A Visit to Hokkaido University

Report by Jed Rothwell

I visited Hokkaido National University in Sapporo for four days, from June 11 through June 14, 1999. Three groups there are working on glow discharge cold fusion and related experiments:

- Electrochemist Tadahiko Mizuno; Tadashi Akimoto, who specializes in high energy particle detection; Tomoki Katagiri, a fourth year engineering student who is learning to operate the quadrupole mass spectrometer in Mizuno's lab, and Tomako Kawasaki, Mizuno's assistant. Mizuno and Akimoto are working on a new paper which I am translating. We hope to publish the entire paper when they finish it. Mizuno has been assisting others to replicate the glow discharge experiments. Dr. Xing-Zhe Zhao of the Kansai Research Institute (KRI) reports that he succeeded, observing as much as 300% excess heat (three times input). Mizuno has sent several prepared tungsten cathodes to Scott Little, of EarthTech International, but Little has so far not seen the excess heat effect, either with Mizuno's cathodes or with cathodes fabricated from locally available materials.
- Tadayoshi Ohmori is conducting his own experiments and collaborating with Mizuno. We published their paper in the last issue.[1]
- Kazuhisa Azumi, Masahiro Seo, and Mizuno are studying the conventional electrochemical behavior of glow discharge systems. They have not looked for excess heat in the reactions. They recently published a paper in the *Japanese Electrochemical Society Journal,* which is described below.

Mizuno's Recent Work

Mizuno spent several months running 100 experiments, each lasting 1000 seconds (16 minutes). He varied current density and temperature with each run, and plotted the energy release as a single data point. He found that tungsten does not produce excess heat at current density below 0.8 amps per cm^2 or above 1.5 amps per cm^2. Tungsten cathodes do not usually produce significant excess heat below 80°C, and the heat increases rapidly as the cell approaches 100°C. Even within the critical ranges of current density and temperature, some cathodes do not produce heat. Current density and temperature are necessary but not sufficient parameters. Some other unknown factor or factors affect the heat.

After electrolysis, cathodes were washed with pure water, dried, immersed in analytical grade acetone, and placed in an ultrasonic cleaner for ten minutes. This treatment removed deposits galvanized onto the cathode surface along with a thin layer of cathode metal. An EDX spectrometer revealed formations of new elements extending below the remaining surface layers. Different new elements were found depending on the elements originally present. The mass and distribution of the anomalous elements depended upon the electrochemical treatment, the type of electrolyte and other parameters. However, in every case in which excess heat was generated, Si, Ca, Ti, Cr, Mn, Fe, Cu, and Zn were observed. When ordinary, non-glow discharge electrolysis was performed for 1000 seconds on other samples, or when glow discharge did not produce excess heat, no new elements were found inside the cathode.

The EDX analysis shows elements, not isotopes. Mizuno has not been able to investigate the isotopic distribution of the new elements yet, because they appear in small, widely scattered groups, which are difficult to find with his SIMS spectrometer. A SIMS reveals only one tiny spot on the surface at a time. He wants to try some other instrument that tests the entire sample at once.

These 1000-second tests were performed with the equipment configured as a static (isoperibolic) calorimeter. This type of calorimeter depends upon calibrations. A quartz glass cell is filled with water or electrolyte and an electric joule heater is placed inside it at the same spot the anode and cathode will later occupy. A magnetic stirrer is placed on the bottom of the cell. The cell is placed inside an incubator (Yamato 1L-6) which is a small refrigerator-like box with circulating constant temperature air, at 23 +/- 0.1°C. The joule heater is turned on, and the power is held at one level until the fluid temperature stabilizes and remains constant for several hours. The average stable value constitutes one calibration point. Power is increased to another level and another point is established. With a properly designed cell, the points line up in a linear calibration curve. After calibration, the cell is washed and filled with fresh electrolyte. The anode and cathode assembly are installed and glow discharge electrolysis is performed. The cell temperature is compared to the calibration curve to determine how much power the reaction produces. Energy lost to water vapor and effluent hydrogen and oxygen gas must be taken into account. Water vapor from the cell is cooled and condensed externally, and later measured. Vapor and gas lost from the cell can be estimated by weighing the cell before and after the run on a milligram scale, but this method is not very accurate, because very little gas is lost.

After performing the 1000-second tests, Mizuno rearranged the equipment to make a flow calorimeter. A quartz glass cell with a double wall was used. Pure cooling water from a constant temperature bath was pumped through the space between the inner and outer wall. The difference between the inlet and outlet temperature indicates how much heat is produced in the cell. This method does not depend upon electrolyte temperature. (By coincidence, Edmund Storms also recently began using double walled cells for flow calorimetry.) A reflux condenser returned evaporating water to the cell. Because the cell was not well-insulated and heat from the condenser was not captured, heat recovery was low, only 87 to 89% during calibration, but it was consistent. When 97 to 102% heat was later recovered, it is safe to conclude that significant excess heat was being generated, even though the recovered energy was almost equal to input energy. The flow configuration is handy for holding the cell in a stable state by adjusting the flow rate.

> *If I had several lifetimes, I could reinvent most of the techniques for purifying, cleaning, assembling and testing cells, wrapping and trimming wires, spot-welding, and so on. Anyone handy with tools could do it. But to get the job done in one lifetime you must learn from experts.*

The first experiments reported by Mizuno at ICCF-7 were performed with poorly-insulated cells using heat release calorimetry. With this method, you measure a one-time change in the temperature of the thermal mass, that is, the mass times specific heat of the electrolyte fluid and the vessel glass. The fluid is mostly water and the specific heat can be taken as that of water. The specific heat of quartz glass or Pyrex glass is one-fifth that of water. The mass and specific heat of the metal electrodes and other parts is negligible, and need not be taken into account.

With an ideal, perfectly insulated adiabatic cell holding 100 grams of water, 100 calories of electrical energy would heat the water by 1°C. (No real cell can be perfectly insulated.) With the

poorly insulated quartz glass cells used in Mizuno's initial experiments, and still used today by Ohmori, much of the energy quickly escapes as radiation from the cell walls, so the water heats a fraction of 1°C. To determine how much heat was escaping, Mizuno and Ohmori measured the heat decay curve after power was turned off. Starting in July 1999, Mizuno began using heat release calorimetry with a well-insulated cell made of a Pyrex vessel fitted into a Styrofoam shell, filled with 1 kg of electrolyte. At low temperatures, the performance of this cell approaches that of a perfectly insulated cell which simplifies computation of the heat balance. At high temperatures heat losses become significant and must be taken into account.

The insulated heat release calorimeter is accurate and easy to understand based on first principles. During calibration runs the energy balance repeatedly came out close to unity, with values like 99.990% and 100.008% output as a percent of input. Zhao, at the KRI, used an insulated heat release cell (a Dewar) with 2 liters of water. In September he visited Mizuno and brought a 4 liter Dewar cell. They tested it and observed 140% excess heat for the entire run.

To summarize, Mizuno has now used four methods of calorimetry: uninsulated heat release, static, flow, and insulated heat release. Two of these methods have been successfully used by Ohmori and Zhao. The more methods you use to measure a phenomenon, the more confidence you have that it is real. The weaknesses of one method are canceled out by the strengths of another. Heat release experiments can only last a short time until the water reaches boiling, whereas static or flow experiments can continue indefinitely. Heat release and static cells might be affected by transient changes in the insulating qualities of the fluid in the cell, whereas flow calorimeters are immune to this problem.

All four calorimeter types employed until now suffered from an important limitation: they cannot reach temperatures above the boiling point of water. The data indicates that the reaction efficiency increases swiftly above 80°C, climbing exponentially as the cell approaches boiling. We do not know what happens after this because the cells are run at atmospheric pressure so the temperature never goes above 100°C. To overcome this limitation, Mizuno and the Santsuri Company are building a heavy, stainless steel, pressurized cell.

Why the excess heat reaction efficiency increases at temperatures above 80°C is an interesting mystery. The glow discharge reaction itself occurs at 2000 to 3000°C. It is hard to imagine why a relatively tiny change in water temperature, from 20°(room temperature) to 80° (hot coffee) could affect a 3000° plasma (half the temperature of the Sun's photosphere). Mizuno believes that the water temperature probably affects ordinary electrochemical reactions that occur outside of the glow discharge, perhaps at the anode, and these ordinary electrochemical reactions promote the mysterious glow discharge excess heat reaction.

Trying to Learn Why Replications Have Failed

I made this trip to learn the latest news about Mizuno's work, to work on the translation of the new paper, and to try to determine why our group (NERL) and Scott Little did not observe excess heat in our replication attempts. We still do not know why, but I did learn some things about the experiment that were not described in the papers. We have some new ideas and approaches to try, but there does not appear to be a missing step or a secret that Mizuno forgot to tell us.

If the excess heat is real, Mizuno must be using better materials and techniques, even though Little has strived to make the experiment as similar as possible. Mizuno examined Little's website reports and photos describing the replication[2] but he did not spot any important differences. If the heat is an artifact, there must be something wrong with Mizuno and Ohmori's calorimeters. This seems unlikely because they have successfully used different types of calorimeters and a variety of temperature sensors including grounded, compensated thermocouples, and mercury thermometers. Since I have not visited Little's laboratory, I cannot pinpoint the detailed differences between the experiments, but I can help by gathering information and forwarding it to Little. I sent him raw data from recent experimental runs with two types of calorimeters, two papers (one is published),[3] a recent paper by Sengupta[4] about the glow discharge effect (described below), more than 150 electronic photographs of equipment, and two hours of video showing Mizuno performing the experiment and Mizuno and Ohmori discussing it. Little is studying this material. Even if he finds few new ideas to try out, it will be good preparation should he later decide to visit Mizuno himself. Acting on a suggestion made by Ed Wall, Little mailed five cathodes, including a used one, back to Mizuno. Mizuno is analyzing the cathode with his microscopes and mass spectrometers. He may find surface contamination or some other problem with the metal. Later, he plans to subject the cathodes to glow discharge electrolysis in his own calorimeter to see whether he can produce excess heat. Little fabricates his cathodes by TIG welding the tungsten foil to the tungsten lead wire, whereas Mizuno uses spot-welding. Perhaps this makes a difference which can be detected with the instruments.

The only firm conclusion we can reach today is that if there is a difference between Mizuno's experiment and Scott Little's, it must be subtle. It is probably related to surface preparation. What seems like an inconsequential difference might cause a large problem, the way a temperature of about 75°C will make a soufflé fall flat. To take a less homely example from a recent *Scientific American* article about materials: . . . it is not understood why three atoms of hydrogen per million atoms of iron can make normally ductile steel dangerously brittle.[5]

You should not expect revelations during a visit unless you come unprepared. I did my homework; I knew what I would be seeing, so I devoted most of the time to discussing nitty-gritty details. I learned two things about material preparation which were not explained in the papers and which may be important: 1) A cathode should be prepared by scoring the surface, that is, by scratching the surface with glass. 2) A cathode should be electrochemically aged. It is not clear whether scoring and aging are crucial to success, but they do appear to enhance the effect. Little has not yet had a chance to try these techniques.

Aging means subjecting the cathode to electrolysis in order to condition the metal. Ohmori ages a new cathode for at least one hour at 17 to 18 volts, 2.0 to 2.3 amperes. This is vigorous electrolysis, but it is not powerful enough to cause a glow discharge. Ohmori formerly aged cathodes for at least twenty-four hours, but lately he has come to believe that an hour is long enough. Mizuno ages by performing glow discharge electrolysis for about a half-hour at voltages too low for excess heat.

Ohmori seems more methodical than Mizuno, and he has achieved more consistent excess heat. He always performs scoring and aging. Mizuno scored the cathodes during the 100 test runs, but in his later tests with flow calorimetry during June 1999, he did not bother to score the cathodes. These tests produced marginal excess, which is anecdotal evidence that scoring is important. But he did not perform systematic comparisons of scored and unscored cathodes. Ohmori's cathodes look more elegant than Mizuno's. The tungsten lead wire is spot welded close to the edge of the foil, whereas Mizuno's lead wire protrudes halfway down one side of the foil. Ohmori's spot weld seems stronger. When he scored the surface of a cathode, he held it in position by pressing down on the lead wire. With Mizuno's cathode, the spot weld holding the lead wire to the cathode is fragile and it would break if you tried this.

How to Scratch a Cathode

We discussed this topic at length while we ate an elegant lunch in a sparkling new restaurant on campus. (Finding an elegant restaurant on the campus of a Japanese National University was the biggest surprise of this trip. It is like finding a gourmet sushi stand in a U.S. baseball stadium.) After lunch, I took several minutes of video footage of Mizuno and Ohmori demonstrating their respective techniques for scoring cathodes. Ohmori thinks this step is quite important because he believes the effect occurs at microscopic dislocations and uneven surfaces formed along the scratches. Microphotos show melting and apparent transmuta-

tions at the dislocations. Mizuno is not as sure that scoring is important. I asked both researchers why they have not done a careful comparison between scored and non-scored cathodes. Mizuno replied that he is busy looking at other parameters such as temperature and current density. Ohmori said he is convinced that scoring is essential and he does not have time to run a series of tests to prove it, because the problem space is so large and there are so many other areas to explore. It would take a large team of researchers many weeks to settle this issue. Clearly scoring is not essential; some smooth cathodes do produce heat, but it appears to enhance the reaction. If it is done wrong and the cathode surface is contaminated, it might prevent the reaction.

It is not easy to scratch tungsten, which is one of the hardest metals. To score a cathode you start by making glass shards. Here is Ohmori's method:

- Place a clean Pyrex vessel in a plastic bag (Mizuno uses quartz glass).
- Smash it with a hammer.
- Clean the shards in warm aqua regia for ten minutes.
- Wash thoroughly in Milli-Q water, from a Millipore Milli-Q Labo water purifying machine.

After you have prepared the glass, you keep it in a test tube covered with plastic wrap. When it is time to prepare a cathode:

- Sandwich the cathode in sheets of copier paper to keep it reasonably clean, and hold it down, with your finger on the lead wire. Do not touch the cathode surface.
- Pick up a glass shard and hold it carefully, to avoid cuts and to avoid touching the cathode with the part of the glass your fingers touch.
- Scrape each side 100 to 200 times, in a crosshatch pattern.
- Wash the cathode in ultrapure Milli-Q water after scoring. Ohmori does not perform any other cleaning at this stage. He thinks that acetone or an ultrasonic bath will wear down sharp protrusions and uneven surface areas, which defeats the purpose. The cathode is quite clean when he begins, and it still appears clean after electrolysis.

How Clean Must It Be?

Mizuno thinks glow discharge should be easier to replicate than other forms of cold fusion. We were anxious to perform an exact duplicate of his experiment. In e-mail exchanges and discussions, we asked him to describe the precise geometry of the anode and cathode, the steps he takes to ensure cleanliness, and other nitty-gritty details. It turns out he is cavalier about anode-cathode geometry, which surprises me, because electrochemists often make a big fuss about this. Mizuno and Ohmori both use a large, round, platinum gauze mesh anode and they position the cathode above or below the mesh, so that it does not come too close and short circuit, or melt, the platinum with the intense heat of the glow discharge. (The platinum anode costs $600 to $1000, so it must be protected and reused. The tungsten cathode is destroyed after an hour or two of use.)

We asked Mizuno whether he thinks it is necessary to use the ultrapure Milli-Q water, and whether we need to take the elaborate precautions that electrochemists habitually take when preparing electrolyte and cathodes. He assured us these preparations are not necessary. Distilled water from a drugstore should be as good as Milli-Q water. That is what he thinks, but he has never used water from a drugstore, and he has never done the experiment without the elaborate precautions, so he does not know.

The experiment often fails even when Mizuno does it. Paradoxically, this is a reason to be cheerful. It means the experiment is inherently difficult so we should not expect instant, consistent success. It means the effect is probably not an artifact. A temperature artifact would be more regular; it would show up every time under the same conditions, and it would not fluctuate.

Trying to understand the experiment without seeing it first-hand was difficult for us because Mizuno kept changing the instrument configuration. He would mail a schematic and then a few weeks later tell me, By the way, I'm not using that kind of condenser any more; it was too much trouble. The 1000-second tests were all performed with the same configuration. He used scored cathodes which he rigorously prepared wearing gloves and other means to ensure cleanliness. But before and after these tests, he often changed the calorimeter configuration. An experiment is not a museum exhibit. A researcher should tweak his instruments and try new configurations. Using four different calorimeters to detect excess heat is an excellent idea. I am glad that Mizuno is willing to take bold steps and make major changes, but it does make it difficult to follow what he is doing.

A Checklist of Problems and Questions

One of my goals on this trip was to resolve a checklist of issues and questions raised by other people. For example, Scott Little and others worried that the copious radio frequency (RF) noise generated by the glow discharge reaction might affect the thermocouples, creating a false indication of excess heat. Now that I have examined the equipment and looked at many samples of raw data, I conclude this hypothesis is wrong for five reasons:

1. Noise would just as likely cause a false indication of excess cold—an energy deficit. No such indication has been seen.
2. In many runs, thermocouples were replaced or augmented with mercury or alcohol thermometers, which are immune to RF interference. Ohmori said that RF noise was so severe he gave up on thermocouples and used alcohol thermometers exclusively. Mizuno said RF was a problem initially but that his thermowells are well-grounded and the leads are compensated, so it no longer appears to be a problem.
3. The water is pumped from a large constant temperature bath, which has precise control over the bath temperature. The inlet thermocouple agreed closely with the bath temperature. The bath temperature was above ambient and the water traveled three meters to the cell, so it was slightly cooler when it reached the inlet thermocouple. This caused small fluctuations when room temperature changed.
4. In some runs, including the calibration I ran, the electrolyte temperature was measured with a mercury thermometer. The thermocouple agreed closely with the thermometer. The cell came to boil audibly and visibly at the exact moment the thermocouple registered 99°C. Since the inlet and the cell temperature thermocouples were demonstrably correct, it is hard to believe that only the outlet one was wrong.
5. I taped a thermistor to the outside of the outlet tube. It agreed with the outlet thermocouple to within 2 or 3°C. The outlet temperature was 10°C hotter than the inlet, and 15°C warmer than ambient. By the time the water splashed back into the constant temperature bath three meters away, it was several degrees cooler.

David Marett gave a paper during the *Infinite Energy,* Manchester, New Hampshire forum, in which he described a careful replication of this experiment.[6] He saw artifactual excess heat which faded over time. Mizuno and Ohmori tested for the kind of artifact he saw years ago, but let us review his conclusions to complete the record. Marett's main conclusion was that heat was temporarily retained by the cell due to bubble formation, which looked like 142% over unity excess heat after nine minutes. The temperature rose because the cell insulation was temporarily improved, not because more heat was generated. When the cell was run significantly longer than ten minutes, this artifactual heat would dissipate. Since large quantities of bubbles formed during working, the density of the solution changes. This is likely to retain heat in the center of the solution and temporarily cause higher temperature near the center where the thermometer is located. This transient dissipative structure may be responsible for the initial rise and then fall in the rate of heating. Mizuno and Ohmori have now prolonged the reaction as long as eighty-three minutes, and Mizuno has used flow calorimetry, in which electrolyte temperature is not a factor.

The problems listed in Marett's conclusions were:

1) The absence of magnetic stirring introduces non-uniform heating. Both Mizuno and Ohmori added magnetic stirrers two years ago. They recommend stirrers.

2) Ohmori and Mizuno did not report collecting evaporated solution or solution loss, only temperature rise. This has now been done, although in most cases the experiment is terminated when the temperature reaches 95 to 100°C, when evaporation becomes significant.
3) No one has reported using insulation in their experimental vessels. Ohmori and Mizuno's vessel only retained 26% of the heat generated. . . This means that most of the heat generated during the experiment and control was lost to the outside. This, in conjunction with no stirring, compels me to conclude that there was no excess heat generation. Mizuno and Zhao have now tested well-insulated vessels, and flow calorimetry that recovers 80% of the heat generated. Ohmori continues to use poorly-insulated vessels. However, this point is moot. Although they did not discuss this detail in the early papers, Mizuno, Ohmori, and Zhao measured heat losses by examining the heat decay curve after the experiment. The heat was lost to the outside, but it was not unaccounted for.

Little was worried about the calibration heater which is shown in the calorimeter schematic. He thought it might contaminate the electrolyte even if it is covered with Teflon or some other wrapping. It turns out the calibration heater is never placed in a cell with clean electrolyte or a working cathode. First the cell is calibrated with the heater in water or electrolyte, then the cell is cleaned, fresh electrolyte is added, and the anode-cathode assembly attached to the cell lid is inserted. The schematic shows all components in place, but actually they would not fit at one time. Also, the heater is rusted and dirty, so Mizuno would not think of putting them in together.

I did not try to check off every objection raised by every person. For example, one skeptic insists that the excess heat must be an artifact caused by input electric power being under measured. He feels that the glow discharge reaction must cause large spikes of input power with extremely short durations—so short they are not detected by the power meter. However, Mizuno uses two independent power meters: the data logger (Advantest R7326B) and a digital power meter (Yokogawa WT130). They agree to within 0.1%. If a significant fraction of the power was not detected because of spikes (or for some other reason), the instruments might both be wrong, but they would not be wrong to the same extent. They have different performance specifications. The Yokogawa meter would capture more of the short duration spikes than the Advantest, and it would show higher power.

The video I shot showed aspects of the experiment Scott Little and Ed Wall had not thought about. For example, the cathode lead wire is insulated with heat shrink Teflon tube. The glow discharge covers part of the Teflon, because electricity is conducted to the edge of the Teflon covered metal. Ed Wall wondered why the Teflon did not melt in the intense 2000 to 3000°C temperature. When we did the experiment, the Teflon melted and littered the bottom of the cell, whereas Mizuno's Teflon remained intact. The video shows Mizuno shrink-wrapping it with the flame from a small blowtorch. We did not realize such tough material was available. If we cannot find similar Teflon in the catalogs, we will ask Mizuno for some samples. If we had thought about this we would have realized that heat resistant Teflon must be sold somewhere, but we learned that lesson by watching the video, instead.

Ed Wall wondered about the Pyrex container Mizuno used. In previous experiments with a smaller vessel and less electrolyte, Mizuno used heat resistant (and expensive) quartz glass. In the latest series of experiments with the large, insulated vessel, the anode and cathode are farther away from the vessel walls so heat damage is less likely, so Mizuno felt safe with Pyrex, but he still recommends quartz glass.

When you visit a laboratory, look at equipment, and ask questions, you can clear up many misunderstandings and concerns in a short time. In half an hour you can cover more ground than a week of phone calls and e-mail exchanges. Reading papers is essential, but in the end there is no substitute for seeing and touching equipment, and watching things happen. I wish cold fusion scientists would visit one another and interact more often during conferences. Someday we will have video telephones and Internet connections that will allow us to see what other people are doing at distant locations. This may not be much use in ordinary conversations, but when technicians confer and scientists try to understand what their colleagues are doing, video connections may prove to be invaluable, even with the fourteen-hour time difference between Atlanta and Sapporo.

Neutron Claims Retracted

When Ohmori and Mizuno first reported this experiment at ICCF-7, they said a neutron detector showed a large flux of particles. They reported an even larger number than they meant to, because they mixed up the actual detector count with the extrapolated count for the entire cell, based on the incident area of the detector. Mahadeva Srinivasan and others called these results into question. They said the detector was probably picking up RF noise from the cell. Ohmori and Mizuno admitted they do not know much about detecting neutrons. Eichi Yamaguchi of NTT lent them an excellent neutron detector which they placed above the incubator in Mizuno's lab. This instrument has not detected significant numbers of neutrons. Akimoto, who is an expert in detecting particles, doubts that the experiment is producing neutrons or charged particles.

July 8 Tests

On July 8, 1999, Mizuno did five experiments with a tungsten cathode. The first four produced no excess heat, as expected, because voltage was low. These runs were performed to calibrate, and to age the cathode.

Volts Maximum	Duration Seconds	Average Energy Balance Input/Output ratio	
100 V	1200	1.008	(See Figure 1)
120 V	1200	1.024	
160 V	1200	1.028	
180 V	1200	1.028	
200 V	800	1.103	(See Figures 2, 3)

In the fifth run, average excess was 10%. Bursts of excess heat appeared after voltage was ramped up 400 seconds into the run. The run was cut short after 800 seconds when most of the cathode disintegrated.

The fifth run began at 4:01 p.m. At 4:14 the tungsten cathode largely disintegrated, and input power declined. Mizuno turned off the power, ending the run at 800 seconds. After collecting cooling curve data, Mizuno analyzed the data to see whether anything unusual had happened. He found an apparent burst of excess heat starting around 4:11, lasting 160 seconds. (Data points 550 through 710.) During this event, as the current fell, the cell temperature rose faster than expected from input power alone; 21,803 joules of heat from electricity were added to the cell, and 1,243 joules were lost as radiant heat from the sides and top. The thermal mass was equivalent to 1100 grams of water, so the temperature should have risen 4.5°, yet it rose 6.2°. The extra ~1.7° represents 7,995 joules, or 50 watts of excess power on average.

Data was collected every ten seconds. Figures 1 and 2 show one-minute moving averages, six points averaged together. When data points are not averaged, as shown in Figure 3, output power fluctuates. It even includes negative excursions: an example can be seen at second 650, when the temperature drops from 72.9° to 72.1°C. This translates into 3680 negative joules, energy apparently lost from the cell at the rate of 368 watts. At these temperatures energy cannot leave this cell at such a fast rate. When the cell is brought to boil and power is turned off, heat is lost at the maximum rate of ~27 watts. What caused this sudden temperature fluctuation? I can think of three explanations:

1. Despite the fact that the cell is equipped with a magnetic stirrer which vigorously churns the fluid, at such high temperatures a stream of boiling water might rise from the hot cathode and bypass the temperature sensors. From time to time this stream of hot water may come in contact with the temperature sensor. The problem with this hypothesis is that similar fluctuations did not occur during the calibration runs, when the temperature and operating conditions were nearly identical.

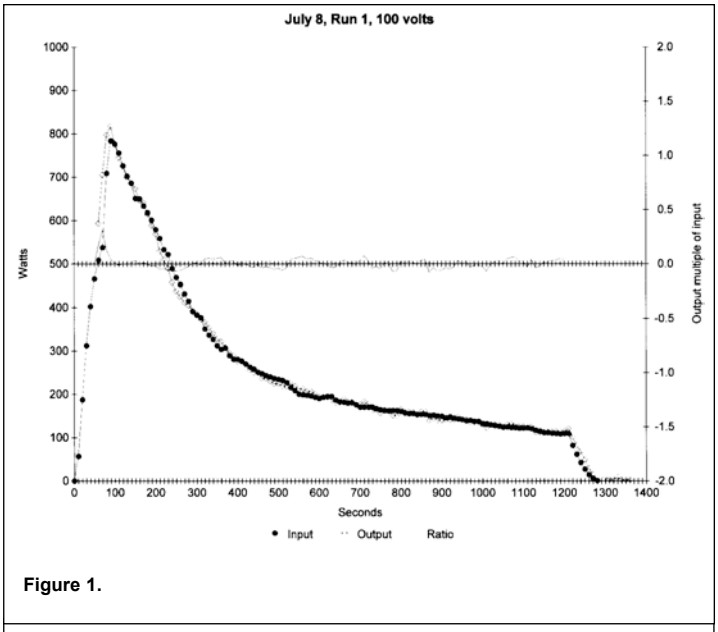

Figure 1.

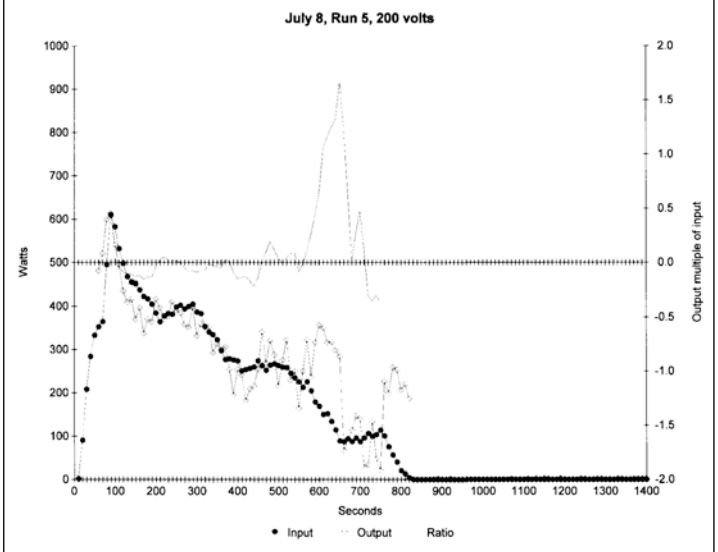

Figure 2.

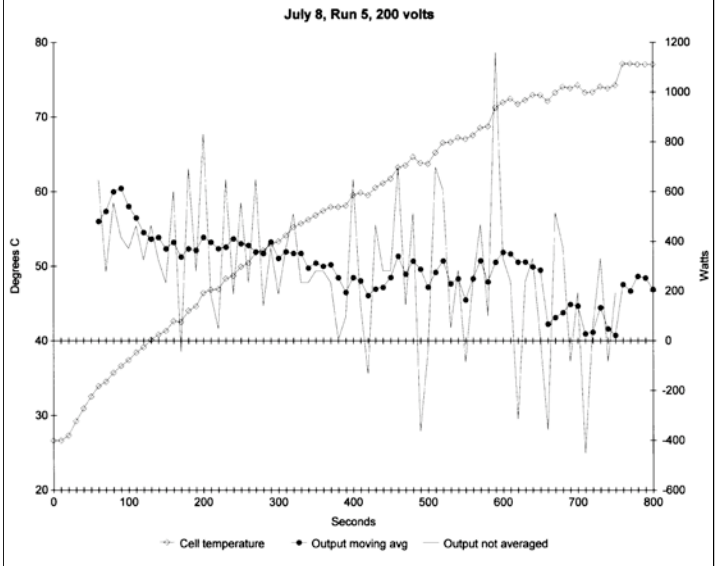

Figure 3.

2. The cathode is generating intense bursts of excess heat. After a burst, it takes a few seconds for the water to mix and the temperature to become homogeneous again. The computer samples the temperature every ten seconds. A burst might occur just before a sample is taken, when a wave of heat is still spreading out from the cathode. A few seconds later the entire mass of water reaches temperature equilibrium and the local temperature around the thermocouple temperature falls back somewhat.

3. Intense RF energy from the glow discharge reaction affects the thermocouple, causing false readings. Mizuno agrees this is happening to some extent, because at the end of the run when the power is turned off, the temperature jumps from 74.2°C up to 77.1°C. Short term fluctuations from one reading to the next cannot be trusted, although overall trends in the moving average are meaningful, because noise will cause both negative and positive jumps which cancel out. However, Mizuno says that the RF noise is known to introduce a slightly negative bias.

RF noise may be a problem, but we can sidestep it by examining the temperatures before the glow discharge began, and after power was turned off. RF noise ceased instantly when the power was turned off. We can disregard all data recorded while the glow discharge occurred. This was the advantage of heat-release calorimetry. The cell temperature began at ambient: 26.6°C. At time 780 after the power was turned off, the temperature reached the peak value of 77.1°C. Total heat evolution was:

(77.1° - 26.6°) x 4.187 joules per calorie x 1100 gram thermal mass + 3421 joules radiant heat losses = 236,008 joules

Input energy was 214,373 joules. Excess energy was 21,635 joules, or ~10% of input. There are only two potential errors with this method:

1) Errors measuring input power. As noted above, this seems unlikely because in some runs Mizuno compared input power measured by the data logger to a recording digital power meter, and he found less than 0.1% difference.

2) Recombination. This figure for input energy is reduced to account for the loss of hydrogen and oxygen gas from electrolysis. It is conceivable, although unlikely, that the effluent gas recombines without leaving the cell. However, only 1.48 volts out of 200 volts go into electrolysis. Complete recombination would add only 900 joules to input power.

Some Informal Impressions: A Day in the Life of a Cold Fusion Researcher

A glow discharge experiment is the most dramatic form of cold fusion, but being in the room while a test is run, you would not guess that anything important is happening. Most of the day is devoted to preparations. A batch of electrolyte is mixed. The anode and cathode have already been cleaned, prepared, and put aside. The anode is stored in acetone. Mizuno retrieves a cathode, scores it, and carries it downstairs to another lab where he spot welds it to a lead wire, with a brief, intense spark and a puff of smoke. Shrink-wrap is applied. Parts of the cell are fitted and repaired. As he works in the cluttered space, Mizuno accidentally knocks a box of plastic wrap off a stack of petri dishes onto the floor. Kawasaki laughs, Stop breaking things! We have enough broken stuff here already. Was that a dish? I ask. No, nothing, she replies, just plastic wrap. Mizuno mutters, Let me at it: I'll break anything. . . . I don't like the looks of this anode . . . He goes downstairs to repair it with the spot welder. Finally, the anode, cathode, and thermocouples, which are attached to the lid of the cell, are installed. A blue Styrofoam shell is placed around the cell and taped together. The cell is placed on the magnetic stirrer inside the incubator. The stirrer is turned on. Is the Teflon coated magnet at the bottom of the cell spinning freely? We listen for the knocking, clattering sound, and we look through the peephole in the blue insulation. We see flashing light reflected from the spinning magnet. We turn off the stirrer, the noise goes away, the light stops flashing. Turn it on again, the noise and light reappear. The stirrer is spinning clear of the thermocou-

ples and other cell components.

It is slow and patient work. It was often interrupted during my visit by students dropping by to pick up tests or the key to the lab across the hall. The phone rang frequently because Mizuno's work was recently described in *Sentaku* (Choice), a pricey executive newsletter with a large circulation. Corporate laboratory electrochemists called for information, preprints, and advice about materials.

There is no sense of drama during a test. Mizuno turns the power on and stands around watching the meters. He gradually increases the power, minute by minute, as quickly as he can without melting the cathode. He and Kawasaki gossip and complain about the hot weather. Every ten seconds, the computer records the date, time, room temperature, the incubator air temperature, and the cell electrolyte temperature, voltage and current. After glow discharge begins and the final adjustments to the power settings are made, Mizuno and Kawasaki attend to other tasks while the water comes to boil in ten or fifteen minutes. Mizuno turns off the power and waits for the cell to cool, to measure the heat decay curve. It is nearly the same curve with every run, but for maximum accuracy he measures it every time. He does not know whether the cathode produced excess heat until about an hour after the test finishes. He transfers the data from an ancient 5.25 inch diskette on the data collection computer, to a 3.5 inch diskette on another old computer, and finally to the hard drive on a third computer. He loads the ASCII data into a spreadsheet, computes the heat loss and energy balance, and prints color graphs. Mizuno and Kawasaki have done this hundreds of times over the years, and they have seen excess heat more than one hundred times. It is a work-a-day occurrence to them. While watching the blue glow discharge, Mizuno said, I pity anyone who is trying to do this with palladium. It takes so long! It is so much trouble . . . This method brings us directly to a hot, dynamic reaction.

Powerful cold fusion reactions with other metals are also triggered by high temperatures, but with other metals it is not possible to raise the temperature quickly. In 1992, Pons and Fleischmann took anywhere from eighteen hours to several days to fully load a palladium cathode at low current density.[7] When the cathode was loaded it would begin producing low-level heat. They would turn up electrolysis power briefly, in a pulse lasting less than three minutes. This would drive the cathode temperature up to 180° to 200°C, which would trigger high excess heat. The electrolyte would boil off and the cathode would remain hot in a heat after death reaction, which would sometimes last for hours. A heat pulse applied before the cathode was fully loaded would not trigger a boil off or a heat after death event.

Other cold fusion scientists have worked for years trying to achieve excess heat, without success. They would be thrilled to see results like Mizuno's. This test would be high drama in most labs. Scott Little worked unsuccessfully for weeks trying to replicate heat in this experiment. Naturally, he has doubts about Mizuno's calorimetry. This situation is frustrating to everyone, and deeply unsatisfactory, but it is hard to know what we can do about it.

The State Room Scene in A Night at the Opera

I described Mizuno's cramped laboratory in the book *Nuclear Transmutation: The Reality of Cold Fusion* (Infinite Energy Press, 1998). I can report that the University finally did get around to fixing the leak in the roof, but the room remains as crowded as ever. Mizuno removed a large hydrogen purification apparatus, but he is still running three cold fusion experiments and one conventional experiment in corrosion. His assistant, Tomako Kawasaki, occupies a cubbyhole behind the incubator cabinet and shelves, and a third desk has been brought in for Tomoki Katagiri, an undergraduate senior who is operating the quadrupole spectroscope. They have crammed in a small refrigerator; five computers; several equipment racks; pen recorders; an oscilloscope; a huge, deluxe constant temperature water bath remaindered from the NHE project; knickknacks; bric-a-brac; a large, stuffed, talking Pokémon doll; and the inevitable doily-covered table where they serve ice tea and cakes or hot coffee brewed over a Bunsen burner. While Ohmori and I spent a few hours in the afternoon reviewing data over tea and cake, Katagiri dropped by between classes, and someone from administration delivered a stack of papers for Mizuno to sign. It began to look like the stateroom scene in the Marx Brothers' movie A Night at the Opera.

National University buildings are not air conditioned even in the subtropical parts of Japan. Hokkaido normally has a mild summer climate, but this year the temperature was over 30°C outside (86°F), and with the experiment running, heavy power supplies, computers, and other equipment in the room was turned on, adding to the heat. The fans were blowing, the windows were open. The hallways and other labs were quiet. Most of the students were outside enjoying barbecues instead of studying. (Japanese college students know how to take it easy. I have not seen them study hard at any time of the year, but especially not during the last week of classes before summer vacation. They concentrate on cookouts, club activity, and learning how to ride a bicycle while lighting a cigarette and talking on a cell phone—preferably with a girlfriend riding sidesaddle on the back. She holds the umbrella when it rains.)

Japan is a crowded country, and National University facilities are Spartan. The hallways are filled with clutter, broken equipment, trash, ashtrays, and barbecue grills. The buildings are falling apart. It is a friendly, relaxed atmosphere, conducive to learning. It is not conducive to electrochemistry, which requires cleanliness and space to work.

There is plenty of space available on campus; Hokkaido is the most spacious of the National Universities, but the other professors do not like this research. They asked Ohmori to move his experiment out of the regular lab and into a small room behind a large, abandoned experiment. They wanted him to move ostensibly because cold fusion experiments might produce neutrons or charged particles which could endanger students, but actually because this research is an embarrassment. He soldiers on. Without a research budget he has gradually recapitulated the history of chemistry in reverse. He started with old computers, then went back to analog pen recorders, circa 1900, and now he is reduced to doing calorimetry with a mechanical stopwatch and a mercury thermometer, circa 1840. This method works as well today as it

Other Glow Discharge Research at Hokkaido University

Azumi recently published a paper about glow discharge in the *Japanese Electrochemical Society Journal*.[12] The paper is in Japanese but the title and abstract are in English:

Abstract

Light emission from the metal electrodes cathodically polarized at cell voltages up to 250 V was investigated in various aqueous electrolyte solutions. The light emission was observed when the temperature of electrodes exceeded the boiling temperature of the electrolyte due to the intense cathodic polarization a thin vapor layer was formed at the metal/electrolyte interface in which a high electric field ionized vapor molecules to generate the plasma state. The light emission was caused by a glow discharge at relatively low cell voltages and by a spark discharge at high cell voltages. The spectra of the emitted light were assigned to the constituents of the electrolyte solution, electrode material and gaseous hydrogen evolved at the electrode.

The authors divide glow discharge and electrolysis into three phases:

1) Ordinary electrolysis producing hydrogen evolution. Occurs from 0 to 100 Volts. The mechanism is direct electron transfer from cathode to solution.

2) Glow light emission, 100 to 175 V, indirect electron transfer through a plasma layer.

3) Spark light emission, 175 V and above.

Another paper about this subject was recently published: Sengupta *et al*.[4] describe the relationship between voltage and chemical products, which does not fit the conventional Faradaic laws. They make no mention of cold fusion, excess heat, or calorimetry. They measured input, but it seems unlikely they measured output. They probably assumed the two are equal and no source of significant energy exists within the cell.

did when J.P. Joule invented it, and it has a certain elegant simplicity, but it takes a lot of work. You cannot let an experiment run for long. You have to babysit, periodically writing temperatures in a notebook. Mizuno has much grander equipment, because he paid for most of it himself, including a new Ulvac quadrupole mass spectrometer, which costs about $25,000. In September a large Japanese corporation donated $10,000 for his experiments.

Mizuno's Note About Heat Release Calorimetry (translated)

Temperature is measured with three K-type thermocouples. One records the cell temperature, and the other two record room and incubator temperatures. The thermocouple leads are covered in 0.1 mm Teflon shrink-wrap. These thermocouples have all been calibrated against a standard (mercury) thermometer. The heat release style cell is made of Pyrex, and it has the capacity of 1000 cubic centimeters. The top portion has a silicon plug. This plug has holes opened in it to allow the passage of the electrical leads and thermocouples. The cell is surrounded by Styrofoam insulation. The cell is placed on a magnetic stirrer, which drives a Teflon mixer placed at the bottom of the cell. The magnetic stirrer is a Yamato brand, model MA300, which spins at selectable constant rate.

The formula for determining the heat balance with this heat release cell system is as follows:

Input = 1xV (1)

Output = Hw+Hc+Hr+Hv+Hg (2)

Here, input and output are measured in joules. I is current (amperes), V is voltage, Hw is the quantity of heat in the water, Hc is the quantity of heat in the cell glass material, Hr is heat radiated from the cell, Hv is heat lost to vapor, and Hg is heat lost to the electrolytic decomposition of hydrogen and oxygen. The terms in detail are:

Hw = mass of fluid x specific heat of fluid x temperature change
Hc = mass of cell Pyrex material x specific heat of Pyrex x temperature change
Hr = (mass of fluid x specific heat + mass of cell x specific heat) x temperature decline
Hv = mass of vapor x heat of vaporization
Hg = 1.48 x current

The amount of fluid is taken as 1000 grams. The specific heat of the fluid varies with temperature, but it is approximately 4.18 joules/g x deg. Hr is computed based on the temperature drop, which is determined by examining the heat decay curve produced after the power is turned off. The rate of change in temperature at every data point is determined. The logarithm of these points is plotted as a function of the temperature difference, and a linear relationship between temperature and energy content is derived. When this formula is applied to the cell mass and heat capacity, Hr is derived according to the following formula: Hr = Mx4.18xAx10^bxT

where M is the thermal mass of the cell, including the thermal mass of the fluid, electrode metal and cell material, based on the weight of the material and a calibration. In this case M equals 1100. Factors A and b are based on the heat decay curve of the fluid temperature. In one example, A equals 0.00190 and b equals 0.0227. T is the ΔT temperature difference between the cell and the incubator air temperature. Hv is the mass of vapor multiplied by the heat of vaporization, which is taken as 2256 kJ/g. However, in the graphed examples of July 8 data, Hv was not taken into account. The last factor in the equation is Hg, heat required for electrolytic decomposition. This varies depending upon conditions at the electrodes, however here is taken as 1.48xI.

Heat generation is computed based on these terms, and input is compared to output. Any difference constitutes excess heat energy.

Comments

If Hr (radiation) is not accounted for, when the cell is run at high temperatures output appears to be less than input. On July 12, a 640-second run was made starting with hot electrolyte at 86.0°C. Input was 68 kilojoules. The water and Pyrex container rose 13°C, absorbing 60 kilojoules, which is only 89% of input. According to Mizuno's calculation the cell radiated 16 kilojoules during the run. Total heat absorbed and radiated was 76 kilojoules, which is significantly more than input. (After the run, as the cell cools, it slowly radiates the 60 kilojoules of absorbed heat until it reaches room temperature.)

Did the cell really radiate 16 kilojoules? Mizuno derived this with the algorithm described above. I reached a similar conclusion with a rough estimate. 16 kilojoules over 640 seconds equals 25 watts average radiant losses. The rate is higher at higher temperatures according to Newton's law of cooling. Just after the power was turned off, the temperature dropped from 99.2 to 97.4°C in 310 seconds. That is, 1.8°C x 4.18 1,100 grams = 8,276 joules. Divided by 310 seconds it equals ~27 watts radiation loss at the peak temperature.

No Easy Path to Technology

One disadvantage of this experiment is that the tungsten cathodes are rapidly destroyed, which would make this an impractical and expensive method of generating power. It does not seem likely that this problem can be easily overcome. The tungsten is not used up in a chemical or nuclear sense. It is not oxidized like burning coal, or transmuted like the uranium in a power reactor. However, it breaks into fine powder which precipitates to the bottom of the vessel. Perhaps the powder could be remanufactured into cathodes, but this would take a great deal of energy—far more than is generated in the time it takes the cathodes to disintegrate. Perhaps something like tungsten black could be used instead of foil cathodes. (Tungsten black is fine powder that is already disintegrated. Arata and others have observed the cold fusion effect in palladium black.) Powder may not work: the geometry of the cathode appears to be important. Only foils have generated heat, not wires, rods, or foils with the edges broken off and rounded after extensive use. In a discussion of Mizuno's experiments, Robert Huggins wrote:[8]

> The disintegration of the electrode in the glow discharge experiments is a major disadvantage. It may be that one needs to cool it internally by flowing water. That is what is done in TIG (tungsten electrode inert gas) welding. It might make the calorimetry more complicated, however.
>
> In addition, what happens on, or near, the surface of the tungsten is apparently very different in the two cases [of CF glow discharge versus TIG welding].
>
> What I think is needed is an experiment that can run in steady state for a long time, so that one can think of making a technology out of it. Short term or transient experiments done to demonstrate the reality of an unexpected phenomenon are just too susceptible to criticism. Especially in the present climate.

Mizuno and Ohmori feel this experiment could be scaled up without much difficulty. More excess heat would probably be generated by a larger foil cathode. The input to output ratio might improve. They cannot test larger samples because their power supplies only have enough capacity to maintain a glow discharge on a 1 cm^2 foil (counting both sides of a 5 x 10 mm foil). As noted above, Mizuno thinks a pressurized cell run at temperatures above 100°C may produce a higher input to output ratio. It might also disintegrate faster. We cannot predict what will happen.

Conclusion

I wrote, "There does not appear to be a missing step or some secret Mizuno forgot to tell us. I did not expect to learn an arcane trick that makes the experiment work. Success will probably depend upon, a plethora of small continuous improvements,[9] and skill developed through training and practice." Mizuno left some steps out of the papers, but we cannot blame him. A paper that explains every detail of an experiment would have to be as thick as a chemistry textbook. Mizuno did not spell out the fact that when he pours the reagent from a jar into a test tube, he tilts the jar and shakes it. He never uses a spoon, because the spoon might contaminate the reagent powder. He did not say this because it is common knowledge; any chemist would know it. Scott Little probably knew it.[10] But Little may not know some other critical piece of electrochemists' lore, which is not common knowledge to most scientists. This would explain why Zhao had no trouble replicating. The KRI has a large electrochemical research laboratory devoted to projects in batteries, fuel cells, and other energy applications.[11]

Mizuno soaks a new platinum mesh anode in aqua regia overnight, dissolving the outer layer of metal. He says an electrochemist will do this out of force of habit, without thinking and without documenting the procedure. We always have a bottle of the stuff handy, and that's the way we do things in this business. Scott Little, on the other hand, may not keep a bottle of aqua regia

handy, because it is toxic, fulminating acid. Perhaps this step is essential, or perhaps it makes no difference. Perhaps it depends on where you buy the platinum, how thick the wire mesh is, how you prepare the mesh before the acid bath treatment, and whether the wires were drawn through a die coated with organic lubricant.

I cannot spot a critical difference between Mizuno and Little's work because I am not an electrochemist and I have not seen Little's laboratory or watched him do the experiment. The best I can do is to act as a go-between and translator. The used cathodes Little sent back to Mizuno may tell the story. Mizuno himself does not know exactly what he is doing, as evidenced by the fact that the experiment sometimes fails, but it is gradually improving. Kawasaki said that after Mizuno began the glow discharge experiments, prompted by Ohmori's encouraging results, it was several months before they saw excess heat. After I returned to Atlanta, Mizuno did some steady-state, 1000-second runs, and most of them produced excess heat, usually at 150% average. He e-mailed me this news in Japanese. After the usual poetic preamble about warm weather and the sound of cicadas he said, Thanks to your suggestions I have improved reliability. Since I do not recall making any suggestions, and the only thing recorded in the two-hour video are my puzzled questions, I think this means that the discussions I catalyzed between Mizuno and Ohmori were fruitful. They do not often eat lunch together or pause for an hour to discuss their work in front of a video camera. I gave them an opportunity to compare notes.

When you visit a laboratory and spend hours looking over the shoulders of electrochemists at work, you reach the unsurprising conclusion that this research is a mixture of drudgery, common sense, skilled labor, and deep knowledge of chemistry and physics. Since Mizuno does not have much money, he invents simple, cheap, *ad hoc* ways to do things. To make the Styrofoam shell fit the Pyrex vessel snugly, he used two blocks of Styrofoam, an old coffee can the same size as the Pyrex vessel, and a blowtorch. Working in the parking lot outside the building, he heated the inside of the can and pressed it against the Styrofoam, which melted, leaving a gap just the right size. Most of the day-to-day techniques are so simple you wonder, Why didn't I think of that? Many are based on ancient tools like siphons, pliers, and balance scales. Before you insert a mercury thermometer into a cell, you scrub it in pumice and wash it in water, which is probably how an ancient Roman would have cleaned a piece of glass. And why didn't I think of that? If I had several lifetimes, I could reinvent most of the techniques for purifying, cleaning, assembling and testing cells, wrapping and trimming wires, spot welding, and so on. Anyone handy with tools could do it. But to get the job done in one lifetime you must learn from experts.

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8. Private communication, August 1999.

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10. I asked Little whether he knew this. His reply was ambiguous: Well, I'm certainly aware that contamination is possible with a spoon but I'm also aware of the likely level of such contamination, assuming the spoon is visibly clean to start with. . . If I was doing ppb trace element studies it would be a whole different ballgame. Lots of things would have to go, including all spoons. . . I normally don't use a spoon but, if the reagent is clumpy, I sometimes have to resort to a slender, clean digging tool to loosen the stuff before pouring. I always use a stainless steel rod that has been cleaned thoroughly.

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Letters/CNEA—From page 8

U.S.A.; Beverly Rubik, Ph.D., President, Institute for Frontier Science, San Francisco, California, U.S.A.

*Domestic corps and the overseas corps in Japan which were built under the Japanese law can be the members of this committee with payment of due participation fee.

JTTAS is located in Akasaka, Tokyo. The address: Kyodo Bldg. 4F, 4-3-1 Akasaka, Minato-Ku, 107-0052, Tokyo , Japan. Tel (03) 5573-2701, Fax (03) 5573-2722.

[Note: Ki is equivalent to Spirit in the West. For Ki-energy, refer to S. Inomata, Science of Consciousness and New Scientific World-View: We Are in the Midst of the Second Copernican Revolution, *J. New Energy,*

In Memorium—Mrs. Babbs Clarke

"Our heartfelt condolences go out to Fred and all the Clarke family following the recent death of Babbs.

Our thoughts are with them at this very sad time." *IE Staff*

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