

The Arata Demonstration: A Review Summary

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On May 22, a special announcement/presentation was held at Osaka University by Prof. Yoshiaki Arata in the presence of colleagues, guests, and press. The announcement of new results took place in Arata Hall, a campus building named for Prof. Arata, and a demonstration took place in the Arata-Zhang laboratory room in a nearby research building. A research paper describing recent results was made available in Japanese and English versions. The English version has just been published in the *J. High Temp. Soc. Jpn.*¹ The big event seems to have been disclosure of a new deuterium-fueled cold fusion reactor using no electrical power. The reactor contains pressurized D₂ gas and releases a steady flow of heat to its surroundings. It is hard to explain the observed heat flow without accepting the reality of cold fusion. This review is based on the new results as interpreted in terms of previous papers by the Arata and Zhang (A-Z) collaboration.

To understand the significance of the new A-Z work it is helpful to review a few aspects of Arata's professional career, and of the A-Z collaboration. I'm writing from memory and not as a historian. Arata was a young scientist starting his career after World War II. His interest was in thermonuclear fusion and in the engineering of very high temperature plasma devices to release nuclear energy. At the time there was no deuterium gas available in Japan, but there was heavy water D₂O. He built his own electrochemical deuterium production cell in which D₂O was electrolyzed onto a Pd separator-wall cathode producing pure deuterium on its gas-col-

lecting side. He used the very high purity deuterium gas product in high current density plasma devices in which condenser bank discharges created conditions approaching plasma fusion temperatures. One experiment used a palladium bottle with walls packed with fine Pd crystals, seeking high temperature "solid fusion" conditions. For a period of time his arc discharges held a world record. Later he developed a program for electron beam and laser welding, became Director General of the Welding Research Institute at Osaka University, and received many prizes. One of the prizes was the Arthur Schawlow Award, given him by the American Society for Metals. He also was elected member of the Japan Academy and twice received recognition from the Emperor of Japan for his work.

I go through this history to emphasize that Arata's main work has been in classical physics and engineering, and that he came to the cold fusion field in 1989 with unusual skills, but with the cold fusion skepticism possessed by most scientists. But he was also determined to find out whether cold fusion is real. His collaboration with Dr. Yue-Chang Zhang was already established at this time. Dr. Zhang is from Shanghai Jiotong University. The research has been a hands-on laboratory effort conducted with mutual dialog and respect.

The A-Z team has been exploring the use of nano-scale Pd powder to catalyze the generation of cold fusion heat. They have been the pioneers of what could be called "nanotechnology nuclear fusion." Between 1994 and 2002 their work focused on exploring the use of Pd-black to promote deuterium nuclear fusion reaction. Their 1994 paper,² designated A-Z (1994), is especially important, not only for the large amount of excess heat observed, but also for the protocol that they invented to select suitable catalytic material. The material evaluation protocol is shown in Figure 1. It set the stage for later work. It involves the controlled flow of hydrogen gas into a known amount of carefully prepared catalytic material inside a vessel of known volume. In their latest work they similarly use needle-valve control to set the rate of gas flow into a single-vessel reactor. During the start-up interval of gas-loading, the reactor catalyst bed rises to a relatively high initial operating temperature.

The first A-Z study to use a nano-material catalyst other than Pd-black is one published in 2002, designated A-Z (2002).³ All their subsequent papers have used this new type of catalyst, which was invented at the Institute for Materials Research at Tohoku University.⁴ (A detailed protocol for cat-

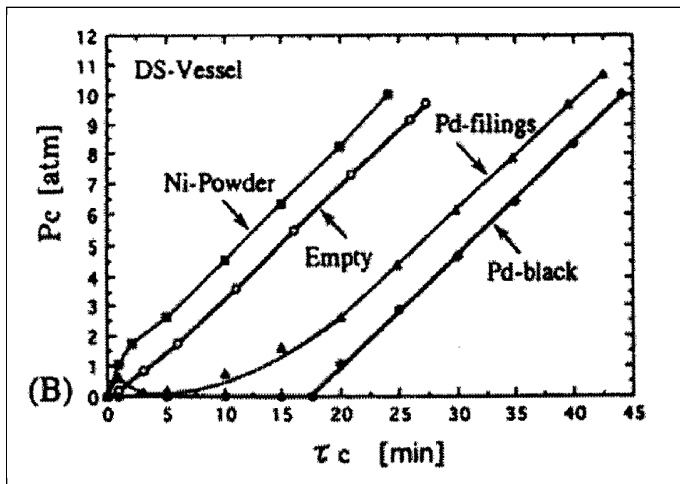


Figure 1. [A-Z (1994) Figure 6B] Hydrogen absorption characteristics of various metal samples. Test sample is placed in test vessel and thoroughly evacuated. Hydrogen is flowed into test vessel at standardized flow rate in cc-atm/min. Pressure vs. time is recorded. Pd-black catalyst acts as chemical getter pump keeping pressure below pressure gage threshold for 17.6 minutes. Data reported at ICCF10 showed that the "zero-pressure period" for ZrO₂ + nanoPd catalyst is 25% longer than for Pd-black.

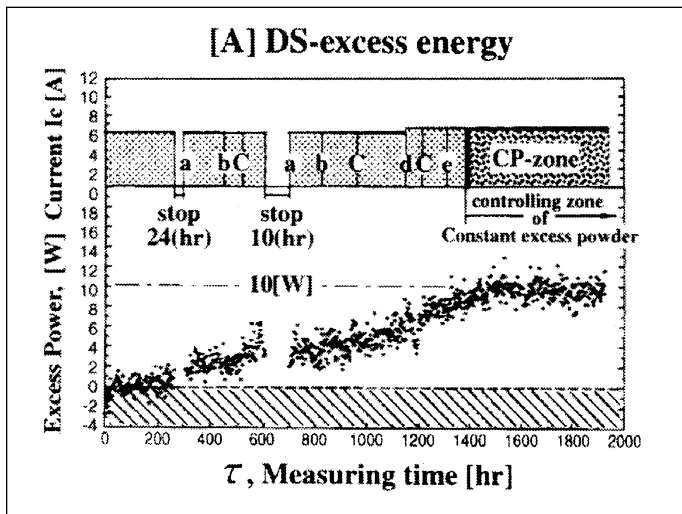


Figure 2. [A-Z (2002) Figure 4A] Run data showing ~10 Watts of excess heat power for three weeks.

alyst production is presented in the reference.) The many deuterium + Pd-black studies subsequent to A-Z (1994) consistently achieved “excess heat,” but not with the quantitative repeatability needed for engineering devices. A non-A-Z study showed that Pd-black can lose its nanometal properties by crystal growth.⁵ The new family of nanometal powders avoids this problem. The new powders were successfully tested in an electrochemically driven reactor in 2002, and in a gas loading reactor operating at elevated temperature in 2005. The 2008 paper shows for the first time a reactor that continuously generates fusion heat in a hermetically sealed vessel isolated from its environment except for heat flow from the reactor to the room. A-Z (2002) used the same double concentric-vessel reactor geometry (DS-cathode geometry) used in A-Z (1994). All the A-Z electrolysis studies have used electrochemistry to deposit deuterium onto a Pd metal cylinder which is part of the inner vessel containing the catalyst. Figure 2 in this paper [A-Z (2002) Figure 4A] shows that they achieved a steady fusion heat generation of ~10 W throughout a three-week period using a $ZrO_2 + \text{nanoPd}$ catalyst.

The A-Z study reported in 2005 was their first reactor to use gas loading instead of electrolysis.⁶ A-Z (2005) used the A-Z (1994) DS-cathode geometry, but eliminated electrolysis. Because no electrolysis input energy was used, there was no need to subtract electrolysis input energy from the total output energy to calculate fusion energy produced. They carried

out four studies using a programmed electrical heater element to raise the reactor wall temperature to a stable elevated working temperature. The first test used an empty reactor (no catalyst). The heater power was varied with time so as to raise the reactor wall to a steady operating temperature of 141°C. The outer vessel was quickly filled with D_2 gas to a pressure of 40 atm, at which time the gas flow was turned off and the heater power was held constant. Using this protocol, tests two and three were carried out with the inner vessel containing Pd-black catalyst. Operation using H_2 inflow was compared with operation using D_2 inflow. When H_2 was used, the reactor stabilized with the reactor wall temperature hotter than the catalyst. When D_2 was used, the catalyst was hotter than the reactor wall, indicating that nuclear reaction was being catalyzed. In a fourth test $ZrO_2 + \text{nanoPd}$ catalyst was substituted for the Pd-black. The temperature difference between catalyst and reactor wall increased by about a factor of ~8 relative to test three and the reactor wall temperature increased by about 42°C using the same heater power. A-Z (2005) provides strong evidence that significant cold fusion power can be produced at 183°C. Quantifying fusion power output requires subtraction of heater power from total output power to prove a net gain in energy.

The A-Z (2008) study, the results of which were reported at the May 22 presentation, was the first study to use gas loading without use of electrical heating and with reactor operation beginning at room temperature. No electrical power of any kind was ever employed. This feature means that all heat flow produced must be associated with gas compression, chemical reaction, nuclear reaction, or some other unidentified new physics. Gas compression heating is in accord with thermodynamics, and chemical reaction heating varies with D/Pd ratio in accord with reversible chemistry. A-Z (2008) provides a time history of heat release which separates chemical heat release from pure nuclear heat release. The non-nuclear heat releases are early events, occurring only during the gas pressurization of the reactor or within a short period thereafter. Therefore, any heat flow observed long after the experiment’s start must be due to nuclear heat, since no believable alternative radiationless power-producing process has been suggested. This makes the new studies of unique importance for demonstrating to the world that cold fusion is a real phenomenon.

This summary is intended primarily as a review of the A-Z (2008) paper, “The Establishment of Solid Nuclear Fusion Reactor.” A-Z (2008) is best viewed as two separate studies.

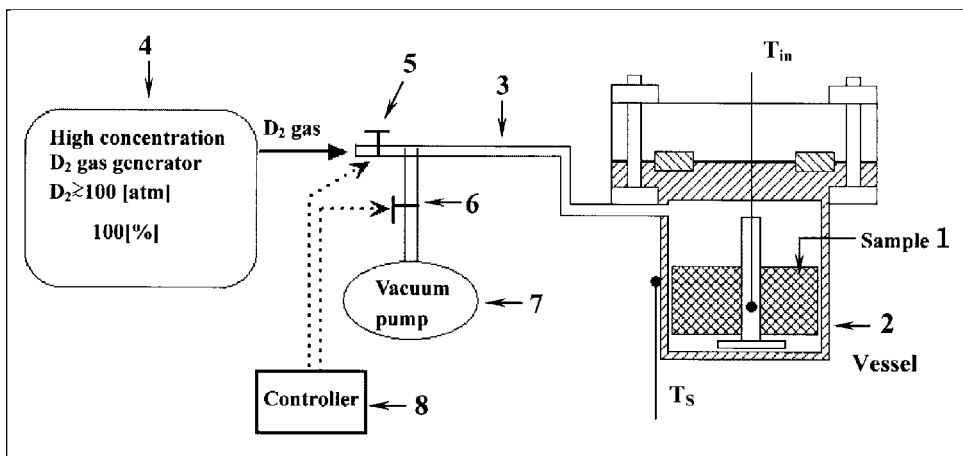


Figure 3. [A-Z (2008) Figure 1] Experimental device.

Both studies made use of a much simplified single-vessel reactor, as shown in Figure 3. A-Z eliminated the inner vessel with its Pd cylinder wall, which had functioned as a gas purifier and had slowed down hydrogen flow onto the reactor’s catalyst bed. The single-vessel reactor uses needle-valve gas inflow control directly onto the catalyst bed. Study A compared reactor operation using $ZrO_2 + \text{nanoPd}$ catalyst and D_2 pressurization with operation using H_2 pressurization. When H_2 pressurization was used, an initial temperature rise occurred. After

a relatively short initial interval during which both catalyst and wall temperatures were well above room temperature, both temperatures rapidly fell towards and remained at room temperature. When D₂ pressurization was used, the initial temperature rise was increased, and the temperatures then fell and stabilized at constant values that were measurably above room temperature. Moreover, the catalyst temperature remained higher than the wall temperature. These elevated reactor temperatures continued for at least hundreds of hours. This temperature behavior demonstrated that a steady level of nuclear reaction had been initiated by deuterium inflow and had subsequently continued for hundreds of hours.

Let us look at A-Z (2008) in more detail. Figure 3 [in this review] shows the central location of the catalyst bed and the placement of a thermocouple therein. The catalyst temperature is designated T_{in}. The location of the thermocouple measuring reactor wall temperature is also shown. Wall temperature is designated T_s, where subscript s refers to stainless steel. For each of the two runs described above, the catalyst bed contained 7 grams of ZrO₂ + nanoPd catalyst.

The run histories are shown in Figures 4 and 5 [A-Z (2008) Figure 5A and Figure 5B]. A-Z divide up the run time into two intervals. They designate the start-up interval as the "Jet-Fusion Zone" and the rest of the run is designated the "Skirt-Fusion Zone." A-Z like to provide visual pictures of what may be happening, like the pictures of electric and magnetic field lines used by Michael Faraday. These picture names are chosen to help readers. The catalyst is initially under vacuum. The Jet-Fusion Zone begins when gas inflow begins and ends when a noticeable pressure is registered by a gage measuring vessel pressure. During this start-up period, the gas molecules are pictured as moving through vacuum like a jet onto the catalyst bed. The catalyst acts like a chemical getter pump, absorbing all the incident molecules and releasing the chemical heat of hydride formation. The name "skirt" seems to be taken from the verb "skirt," as used in "the river skirts the hillside." Figure 4 shows reactor temperatures during the first part of the Skirt-Fusion Zone for the H₂ and D₂ pressurization runs. [Ignore Curve B, because it relates to Study B.] With H₂ pressurization, the Skirt-Fusion Zone starts with T_{in} at 62°C, marked by point C₀, whereas with D₂ pressurization the Skirt-Fusion Zone starts with T_{in} at 72°C, marked by point A₀. A-Z consider the higher value of A₀ relative to C₀ as evidence that deuterium fusion begins during the Jet-Fusion interval. Subsequently, both T_{in} and T_s decrease towards stable values. Figure 5 shows what happens to Curves A and C over the next 2700 hours. For the H₂ loading study, Curves C show that both T_s and T_{in} rapidly fall to room temperature. There is no fusion. For the D₂ study Curves A show that both T_s and T_{in} gradually approach stable constant values that are higher than room temperature, with T_{in} being higher than T_s. Fusion is occurring and heat is flowing from the catalyst volume outward toward the room.

The constant heat flow period is observed after the initial chemical-reaction heat transient had gone away. This is strong evidence for cold fusion reality. Persons believing in conservation of energy and believing that heat always flows from high temperature to lower temperature must conclude that a nuclear source of heat was present. I say nuclear because no plausible large magnitude alternative energy

source has been identified.

The evidence that at least some of the heat was due to the nuclear fusion of deuterium to helium-4 is redundantly demonstrated by the presence of helium-4 in both post-run gas and post-run catalyst for the D₂ run, whereas no post-run helium-4 is observed for the H₂ run. Study A includes the results of mass spectrometer measurements on post-run material recovered from the reactor after operation. In their previous studies A-Z have recovered samples of gas and catalyst after their experiment runs had been completed. They examine samples of gas recovered from the inner vessel using a quadrupole mass spectrometer specially programmed to repetitively scan the mass-4 peak. Their instrument clearly resolves the peak associated with D₂ gas from the peak associated with ⁴He. For post-run catalyst powder, their procedure is to place the powder sample in a small oven, thoroughly pump away all adsorbed gas that is removable at slightly elevated temperature, raise the oven temperature, and record spectra as previously described. Paper A shows such spectra for the H₂ run and for the D₂ run. These

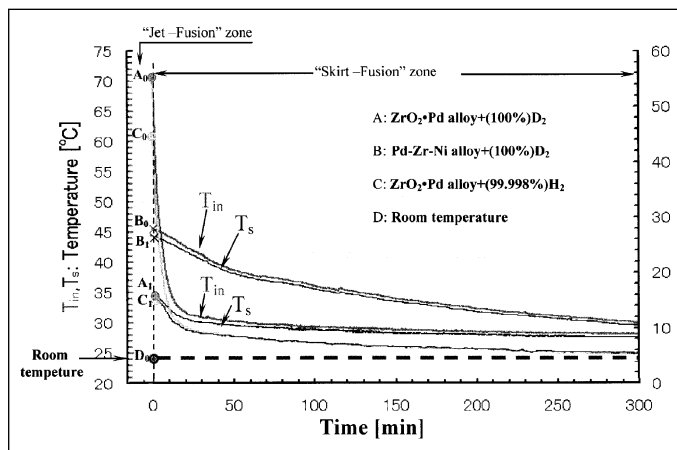


Figure 4. [A-Z (2008) Figure 5A] Temperature and pressure vs. run time. Catalyst temperature T_{in} and reactor wall temperature T_s are plotted for three runs beginning after pressure gage shows non-zero reading. Time history curves A₀ and A₁ are for ZrO₂ + nanoPd with D₂ gas. Curves C₀ and C₁ are for the same catalyst with H₂ gas. Curves B₀ and B₁ are with D₂ gas and test catalyst containing ZrO₂ + Ni,Pd alloy. Catalyst weights = 9 g for ZrO₂ + nanoPd, and 18 g for ZrO₂ + Ni,Pd alloy.

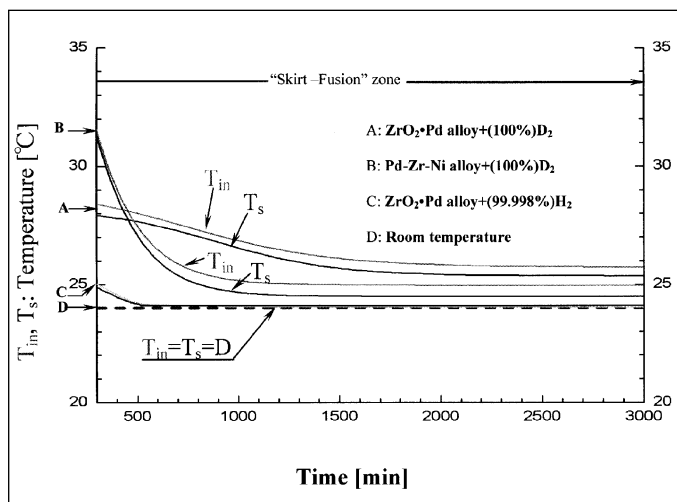


Figure 5. [A-Z (2008) Figure 5B] Same as Figure 4, but run time goes to 3000 min.

data are shown in [A-Z (2008) Figure 7], which is not included in this review. Strong ^4He peaks are shown for material recovered from the D_2 inflow reactors and no ^4He peaks are shown for the H_2 inflow reactors.

Study B is solely concerned with the first test of a ZrO_2 + nanometal catalyst in which the nanometal is something other than nanoPd. In Study B the nanometal tested was a Ni,Pd alloy. The catalyst was probably prepared by oxidizing a 65%Zr,30%Ni,5%Pd alloy. This conclusion is based on the long "Jet-Fusion" interval shown in [A-Z (2008) Figure 3] (not shown in this review). In the alloy study 18 grams of catalyst was used instead of the 7 grams used in the studies described in Study A. Compared with the Study A, higher temperatures are shown in the early intervals of run time, but the wall temperature T_s approached during the later part of the Skirt Fusion Zone shown in Figure 5 is closer to room temperature than that shown for ZrO_2 + nanoPd catalyst. The T_s value shown in Curve B of Figure 5 demonstrates fusion heating, but the fusion heat per Pd atom may be about the same as for the ZrO_2 + nanoPd catalyst.

Looking towards the future, there are three studies that come to mind. The A-Z (2008) work would be more impressive if higher T_{in} and T_s were achieved. Studies using larger amounts of ZrO_2 + nanoPd catalyst should be able to achieve this goal. Second, tests with ZrO_2 + nanoNi are needed to see if cold fusion heaters can be made without use of Pd. A third type of study might be to use a gas loading reactor system that provides reaction stimulation by deuterium flow. Deuterium fluxing seems to increase fusion rate. Non-stimulated and stimulated fusion rates should eventually be calculable.

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