Excess heat generation by simple treatment of reaction metal in hydrogen gas

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ICCF-21 3-8 June 2018, Fort Collins, CO
The 21st International Conference for Condensed Matter Nuclear Science

Abstract

Reports of heat generation of reactions in the nickel-hydrogen system recently are increasing. These reactions mainly occurred with nickel together with other additive elements and hydrogen gas. We carefully cleaned the reactants and reactor and then processed in situ in the test system without exposure to air and have detected the excess heat. In these test, the thermal energy greatly exceeding the input and was continued for long time. In the best results so far, the output heat energy is twice of the input electric energy and can be lasted for several month. For example, when the input was 500 W, the excess heat can be continued for several hundred watts. It was found that the rise in temperature can be increased the output energy. We recently improved the method of preparing reactive materials and heat generation technic. This makes easier to obtain the excess heat. Here, we report the results of the new method for reactant preparation and results.

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Tadahiko Mizuno, Jed Rothwell

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Notes by Jed Rothwell

Mizuno was not able to attend this conference, so I delivered this presentation on his behalf. Mizuno did all the work in this project. I did none. But he graciously listed me as a co-author of this presentation.

Contents

- In these experiments, glow discharge electrolysis produces excess heat.
- With the previous technique, the reactor and reactants were carefully cleaned, and then processed with glow discharge. This produced nanoparticles *in situ*. (ICCF-18, 2013)
- In the best cases, output heat was twice the input power, and it lasted for months. Output was sometimes hundreds of watts.
- Raising the temperature increased the output energy.
- However, this older method was difficult and too time consuming.
- The new method is to apply palladium to the nickel mesh before the test. This easier and faster, but it only produces 5% to 20% excess heat, at 20 to 30 W.

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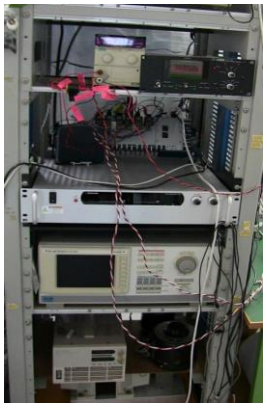
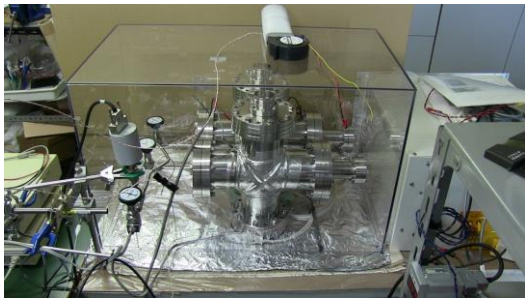
The older method was so difficult and time consuming, it sometimes took months to perform a single test. It took too long to explore the parameter space.

Mizuno has not done additional tests with the older method. He is now focused on the palladium deposition technique.

Air-flow calorimeter system



Equipment cabinet



Cells in box with insulation removed

Reflective padded aluminum insulation

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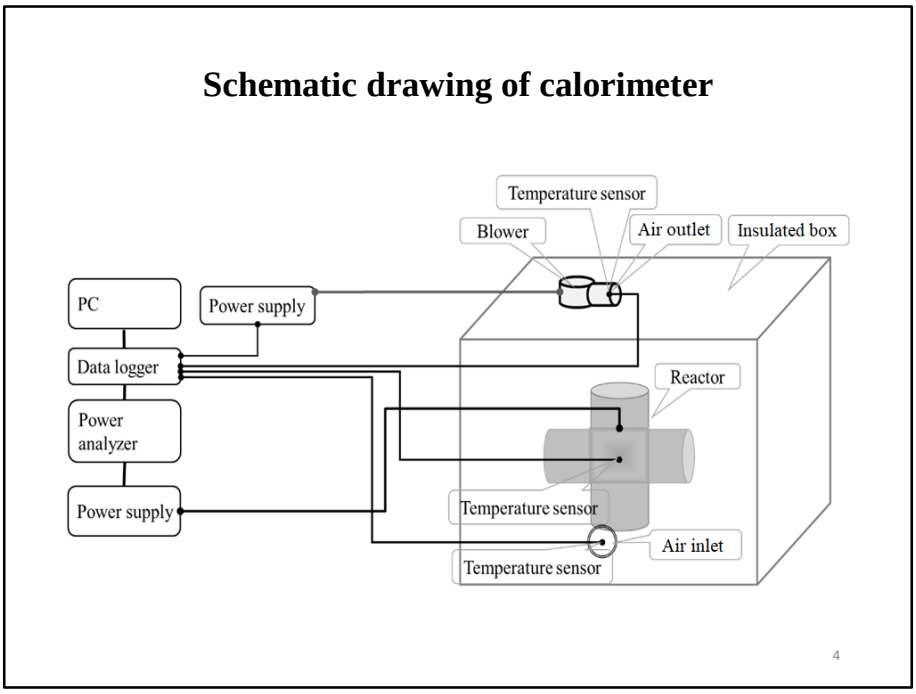
Mizuno previously used three methods of calorimetry: an isoperibolic method; water-based calorimetry; and an adiabatic method which turned out to be a mistake. It did not work. All recent tests have been with air-flow calorimetry. This is easier to understand, and better suited to the high temperature environment of this experiment.

Here is one of his air flow calorimeters. On the left is the equipment cabinet with the power supply, a high voltage power supply, computer and so on.

The photo on the right shows two cells installed in the air-flow box: an active cell and a control cell. They are placed on insulating bricks to reduce heat losses through the table.

During a test, both the inside and the outside of the plastic box are covered with this high tech reflective padded aluminum insulation (shanetsu.com). The minimizes losses to radiation. These losses are low in any case, because the cooling air keeps the inside of the box at ~36°C.

You can see the blower at the top of the box.



Here is a schematic.

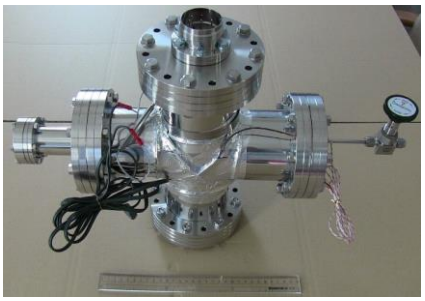
The cooling air comes in the bottom and goes out the top. The temperature of the inlet air and outlet air are measured with RTDs.

The calorimetry is based on the change in air temperature, but other temperatures are recorded, including the cell inside, the cell outside wall, the air temperature in the box. These provide useful information. If you do this experiment, be sure to record those temperatures.

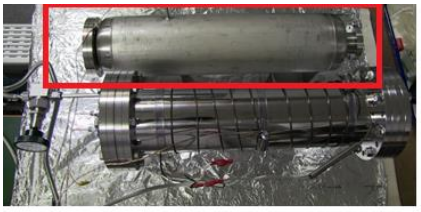
Mizuno confirmed the air flow rate with some nifty reality checks, such as letting smoke from incense into the box and timing how long it took the smoke to clear out. This also confirms that the air flows around both reactors in the box.

Two kinds of reactors

Cruciform reactor. Length and width: 400 mm. Cylinder diameter 120 mm. 20 kg.



Horizontal cylindrical reactor. 500 mm long, diameter 120 mm. 20 kg.



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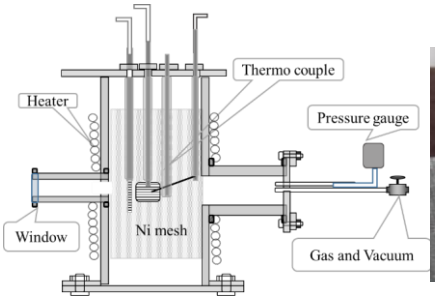
There are two types of reactors: the cruciform shape and the horizontal pipe shape. They both have tight metal seal flanges, and Kovar glass windows. If you are going to do glow discharge experiments, I recommend you include a window, so you can see the plasma.

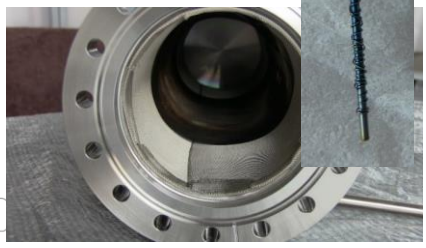
Here is the horizontal pipe reactor, with the control reactor in the red square. They are placed together in the box, as noted above.

Electrodes

Both reactor types have palladium rods in the center. The rods are 250 mm long, wound with palladium wire. This is the positive electrode. The negative electrode is a nickel mesh which is fitted against the inside walls of the cylinder.

High pressure glow discharge is done with hydrogen or deuterium gas at 1 to several kilopascals.





6

Both reactor types have palladium rods in the center. The rods are 250 mm long, wound with palladium wire. This is the positive electrode. The negative electrode is a nickel mesh which is fitted against the inside walls of the cylinder. The mesh is connected to ground.

High pressure glow discharge is done with hydrogen or deuterium gas at anywhere from 1 to several kilopascals.

It is important to understand that the nickel mesh is placed right up around the inside wall of the reactor. This mesh appears to be where the excess heat reaction occurs. Evidence for this includes two things:

1. The reaction increases when the reactor vessel itself is heated up from the outside. This affects the nickel mesh more than other component.

2. The reaction can be triggered with palladium deposited on the mesh.

Control and active reactor tested together

Two reactors of the same size and design were tested, in one calorimeter. One is active and the other is the calibration control.

The control reactor is heated at the outer wall heater the electrode activation process.

The control reactor is kept at the same pressure and input power as the active reactor.

The two are periodically swapped. The control becomes the active cell.

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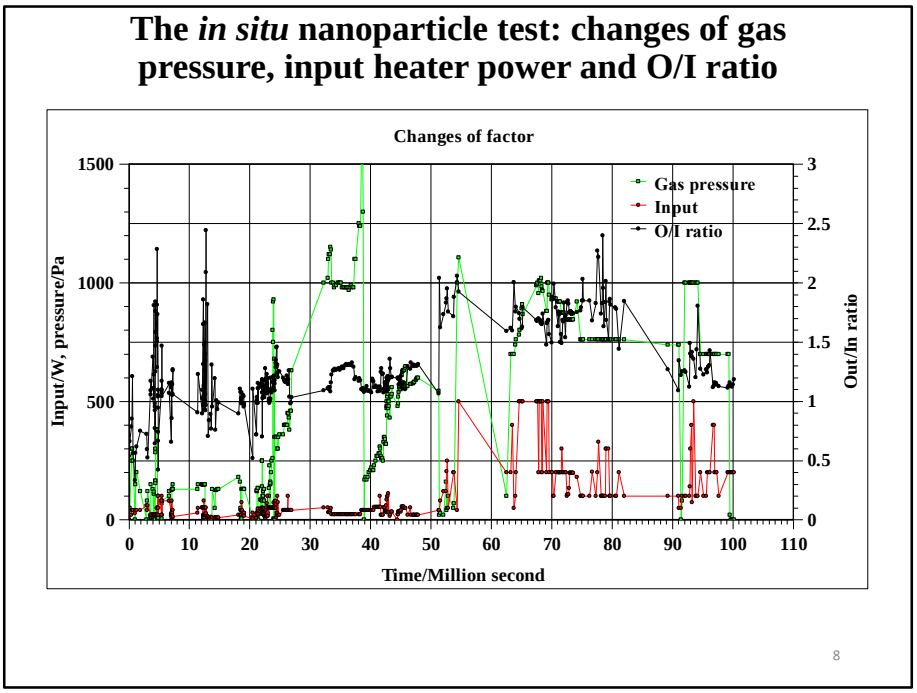
Two reactors of the same size and design are being tested in this photo. One is the active cell, the other is the control.

In this case, the control reactor is heated at the outer wall heater without the electrode activation process.

The control reactor is kept at the same pressure and input power as the active reactor.

The two are periodically swapped. The control becomes active and vice versa.



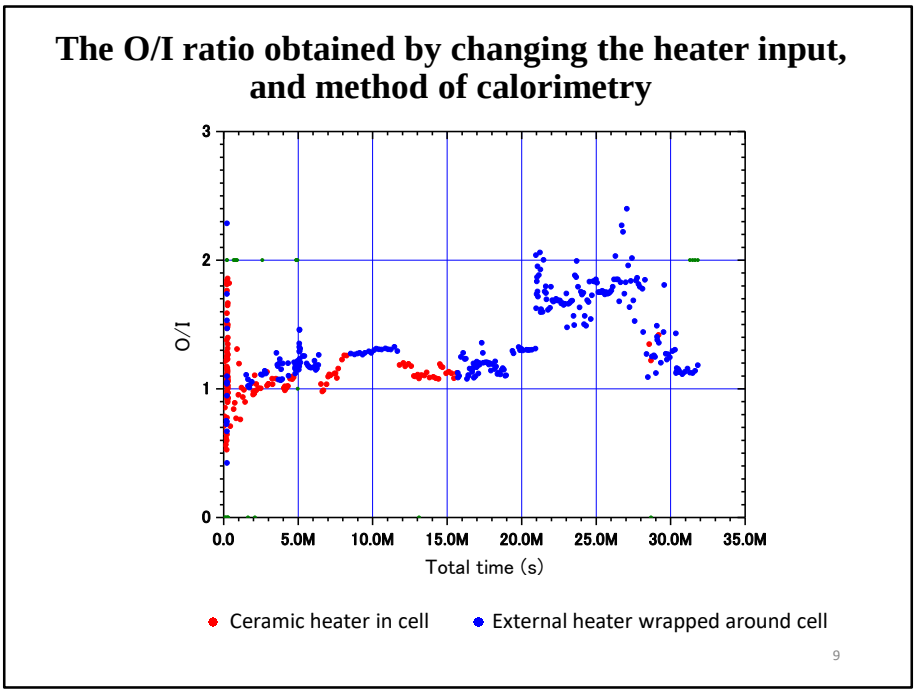
This slide illustrates how long the older method sometimes took.

The units of time are mega-seconds, so this is 3.2 years.

Gas pressure is shown in green. Input power is shown in red, and the ratio of output to input is in black. A ratio of 1 means no excess heat.

The ratio rises at 50 mega-seconds, but it soon falls again. The ratio remained low -- we now think -- because the cell was placed in a water-based calorimeter with a cooling water hose wrapped around the top of the cell, which kept the cell wall temperature low. At 53 mega-seconds, the cell was moved to an air flow calorimeter. The cell wall temperature rose and substantial excess heat began.

At 55 mega-seconds, helium gas was introduced into the cell. At 64 mega-seconds, new D2 gas was introduced. At 92 mega-seconds, air was introduced into the cell. That clobbered the reaction. It deactivated the reaction. The ratio fell to ~1.2.



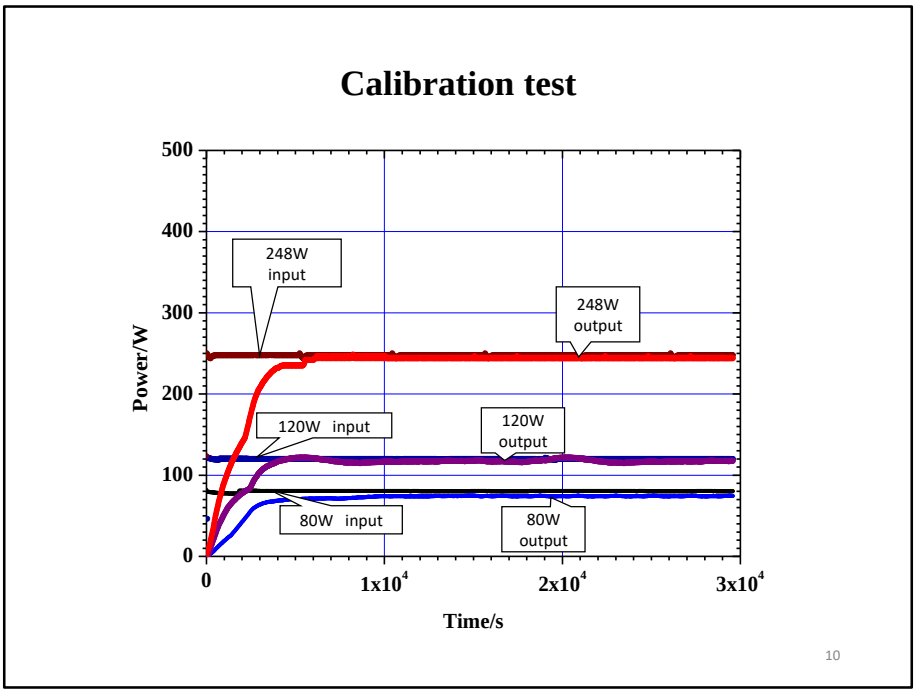
Here is another look at that same data set.

Let me explain there are three ways to heat the cells:

1. Glow discharge
2. A ceramic resistance heater in the center of the cell -- the red dots.
3. With a resistance heater wrapped around the outside of the cell -- the blue dots.

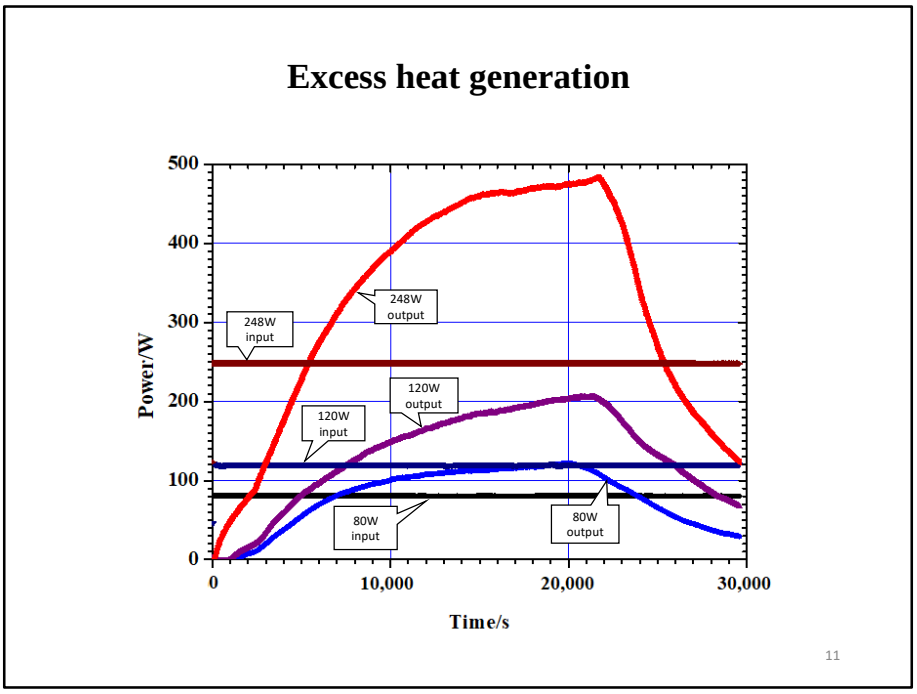
The move to the air-flow calorimeter is at 21 million-seconds. All heating was then done with the external heater. Blue dots only.

The cell walls heated up. As I said, the nickel mesh is wrapped around the inside wall. Heating the cell wall directly makes the mesh hotter than heating it with internal ceramic heater. We know this because there are thermocouples at the cell wall. As I said: use many thermocouples. After this change, excess heat increased dramatically. This suggests that the reaction occurs in the mesh.

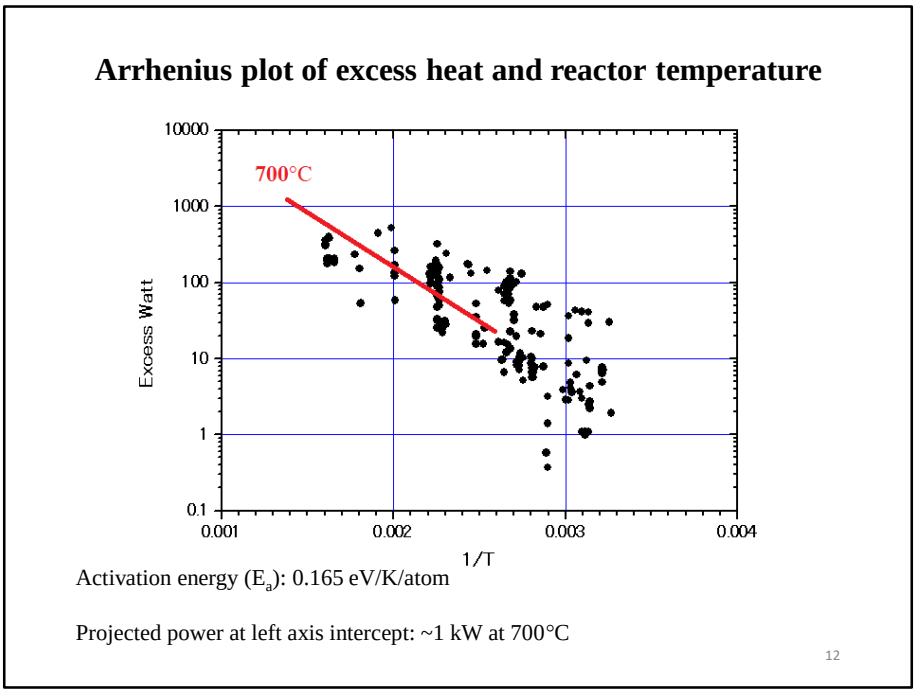


The calibration test at three input power levels. 80 W, 120 W and 248 W. The output power was shown to be close to the input power.

This was with an older air-flow calorimeter.



This shows results of the same input power levels, with the same reactor, in the same calorimeter. The results are dramatically differently. With 248 W input, after 6 hours the power output reaches 480 W, two times input. The shape of the curve is completely different. The output power continues to rise throughout the day, instead of peaking in a few hours.

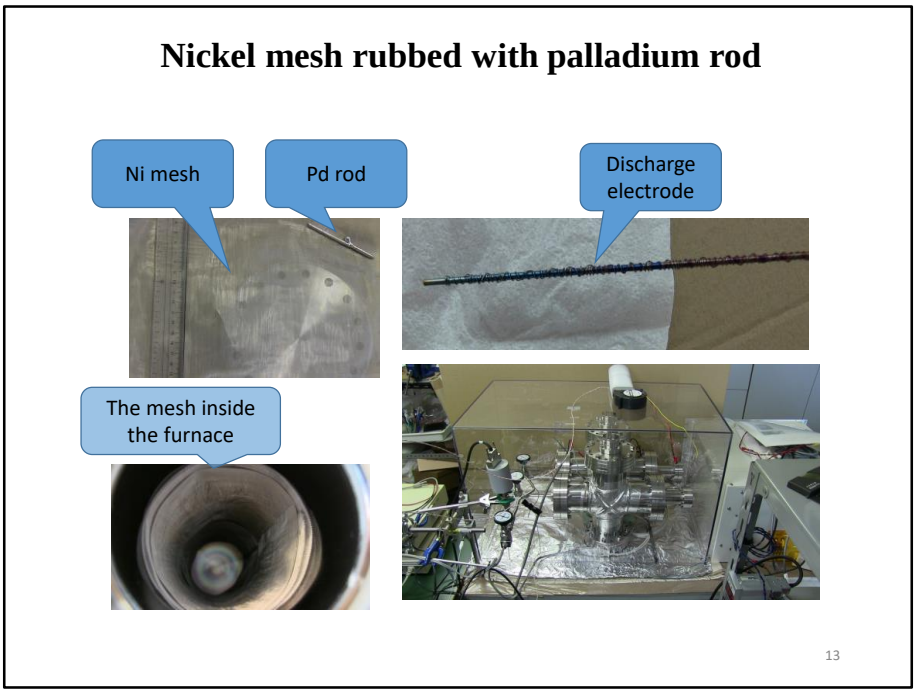


The higher the temperature, the larger the amount of excess heat, expressed here as an exponential function. When the temperature of the reactor (T) is expressed as the reciprocal of the absolute temperature (Kelvin), as shown here, the excess heat relationship is linear.

These data may be useful for elucidating the reaction mechanism. From the linear region between 100°C and 523°C, Mizuno estimated the reaction activation energy is 0.165 eV/K/atom.

Looking at the left intercept, we can speculate that the excess heat would reach the order of a kilowatt at 1/T = 0.001, i.e., approximately 700°C. That is much better power density and Carnot efficiency than a fission reactor core.

Finally, this is data from the old method, but the new method also shows this trend, of higher power at higher temperatures.



Turning to the new method --

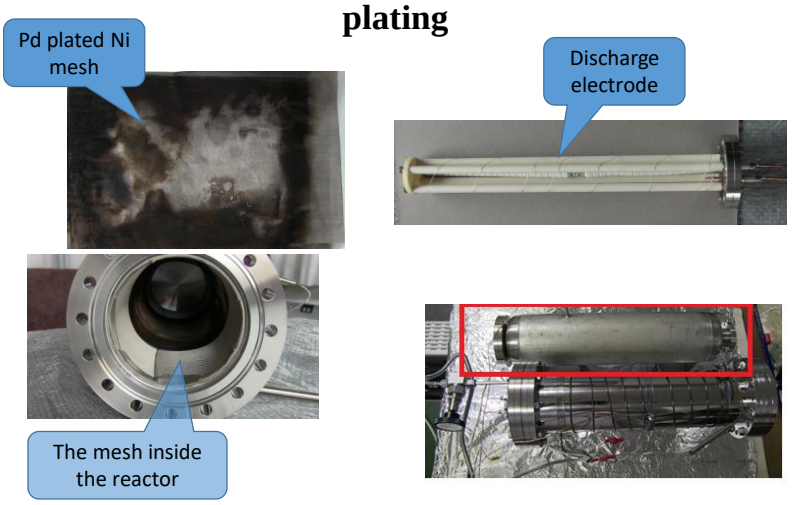
To simplify and speed up the production of electrodes, Mizuno developed a new method: adhering palladium to the nickel mesh electrode before the test.

I think he was prompted to try this because with the older technique, palladium gradually sputtered onto the nickel, and it seems the nickel is the source of the anomalous heat, so he thought he might accomplish the same thing by putting the palladium on there to start with.

His first method was to wash the mesh and then rub it with a palladium rod. He installs the mesh in the reactor, and evacuates to remove air and water. He fills it with hydrogen or deuterium, and evacuates again, cycling 2 or 3 times to remove impurities.

Then he performs glow discharge.

Nickel mesh with palladium electroless thin plating



Pd - 10 Coating composition: palladium, Electroless. Substrate: Copper, nickel. Plating temperature 40 to 60°C, pH 1.5 metal concentration 10 g/L

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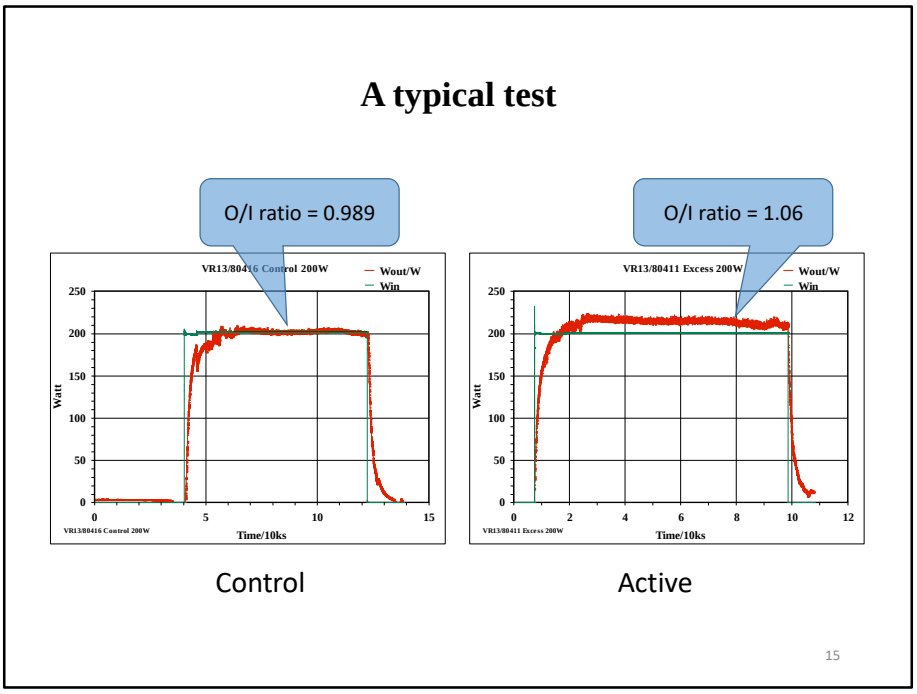
The second method he tried was electroless plating of palladium onto nickel. All of these tests with plating were done using the horizontal pipe reactors.

Here is a different kind of palladium rod electrode.

He did 38 tests of active material, 19 with each of the two methods.

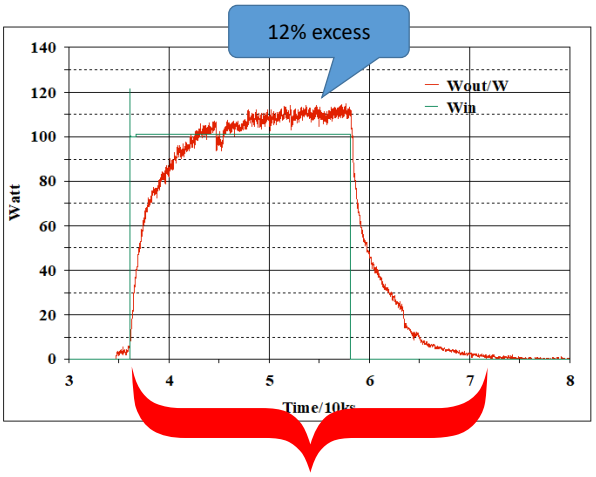


Unfortunately, most of the tests produced only about 5% excess heat.

The left is the calibration. The output to input ratio is 0.989, meaning 99% of the input power is recovered by the calorimeter. The right shows excess heat in the ratio of 1.06, or 6% excess.

Speaking for myself here, recovering 99% of the heat during a calibration seems impossible, as I explain below.

Energy measured from turn on to cool down



Output 2,487,819 Joules ÷ Input 2,223,785 Joules = ratio 1.12
(12% excess heat)

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Here is an example of 12% excess heat.

Energy is measured from the time the experiment is turned, past the turn off, until the cell temperature falls back to ambient. Data is recorded every 5 s. It is collected into spreadsheets, so all you have to do is tell the spreadsheet to compute the number of joules for each 5-second interval, and then add them up to get 2,487,819 joules. It gives the illusion of high precision.

Table of Results available at poster session

Rub surface of Ni mesh with Pd rod							
Reactor Type	**Y/M/D**	**Gas**	**Pressure/Pa**	**Input/W**	**Input/J**	**Output/J**	**Out/In ratio**
Horizontal reactor	2017-07-31	H_2	1000	100	1,682,774	1,849,048	1.099
Cruciform reactor	2017-08-11	H_2	1000	100	1,988,907	1,986,963	0.999
Control reactor	2017-08-11			100	954,939	954,369	0.999
Small reactor	2017-08-16	D_2	4300	100	1,134,604	1,310,820	1.155
Control reactor	2017-08-17			100	1,095,464	1,048,656	0.957
Horizontal reactor	2017-08-22	H_2	4400	100	2,815,777	3,860,532	1.371
Control reactor	2017-08-23			100	1,073,070	1,047,574	0.976
Control reactor	2017-08-24			100	722,292	696,057	0.964
Cruciform reactor	2017-09-03	D_2	5	100	872,596	1,079,700	1.237
Cruciform reactor	2017-09-04	D_2	440	100	2,023,744	2,179,102	1.077
Cruciform reactor	2017-09-05	D_2	440	100	4,681,998	4,727,784	1.010
Cruciform reactor	2017-09-06	D_2	450	10	2,223,785	2,487,819	1.119
Control reactor	2017-09-22			100	7,133,503	7,130,645	.999
Control reactor	2017-10-24			100	5,945,668	5,945,879	.000
Cruciform reactor	2017-10-25	D_2	700	100	6,951,404	6,972,306	.003
Cruciform reactor	2017-10-30	D_2	700	100	8,486,767		

12% excess heat

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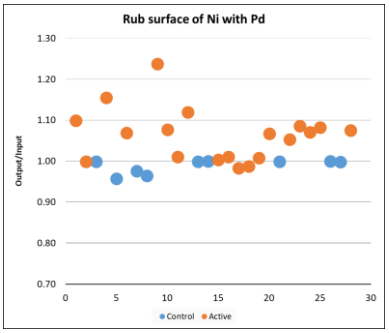
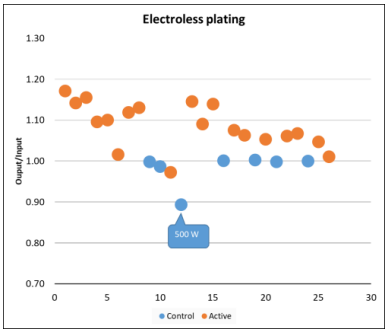
Mizuno sent me tables of the results, which I put up in the poster session. This one shows the 12% excess from the previous slide, in the red box.

The next slide shows a graphic summary of the ratios from these tables.

Results from rubbing surface and electroless plating





Each data point represents the average value from one test.

Most control calibrations are at 100 or 200 W. The recovery rate is ~99%. With the 500 W calibration, the recovery rate falls to 89%.

38 active tests are shown. Most produced ~5%. Five produced 15% or more.

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Here are the ratios from the rubbed and deposited palladium. Each point represents one test. Control tests are blue, and active tests are orange. They are in chronological order. As you see the experiment stopped working back there, and it has not been working well lately.

There are 38 active tests here. Most produced about 5%. Five of them produced 15% or more. [17 control tests; 54 shown here, 55 total. Blank cannot be shown.]

Most control calibrations (the blue dots) are at 100 or 200 W, with a recovery rate of ~99%, and the box temperature of ~36°C. With this 500 W calibration, the recovery rate falls to 89%, because the box temperature rose to ~50°C, so it lost more heat.

When you convert this from percent to power, some of these points are higher and more convincing. One is approximately 40 W excess. This is discussed in a bonus slide.

Calibration O/I ratio 0.989

Data from experiment	
Input power	200 W
Outlet duct diameter	66 mm
Air speed	3.957 m/s
Inlet temperature	18.40℃
Outlet temp.	29.32℃
Outlet – Inlet	10.92 K

Properties of air	
Weight per m^3	1.293 kg
Heat capacity	1.006 Cp

A 66 mm duct at 3.957 m/s gives 13.4 L/s

13.4 L of air weighs 0.018 kg

Energy: 0.018 kg × 1.006 kJ/kg K × 10.92 K = 0.198 kJ/s

That is 198 W. 198 W / 200 W = ~0.99

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Let me talk about the 99% recovery rate. As I said, it seems too good to be true. It is hard to believe such a large box is losing only 2 W to radiation, even with two layers of that high tech insulation.

Here is how the air flow calorimetry works, and how the ratio is computed --

From the experiment we use: input power, the size of the outlet duct; the air speed, inlet and outlet temperatures. These are averages over the whole test, as I showed before. From the textbooks, the weight of air and the heat capacity of air. You can use on-line cheat-sheets to determine that 13.4 L of air pass through the box every second, which weighs 18 g. To compute heat, you multiply weight times heat capacity times degrees Kelvin. It comes to 0.198 kJ/s. 198 W. Which is 2 W below input.

This is hard to believe, but then again, there are indications the calorimetry is working correctly. As expected, losses are proportionally higher at higher power, as you saw with the 500 W calibration.

Let me discuss this in detail, because this calorimetry is at the heart of the claims.

I am uneasy about the 5% excess. I do not know what the margin of error is, but 5% has to be close to it. The 15% to 20% excess heat results are more believable.

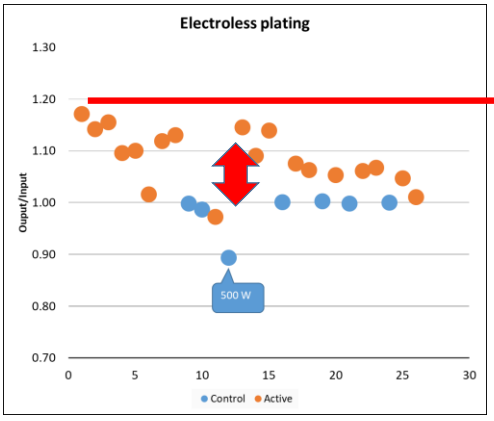
Some people visited Mizuno last year and came up with a list of problems. They worried that one reactor might be in better contact with the table than the other, so it might conduct more heat through the table. That might look like apparent excess heat. Or excess cold, I suppose. Mizuno showed this is not a significant problem by swapping the active and control reactors.

When I heard this, I thought: okay, swapping sounds good, but what if resistance heating itself conducts more heat through the table than glow discharge does? Even if you swap, you get the wrong answer. Mizuno ruled this out. He ran the same reactor with resistance heating and then glow discharge with ordinary electrodes. There was no measurable difference.

A far fetched scenario

For this to be an error:

1. The recovery rate must be over-estimated by 20%, AND
2. Resistance heating must lose more heat than glow discharge.



Even if recovery is 20% in error and active tests recover less heat than input . . .

That still does not explain the gap between control and active tests.

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This is flow calorimetry backed up with calibrations. To disprove it, you have to find not just one error, but two. Suppose you say: "Well, the duct diameter is wrong, and the airspeed is wrong. The measurement if off by 20%, so you are not actually measuring more energy out than in." That doesn't work. Even if measurement is in error, and the active tests recover less output than input, they still recover more than the calibration tests do, as shown by this red gap. You have to explain that gap.

What I mean is: if as the visitors claimed, the measurements are off by 20%, that means the calibrations are also off by 20%, the recovery rate is way down here, and the active runs are positive even though they recover less than input energy.

There were other concerns. The visitors wondered if the calorimeter conditions might be different in the control run and the active test. Mizuno addresses that by putting both cells in the calorimeter and running them one after the other, without opening the box, moving the thermocouples, or removing the insulation. Conditions remain the same, so the comparison is close.

I am not saying that all doubts have been set to rest. We are still worried the air

flow rate may not be measured accurately. There are expensive instruments to do this, and it would be nice if Mizuno could afford one.

You can always improve an experiment.

Mizuno's Summary

- The previous method sometimes produced spectacular results, but it was too difficult and it took too long.
- With the new method, excess heat is more easily generated. However, it is seldom exceeds ~5% excess. That is, 10 to 30 W absolute power.
- Still, it is surprising that significant excess heat can be obtained so easily.

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Mizuno's summary.

Jed Rothwell's concerns

- Previous adiabatic calorimetry was mistaken.
- I have not had time to review the latest work.
- 5% excess heat is close to the margin of error.
- This calorimetry seems too good to be true, especially the 99% recovery rate.
- Independent verification and replication are essential.

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Here are some of my concerns.

In 2013 I visited the lab. I wrote a paper describing the adiabatic method he was using at that time. I concluded that it seemed to be working, but additional calibrations were needed. Months later the additional calibrations were done, and they showed I was wrong. There was no excess heat. I added a retraction to the paper, which you can read at LENR-CANR.org. You would be forgiven for thinking that Mizuno and I don't know how to do calorimetry.

My second concern is that I have not had time to review the latest claims in depth. The last time I did this, it took me two months to get the wrong answer.

I am uneasy about the 5% excess. The 15% to 20% excess is more believable.

The 99% recovery rate seems too good to be true, but that is what the numbers show.

Finally, independent verification and replication are essential. Verification means

one of you people should go there with your own instruments and wring out that calibration. Find out if it really is recovering 99%.

Replication means doing the experiment from scratch in another lab. Mizuno is very cooperative, so if you would like to try to replicate, contact him and ask any questions you like. I stand ready to help translate messages, to avoid misunderstandings.

References

Mizuno, T., *Method of Controlling a Chemically Induced Nuclear Reaction in Metal Nanoparticles.* J. Condensed Matter Nucl. Sci., 2014. **13**: p. 422-431

ICCF18 paper describing *in situ* nanoparticles (Method 1)

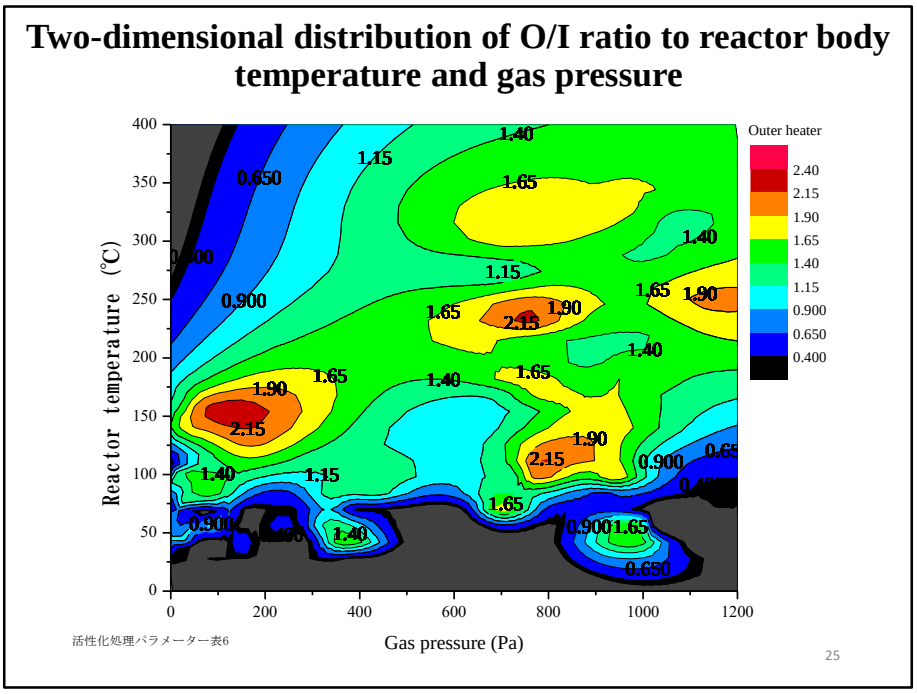
Mizuno, T., *Observation of excess heat by activated metal and deuterium gas.* J. Condensed Matter Nucl. Sci., 2017. **25**: p. 1-25

CMNS paper describing results from Method 1, and a description of newer Method 2 (deposition)

Rothwell, J., *Report on Mizuno's adiabatic calorimetry* 2014: LENR-CANR.org

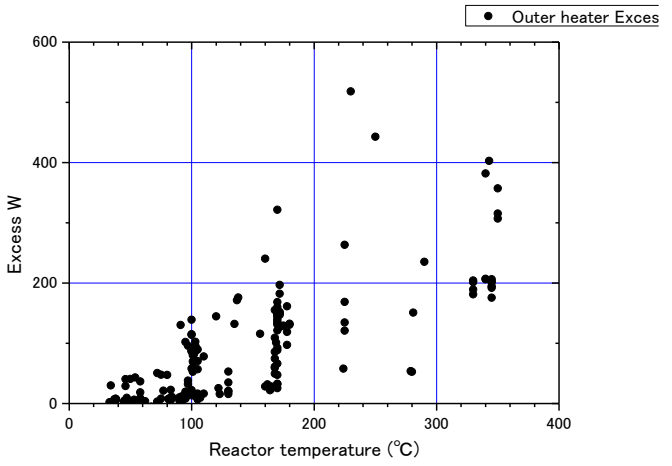
A description of the mistake made in an earlier study with adiabatic calorimetry

Bonus Slides



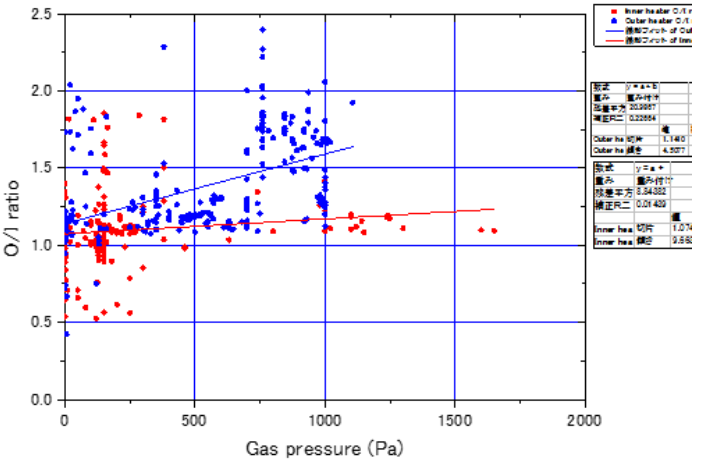
This figure shows the distribution of heat and high O/I ratios. They increase with pressure and temperature, but it is not a simple linear relationship. There are “islands” of high heat and high ratios.

Relation between reactor body temperature and excess heat quantity



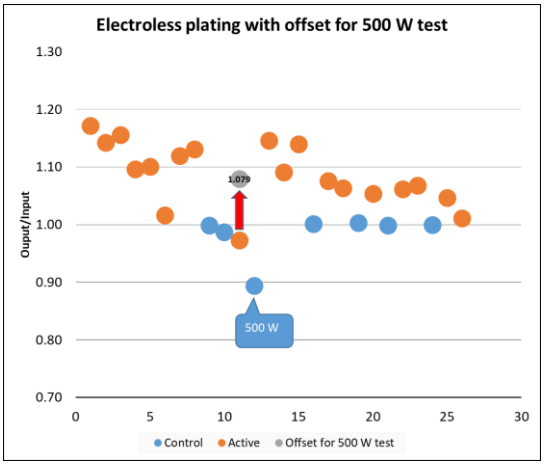
活性化処理パラメーター表6

Relationship between gas pressure and O/I ratio



活性化処理パラメーター表6

500 W test actual power



The 500 W active test adjusted to the recovery rate shown by the 500 W calibration.

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Active tests are paired with calibrations at the same power level. This shows the 500 W calibration. As I said, it recovers 89% of input because the box temperature is high, so the box radiates more heat. It is radiating roughly 50 W. The orange point to the left of the 500 W point is an active test at 500 W. In percent terms, it is recovering a little less than 100%. However, it is also radiating 50 W from the box. When you adjust for this, in percent terms it goes up to 1.079 (8% excess), or approximately 40 W.

Projected power density of ~1 kW at 700°C compared by volume and by surface area

Nickel mesh: 20 g, volume 2.25 cm^3. Wire diameter 0.02 mm, length 960 m, surface area 0.2 m

	Volume	Operating temperature	Power density by volume	Power density by area
Nickel mesh	2.3 cm^3	700°C	444 W/cm^3	0.6 W/cm^2
Fission reactor fuel pellet	1.0 cm^3	300°C	180 W/cm^3	32 W/cm^2
Best Pd-D results *	0.3 cm^3	100°C	300 W/cm^3	16 W/cm^2

* Roulette, T., J. Roulette, and S. Pons. *Results of ICARUS 9 Experiments Run at IMRA Europe*. in *Sixth International Conference on Cold Fusion*.

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Poster

Excess heat generation by simple treatment of reaction metal in hydrogen gas

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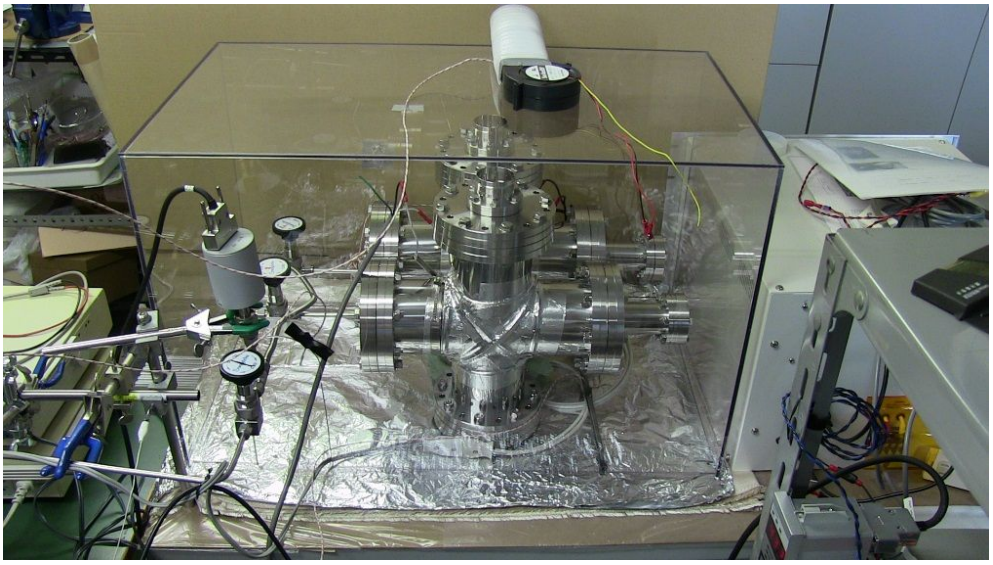
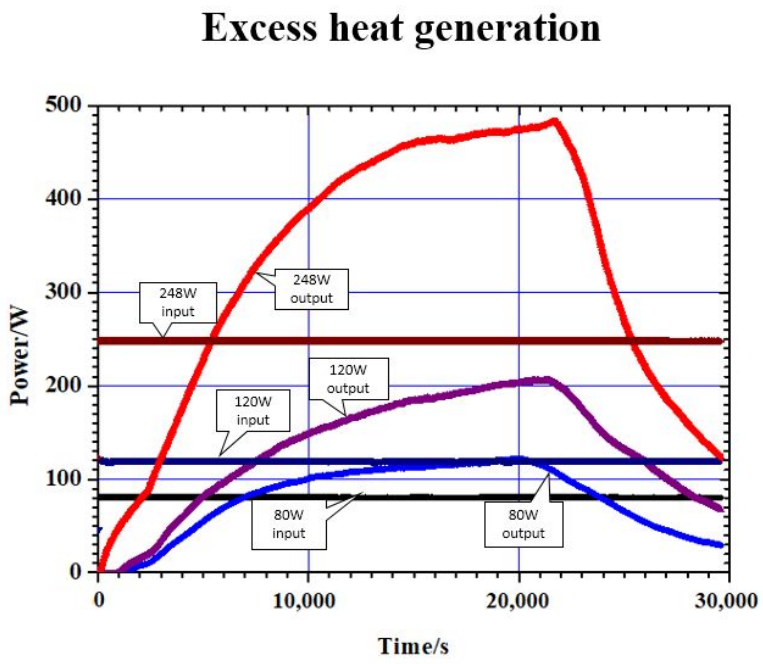
Glow discharge cold fusion

With the previous technique, the reactor and reactants were carefully cleaned, and then processed with glow discharge. This produced nanoparticles *in situ*. (ICCF-18, 2013) In the best cases, output heat was twice the input power, and it lasted for months. Output was sometimes hundreds of watts. However, this older technique was difficult and time consuming. It sometimes took months to perform a single test.

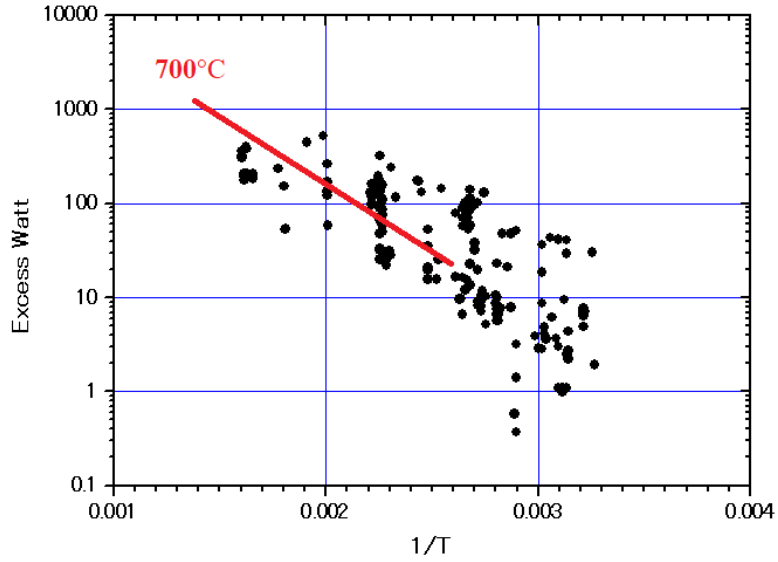
The new method is to apply palladium to the nickel mesh before the experiment. This easier and faster, but it only produces 5% to 20% excess heat, at 20 to 40 W.



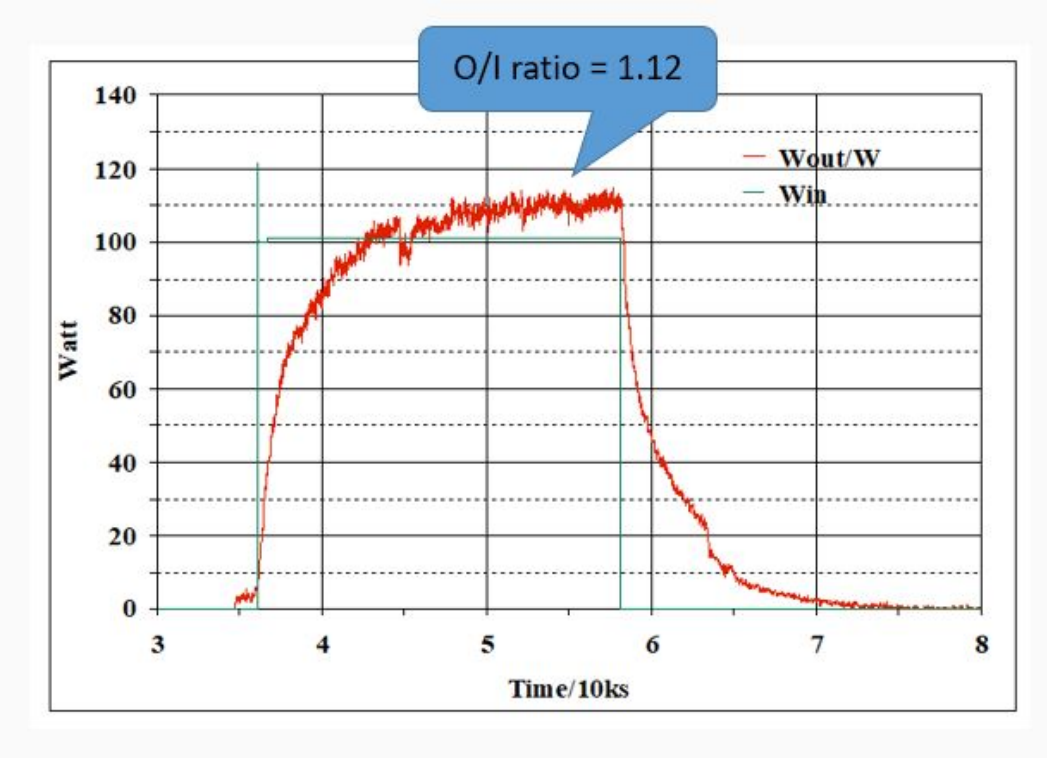
Air flow calorimeter. A control cell and an active cell are placed side by side in an air-flow calorimeter insulated box. They are run in series, under very similar conditions. The active cell produces more heat. In this photo, the insulation has been removed to show the configuration in the box.



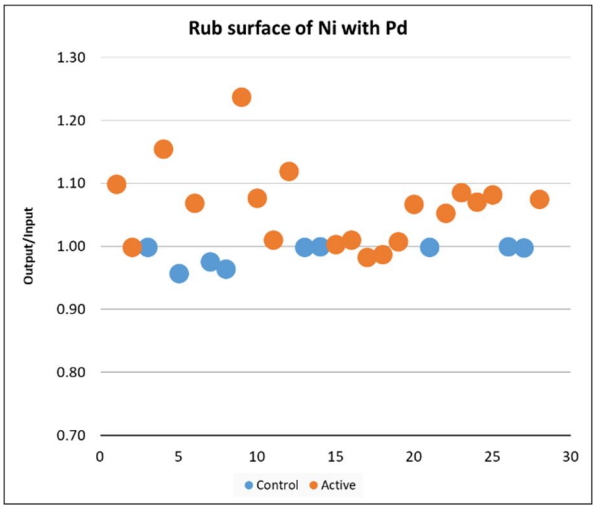
The old method produced high heat and a high output/input ratio

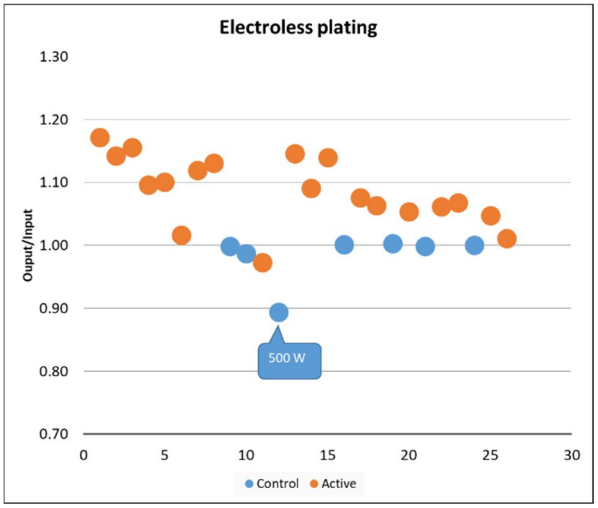


At 700°C projected power is ~1 kW



The new method, of adhering palladium to the nickel mesh, produces less heat at a lower ratio, but it is much easier to do, and faster.





Results from 54 control and active tests of the new method

Data Tables

Where the table indicates a cruciform reactor was used, the control cell was also a cruciform reactor with hydrogen gas and electrodes, but the electrode was not prepared and no electrolysis was performed. The control cell in these cases was heated from the outside.

Where the table indicates a horizontal pipe reactor, another horizontal reactor was used as the control blank, but it did not contain hydrogen gas or electrodes. It contained only air and a resistance heater, which was set to the same power level as the active cell.

Rub surface of Ni mesh with Pd rod

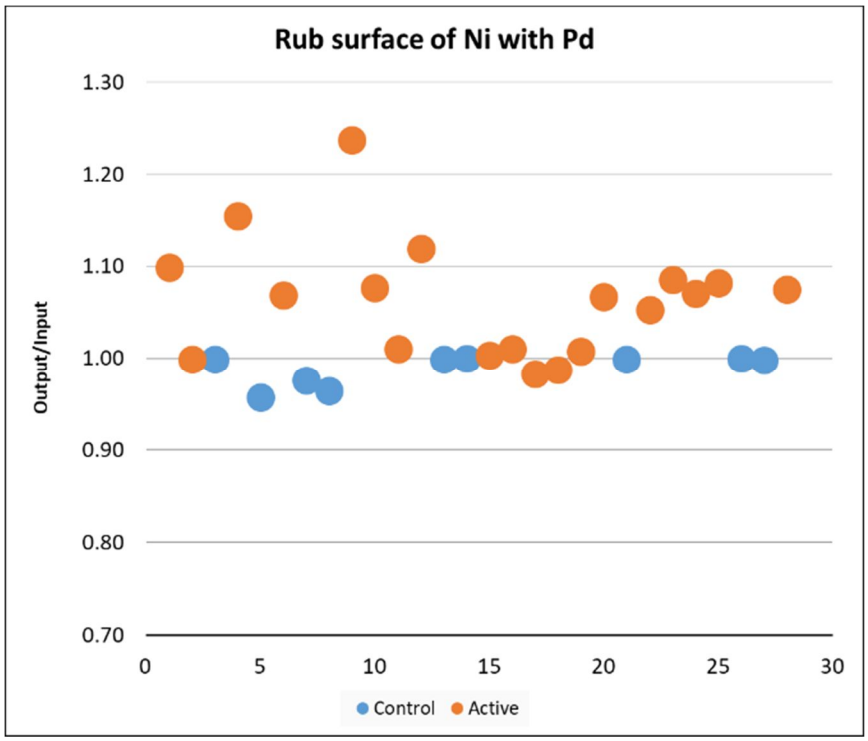
Reactor Type	Y/M/D	Gas	Pressure/Pa	Input/W	Input/J	Output/J	Out/In ratio	Note
Horizontal reactor	2017-07-31	H_2	1000	100	1,682,774	1,849,048	1.099	
Cruciform reactor	2017-08-11	H_2	1000	100	1,988,907	1,986,963	0.999	
Control reactor	2017-08-11			100	954,939	954,369	0.999	
Small reactor	2017-08-16	D_2	4300	100	1,134,604	1,310,820	1.155	
Control reactor	2017-08-17			100	1,095,464	1,048,656	0.957	
Horizontal reactor	2017-08-22	H_2	4400	100	2,475,451	2,645,703	1.069	
Control reactor	2017-08-23			100	1,073,070	1,047,574	0.976	
Control reactor	2017-08-24			100	722,292	696,057	0.964	
Cruciform reactor	2017-09-03	D_2	5	100	872,596	1,079,700	1.237	
Cruciform reactor	2017-09-04	D_2	440	100	2,023,744	2,179,102	1.077	
Cruciform reactor	2017-09-05	D_2	440	100	4,681,998	4,727,784	1.010	
Cruciform reactor	2017-09-06	D_2	450	100	2,223,785	2,487,819	1.119	
Control reactor	2017-09-22			100	7,133,503	7,130,645	0.999	
Control reactor	2017-10-24			100	5,945,668	5,945,879	1.000	
Cruciform reactor	2017-10-25	D_2	700	100	6,951,404	6,972,306	1.003	
Cruciform reactor	2017-10-30	D_2	700	100	8,486,767	8,571,331	1.010	
Cruciform reactor	2017-11-04	D_2	450	200	35,005,062	34,393,145	0.983	
Cruciform reactor	2017-11-06	D_2	450	200	34,872,291	34,419,324	0.987	
Cruciform reactor	2017-11-11	D_2	450	100	9,271,829	9,347,294	1.008	
Cruciform reactor	2017-11-14	D_2	450	400	5,197,115	5,544,791	1.067	
Control reactor	2017-11-15			400	5,188,383	5,120,565	0.987	1
Cruciform reactor	2017-11-16	D_2	450	400	8,697,784	9,158,332	1.053	
Cruciform reactor	2016-11-17	D_2	450	200	4,794,874	5,206,520	1.086	
Cruciform reactor	2017-11-20	D_2	1000	200	17,181,972	18,395,905	1.071	
Cruciform reactor	2017-11-21	D_2	750	200	12,284,247	13,295,871	1.082	
Control reactor	2017-11-22			200	31,018,327	31,029,317	1.000	
Control reactor	2017-11-24			200	7,863,331	7,844,518	0.998	
Cruciform reactor	2017-11-25	D_2	750	100	15,797,170	16,978,538	1.075	

Nickel mesh with Pd deposited by electroless plating								
Reactor Type	**Y/M/D**	**Gas**	**Pressure/Pa**	**Input/W**	**Input/J**	**Output/J**	**Out/In ratio**	
Horizontal reactor	2018-02-07	D_2	730	100	8,358,985	9,795,246	1.172	Note
Horizontal reactor	2018-02-09	D_2	730	200	4,832,873	5,517,399	1.142	
Horizontal reactor	2018-02-11	D_2	670	200	34,735,698	40,143,622	1.156	
Horizontal reactor	2018-02-19	D_2	670	200	16,378,841	17,944,523	1.096	
Horizontal reactor	2018-02-21	D_2	670	200	17,658,467	19,433,779	1.101	
Horizontal reactor	2018-02-23	D_2	670	200	19,987,849	20,300,518	1.016	
Horizontal reactor	2018-02-26	D_2	670	200	24,706,159	27,647,243	1.119	
Horizontal reactor	2018-02-27	D_2	670	200	34,047,355	38,512,169	1.131	
Control reactor	2018-03-02			200	12,017,927	12,011,411	0.999	
Control reactor	2018-03-03			200	40,064,544	39,531,093	0.987	
Horizontal reactor	2018-03-06			500	9,490,128	9,230,065	0.973	2
Control reactor	2018-03-07			500	11,773,594	10,525,780	0.894	3
Horizontal reactor	2018-03-16	D_2	670	200	12,647,145	14,494,439	1.146	
Horizontal reactor	2018-03-29	D_2	670	200	6,938,151	7,567,632	1.091	
Horizontal reactor	2018-04-04	D_2	590	200	14,994,441	17,089,653	1.140	
Control reactor	2018-04-05			200	6,436,231	6,440,424	1.001	
Horizontal reactor	2018-04-11	D_2	310	200	3,615,663	3,890,105	1.076	
Horizontal reactor	2018-04-13	D_2	590	200	10,041,212	10,670,584	1.063	
Control reactor	2018-04-16			200	12,101,014	12,133,129	1.003	
Horizontal reactor	2018-04-20	D_2	490	200	11,927,083	12,566,044	1.054	
Control reactor	2018-05-16			100	4,059,138	4,058,571	0.999	
Horizontal reactor	2018-05-16	D_2	500	100	5,055,918	5,368,056	1.062	
Horizontal reactor	2018-05-18	D_2:500+H_2:6000	6500	100	7,045,026	7,525,274	1.068	
Control reactor	2018-05-21			100	5,454,881	5,454,094	1.000	
Control reactor	2018-05-23			0	4	-1,547		4
Horizontal reactor	2018-05-23	D_2:500+H_2:6000	6500	200	8,042,550	8,421,538	1.047	
Horizontal reactor	2018-05-25	D_2:500+H_2:6000	6500	200	14,031,916	14,182,145	1.011	

Notes

1. This 400 W calibration should have produced a lower Out/In ratio. Perhaps the ratio was high because the test lasted only 3.6 hours.
2. With this 500 W test, the ratio is 0.973. With the 500 W calibration in the next row, the ratio is 0.894. Based on that, this test produced a ratio of 1.079. See graph 2 below.
3. The calibration at 500 W. The temperature in the box rose to 50°C, compared to ~36°C normally, so heat losses were higher. (The recovery rate was lower.)
4. A test with no input power to determine the effects of ambient temperature fluctuations.

Graph 1. 27 tests of palladium rubbed onto nickel.



Graph 2. 26 tests of palladium electroless plating onto nickel. The 500 W active test adjusted to the recovery rate shown by the 500 W calibration.