and thick rubber tubing to ensure that no helium-4 from the atmosphere could have got in. Miles was further convinced by the way the quantity of helium related to the excess energy in the system. Conventional "hot" fusion theory says that each joule of energy produced in deuterium fusion delivers 2.6×10^{11} helium atoms. "From the amounts of helium-4 found in our samples, I could back-calculate the amount of excess energy the cells should be producing," Miles says, "and I found the measurements to be closely consistent."

He published his findings in 1997 in Proceedings of the 32nd Intersociety Energy Conversion Engineering Conference

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