Japan achieves big breakthroughs in cold fusion

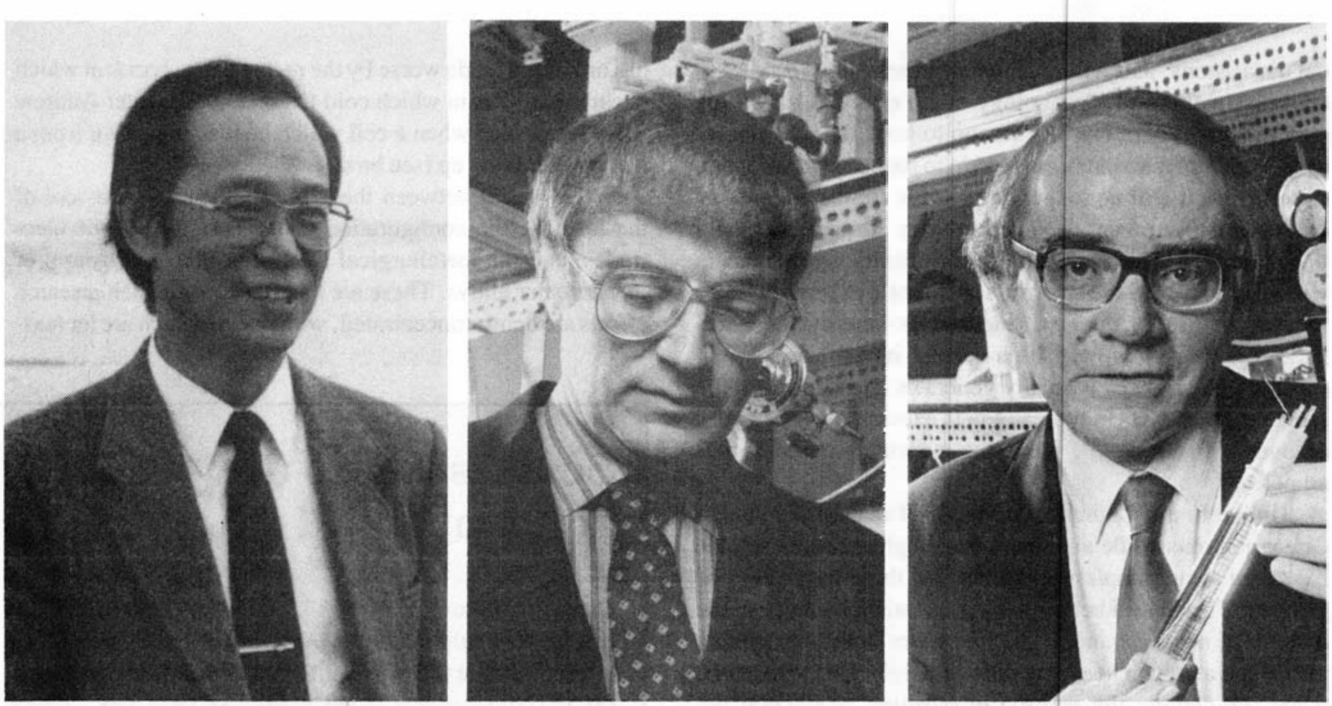
by Carol White

On Jan. 28 and 29, two important meetings on cold fusion were held in Nagoya, Japan, which I was able to attend. The first was a session on cold fusion which opened up a three-day symposium on nonlinear phenomena in electromagnetic fields; the second was an all-day seminar attended by 20 scientists leading cold fusion research teams in Japan.

The conference was sponsored by the Japan Society of Applied Electromagnetics in collaboration with a number of prestigious Japanese scientific institutions and the Institute of Electrical and Electronic Engineers (IEEE) of the United States. After the keynote address, the first panel of the Jan. 28 conference was on cold fusion and featured presentations by Dr. Akito Takahashi, a nuclear physicist who heads the Electrical Engineering Department at Osaka University; and by Dr. M. Srinivasan, coordinator of India's cold fusion effort, who heads the Neutron Physics Division at the Bhabha Atomic Research Center.

At the conference, Takahashi reported achieving power densities in excess of 200 watts per cubic centimeter (cm^3). In the month since his talk, his results have been even more dramatic. On one occasion when he tried to turn off his cell, the temperature began to rise, so that he was led to quickly restart electrolysis in order to gain control of the reaction and avert an explosion. Electrolysis effectively stirs the water of the electrolyte, allowing it to carry off heat from the electrode. Instead of simply turning off his experiment, Dr. Takahashi has gradually reduced the current. He has continued to get high excess heat from the cell even with reduced current.

Even after reducing the current input, he has had two occasions during which excess heat was generated so rapidly that the water in his cell boiled off. He estimates that power densities during these events may have been as high as 500 watts/cm^3. The heats that he is achieving compare with results reported by Martin Fleischmann and Stanley Pons—except that in this one cell, Takahashi is getting steady heat production, while Fleischmann and Pons have only seen such heat events as bursts.



Japanese physicist and coldfusion researcher Dr. Akito Takahashi of Osaka University; from left: U.S. cold fusion pioneers Stanley Pons and Martin Fleischmann. While Japan is backing coldfusion research such as Dr. Takahashi's, and achieving astonishing results, the witchhunt against coldfusion has driven Fleischmann and Pons abroad to continue their groundbreaking efforts.

In this, his latest experiment, an average of 70 watts/cm^3 has been observed continuously over a two-month period. The total excess heat produced over this period has approached 300 megajoules, which he calculates to be 150% the amount of input energy. This has been coupled with weak neutron emissions. (Dr. Takahashi has recently slightly reduced his estimates of power density from those reported at the ISEM conference—by an approximate 30%).

Fleischmann and Pons typically work with a needle-thin palladium cathode, on the order of a millimeter in diameter, and a few centimeters in length. In this latest experiment, Takahashi is using as a cathode (negative electrode) a square-shaped thin plate, with a 25 millimeter side and 1 millimeter thickness. Thus the volume of his cathode is about 10 times greater than theirs.

When Takahashi scales up his maximum excess power density, this compares to the scaling-up by Fleischmann and Pons which gives them on the order of 1 kilowatt/cm^3 excess power-density. This is impressively close to a commercial standard of power emission. A useful parameter in judging the experiment is that the heat output of the Takahashi cold fusion experiment generates more than 10 times the heat output per cubic centimeter of a fuel rod in a nuclear reactor.

The use of a cubic centimeter as a volumetric standard comes from engineering practice, where energy output is balanced against materials and other costs; however, it is useful to bear in mind that, in the Takahashi experiment, the actual power achieved is 10 times greater than that obtained by Fleischmann and Pons. Should it prove to be the case that cold fusion is a near-surface phenomenon rather than a volume phenomenon, then his results are strictly comparable to theirs, not just within range. Where he has actually gotten power emissions as high as 300 watts, Fleischmann and Pons are dealing in the range of tens of watts with their setup. Martin Fleischmann, who is very excited about the implications of Takahashi's work, remains cautious about working with larger electrodes. He warns about problems of heat transfer and other similar considerations, in working with still unknown nuclear processes, since there can always be the possibility of a runaway fusion event.

Takahashi began this latest experiment in December—i.e., it had been running for two months at the time of the conference. It began producing excess heat on Dec. 20, and it is still producing heat at this time. This several-month-long Japanese experiment is stunning confirmation of the work of Fleischmann and Pons, as reported at the Second Annual Cold Fusion Conference in Como, Italy, and elsewhere in print. (*EIR*'s coverage of the Como conference was featured in the Aug. 16, 1991 issue.) Up until Takahashi's recent success there has been abundant confirmation of Fleischmann and Pons's claims that electrolysis using heavy water produced more heat output than could be accounted for by any chemical reaction, but none which replicated the high excess heats that they have claimed.

Experiments using Takahashi's model, or variants of it, are already under way in Italy, the United States, and in other laboratories in Japan. Takahashi himself will be touring the United States in April, where he will be available for technical discussions, and will give major presentations at Massachusetts Institute of Technology and Texas A&M, on his experiments. There is every reason to hope that, as laboratories around the world become able to replicate Takahashi's experiment, it will no longer be possible for the enemies of cold fusion to suppress this extraordinary new science. With this in mind, I hope that even less technically versed readers will want to follow the story of Takahashi's experiments.

Takahashi runs the experiment in six-hour cycles, alternating between low- and high-current input. Low-current input at .25 amperes typically generates excess heat in the range of 50 watts. He typically gets excess power densities of over 150 watts/cm^3, when the current is raised to 4.2 amperes.

Unlike in most other experiments, Takahashi is able to detect neutrons while also measuring high excess heats. He has taken some samples for tritium, but these have yet to be analyzed. Takahashi believes that his statistics show that the amount of neutrons and tritium increases with time up to a maximum at which heat generation really begins to take off; when, he claims, the neutron and tritium production decreases while excess heat generation increases. On several occasions, however, when he experienced large heat bursts, he also noted high neutron bursts.

There is a generally positive climate in Japan toward scientific research, which includes investigation of cold fusion—even though perhaps the majority of scientists in Japan still retain a certain skepticism about the phenomenon reported by Fleischmann and Pons. Their critical attitude, however, is tolerant toward those who wish to go off the beaten path to explore new hypotheses, unlike the situation in western Europe and the United States, where there has been a veritable witchhunt against scientists who dared to work on cold fusion experiments—especially if they reported positive results. Whereas in the United States and, albeit to a lesser degree, in Europe as well, Fleischmann, Pons, and their supporters have been treated as almost common criminals by the leading scientific and popular press, the opposite is the case in Japan. In fact, it is a widely circulated rumor that the two cold fusion pioneers, who are now living in Europe, are receiving financial support from the Japanese, so that they can continue their research in a less pressured environment.

The leading programs in the world today—aside from the ongoing work of the two cold fusion pioneers—are those in Japan and the research work in the United States supported at Stanford Research Institute (SRI) by the Electric Power and Research Institute (EPRI). EPRI is reported to have a $12 million fund available to it over the next four years—during which it hopes to develop a prototype cold fusion generator. Because this is a commercial venture, and because of the generally aversive climate toward cold fusion in the United States today, EPRI has maintained a high level of secrecy in the programs which they sponsor. (This situation has only been made worse by the recent tragic accident which occurred at SRI, in which cold fusion experimenter Andrew Riley was killed when a cell which he was removing from a calorimeter blew up [see box].)

What varies between these programs is the protocol of the loading, the configuration of the structure of the electrodes, and the metallurgical treatment of the palladium or its particular alloys. These are the aspects on which research efforts are being concentrated, with results which are increas-

Some issues of the accident at SRI

Chemist Andrew Riley was killed when the cold fusion cell he was holding exploded Jan. 2 at the Stanford Research Institute (SRI) in California. Riley was working on the SRI cold fusion team led by Michael McKubre. Others present during the accident suffered minor injuries, and a portion of the ceiling in the laboratory was damaged. Although there is as yet no official report about the accident, some details have emerged that raise a question as to the nature of the explosion. The cell involved was 6 inches high and 4 inches in diameter. It was designed as a high-pressure closed cell, and therefore had a half-inch thick steel wall. A portion of the steel container split off during the explosion, striking Riley's face and then denting the laboratory ceiling.

Originally it was supposed that this cell was operating at 30-100 atmospheres, the typical pressure for SRI cold fusion experiments. But this was not the case. This particular experiment, designed to test a new configuration of the electrodes, was working at just above atmospheric pressure. According to one unconfirmed account, the electrode was 1 cc in volume, compared to a typical 0.1 cc and had a plate-shaped geometry. Although the cell was closed, two leaks had developed. This would give the cell something like the conformation of Takahashi's latest experiment.

At high pressures, hydrogen (or deuterium) gas can combine explosively with atmospheric oxygen, particularly if they come into contact with metal, which will act as a catalyst. Here the use of a metal-containing wall may be relevant, although usually the metal wall will be shielded by the formation of steam. Furthermore, such cells routinely contain recombiners, which are made of finely ground palladium and carbon. These recombiners control the rate of recombination, in order to prevent an explosion from occurring. In the cell that exploded, it is known that the sensor attached to the recombiner was out ingly reproducible. A palladium cathode and a platinum anode can, and frequently do, produce excess heat, as well as other products, such as tritium, helium-3, and helium-4, results that indicate some sort of nuclear reaction—although not a traditional hot fusion reaction conducted under vacuum conditions. In future research, the emphasis will be to understand and control what is actually going on, rather than merely to establish that cold fusion does exist.

In Japan there are over 100 researchers who are working at universities, as well as more secret programs being supported by industrial consortia. Like SRI, these commercially oriented research programs deliberately maintain a low profile. The university groups are interdisciplinary and are organized into 20 working groups that are independent of each other, but collaborate in sharing information. The group leaders meet together every few months to review the ongoing work in a friendly but searchingly critical environment, as I saw at the meeting which I attended. The program is coordi-

of order. The recombiner from that cell has decomposed into small spherical balls containing bits of platinum. This would indicate the violence of the explosion, but nothing about the functioning of the recombiner beforehand.

Although the cell was certainly open to the atmosphere, which would argue against a sharp rise in the pressure of the hydrogen and water, perhaps the holes were not sufficiently large to act as adequate vents. The containing steel wall had a bulge at the bottom, which may indicate a slow buildup of pressure inside. Yet, even assuming—for ease of calcuation—that at the time of the accident the canister was three-quarters full of hydrogen (thus overestimating the hydrogen content, since oxygen would have been present and would be needed for a recombination to occur), the force of such an explosion would appear to be at least an order of magnitude too low to account for the damage. This calculation does not assume the buildup of high pressure inside the cell. In the near future, estimates should be available of the dynamite equivalent of the explosion.

Apparently Andrew Riley had disconnected the cell from the current, and was removing it from the water bath in which it was contained during electrolysis. Within a minute, as he was moving to place it upon a work bench, the cell exploded in his hands and a steam cloud erupted. Thus, the explosion occurred *after* the cell was turned off. This suggests that the heating occurred within the electrode rather than in the solution. The experiment had been going on for some time over 1,000 hours. Sensing devices which were functioning during the accident should provide more indication of what caused the explosion.

Stopping electrolysis affects the ability of the solution to transfer heat from the electrode through the solution, and can allow a steam buildup to occur around the overheated electrode. If, in fact, a very high-temperature fusion event had been occurring, inability to vent the heat may have caused the explosion. Here the scale-up of the size of the electrode would be relevant. Another contributing factor could be the deloading of the electrode as it cooled, which could have caused phase-shift oscillations and created an unstable, runaway fusion reaction. If this was a fusion reaction, neither neutrons nor radiation appear to have been detected.

From their first public announcement of cold fusion in 1989, Martin Fleischmann and Stanley Pons have warned of the danger of a runaway fusion event. They have urged that strict safety protocols be followed. Fleischmann and Pons have recommended the use of very thin electrodes, under 1 cc in volume, designed in a symmetrical configuration. Another recommended precaution is to reduce the electric current gradually, thus deloading the electrode gradually and allowing maximum heat transfer as the electrode cools. They have preferred working with open cells in order to allow a slow boil-out of the solution to occur.

Another possibility, one actually tried in some SRI experiments, is to use a deuterium fuel cell anode. In this case there would be no decomposition of the water and thus no oxygen collected at the anode. Deuterium would be fed in at the anode and travel to the cathode, where it would be absorbed within the palladium. In a closed cell, recombination could not occur. Whatever happened at SRI, it is certainly true that the direction of research at present is toward closed cells at high pressure. This implies using sensing devices—as was done at SRI—and monitoring any accumulation of hydrogen in the laboratory. Some researchers have already begun introducing extra shielding into their laboratories and protective gear for laboratory workers.

It is clear that a no-holds-barred review of the accident must be conducted by top researchers in the field in order to reach a consensus on new safety protocols. This implies that concern for safety should override considerations of proprietary interests, which have otherwise hampered scientific cooperation. In any case, this will improve the conditions for more rapid scientific progress. Andrew Riley was young—34 years old—but he had already achieved an impressive record as a chemist specializing in materials science at the University of Utah National Cold Fusion Institute and the Materials Science Department. His death is a painful loss to us all.—*Carol White* nated by Hideo Ikegami, a professor at the National Institute of Fusion Science, located at Nagoya University.

Cold fusion hits the headlines

It is an extraordinary sidelight on the viciousness of the attacks to which Martin Fleischmann and Stanley Pons have been subjected over the past three years by the popular and scientific media and the hegemonic scientific societies, that the English-language edition of the monthly *Scientific American* continues to deprecate cold fusion, while the Japanese-language edition of the same magazine (which is published in Japan) has featured Dr. Takahashi's work in its March issue. There, the editors apparently felt constrained to admit that his results add significantly to the weight of evidence confirming the discovery of the phenomenon of fusion-in-a-bottle at room temperatures.

> *As Takahashi says, this is "unusual fusion," and he has a complicated theory which includes the fusion of several nuclei simultaneously—a theory which, in the end, may or may not be borne out—but the excitement of his recent results lies more in the vitality of the experiment itself.*

On Feb. 13, some 100 scientists and media representatives gathered in Italy—at the National Center for Nuclear Research at Frascati, on the outskirts of Rome—to hear a report on the Japanese cold fusion program by Dr. Ikegami. He reported on the work of Dr. Takahashi and other Japanese researchers who have begun to report very high excess heat from their cold fusion experiments. Interest was high among the audience, although there is still a good deal of skepticism in Italy, as elsewhere, about the reality of cold fusion.

Ikegami's talk was given favorable coverage in major Italian newspapers such as *La Repubblica,* on Feb. 17. Capturing the mood in the scientific community which was generated by the news from Japan, *La Repubblica* ran coverage of Ikegami's speech with the dramatic headline: "From a Test Tube, the Energy for Lighting a 110 Watt Bulb: Here Comes Cold Fusion." The article opened: "Japan wins the challenge of the artificial Sun. A hundred or so Japanese scientists with funds from the Tokyo government, have worked for almost three years on the project. Said the Italian researchers: 'We stood there with our mouths open.' " On the next day, the daily *La Stampa* ran an article on the science page with the headline, "Cold Fusion Returns." The article characterized Takahashi's experimental results as confirmation of the claims of Fleischmann and Pons.

Also on Feb. 18, *Il Sole 24 Ore,* an Italian financial newspaper, ran a feature by the prestigious Italian physicist Giuliano Preparata, headlined: "Japanese Cold Fusion Technicians Begin to Think about New Power Plants," with a subtitle, "Meanwhile, in our country, a nucleus at the vanguard of Europe works without support." There was also a companion piece headlined "The 'Open' Cell of Tokyo Creates Energy for Two Months," by reporter Maria Rosaria Zincone. She quotes Italian nuclear physicist Dr. Francesco Scaramuzzi, who was present at the lecture, commenting on the sorry state of cold fusion research in Europe and the United States. With absolute accuracy, Scaramuzzi said of the Japanese program: "What has been going on now for these last few years is not a miracle. What has been evidenced in Japan, besides the scientific results, is above all the example of a coordinated research which might have also been carried out also in Europe or the United States."

What is cold fusion?

On March 23, 1989, Martin Fleischmann and Stanley Pons startled the scientific world and the general public when they revealed the results of thousands of experiments in which they had achieved heats in excess of any that could be accounted for by a chemical process, by conducting a tabletop electrolysis experiment.

Using a deceptively simple battery setup (the experiment is still hellishly difficult to replicate), with a platinum anode (positive electrode) and a palladium cathode, and a simple electrolyte of heavy water doused with a lithium compound, they were able to replicate the energy source of the Sun and stars, but at room temperature. The secret appeared to lie in the propensity of palladium to absorb enormous amounts of hydrogen—the gas produced at the cathode when water is subjected to electrolysis and decomposed. (Oxygen flows to the anode.)

Fusion occurs when the nuclei of two atoms are fused, despite the fact that they are positively charged and generally repel each other. This is called, in common scientific parlance, overcoming the Coulomb barrier. In controlled hot fusion experiments, plasmas made of ionized steam are generally exceedingly thin, and the hydrogen nuclei are brought together at high speeds in order to accomplish their fusion and the consequent release of energy. The speed to which the hydrogen (or deuterium) nuclei are accelerated is generally calibrated as a temperature, in this case in the hundreds of millions of degrees. In the case of the Sun, the fusion plasma is much more densely compacted, and fusion can occur at temperatures in the tens of millions of degrees. How, then, can fusion occur at room temperature?

Clearly, there must be several extraordinary properties of the palladium lattice, into which deuterium, the heavy isotope of hydrogen, is compacted. (Deuterium is hydrogen which contains in its nucleus a proton and a neutron, instead of merely one proton.) When two deuterium atoms fuse, they produce another heavy isotope of hydrogen called tritium and release a proton; or equally likely—in the case of hot fusion—they will produce the next higher element, helium, which has two protons in its nucleus.

The isotope helium-3 (with two protons and one neutron in its nucleus) is produced with an additional neutron being released as well. It is this neutron which is typically detected in order to measure the production of helium-3, but in the case of cold fusion, only a very minute amount of helium-3, compared to tritium, is produced. Like helium-3, deuterium is an isotope, but of hydrogen. Tritium is another isotope of hydrogen, which has two neutrons and one proton. Isotopes of a given element will react chemically in the same manner—thus light and heavy water will undergo similar chemical reactions—but certain isotopes like helium-3 (in the case of helium), and deuterium and tritium (in the case of hydrogen) are inherently more unstable and therefore fuse more easily.

There are serious problems raised by cold fusion experiments. They simply do not behave like typical fusion experiments. Despite the presence of tritium in the electrolyte after heavy-water electrolysis, which was not there at the beginning of the experiment and which could not have been produced by any known chemical means, the amount discovered is too low by up to as much as a billion times, to account for the kinds of heat which the cell produces. Similarly, far too little helium-3 is discovered. The phenomena are still sporadic; the occurrence of two distinct peaks of neutron generation also needs explanation.

By the criteria of traditional physics, a fusion reaction cannot be taking place; it should not be possible under the conditions of the Fleischmann-Pons experiment or Takahashi's version of it. The occurrence of fusion under these conditions is wildly improbable. Relying on their theory rather than the evidence before their eyes, many scientists deny the reality of cold fusion, on the grounds that this would mean hegemonic theory has been challenged by Fleischmann and Pons's unique experiment.

As yet, even those scientists who are fully convinced that some nuclear event is taking place—which it is convenient to call cold fusion, although it is likely to be far more complicated than traditional fusion events—cannot explain what exactly is occurring.

Clearly there are unusual conditions created within the lattice. Palladium is known to absorb high amounts of hydrogen (and all of its isotopes including deuterium). For cold fusion to occur, it is desirable to have at least one deuteron—that is, a deuterium nucleus—packed into the lattice for every palladium nucleus. This is known as a one-to-one *loading ratio*. It is better still if the deuterons are packed in even more densely. This, as we shall see, is one of the secrets of Takahashi's dramatic success story after three years of painful effort. A good deal of the art of a successful experiment is in raising the loading. Even so, it is still impossible to account for the lattice-deuteron interaction (a phonon-photon interaction) by conventional means.

As Takahashi says, this is "unusual fusion," and he has a complicated theory which includes the fusion of several nuclei simultaneously—a theory which, in the end, may or may not be borne out—but the excitement of his recent results lies more in the vitality of the experiment itself. We shall explore Takahashi's theory below, when we go into the detail of his experiments as they developed over a three-year period.

Takahashi's account

At the Jan. 28 meeting in Japan, Takahashi reported power levels over 200 watts/cm^3, and, just as exciting, he said that over the one-month duration of his ongoing experiment (his cold fusion experiment #115), 100 megajoules of more energy had been produced than was input. (The 30% downward revisions from these figures noted above may be too stringent, but he requested that we publish them pending a rigorous review of his data which he is undertaking.)

At the beginning of his presentation, Dr. Takahashi stressed just how anomalous cold fusion results really were, but he pointed to the fact that many experimenters, such as Dr. Srinivasan and Dr. John Bockris, as well as his own group, have found high tritium production; and several experimenters have also observed high-energy neutrons, in the range of 3-7 MeV.

From the work of his own group, Dr. Takahashi, a nuclear physicist, is sure that there is always a correlation between neutron emissions and the production of tritium, although sometimes there is a problem in detecting the tritium due to the extremely low level of neutron emissions. He also reiterated a point which the detractors of the Fleischmann-Pons effect attempt to overlook. The production of excess heats of more than 10 megajoules, cannot be explained by a merely chemical reaction.

In his earlier experiments leading up to the Como conference last summer, he had overlooked the crucial importance of achieving a loading ratio greater than .9 or 1, and as a result he was able to generate very little excess heat. In this talk he emphasized just how important the loading ratio is (see **Figure 1**). One problem in his earlier experiments was that he configured the cathode and anode in his cell side-by-side, whereas Fleischmann and Pons emphasize the importance of symmetry. Thus, they favor an axially symmetric design with a cylindrical, platinum anode fitting around a needle-thin palladium cathode. Improving the loading ratio is, as we shall see, one of the secrets of Takahashi's dramatic success story after three years of painful effort.

Takahashi and a group of collaborators at Osaka University began performing their own cold fusion experiments shortly after Fleischmann and Pons made their historic an-

FIGURE 1

Cell for pulse-electrolysis experiments using D_2O+LiOD electrolyte (500 ml) with Pd cathode

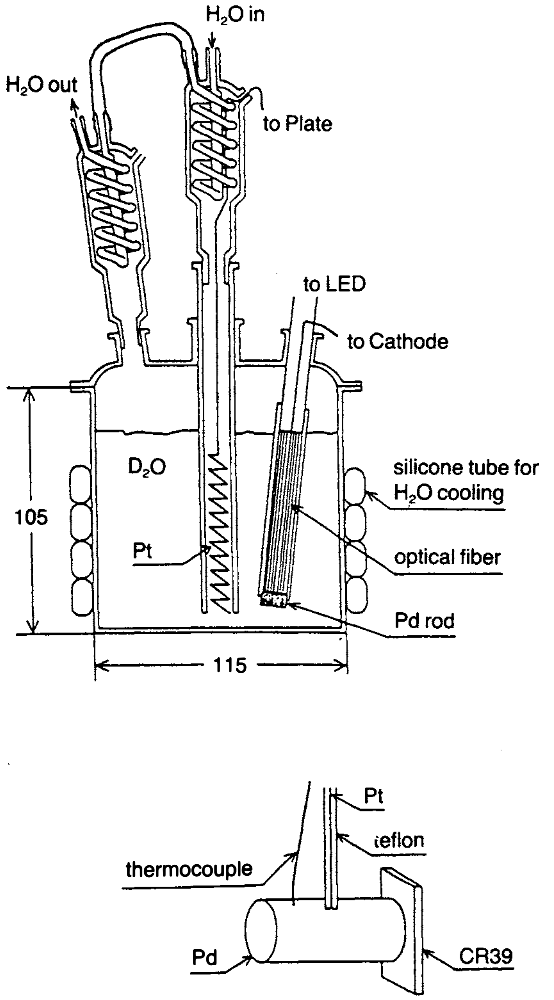
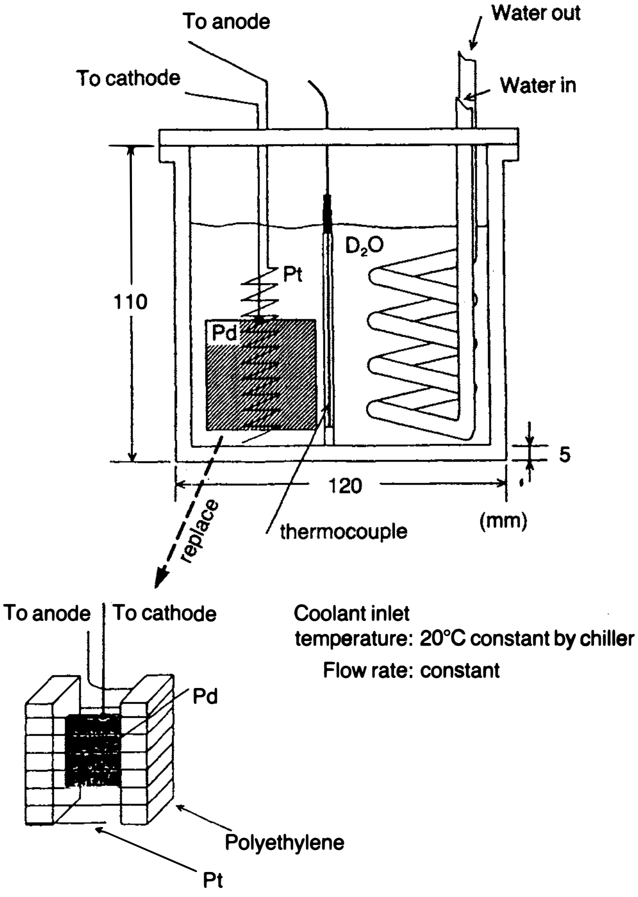


FIGURE 2

The experiment that really worked: Takahashi's Experiment D

Homogeneous D-load from two sides



Coolant inlet temperature: 20°C constant by chiller
Flow rate: constant

nouncement.

Takahashi groups his three years of experimental work into four categories which he labels A, B, C, and D (see **Figure 2**). In his first, A-series of experiments, he achieved only a very low level of neutron emissions, and these showed a peak energy level of 2.45 MeV. He introduced 30-second and 4-minute pulse of the current in order to cause deuterons trapped in the palladium lattice to oscillate. To improve this performance he began to lengthen the pulse of the current in his second, B-series. The thinking behind this was to introduce a certain disequilibrium which could catapult the deuterons into sufficiently close proximity to fuse. The pulse durations were only minutes long.

In the B-series of experiments, for the first time he observed another broad peak of neutron emissions, which occurred between 3 and 7 MeV. This gave Takahashi and his collaborators at Osaka University confidence that they were observing a new kind of fusion. In the C-series of experiments, he was also able to detect the presence of tritium. It was with this C-series, that he first began pulsing from low to high currents, in six-hour sweeps. Here he achieved heats in the range of 1 watt/cm^3, which was also a definite advance.

Over the three-year period of experimenting, Dr. Takahashi and his collaborators achieved several essential improvements in their experiment. For one thing, they increased their maximum current from a high of only .8 amperes in A-series, to 1.4 amperes in B, to 2.8-3 amperes in the C-series, until recently when they have been working with currents as high as 4.2-5 amperes. In order to work safely with these high currents, it was necessary for them to employ better and better external cooling systems—these allow ordinary water to flow through a cooling pipe during the experiment to avoid boiling out the electrolyte. They also went from a pulse range from 2 to 20 minutes in the A- and B-series, to six-hour sweeps in series C and D.

One result was the increase in neutron yields, which rose from an original sporadic one to two neutrons per second per cubic centimeter, to as high as 100, simply as a result of pulsing the current. In the B-series, the neutron yield increased to 15 neutrons/second/cm^3. Now they were able to observe the two peaks, which encouraged them in their belief that they were witnessing a new phenomenon of cold fusion, since with "traditional" hot fusion only one 2.45 MeV peak would be expected.

For maximizing neutron emissions, an 18-minute pulse appears to be optimum along with a 3 ampere current; however, this regimen did not produce significant excess heat. The six-hour high-current/six-hour low-current mode created conditions in which they were able to gain the remarkable excess heats of experiment D. The key here seems to be that moving from a high-current mode back to a low-current mode apparently enables the electrode to "heal" itself of damages and achieve successively higher loadings of deuterium in the palladium electrode.

At the time when they performed experiment A, they believed that the cathode loading ratio was only .3; however, they measured this loading only after taking the cathode out of the electrolyte, and therefore, in all probability, a significant amount of deuterium would have escaped before they were able to measure the ratio, using a secondary emission mass spectrometer. Still, the conditions under with the experiment was performed indicate that the loading ratio would have been maximally at around .6, if that. They were not able to measure tritium from experiment A, because with existing techniques, at least 10,000 more atoms of tritium are required for detection than is needed to detect helium-3, using state-of-the-art neutron detection equipment.

As was first established at Como, it is necessary to be in the range of one-to-one deuterium to palladium, before high excess heats are produced. Experimenters in Japan now believe they can go up to 2:1 or even 3:1 loading ratios, with suitably enhanced results. Key here is the fact of identifying and filling not only octahedral sites in the palladium lattice, but tetrahedral sites as well (see **Figures 3** and **4**).

Takahashi had several problems which lowered his loading ratio in his experimental design. Even after adopting a plate configuration, Takahashi at first loaded the plate from only one side. Only when, in this last experiment, he used two anodes—placed in front of and behind the cathode—did he receive his startlingly successful results.

Takahashi has always worked with relatively large cathodes. In his first experiments he used palladium of 99% purity, with radii between 4 and 5 millimeters in diameter and 11 millimeters in length. In experiment B, cathodes were 10 mm in diameter and 30 mm long. In the C-series, he used both a 20 mm diameter and 30 mm-long cylindrical palladium rod, and a palladium plate of the same dimensions as the plate in experiment D. While the excess heat level in the C-series from the rod was about 1 watt/cm^3, there was no detectable heat here, from the plate.

In the D-series, in the first experiment (#113), current was applied to one side of the plate only, and for one month the ramped current was alternated in 20-minute periods, before they introduced six-hour sweeps each of low and high current. They achieved a 50-watt excess power level for a week, after which they terminated the experiment. They then began experiment #114 (which is, in reality, their present experiment #115 in its loading phase). Here, they used a higher, 5 ampere current and loaded the plate, using 20-minute ramped pulses, for just a week. (The ramped pulse—also known as a saw-toothed wave—increases from zero to the maximum 5 amperes and then is brought back down to zero, all within a given period—in this case, 20 minutes.) This is obviously a key feature of their success in a rapid, high-loading of the cathode. Five amperes was also the highest current that Takahashi has ever used in his experiments. Clearly another major factor in the success of the experiment is the fact that the plate was loaded on both sides simultaneously.

Dr. Takahashi typically uses .3 moles of lithium oxide (LiO) for every liter of heavy-water electrolyte, which is about three times more than that used by Fleischmann and Pons. This allows him to run his experiment at a lower voltage, at which he experiences less ohmic heating. In his first experiments, series-A, however, he added lithium sulfate rather than lithium oxide to his heavy-water electrolyte, which may have been a contributing factor in his poor results of the time. To summarize, over the series from A through D, not only did Takahashi improve the loading of the cathode, but he also ran his experiments at increasingly high currents.

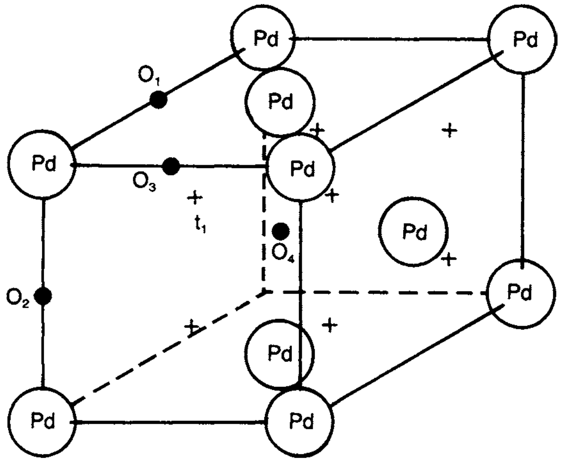
Experiments make progress

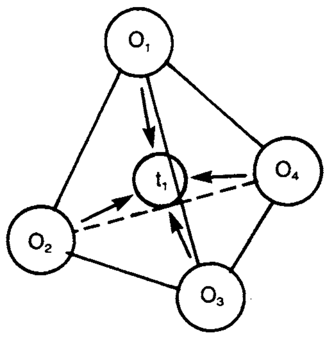
To begin with, Dr. Takahashi hoped to cause cold fusion to occur by rapidly alternating from low to high current. His intention was to create disequilibrium conditions which would accelerate the deuterons, so that they would oscillate and thereby come into closer proximity with each other. Even from the beginning he believed that the Fleischmann-Pons effect was caused by multi-body fusion. At the same time he looked to the excess electrons in the palladium lattice to screen the deuterons, so that their effective positive charge was lowered. This was a mechanism by which he hoped to explain how the deuterons could overcome the Coulomb barrier under room-temperature conditions. Since palladium has 10 valence electrons (the outer-shell electrons free to interact in chemical reactions), such screening can occur.

While he did not achieve the kind of excess heat he had hoped to see—in the range of 10 watts/cm^3—the fact that he did observe neutron yields of 2-5 neutrons/second/cm^3

FIGURE 3

How the deuterium is loaded into both octahedral and tetrahedral sites

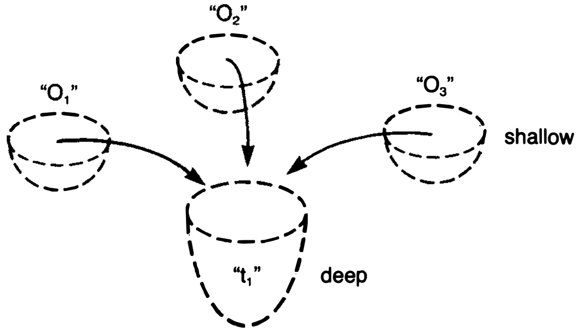




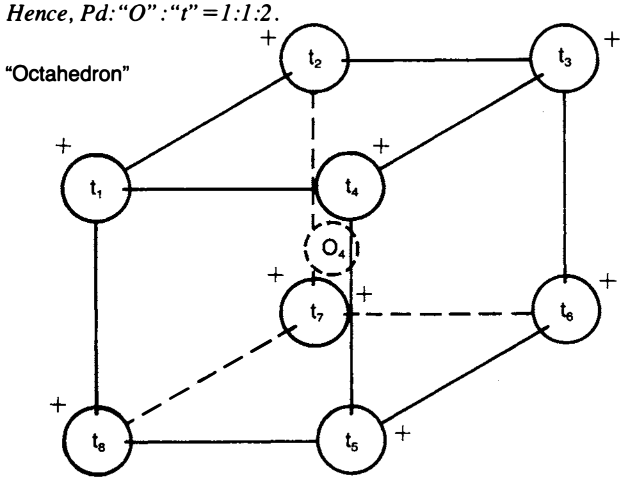
"Tetrahedron"
("t_1" is surrounded with 4 "O" sites)

	Combination
One Đ falling to "t"	= 4
Two Đ falling to "t"	= 6
Three Đ falling to "t"	= 4
Four Đ falling to "t"	= 1

a) In principle, we can consider up to 5Đ process, which is omitted here, because of less "combination," so the potential picture becomes:



b) If you see "O" site at the center, it is surrounded with 8 "t" sites. From a) and b), ratio of "O"/"t" numbers is 4/8=½. Hence, Pd:"O":"t"=1:1:2.



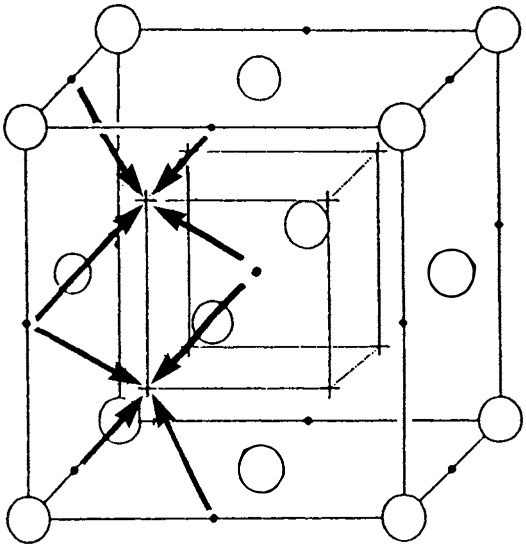
encouraged him in his belief that a fusion event was occurring. This series of experiments did not yet point to what he calls "unusual fusion," although the existence of room-temperature fusion itself is certainly anomalous. Experiments at Los Alamos National Laboratory in New Mexico, Italy's Frascati University, and the National Fusion Institute at Nagoya have definitely confirmed significant neutron yields from experiments using the Fleischmann-Pons paradigm, and even the level of neutron emission achieved by Stephen Jones has been verified at the Kamiokande neutrino-detection facility in Japan, although scientists there are still rechecking the results. Takahashi's first results were only comparable to those that Jones had achieved.

At room temperature, in a vacuum, the expected number of fusion events between two deuterons comes to 10^{-3800} per second per deuteron (in other words 1/100,000,000,000, . . . with 3,800 zeros in the denominator). The probability is improved in the palladium lattice because of the enforced proximity of the deuterons, which take up positions in the lattice known as octahedral sites. The probability is then a mere (!) 10^{-150}, still a ridiculously low probability for fusion to occur. If fusion can be assumed to occur in lattice vacancies, where densities are magnified a hundred-thousandfold, then the probability is increased to 10^{-8}.

Takahashi assumed that in the first stage of room-temperature fusion—within the palladium lattice—with deuterium-deuterium fusion, a 50% branching ratio would occur between production of tritium and helium-3 (a contention which other researchers would deny for cold fusion), and that therefore he was finding between two and five fusion events occurring per second in a cubic centimeter volume cathode. Assuming more tritium-producing events to helium-3, neutron-producing events would raise the number of fusions accordingly, and thereby establish Takahashi's point even more dramatically. To realize the incongruity of his results with established theory, just compare a probability of fusion occurring, which is 1/100,000,000, to a reality of one event per second!

FIGURE 4

Face-centered cubic PdD lattice



- ● Deuteron at octahedral site
- + Tetrahedral site
- ○ Palladium

The deuteron wave function at a highly excited state has eight wings spreading toward the eight nearest tetrahedral sites of the four surrounding fcc cubes, hence three deuterons meet at a tetrahedral site as indicated by the arrows.

$$3D \rightarrow d + {}^4He + 23.8 \text{ MeV} \quad (14)$$

$$\rightarrow t + {}^3He + 9.5 \text{ MeV} \quad (14')$$

and

$$4D \rightarrow {}^4He + {}^4He + 47.6 \text{MeV} \quad (15)$$

Takahashi pointed to the difficulty facing those people who try to explain the occurrence of fusion in the lattice by an exchange of energy between the fused deuterons and oscillating palladium lattices (although there are theories such as that of Giuliano Preparata which do, at least in principle, deal with the question by supposing that a special coherence domain is maintained in the lattice). In any event, Takahashi proposes a multi-body fusion reaction to circumvent the difficulty, along with a special geometry within the lattice. The problem of lattice-deuteron interaction can be summarized as follows: When two deuterons fuse, they will briefly form an excited helium-4 nucleus, but this compound nucleus is extremely short-lived, only 10^{-20} or 10^{-21} seconds. The palladium atoms in the lattice can only vibrate at 100-millionth of that velocity; therefore there is no easy way for the compound nucleus of the fused deuterons to transfer energy to the palladium lattice.

Takahashi's solution is quite audacious. He points to the fact that palladium forms what is called a face-centered cubic lattice (see Figures 3 and 4). The palladium appears at the vertices of the cube, and the center of each face. The *octahedral sites* which are entered by the deuterons are located on the edges of the cube, at their midpoints, and also in the center of the cube. These form shallow potential wells, so that the deuterons are not fixed in these positions. An analogy might be to balls located in valleys at the bottom of relatively short hills. At the point when the octahedral sites are filled, a one-to-one loading ratio of deuterons to palladium atoms will have occurred, and most of the free electrons will be bound up around the deuterons to create the shallow potential wells. Electron screening is initially quite effective in enhancing the fusion rate, but this effectiveness decreases as the octahedral sites fill up and there are more deuterons per free electrons.

To begin with, Takahashi supposed that a new mechanism was needed, and he proposed that three-body fusion might be occurring along with traditional two-body fusion. To achieve this, the deuterons would have to be excited to the point that they would begin to oscillate harmonically.

Takahashi proposed that the deuterons located in three of the four shallow octahedral sites surrounding a tetrahedral site, might come together at tetrahedral sites of the palladium lattice to fuse there. These tetrahedral sites are located at the vertices of what would be a smaller cube placed with the cubic structure of the palladium lattice.

Four octahedral sites surround each tetrahedral site—thus creating a tetrahedral, pyramidal geometry. Eight tetrahedral sites surround each octahedral site, giving double the number of tetrahedral to octahedral sites open to occupation by a deuteron. He supposes that over time, more and more tetrahedral sites are also occupied with deuterons, although this also goes against conventional theory. It is generally believed that tetrahedral sites remain vacant. He hypothesizes that his three-body deuteron fusion would create two different possible reactions, either one deuteron traveling at high speed and a helium-4 nucleus (which would contain two protons and two neutrons), or tritium and helium-3. It is the two-body fusion of the high-speed deuterons which Takahashi supposes to account for the 3-7 MeV neutron peak, which he has observed subsequent to his first series of experiments.

Another look at his experiment

In the B-series of experiments, Takahashi and his collaborators used an experimental setup similar to their first one, but with a higher current input. For three weeks they loaded the cathode, alternating high and low current in 2.25-minute periods. During the fourth week they measured the neutron background, and then in the fifth week they began the experiment.

They measured neutrons, tritium, and heat. At the beginning of the experiment, during loading, they registered a slight increase in neutron emissions, which decreased in the third week. After increasing the density of lithium oxide in the electrolyte, however, the neutron emission rate doubled.

It was at this point that they extended the pulses from 4.5 to 19 minutes. After a fluctuation, the neutron rates settled into a ratio of 1.15 to the background level, with a maximum rate of emissions after 180 hours of about 15 neutrons/second/cm^3 of palladium.

Fifty percent of the neutrons which they measured fell within the high-energy 3-7 MeV bandwidth. Under the given conditions, the expected energy level of the neutrons would have been 2.45 MeV for deuterium-deuterium fusion, 14.1 MeV for deuterium-tritium fusion, 3.76 for tritium-tritium fusion, 10.1 for tritium-helium-3 fusion, and similarly different values than were found for deuterium-lithium fusion. Takahashi's conjecture is that there is a compound reaction going on. First, three deuterons fuse to produce a deuteron traveling at 15.9 MeV kinetic energy, and a fast-traveling alpha particle (a helium-4 nucleus) is also emitted. Then the fast deuteron slows down in the lattice and fuses with another deuteron, to produce the requisite fast neutrons in the 3-7 MeV range. At this point in their cold fusion experimental effort, Takahashi and his associates believed that his theory accounted for the observations of excess heat and anomalously high tritium-to-neutron ratios that had been found by other experimenters, but they themselves had only succeeded on the level of producing neutron emissions. Not content with merely fielding a theory, they continued their experimental program, despite a certain amount of frustration.

In a repeat of the B-series experiments, as before, they made careful checks against background radiation. They found that neutron bursts were correlated with the appearance of high-energy neutrons. Whereas in the beginning of the experiment, 2.45 MeV neutron emissions predominated, between 500 and 600 hours into the experiment, the higher energy peak was dominant. When they changed cathodes, they were still able to repeat the experiment.

Takahashi himself admits that his three-body model is problematic, in that it supposes an occurrence even more improbable than deuteron-deuteron fusion at room temperature—i.e., that three deuterons can overcome the Coulomb barrier simultaneously. His explanation includes quantum excitation of the deuterons resident in the octahedral sites and the existence of free electron clouds (plasmons) around tetrahedral sites, which help to enhance the barrier penetration probability. Further, according to his theory, at a certain point, the existence of three-body fusing clusters of deuterons will exclude the continuation of two-body deuterium fusion.

Proceedings of Como conference released

On Jan. 31, Martin Fleischmann and Stanley Pons presented one of their first cold fusion cells to the Leonardo da Vinci Museum of Science and Technology in Milan, Italy, at a press conference which was attended by 250 people. The occasion was the release of the book-length proceedings of the Second Annual Cold Fusion Conference in Como (see *EIR,* Aug. 16, 1991 for our report on the conference).

The press conference was opened by Dr. Fontanesi, a physicist and director of the museum, who made a strong statement on the importance of research such as that into cold fusion: "Science is not made of absolute truths. We are constantly modifying, we are constantly learning. We are proud to host this press conference because we believe that the scientific dialogue in search of the truth must continue. No one today can simply ignore the work done in the area of cold fusion, and I am one who has spent most of my professional years working on hot fusion."

Como conference organizer Dr. Emilio Del Giudice of the University of Milan emphasized why the title given to the proceedings was "The Science of Cold Fusion"—because cold fusion is no longer a phenomenon or curiosity; it is a new area of science, which must be seriously investigated.

"There is a story," Del Giudice continued in a humorous vein, "of the fellow who discovered boiling water, and explained to his astonished colleague how he went about lighting a fire under a pot of water, and how this soon began to produce bubbles and vapor. His colleague tried to 'repeat' the experiment by taking a large pot of water and lighting a match under it. He concluded that the experiment was not repeatable, and that the first scientist was a fraud. To put the matter simply, certain conditions must be satisfied in order to achieve a positive result."

He summarized the basis for believing that the Fleischmann-Pons experiment is a true example of a fusion reaction. "We hypothesize that there are various nuclear reactions being observed, because some people see tritium, others neutrons, and others observe heat. When a significant amount of heat is observed we also see helium-4 and gamma rays; and these are always in a quantity proportional to the heat. This is a key reaction. You can say that it is the smoking gun in the hand of the assassin."

Martin Fleischmann and Stanley Pons both spoke. Fleischmann described how he and Pons were led to their historic discovery. Describing himself as a "scientific archeologist," he explained that he had knowledge of re-

Only in his C-series of experiments was Takahashi actually able to observe tritium along with the neutrons that he produced. He did so by taking weekly samples of the electrolyte. These results were reported in the summer of 1991 at the Como cold fusion conference, where Takahashi elaborated his theory to incorporate Giuliano Preparata's superradiance theory to explain how the Coulomb barrier is overcome (see box).

At Como, he also suggested that a number of subsidiary fusion reactions might also be occurring, such as accelerated tritium fusion with deuterium to produce a very fast neutron and helium-4. It was only in this series of experiments that Takahashi and his associates were able to detect tritium. In this C-series of experiments, he also used a cubic geometry for his electrode, which was actually a cubic centimeter in diameter.

In this experiment, which also utilized alternating six-hour sweeps in high- and low-current mode, Takahashi's team found that neutron emissions increased over time, with the largest excess neutrons occurring over a 1,050-second period—approximately three sweeps. In general, higher neutron emissions occurred for the high-current intervals than the low-current intervals, and for both modes over time. These appeared to be correlated with the production of tritium, which also increased over time. It was in another experiment in this C-series, during early autumn in 1991, Takahashi first used a plate configuration. A similar neutron spectrum was emitted from the plate, along with tritium in the C-series; however, they did not get excess heat from this plate.

search done in the early part of this century, which indicated the possibility of such a reaction.

Contrasting "cold" to "hot" fusion, he said: "We were before a high-concentration plasma, in an ordered state. This plasma has a low temperature but a high energy, as opposed to the disordered state which we find in hot fusion. Well, you have a choice when you observe something like this. You can say it is inconvenient and ignore it, or you can investigate it. We were skeptical, so we were not surprised by the skepticism of others. The leading opinion of many at the time was that, as the experiments improved, the phenomenon would just disappear. Instead, evidence has increased in favor of cold fusion."

Stanley Pons continued with the same theme, remarking that the skepticism came from the fact that the observations contradicted "modern theory," and therefore scientists believed the experiments to be wrong. "This," he said, "is the antithesis of modern science, which is based upon the observation of phenomena. When we observed one watt per cubic centimeter, we had an interesting scientific curiosity, but today, with one kilowatt per cubic centimeter of energy produced, which has been observed in various labs, we have something with technological implications. Now we have to see if we can contain and sustain this. This will be a hard road, but we cannot say that it will not happen."—*Carol White*

Japanese scientists are now explording the hypothesis that it is possible to load a palladium lattice at the tetrahedral as well as at the octahedral sites. Tetrahedral sites are deep-potential well sites, and can only be loaded with difficulty over time. It is now believed that the alternation of low and high current causes the octahedral sites in the lattice to unload and reload—but on each reloading, a certain percentage of tetrahedral sites are already filled. These tetrahedral sites, unlike their octahedral counterparts, will tend to remain filled, even as the current is shifted. Since there are double the number of tetrahedral to octahedral sites, filling both could give a 3:1 loading ratio of the deuterium to the palladium.

Whatever the specific details of Takahashi's theory prove to be, it is likely that the conditions which he identifies with the alternation of two-, three-, and four-body fusions (and possibly even higher) are identified with phase-shifts of the loading with the palladium lattice of the cathode.

According to Takahashi's theory, the high heats that he is now seeing come from four-body fusion in which deuterons from three surrounding octahedral sites are excited and "fall into" the tetrahedral site (central to the tetrahedron formed by four octahedral sites) in which a deuteron may also be located. In experiment D there are indications that, as excess power density neared 100 watts/cm^3, there was a falloff of neutron emissions which was negatively correlated to the increase in power generation.

Already in the C-series, Takahashi believes that two-, three-, and four-body fusions were occurring, with the latter two beginning to play major roles. In experiment D, he explains the high heats as the prominence of four-body fusion.

In the two-month period from January through February, according to his original preliminary estimates, the total input energy was approximately 250 megajoules; the total ouput energy was 730 MJ. This gave an excess energy total of 480 MJ. Power input on average was 50 watts, and excess power was about 96 watts, which would scale to approximately 200 watts/cm^3. After 40 days, Dr. Takahashi and his collaborators tried to terminate the experiment. They stopped electrolysis while it was in the low mode for about 10 minutes, but as we noted above, to their horror, they found that the cell temperature began to slowly increase. Fearing an accident such as occurred at SRI, they resumed electrolysis. They have been steadily decreasing the current since then, and now believe that the experiment is sufficiently under control so that they can bring it safely to an end, and move on to new tests of their theory.