

Replications

Since Martin Fleischmann and Stanley Pons first reported anomalous heat generation in deuterated palladium electrolysis, most AHE experiments have built upon historical reports. While Callisto has sought to probe the less explored gas loading systems and utilize novel stimulation, we have attempted to replicate some of the previously published reports of AHE, primarily those for gas-loaded systems. Experiments were prioritized to be replicated if the work had commonalities with our D-D thesis regarding AHE, the publishing scientist was a particularly credible source, and the work had been reported to have been successfully reproduced by others.

Arata

Japan has a long history of research in the LENR field, particularly with a focus on gas phase loading and nano-structured palladium samples. Funding in Japan has come from both government and major industry and has attracted some reputable scientists. Yoshiaki Arata was known as an established physicist and leader in nuclear physics in Japan. His early work in LENR involved palladium nanoparticles and palladium nanocomposites in a thick-walled palladium vessel used as a cathode in electrolytic experiments which he termed the ‘double structure cathode’ or DS-cell. Later, this same approach was used in gas loading where he reported elevated temperatures on the interior of the DS-cell when the process gas was deuterium, but no excess heat was detected under protium³⁷. In his final work he stopped using the DS-cell and focused on nano-composite samples in a custom apparatus. Throughout his entire body of LENR work, Arata et al. reported the detection of excess heat.

We elected to replicate two of Arata’s experimental campaigns. The first used the DS-cell and a nano-composite sample composed of ZrO₂ and Pd atomic clusters (nano particles having D=<5nm). This experiment was intriguing due to our findings that Pd nanoparticles tend to agglomerate when loaded (Figure 1), and possibly lose the potentially unique properties of nanoparticles. However, when anchored to a support matrix of ZrO₂, they are prevented from agglomerating allowing the testing of loaded and isolated nanoparticles. The publications regarding these experiments provided details of numerous control experiments showing the effect only occurred with a specific sample and gas type.

³⁷ Arata, Y., & Zhang, Y.-C. (2005). Development of "DS-Reactor" as a practical reactor of cold fusion based on the "DS-cell" with "DS-Cathode". In Proceedings of the 12th International Conference on Cold Fusion (ICCF-12).

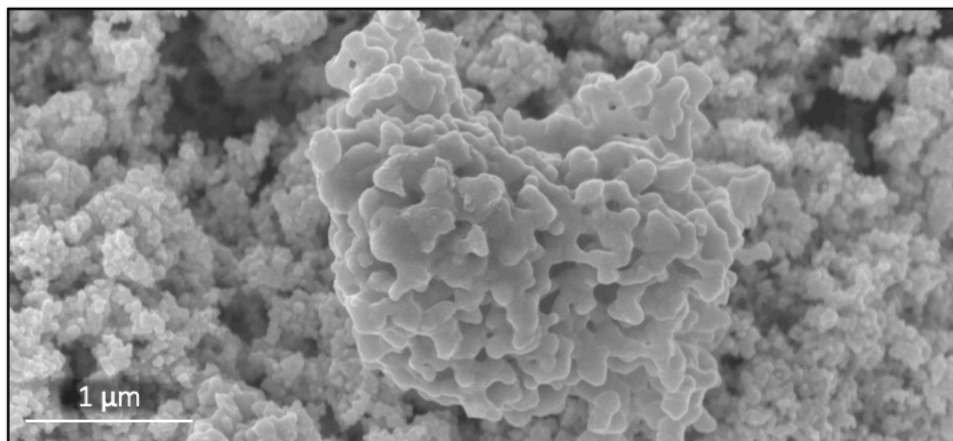


Fig 1. Callisto SEM image shows the agglomeration of palladium nanoparticles following exposure to H_2 gas.

The second of Arata's experiments replicated by Callisto focused on alternative nano-composite compositions in a more sophisticated heat detecting apparatus. We were able to successfully replicate some of the reported samples and match experimental conditions in state-of-the-art Setaram calorimeters.

Arata : Material Replication

The nanocomposites that Arata claimed were a key component of his success were comprised of a zirconium dioxide matrix with interspersed palladium atomic clusters, or sub 5nm nanoparticles. As outlined in his ICCF12 presentation and references therein, the nanocomposite was synthesized by first melt-spinning an alloy of 65at% Zr, 35at% Pd into thin, amorphous ribbons. The glassy alloy was then annealed in air to oxidize the zirconium and allow the palladium to precipitate into atomic clusters. For our replication (Figure 2), the alloy was first made by arc melting zirconium and palladium in proper ratios under an Ar atmosphere. The resulting alloy pellets were strip cast into amorphous ribbons at the Royce Institute at the University of Sheffield. This process involves inductively melting the alloy and injecting the molten alloy onto a liquid nitrogen cooled, spinning copper wheel. This process can quench the liquid at a rate of $>1,000,000\text{C/s}$ preventing the formation of any crystalline structure during freezing. Due to the highly reactive nature of zirconium, we used custom quartz crucibles for this process which proved to maintain purity of the amorphous alloy. The calcination of the amorphous ribbons using the conditions provided by Arata et al. did not yield results matching his characterization, so many different annealing conditions were tested until characterization matched. Annealing for 10 hours at 500C in atmosphere yielded the closest results to the literature reports (Figures 3,4). {However, all of the other synthesized materials were also tested for AHE activity.} The resulting brittle ribbons were ground into a fine powder using a planetary ball mill at 600RPM for 30 minutes. XRD analysis

with phase identification and crystallite size was the primary method which we used for characterizing each batch of material. In the XRD analysis, the desired result would show complete segregation of the palladium and zirconium (no intermetallic phases identified), full oxidation of the zirconium, no oxidation of the palladium, and small average crystallite size for pure palladium phases. Annealing for 10 hours at 500C fulfilled nearly all of these requirements but did show oxidation of the palladium. The nano-composite was then reduced in a tube furnace for 30 minutes at 400C under flowing forming gas (5% H_2 , balance Ar).

Synthesis of nanoPd·ZrO₂ composite

1. Zr₆₅Pd₃₅ is melted and rapidly quenched resulting in an amorphous alloy
2. The amorphous alloy is annealed in air allowing the Pd and Zr to phase-segregate. The Zr reacts with air to form ZrO₂ while the Pd precipitates into atomic clusters
3. The material is further annealed under reducing conditions to remove any oxide from the Pd

X-Ray Diffraction Analysis

Step	Identified phases	Avg crystallite size (nm)
1	Amorphous	N/A
2	ZrO ₂ PdO	9.5 4.9
3	ZrO ₂ Pd	7.6 7.8

Fig 2. Steps in synthesis process and XRD characterization after each step

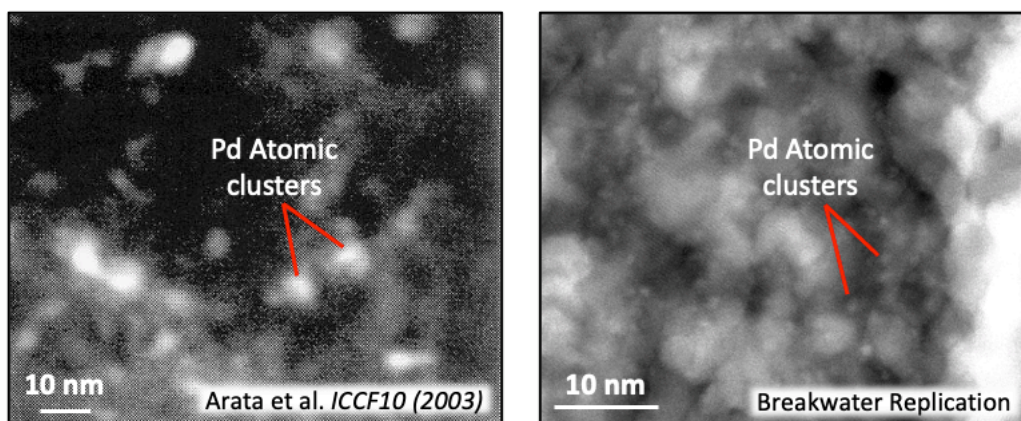


Fig 3. Comparison of transmission electron micrographs published by Arata et al.³⁸ and Callisto's replicated material.

³⁸ Arata, Y., & Zhang, Y. C. (2003). Development of compact nuclear fusion reactor using solid Pycnodeuterium as nuclear fuel. Paper presented at the 10th International Conference on Cold Fusion.

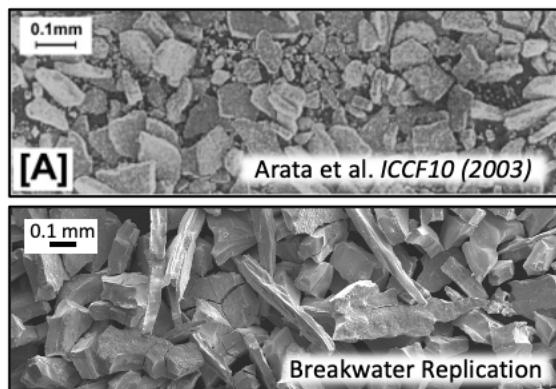


Fig 4. Comparison of scanning electron micrographs published by Arata et al. and Callisto's replicated material.

In addition to claiming nano-palladium facilitated AHE, Arata also reported that loading measurements on the nanocomposite showed 250% D/Pd loading at only 3atm and up to 400% D/Pd loadings near 100atm. Using a Quantachrome iSorb HP1, we measured the uptake of our replicated nanocomposites. When H₂ or D₂ uptake was normalized to the palladium content of the sample, the corresponding loading fraction very closely matched the expected loading for bulk palladium (Figure 5). It did not match the much higher loadings reported by Arata.

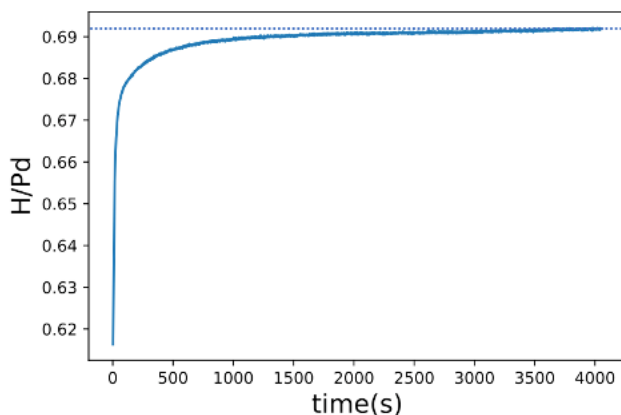


Fig 5. A hydrogen uptake measurement of replicated nanocomposite with <10nm palladium particles taken at 40C and 20bar. The uptake was normalized to the palladium content of the sample. Expected fractional loading for bulk palladium under these conditions is 0.71 H/Pd.

Arata : Experimental

Arata's DS-reactor was comprised of a 3mm wall thickness palladium pressure vessel containing sample material nested inside a stainless steel pressure vessel. Each vessel had isolated pressure

and electrical access. A heating mantle surrounded the outer pressure vessel and was used to heat the entire apparatus. The DS-cell had access to vent/vacuum, a pressure gauge(P_{in}), and a temperature sensor embedded in the sample material(T_{in}). The outer vessel was equipped with vent/vacuum, a pressure gauge(P_{out}), a temperature sensor(T_{out}), and a high pressure process gas inlet.

For Arata's experiments, the initial conditions were ambient temperature and vacuum in both the inner and outer vessels. The outer vessel was then pressurized to $P_{out} \sim 40\text{--}80\text{atm}$ of process gas (H_2/D_2) and the heating jacket turned on targeting a temperature $T_{out} \sim 140^\circ\text{C}$. The process gas was then able to diffuse through the palladium DS-cell walls and into the sample. Because the heater was wrapped around the outer vessel and heat must conductively diffuse from the outer wall to the sample, it is to be expected that $T_{out} > T_{in}$. Arata reported this to be true for control experiments using H_2 process gas and for bulk palladium when using D_2 gas. However, when using palladium black or zirconia supported palladium nano particles with D_2 , it was reported that the sample temperature was hotter than the temperature outside of the DS-cell, i.e., $T_{in} > T_{out}$ (Figures 6,7).

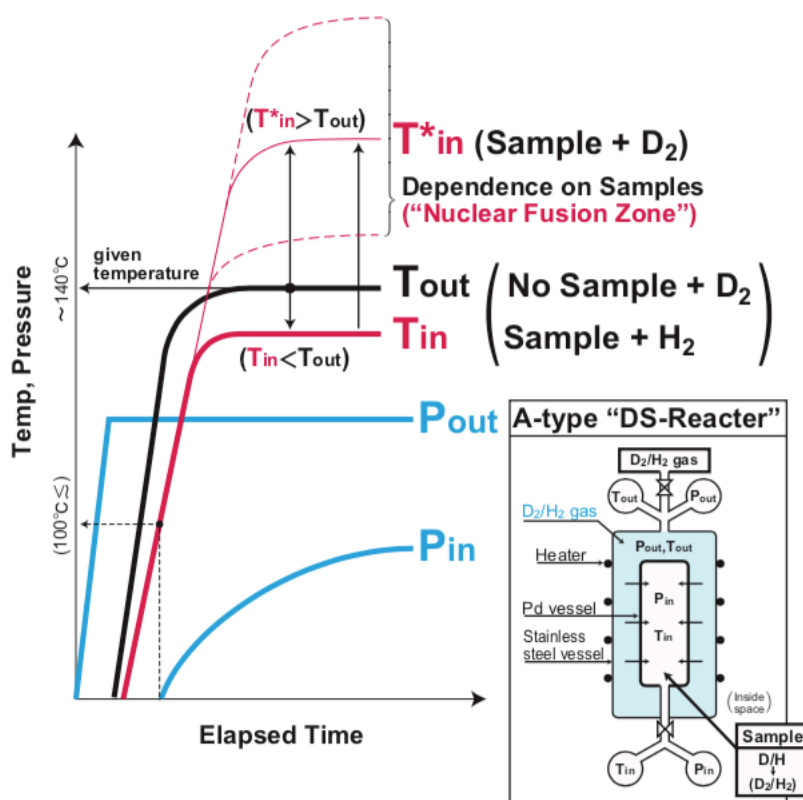


Fig 6. Apparatus and experiment description from "ICCF12: Yoshiaki Arata, M.J.A. Yue-Chang Zhang Center for Advanced Science and Innovation, Osaka University."

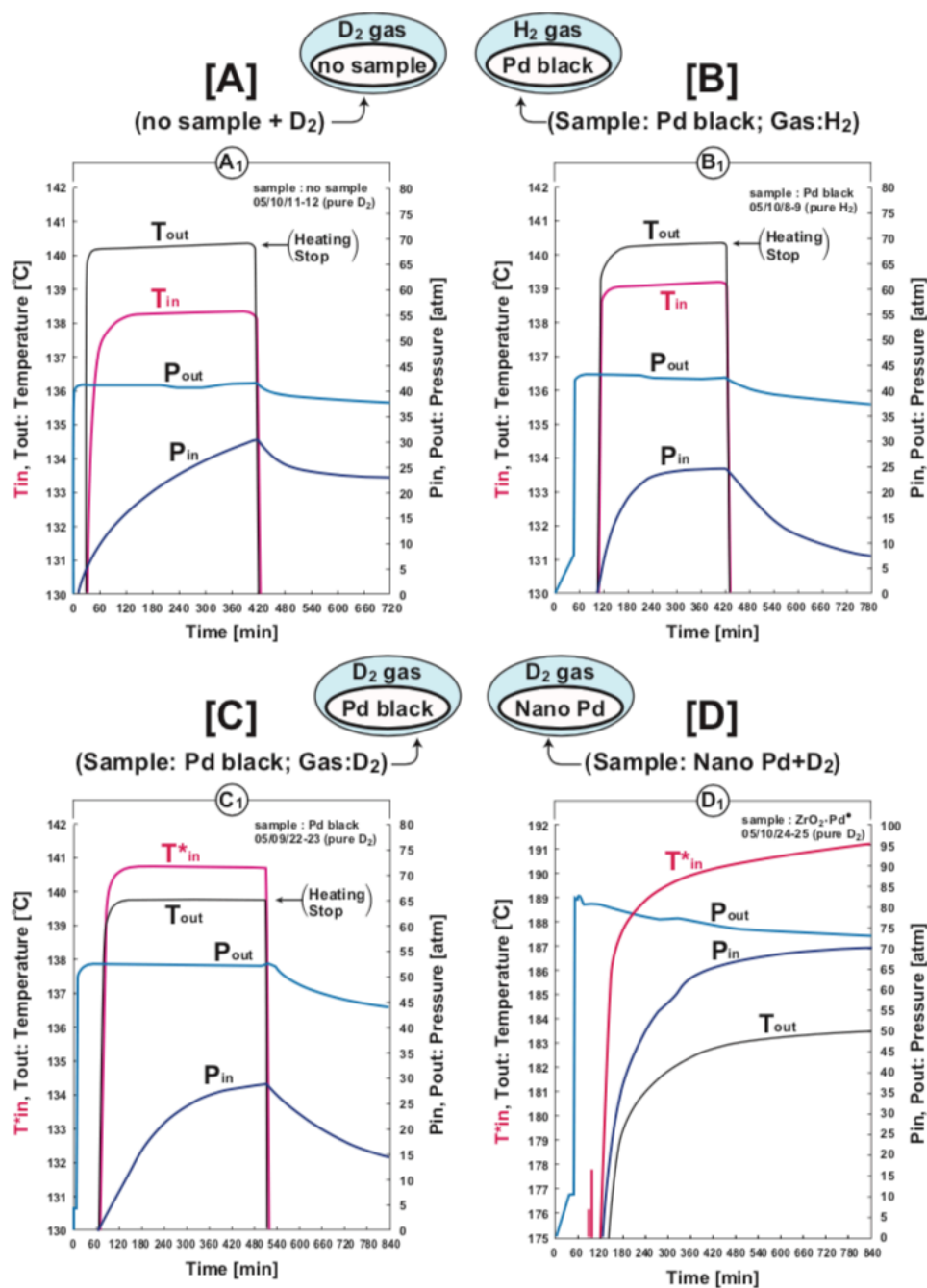


Fig 7. Experiment summaries from "ICCF12: Yoshiaki Arata, M.J.A. Yue-Chang Zhang Center for Advanced Science and Innovation, Osaka University."

Our replication apparatus (Figure 8) connected the outer stainless steel vessel to a manifolded pressure system with vent/vacuum, hydrogen, deuterium, and helium process gasses. A pressure transducer and electrical passthroughs were installed between the manifold and vessel using 125 μ m diameter insulated platinum wires connected to an RTD element in contact with the outer wall of the DS-cell to represent T_{out} and P_{out}. The DS-cell was machined from a palladium rod with

14mm outer diameter, 50mm length, to reach an 8mm diameter bore, with 47mm bore depth. The DS-cell was sealed by brazing the palladium to an Inconel cap/tube stub using Nicro (82Au 18Ni). The cap was connected to a 1/8in tube which was fed through the 1/4in inlet line to the stainless steel vessel. The inner tube contained electrical passthroughs connected to an RTD which was immersed into the sample material installed in the DS-cell.

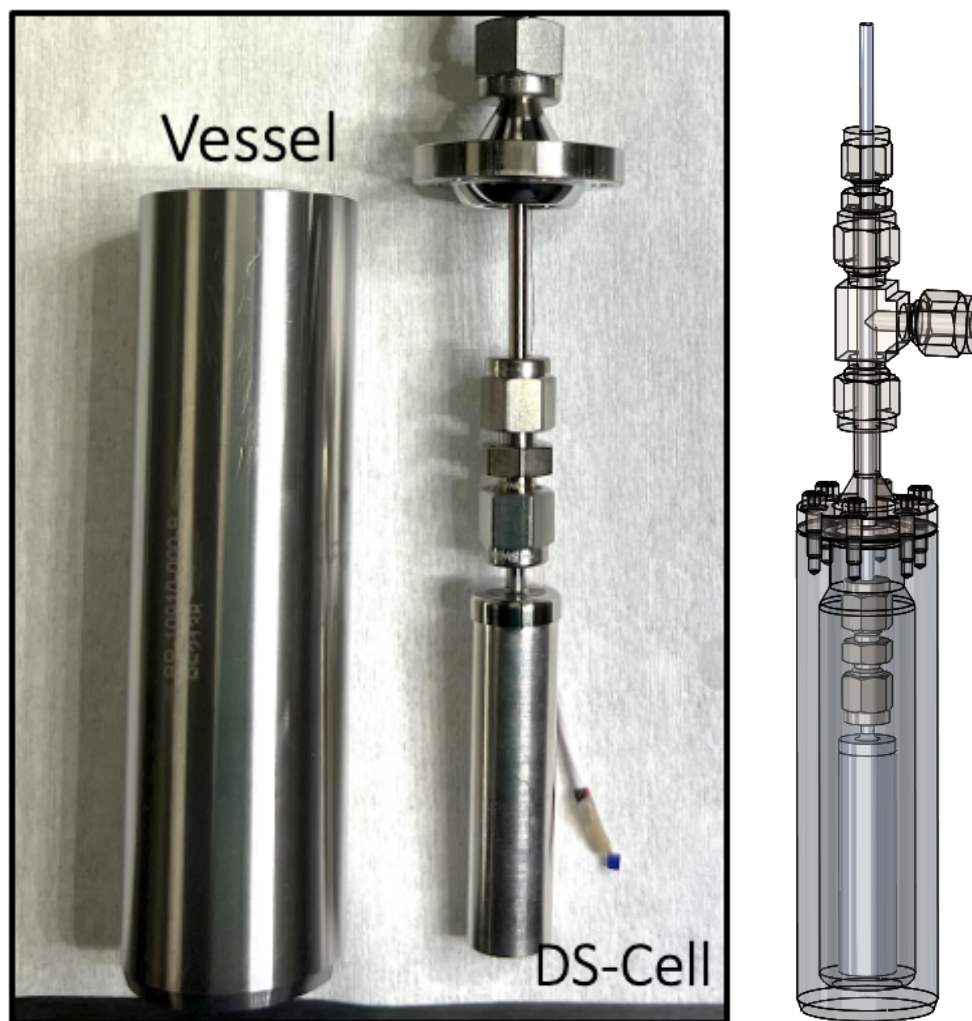


Fig 8. Callisto replication vessel and DS-cell

This apparatus was used to screen multiple batches of replicated Arata nano-composite samples and multiple variations of the procedures. In nearly all experiments, $T_{in} < T_{out}$, indicating a negative AHE result. In the set of experiments where $T_{in} > T_{out}$, it was determined to be caused by irreversible changes to the RTD upon pressurization as the offset persisted after the heater was turned off and the system returned to ambient conditions (Figure 9).

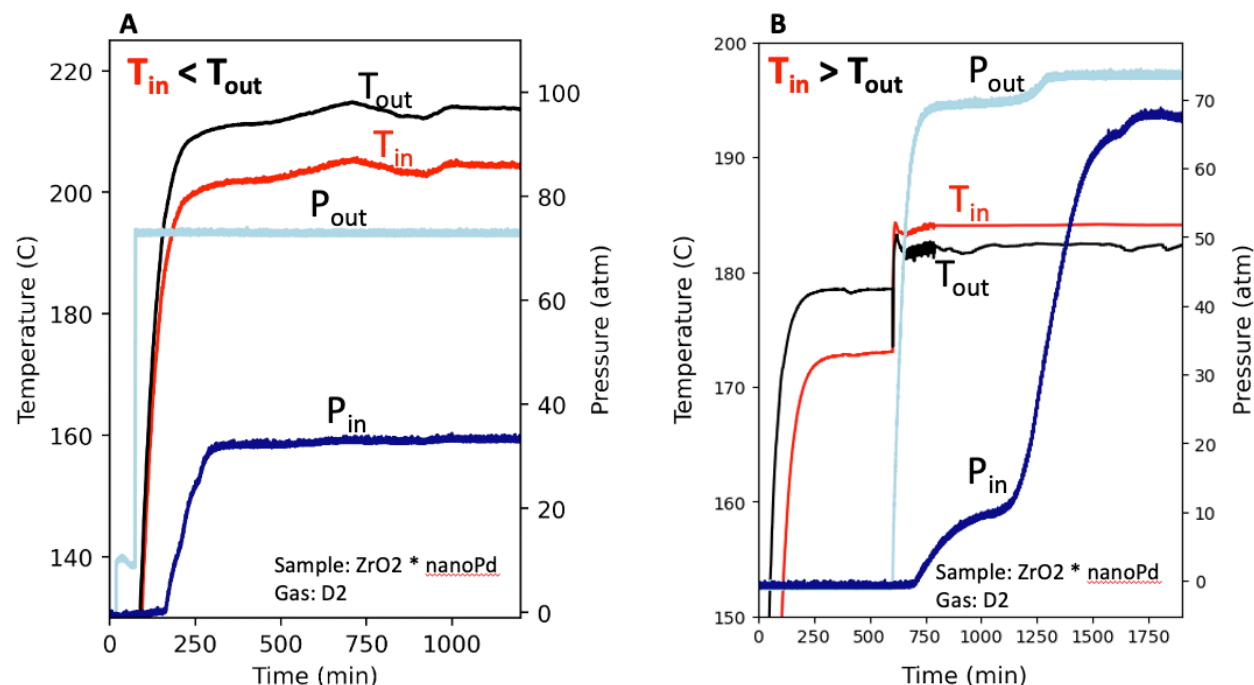


Fig 9. A) Callisto Experiment BE2606. The outer vessel was pressurized while simultaneously turning on a constant power heater. A leak was suspected but it was unclear why P_{in} did not equilibrate with P_{out} , however, many of Arata's published experiments show similar characteristics. As expected $T_{in} < T_{out}$. B) Callisto Experiment BE2758. The heater was commanded to a setpoint of 200C and both RTDs were allowed to equilibrate before pressure was introduced to the outer vessel. Upon pressurization, the reading of both RTDs increased with $T_{in} > T_{out}$. While this was unexpected, D₂ gas had not diffused into the sample at the time of the inversion and so the cause was not suspected to be AHE. Further testing revealed the pressure caused irreversible changes to the RTD.

While the temperature probes in different locations could theoretically indicate the generation of heat within the sample material, it is not an accurate or sensitive metric.

A more sophisticated approach is to use differential calorimetry where heat flow is directly measured between two nearly identical systems with one exposed to D₂ and the other exposed to H₂. This methodology, employing a C80 Setaram calorimeter, is further discussed in the Calorimetry section of this report.

For the Arata-replication calorimetry experiments, custom sample vessels were designed to maximize sample volume and minimize thermal mass. Early designs showed standard hardware was inconsistent at sealing at 175C and eventually, a mono-block vessel was designed which had all welded joints and VCR fittings (Figure 10).

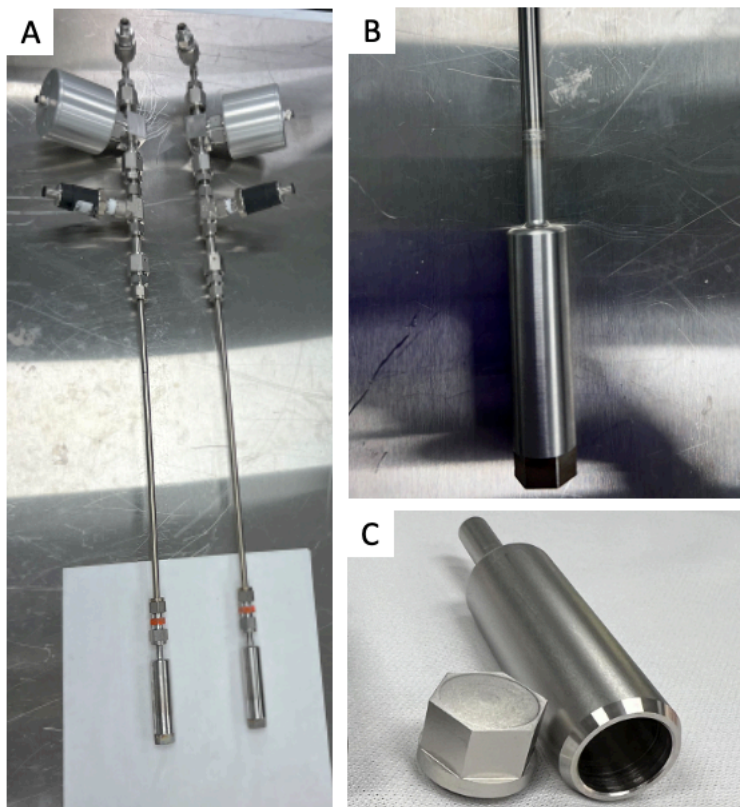


Fig 10. A) Early downtube assembly showing pressure inlet, isolation valves, pressure transducers, and filtered fittings to the vessels. B) Leaks were prevented by orbital tube welding the mono-block vessel to the downtube assembly. C) In order to achieve leak free mono-block vessels with large sample volume and small thermal mass, the vessels were cut open, precision hollowed out, and welded back together.

In these experiments, sample masses were matched within 1%, typically between 5-10g each, and exposed to 1000psi at 175C. Each experiment exposed the samples to multiple pressure/temperature cycles lasting 4-100 hours. During the active period of each cycle, pressures and temperatures were allowed to equilibrate before an isolation valve was closed on each channel. Between cycles, the samples were allowed to degas at 175C under vacuum. Figure 11 shows the results of a representative experiment, displaying no measurable excess heat.

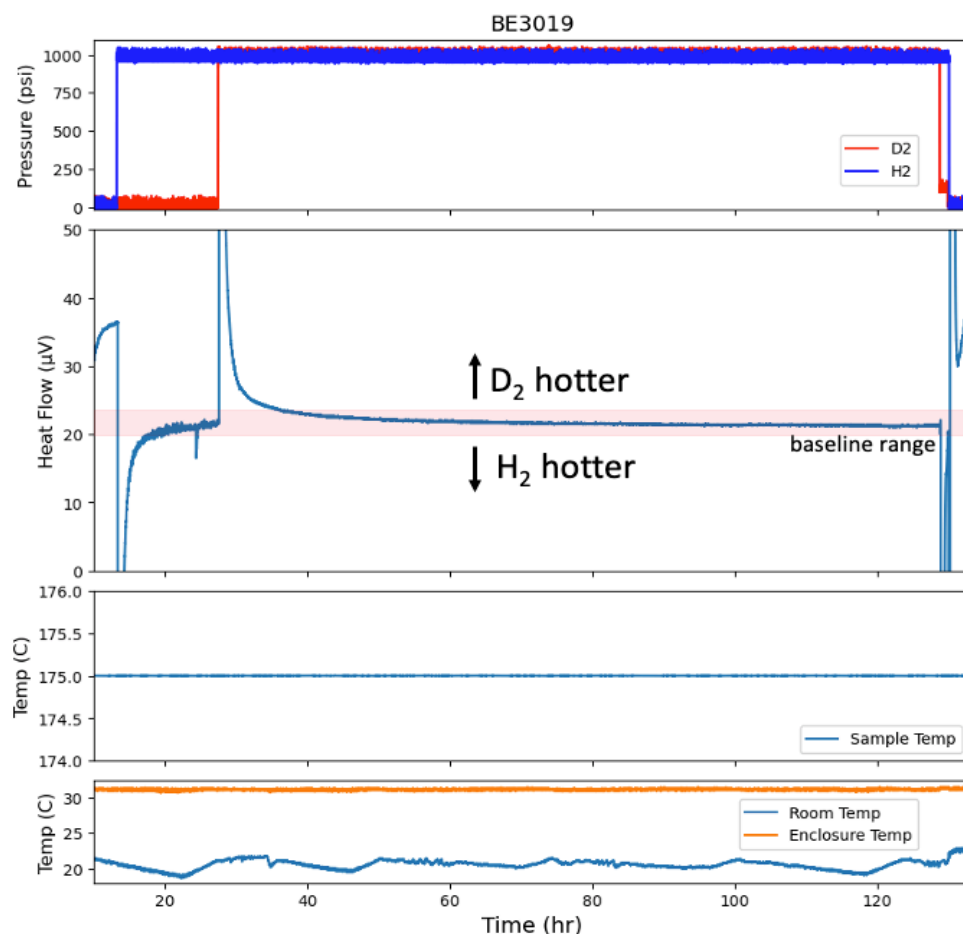


Fig 11. Callisto Experiment BE3019. Replicated ZrO₂ nano-composite is tested via differential calorimetry at 1000psi H₂/D₂ and 175C. Heat flow data does not show evidence of heat generation in either channel. The conversion from μV to milliwatts is not fully characterized but expected to be near 20-30 $\mu V/mW$. The bottom plots show highly stable temperature of the calorimeter and in the calorimeter enclosure.

Following extensive testing of the Arata work, post-Arata work of the same type was explored in Japan. These experiments utilized similar nano-composite materials but replaced some of the palladium with varying ratios of nickel. The materials were exposed to H₂/D₂ pressures up to 1MPa and temperatures up to 300C in an improved apparatus which did not use the DS-cell. The updated apparatus contained six thermocouples and four RTD's which were calibrated to applied-heat using a heater in the sample chamber, and a mass flow controller to measure gas uptake by the sample. This body of work reported as much as 24watts of excess heat. The experimental apparatus was, in effect, a calorimeter and only required the development of samples for our replication effort. Of the fifteen samples listed, we elected to replicate the one with the highest reported excess heat. This nanocomposite was fabricated using the same basic procedure used in Arata's nano-palladium samples with a change to the starting alloy composition. Denoted 'PNZ7', the starting alloy contained 65at% zirconium, 30.625at% nickel, and 4.375at% palladium. The alloy was again made via arc melting and melt-spun into amorphous ribbons for us using the same procedure as

previously described at the University of Sheffield. XRD analysis of the material following the specified anneal (400C, 60hrs) revealed all nickel and palladium constituents were bound to Zr; analysis results are listed below (**Fig. 12**) from BE3834.

Sample ID	Phases Identified	Average Crystallite Size (nm)
BE3834	Zr ₂ Ni – Nickel Zirconium Tetragonal, S.G.: I4/mcm (140) PDF# [04-003-7047]	19.7 ± 3.7
	ZrO ₂ – Baddeleyite Monoclinic, S.G.: P21/c (14) PDF# [04-002-5426]	16.1 ± 1.7
	Zr ₃ Pd ₄ – Palladium Zirconium Hexagonal, S.G.: R-3 (148) PDF# [04-003-1186]	9.8
	ZrO ₂ – Tazheranite Cubic, S.G.: Fm-3m (225) PDF# [04-002-8314]	6.6

Fig 12. XRD analysis of PNZ7-1. Amorphous ribbons were annealed in air at 450C for 60 hours. The analysis failed to identify any phases of Ni or Pd which were not bound to Zr. Zr was not fully oxidized.

The temperature and calcination time were adjusted for a series of subsequent batches prepared with the intention of fully oxidizing and segregating the zirconium from the palladium and nickel (Figures 13,14).

Sample ID	Phases Identified	Concentration (± 5 wt%)	Average Crystallite Size (nm)
BE4066	ZrO ₂ – Baddeleyite Monoclinic, S.G.: P21/c (14) PDF# [04-002-5420]	65.2%	14.5 +/- 0.2
	NiO – Bunsenite Cubic, S.G.: Fm-3m (225) PDF# [04-006-6925]	13.6%	10.8 +/- 0.2
	Zr ₂ Ni – Nickel Zirconium Tetragonal, S.G.: I4/mcm (140) PDF# [04-003-7047]	10.1%	29.6 +/- 0.5
	ZrO ₂ – Tazheranite Cubic, S.G.: Fm-3m (225) PDF# [04-002-8314]	9.9%	9.2 +/- 0.2
	Zr ₂ Pd – Palladium Zirconium ?? Tetragonal, S.G.: I4/mmm (139) PDF# [04-007-7762]	1.3%	8.0 +/- 0.5

Fig 13. XRD semi-quant analysis of PNZ7-3. Amorphous ribbons were annealed in air at 600C for 15 hours. A phase of nickel was identified not bound to Zr. Annealing parameters still appear to be insufficient for full Zr oxidation and segregation.

The loading of each material batch was measured at 40C and 300C under 20bar H₂ (Figures 15,16). The iSorb HP1 carefully calibrates the void volume of the sample vessel and measures the pressure lost when the vessel is dosed with H₂ gas to report moles of gas lost to sample absorption. Using the assumption that no gas is absorbed by the Zr/ZrO₂, the loading fraction is calculated based on the nickel + palladium content. Because the degree of oxidation within the sample is not well known, XRF measurements were used to measure the mole fraction of nickel and palladium in the nanocomposite sample (Figure 17).

Element	Conc.		Element	Conc.
O	17.4		Ni	17.4
Al	0.10		Cu	0.037
Si	0.12		Zn	0.007
Ca	0.027		Zr	58.5
Cr	0.085		Pd	8.12
Mn	0.024		W	1.05
Fe	0.24			

Fig 14. XRF analysis of PNZ7-2. Amorphous ribbons were calcined in air at 500C for 10 hours. This annealing condition was taken from the process used to match Arata's nanocomposite. Concentrations are reported as wt%.

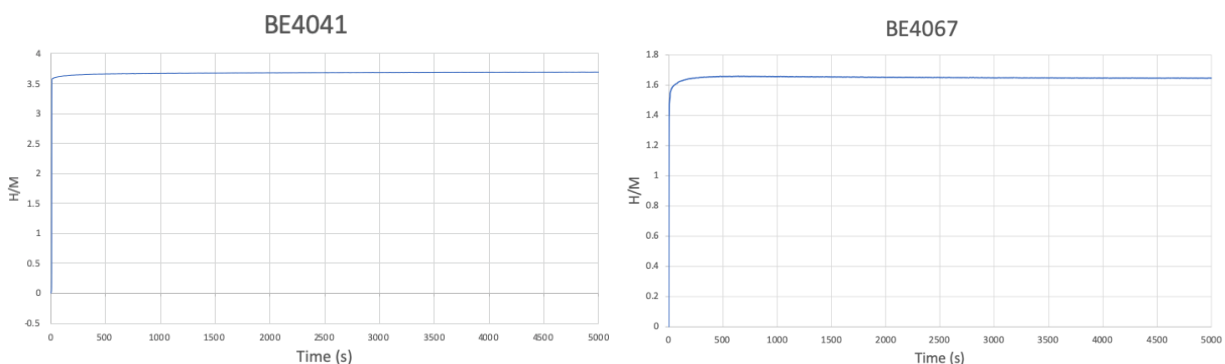


Figure 15. BE4041) 40C 20bar H₂ loading measurement of PNZ7-2. Measured uptake of 3.69H/M, M=Ni+Pd. Kitamura et al. reported 3.4H/M for room temperature D₂ loading at <1MPa. BE4067) 300C 20bar H₂ loading measurement of PNZ7 synthesis trial 2 shows measured uptake of 1.65 H/M compared to reported 1.3 D/M at '>250C' and <1MPa.

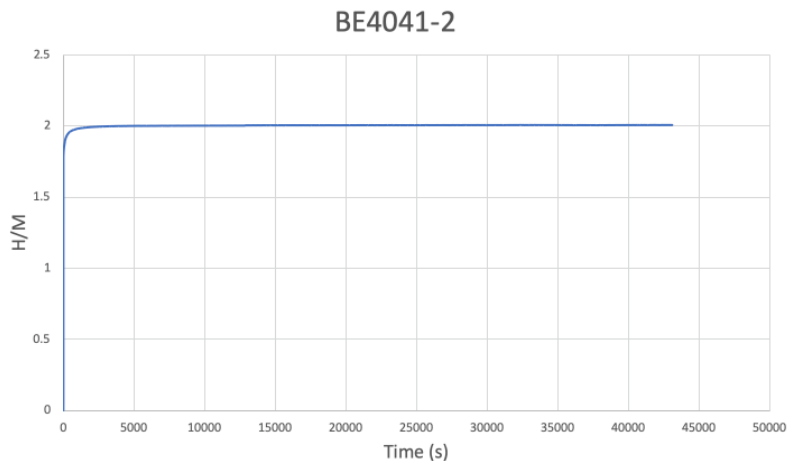


Fig 16. BE4041-2) A second 40C 20bar H_2 loading measurement of PNZ7--2 was performed following BE4041 and BE4067. This result showed a substantial decrease in measured loading indicating a possible irreversible mechanism for pressure loss during measurement such as reduction of NiO species. H_2 absorption by Pd and Ni is expected to be reversible and should not vary with cycle number.

Sample ID	Phases Identified	Concentration (± 5 wt%)	Average Crystallite Size (nm)
BE3908	ZrO ₂ – Baddeleyite Monoclinic, S.G.: P21/c (14) PDF# [04-002-5420]	47.5	17.6 $\pm$ 7.0
	Zr ₂ Ni – Nickel Zirconium Tetragonal, S.G.: I4/mcm (140) PDF# [04-003-7047]	45.0	11.8 $\pm$ 5.6
	NiO – Bunsenite** Cubic, S.G.: Fm-3m (225) PDF# [04-006-6925]	6.9	11.6
	ZrO ₂ – Tazheranite** Cubic, S.G.: Fm-3m (225) PDF# [04-002-8314]	0.5	12.5
	Zr ₃ Pd ₄ – Palladium Zirconium** Hexagonal, S.G.: R-3 (148) PDF# [04-003-1186]	0.1	6.6

Fig 17. XRD analysis of PNZ7-2 shows the presence of reduceable species in significant concentrations.

AHE tests were performed in a Setaram C80 calorimeter by loading each calorimeter vessel with identical samples and exposing them to ~ 100 psi H_2/D_2 at 275-300C. Shorter ‘conditioning’

pressure cycles were used as described by Kitamura et al.³⁹ followed by long duration isolated holds under static pressure/temperature where heat flow was carefully observed at equilibrium conditions. Figure 18 shows an example of such an AHE test.

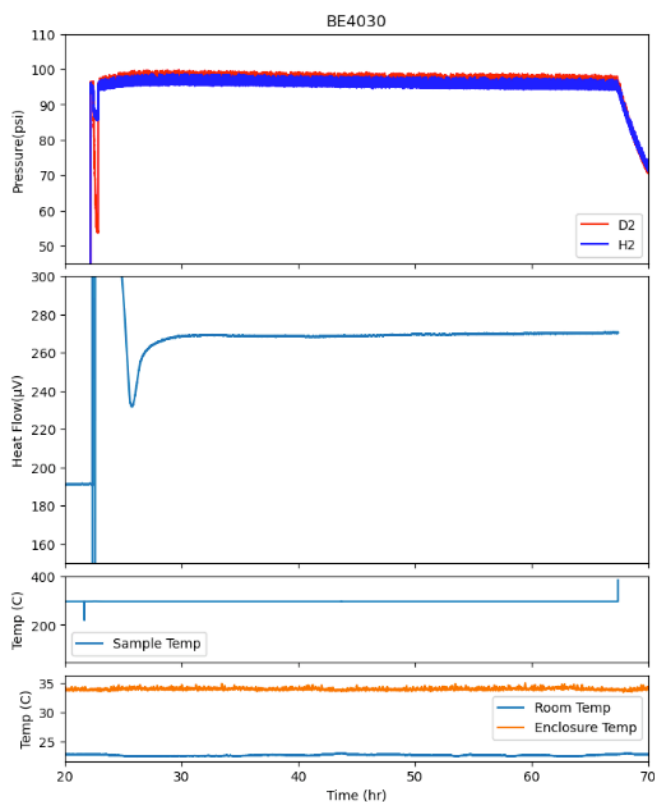


Fig 18. Callisto calorimetry experiment BE4030. PNZ7 synthesis trial 2 material was tested at 300C and 100psi H₂/D₂ via differential calorimetry for AHE activity. No indications of AHE were detected over the long hold. Note that baseline heat flow is unique for each system build and offsets from 0µV are not an indication of heat generation in either channel.

Arata : Conclusion

In total, 15 AHE tests were carried out replicating the Arata and post-Arata body of work (Table 1). While some of these experiments included slight pressure leaks, temperature sensor drift, or other apparatus related anomalies, none of our testing showed any indication of AHE.

³⁹ Kitamura, A., Takahashi, A., Takahashi, K., Seto, R., Hatano, T., Iwamura, Y., Itoh, T., Kasagi, J., Nakamura, M., Uchimura, M., Takahashi, H., Sumitomo, S., Hioki, T., Motohiro, T., Furuyama, Y., Kishida, M., & Matsune, H. (2018). Excess heat evolution from nanocomposite samples under exposure to hydrogen isotope gases. *International Journal of Hydrogen Energy*, 43, 16187–16200. <https://doi.org/10.1016/j.ijhydene.2018.06.187>

Table 1: Arata replication experiments

Exp ID	Apparatus	Process pressure (psi)	Process temperature (degC)	Sample type	AHE Detected?
BE1578	Case style apparatus	50	240	Arata nanocomposite	No
BE1639	Case style apparatus	930	240	Arata nanocomposite	No
BE1673	Case style apparatus	930	170	Arata nanocomposite	No
BE1766	Case style apparatus	1085	200	Arata nanocomposite	No
BE1878	C80	1085	180	Arata nanocomposite	No
BE1928	C80	1000	175	Arata nanocomposite	No
BE2023	Arata DS-cell	72	230	Arata nanocomposite	No
BE2173	C80	850	175	Arata nanocomposite	No
BE2261	Arata DS-cell	1085	210	Arata nanocomposite	No
BE2606	Arata DS-cell	1085	180	Arata nanocomposite	No
BE2758	Arata DS-cell	1085	230	Arata nanocomposite	No
BE3019	C80	1000	175	Arata nanocomposite	No
BE3957	C80	100	300	PNZ7-1	No
BE4030	C80	100	300	PNZ7-2	No
BE4126	C80	100	275	PNZ7-3	No

Case

Dr. Les Case was an MIT trained chemical engineer prior to pursuing LENR research. His work focused on very simple methods to achieve the anomalous heat effect using commercially available hydrogenation catalysts. In addition to the straightforward activation and detection of the effect, his experiments were reportedly successfully reproduced at Stanford Research Institute by Mike

McKubre and Russ George^{40,41} giving sufficient credibility to the work to warrant testing. The Case experiments exposed hydrogenation catalyst (typically palladium particles on activated carbon) to D₂ gas at elevated temperatures and moderate pressures using constant power heating. The equilibrium sample temperature using D₂ was reportedly higher by 5-20°C relative to that involving similar H₂ exposure. A common theme between this work and the experiments by Arata et al. were the use of nano particles and a support structure to prevent agglomeration upon loading. Both Les Case and Russ George presented on this work citing a $D + D \rightarrow He^4 + 24 \text{ MeV}$ reaction.

In our replication of the Case experiments, we employed a number of commercial catalyst materials matching the descriptions stated by Case and exposed them to the same processes. This included moderate H₂/D₂ pressures and high temperatures. In addition to a setup designed to mimic the apparatus used by Case where temperature sensors are used to monitor the sample temperature throughout testing, the sample materials were each subjected to the same conditions and processes in a high sensitivity differential calorimeter.

Case : Materials

Case reported at ICCF7⁴² that AHE was detected in his apparatus. He investigated using many different platinum group metal catalysts supported on activated carbon including about 0.4-1% palladium, platinum, iridium, and rhodium, with palladium being by far the most active and other substrates appearing inactive. While extensive characterization of these materials was not presented, the preferred material used by Case was G-75E (0.5%Pd on activated carbon) and G-75D (0.4%Pd on activated carbon) sourced from United Catalysts, Inc. Unfortunately, at the time of this replication work, this company was no longer operating. Instead, 5 candidate materials were selected with varying forms of activated carbon and palladium content (Figures 19,20).

⁴⁰ Mallove, G. (1999, July). Progress in Les Case's Catalytic Fusion. *Infinite Energy Magazine*, 4(23).

⁴¹ George, R. (1999, March 26). Production of 4He from deuterium during contact with nano-particle palladium on carbon at 200° C and 3 atmosphere deuterium pressure. Paper presented at the American Physical Society Centennial Conference.

⁴² Case, L.C. (1998). Catalytic Fusion of Deuterium into Helium-4. In *Proceedings of The Seventh International Conference on Cold Fusion*. Vancouver, Canada: ENECO Inc.

<i>Callisto Material</i>	Palladium Content	Activated Carbon Source	Vendor
<i>BM524</i>	1%	Egg shells, unreduced	Fisher Scientific
<i>BM536</i>	5%	Unreduced	Fisher Scientific
<i>BM537</i>	1%	Coconut shells, reduced	Cocoworks
<i>BM538</i>	0.5%	Coconut shells, reduced	Cocoworks
<i>BM891</i>	5%	Unreduced	Acros Organics

Figure 19. Case replication materials list.

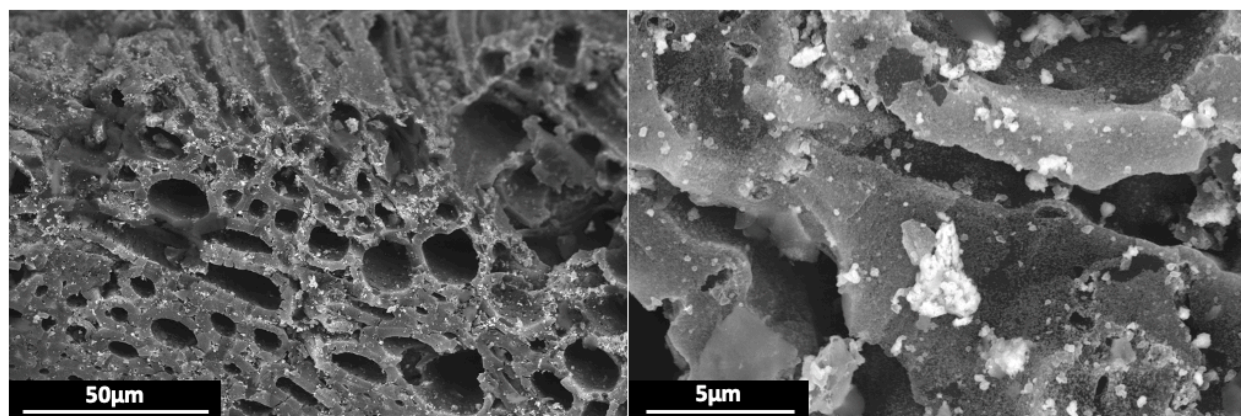


Figure 20. SEM images of BM537.

Case : Experimental

As outlined in the writings of Case from ICCF-7, Russ George via Catalyst Helium online, and interviews of Les Case by Gene Mallove published in Infinite Energy magazine, the protocol for generating excess heat was as follows; first, the candidate sample material is loaded into an oval stainless steel pressure reactor (1.6L) which is nested in a constant power heating jacket. The vessel is pumped down to vacuum and hydrogen gas is introduced to approximately 50psi. The heating jacket is then turned on targeting an equilibrium temperature of approximately 150-200C and the

thermocouple on the inside of the reactor is monitored until a stable temperature is reached. Once this temperature is recorded, the heater is turned off and the gas vented. This process is repeated until a consistent temperature is measured between cycles. These ‘conditioning’ cycles were reportedly to take any chemical reactions to completion and establish a baseline temperature. The following cycle would introduce deuterium gas in place of hydrogen and reportedly, for AHE active materials, the resulting equilibrium temperature would be higher than the baseline temperature by 5-20°C. Case also performed mass spectroscopy on the resultant gas from experiments where AHE was detected which found above ambient levels of helium. Helium detection as a diagnostic for AHE, however, is difficult to perform properly, and the presence of background helium can easily lead to false positives.

In Callisto’s replication experiments, a stainless-steel vessel of similar geometry and volume was fitted with pressure and temperature sensors and installed into a heating jacket connected to a variac for adjustable constant power output (Figure 21).

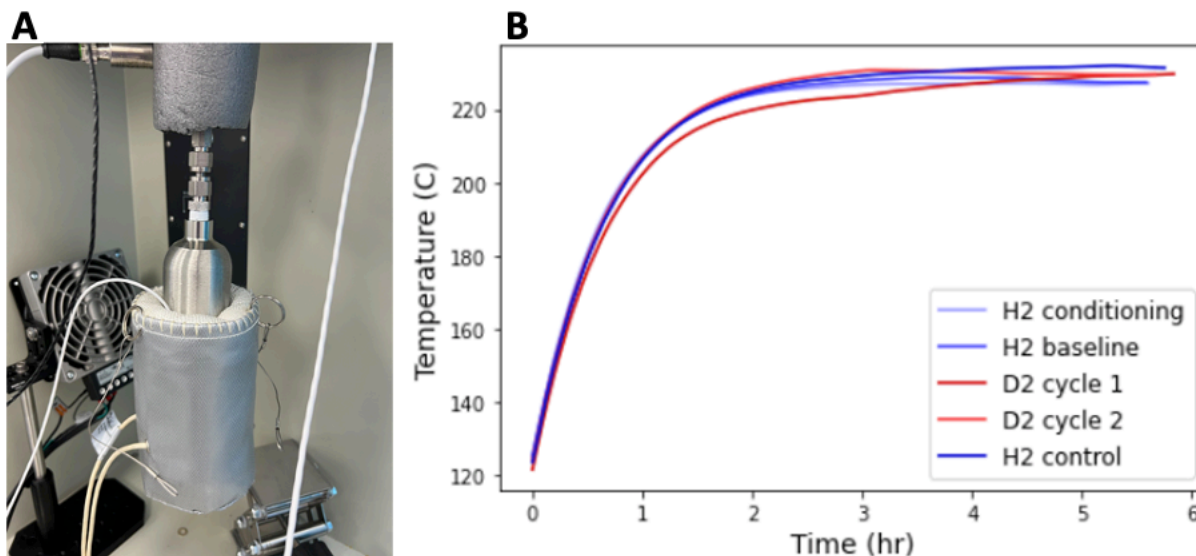


Figure 21. A) Case replication apparatus containing pressure and temperature sensors, a temperature-controlled enclosure, and constant power heating jacket. B) Callisto replication experiment BE1530. 42g of 1% palladium on activated carbon is exposed to repeated cycles of H_2 and D_2 gas. After pressurizing, the heater is turned on and the system is allowed to reach an equilibrium temperature. The plot shows the temperature profiles for each cycle. No significant difference between the H_2 and D_2 cycles was observed.

As with the Arata experiments, the experiments were ultimately moved from the replication apparatus to the Setaram C80 calorimeter to directly test for the generation of heat. Representative experimental results are shown in Figures 22, 23.

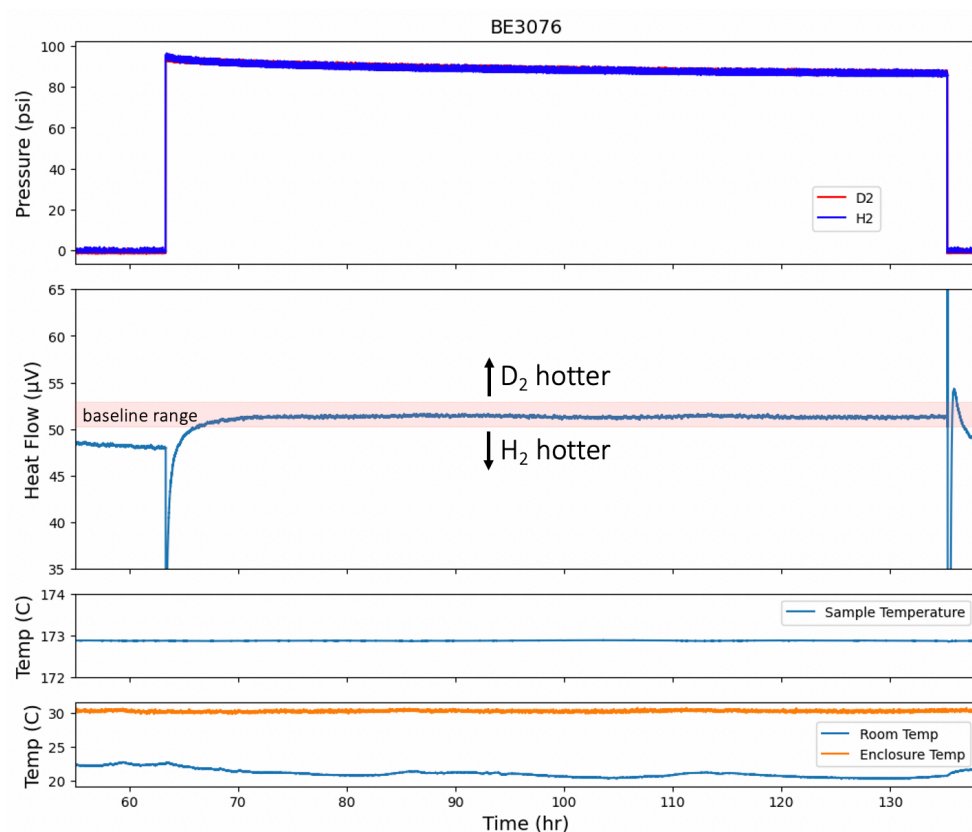


Fig 22. Callisto calorimetry experiment BE3076. Samples of BM538 with mass 2.727g (H_2 channel) and 2.737g (D_2 channel) were subjected to 2x conditioning cycles and 2x long holds at 175C set point. Samples were left under vacuum for 12 hours between pressure cycles to degas. Each channel used only one isotope through all cycles. No indication of excess heat was detected.

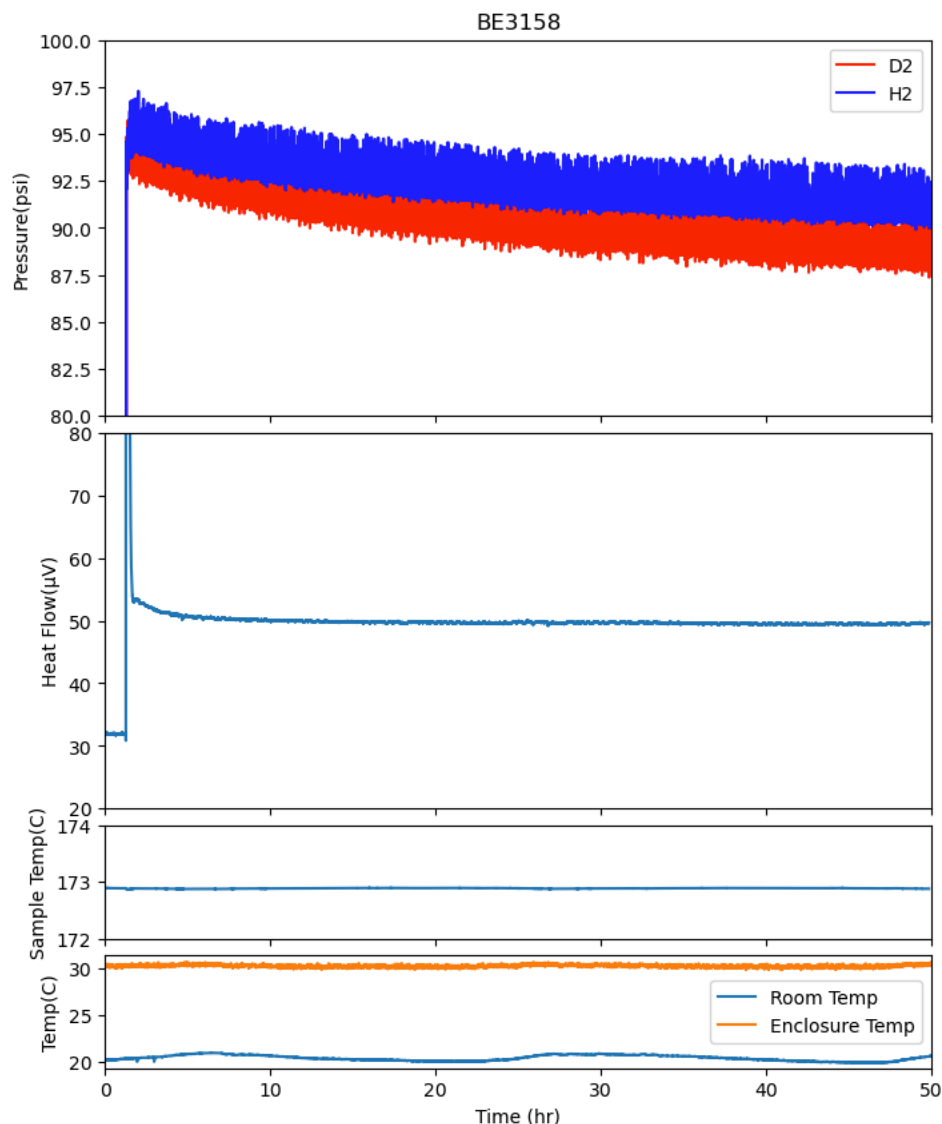


Figure 23. Callisto calorimetry experiment BE3158. Samples of BM536 with mass 2.51g (H_2 channel) and 5.21g (D_2 channel) were loaded into calorimeter and exposed to 6 pressure cycles at setpoint $T=175C$. The heat flow data for the final long duration pressure hold shown here shows no evidence of heat generation from either channel.

Case : Conclusion

Sixteen AHE experiments were carried out between the Case replication apparatus and the Setaram C80 calorimeter. Many of these experiments showed slight pressure decay within the vessels when isolated, which was suspected to be adsorption or chemical reactions. In the Case replication apparatus, no experiment showed significant temperature discrepancies between pressure/temperature cycles of different isotopes using equal heating power and pressure. In

differential calorimetry experiments, no significant heat flow was detected between H₂ and D₂ channels for any experiment. In conclusion, none of the evidence for AHE or isotopic contrasts reported by Case were detected in Callisto replication experiments.

Table 2: Case replication experiments

Experiment	Apparatus	Material	AHE Detected?
BE1399	Case style apparatus	BM524	No
BE1437	Case style apparatus	BM537	No
BE1477	Case style apparatus	BM538	No
BE1530	Case style apparatus	BM537	No
BE1721	Case style apparatus	BM891	No
BE2300	C80-calorimeter	BM537	No
BE2381	C80-calorimeter	BM537	No
BE2439	C80-calorimeter	BM538	No
BE2513	C80-calorimeter	BM538	No
BE2591	C80-calorimeter	BM538	No
BE2690	C80-calorimeter	BM537	No
BE2822	C80-calorimeter	BM538	No
BE3076	C80-calorimeter	BM538	No
BE3158	C80-calorimeter	BM536	No
BE3264	C80-calorimeter	BM524	No
BE3327	C80-calorimeter	BM524	No

LLNL : 1989 Experiment

Nearly all AHE claims involve small amounts of excess heat relative to input power (i.e., 5-50%) and so can potentially be explained by measurement errors, lack of controls, and conventional mechanisms. However, a few historical AHE claims observed exotic thermal runaways, well above such small levels.

A specific observation that strongly motivated our investigation into AHE was Lowell Wood's 1989 observation at LLNL (Lawrence Livermore National Laboratory). After Callisto electrochemical loading spent 3 years running LLNL replications without (yet) observing AHE, Callisto investigated potential classical (non-nuclear) explanations and found plasma electrolysis to provide a reproducible explanation that qualitatively matches Wood's observations.

Since no recorded data exists from the 1989 experiment, we will summarize Wood's recalled observations (**Fig. 24**).

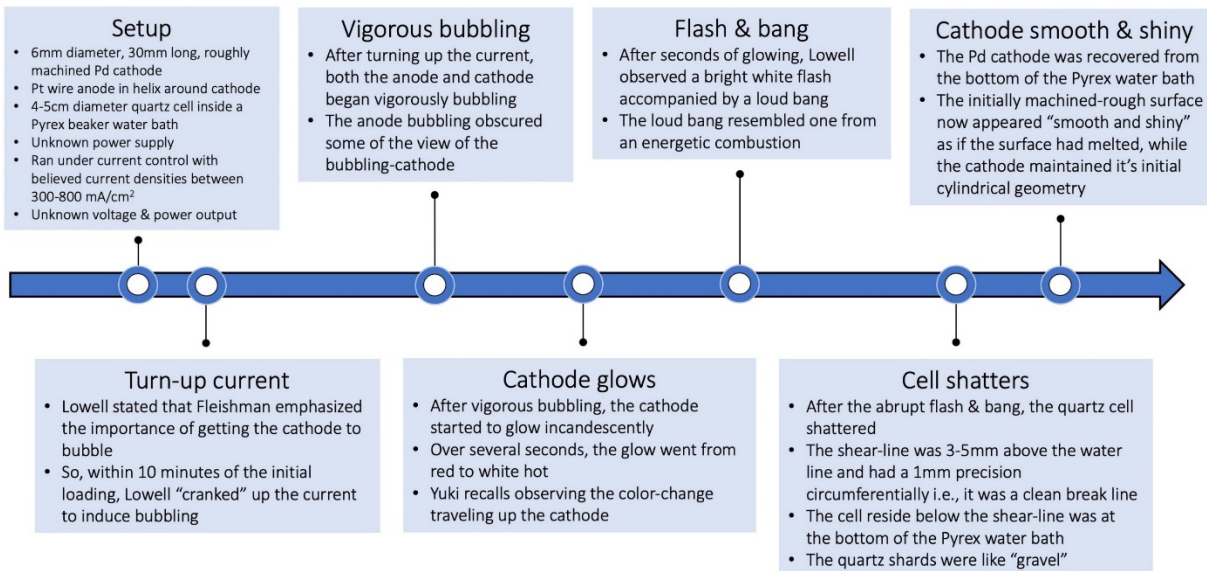


Fig. 24: Wood's recalled observations from the 1989 LLNL thermal runaway experiment.

The apparatus involved a 6mm diameter, 30mm long, roughly machined Pd cathode. Prior to the experiment, the Pd cathode had visible surface deformations from the rough machining. A Pt wire was used as the anode and wrapped in a helix around the Pd cathode. The Pd cathode and Pt anode were placed in a 2-5cm diameter quartz cell with D₂O (heavy water) and ~0.5M ⁶LiOD (Lithium-6 deuterioxide), which resided in a larger Pyrex-beaker water bath. Wood did recall at one point that the experimental cell was capped (similar to 1989-1990 Fleischmann cells), but this detail was fuzzy and not consistently recalled. The experimental cell and water bath had comparable water-levels, started at room temperature, and were believed (there was no temperature diagnostic) to warm up to 70-80°C throughout the experiment. **The exact power supply is unknown** (it was believed to be a readily available power supply from Wood's lab). The power supply was run in current control at current densities between 300-800 mA/cm²; the voltage was unknown and ultimately depends on the exact power supply. Wood specifically remembers discussing with Fleischmann the importance of running at current densities above 300 mA/cm²; so, Wood used whatever voltage was necessary to achieve >300 mA/cm².

During the experiment, Wood stood 1-2 feet away from the apparatus. Fleischmann emphasized to Wood the importance of getting the cathode to bubble; so, approximately 10 minutes into the initial loading of the Pd cathode, Wood "cranked up" the current to induce bubbling. It's important to note that ~10 minutes of electrolytic loading of a 6mm diameter Pd cathode means that while the surface may have been well loaded, the overall sample was only ~1% loaded⁴³. After increasing

⁴³ After loading 100's of Pd wires, we've empirically observed a loading rate of ~100 μm/hr at room temperatures (e.g., it takes ~1 hour to load a 250 μm diameter Pd wire at 25°C). This abstracts the kinetic components (i.e., water splitting and H⁺ diffusion), but typical timescales indicate loading is surface limited at room temperatures. Assuming

the current, both the Pt anode and Pd cathode started vigorously bubbling; the bubbling from the Pt anode obscured some of the view of the Pd cathode. Some unknown time after the vigorous bubbling started (it was likely within minutes), the Pd cathode started to incandescently glow. Over several seconds, the glow went from red to white hot. Another participant, Muriel Ishikawa, recalls observing the color change travel up the Pd cathode. After seconds of glowing, Wood observed a bright white flash, which was accompanied by a loud bang (one that “resembled an energetic combustion”). Roughly coincident with the abrupt flash-&-bang, the experimental cell shattered. The quartz cell had a shear-line 3-5mm above the water line with ~1mm circumferential precision and everything below was in shards (described like “gravel”) at the bottom of the water bath. The Pd cathode was recovered from the bottom of the water bath. The initially rough surface now appeared “smooth and shiny” as if the surface had melted, while maintaining its cylindrical geometry.

Wood attempted “sporadic” replications in the following weeks but was largely preoccupied with programmatic responsibilities and was unable to replicate the runaway. The replication attempts were believed to use the same equipment (power supply, Pd cathode, etc.). Wood does recall that they *did not* precisely reproduce the anode/cathode geometry.

At Callisto, we investigated 3 possible classical (i.e., non-nuclear) explanations to the '89 LLNL runaway: intermetallic alloying, H₂/O₂ recombination, and plasma electrolysis.

LLNL : Intermetallic Alloying

It's likely that many “excess heat” reports are nothing more than calorimetry errors and less-than-rigorous scientific methods. However, there are a few interesting sidenotes that indicate traditional chemical reactions could produce excess heat, particularly from authors reporting frequent production of LENR.

In Storms' well-known 1996 paper⁴⁴, he added Aluminum metal powder to his electrolyte: “... Aluminum metal (2-20 ppm) added to the electrolyte after the palladium has achieved its maximum deuterium content is sometimes useful in initiating excess heat production.” The enthalpy of formation for a Pd-Al alloy is 95 kJ/mol: this mixture is commonly used in pyrotechnics and as a reactive nanolaminate; it's akin to thermite without oxygen transfer.

Similarly, McKubre found that Al and Si additives enhances loading⁴⁵ (and thus AHE): “... the presence of approximately 200 ppm of dissolved aluminum (or silicon) in the electrolyte was found to facilitate the reproducible attainment and maintenance of high loadings.” Palladium silicide can be readily formed and has a (stoichiometry-dependent) enthalpy of formation of ~60 kJ/mol.

a constant loading rate of 100 μm/hr, the 6mm diameter Pd cathode only loaded ~16 μm of its surface or ~1% of the total volume.

⁴⁴ E. Storms, *J. Fusion Technol.* **29**, 261 (1996).

⁴⁵ M. McKubre et al., *Frontiers of Cold Fusion*, Universal Academy Press, Inc., Japan (1992).

Finally, Letts added an unknown rare earth to his electrolyte⁴⁶: “The cathode was a Gold substrate 5mm x 8mm x 0.75mm with Palladium plated onto the substrate with a rare earth additive provided by Cravens. The cathode didn’t respond well to the laser stimulation until the rare earth solution was added to the electrolyte. With the additive, the cathode became responsive to a laser operating at 657nm with a radiant output of 30 mW.” One can only guess what was added; nevertheless, this is another example of a potentially highly reactive alloying additive being added to the electrolyte.

The authors in the above experiments do not discuss whether the amount of their additives are sufficient to account for the reported amounts of excess heat.

To test whether intermetallic alloying reactions could qualitatively explain the ’89 LLNL observations, we intertwined 200 μm Pd and 200 μm Al wires and drove power across them while in both air and water (**Fig. 25**). As expected, the Pd-Al reaction energetically proceeds in air but cannot propagate in water i.e., the 95 kJ/mol from the Pd/Al reaction cannot overcome the strong cooling power of water. Thus, intermetallic alloying reactions produce heat in gaseous environments over short durations but not enough to produce the ’89 LLNL major thermal runaway in water.

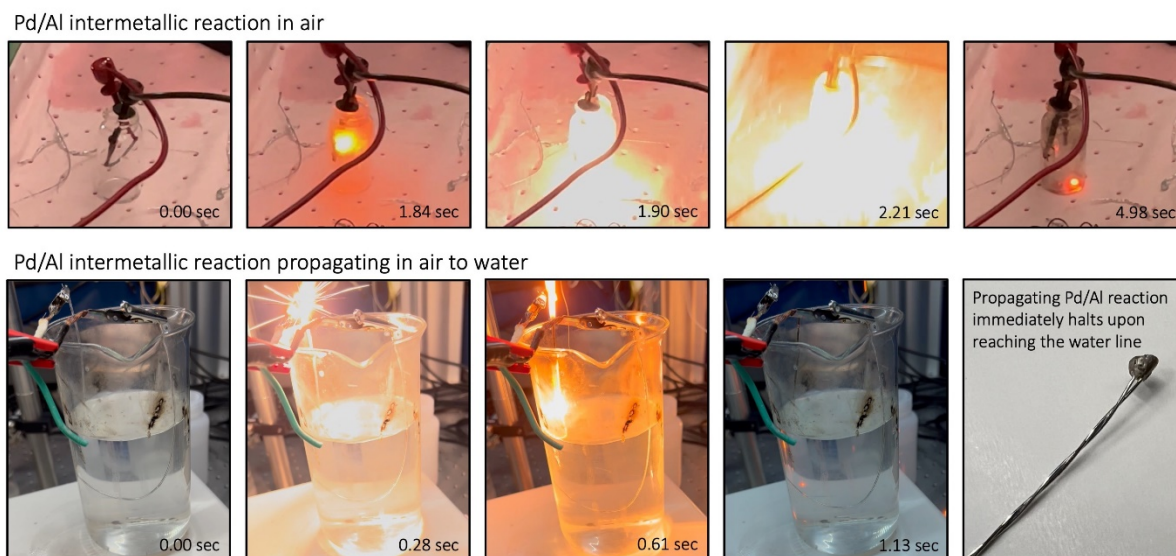


Fig. 25: Pd-Al intermetallic alloying produces 95 kJ/mol but cannot propagate in water.

LLNL : H_2/O_2 Recombination

⁴⁶ Letts et al., *Condensed Matter Nuclear Science*, pp. 159-170 (2005).

In thermodynamic equilibrium, loading decreases with temperature at a fixed pressure. In other words, a loaded lattice can be deloaded through heating. Furthermore, the deloading rate increases with temperature and the enthalpy of formation of water is ~ 286 kJ/mol. So, as a sample deloads H/D, the H/D can recombine with O_2 to form water, which heats the sample surface. As the surface heats up, the deloading rate increases, which in turn further heats up the sample i.e., it can create a thermal runaway scenario. An ideal sample geometry has a high surface-area to volume ratio (e.g., a foil), which enables more surface sites for recombination and reduces the deloading distance.

To test this hypothesis, we loaded a 50mm x 50mm x 2mm Pd foil in 1 bar H_2 and subsequently removed it from the vessel and placed it in air. As the sample deloads, water forms on the surface and reduces the available surface sites for recombination. So, we heated the foil to $100^\circ C$ to evaporate the surface water and subsequently removed the heating source. As anticipated, the foil underwent a thermal runaway, eventually reaching $>400^\circ C$ (based on an IR camera measurement) and incandescently glowing red hot (**Fig. 26**).



Fig. 26: Thermal runaway of a Pd foil from H_2/O_2 recombination in air.

To better quantify the temperature rise and timescale, we used our Thermal Ignition apparatus to run a highly controlled experiment. We elastically loaded a Pd slug with protium and subsequently reduced the temperature to $-100^\circ C$ to lock-in the loading. Prior to loading the Pd slug, we took control measurements with 20 psi N_2 at $-100^\circ C$ and laser heated the Pd to $137^\circ C$ over 10 seconds. This calibrated our required laser input to heat to $>100^\circ C$ and showed the expected heating/cooling rates without excess heat produced. With the PdH slug loaded at $-100^\circ C$, we fully purged our system and switched gases to 20 psi O_2 . We then laser heated the PdH to $137^\circ C$ over 10 seconds and shutoff the laser. The PdH slowly self-heated to $\sim 200^\circ C$ over 18 seconds and eventually ran away to $965^\circ C$ over 3 seconds (**Fig. 27**).

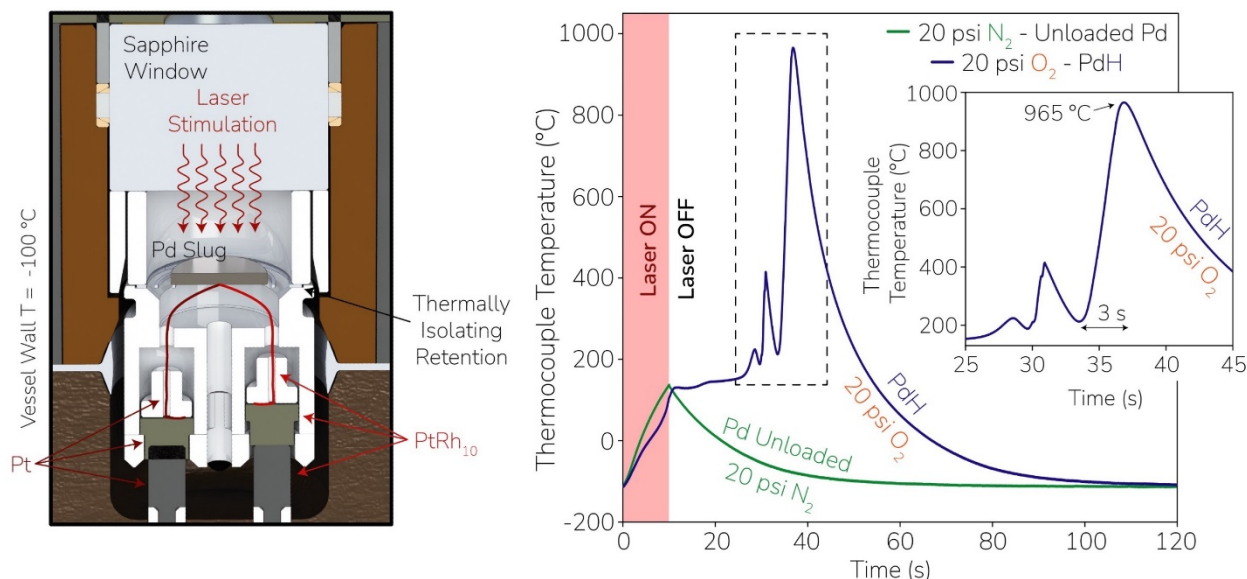


Fig. 27: Thermal runaway of a PdH slug in 20 psi O₂ from H₂/O₂ recombination.

After clearly establishing thermal runaways from H₂/O₂ recombination in gaseous environments, we developed a split cell to empirically determine if the ~286 kJ/mol from H₂/O₂ recombination could overcome the strong cooling power of water. Our split cells allow for fluid/gas, gas/gas, and fluid/fluid experiments with electrical and optical access. In a pure liquid environment, it's a stretch to explain how enough O₂ could contact the PdH surface to enable significant levels of H₂/O₂ recombination. In electrolytic cells, O₂ is generated at the anode during water splitting and would need to contact the PdH surface at sufficient quantities and rates. To test the best-case scenario, we used our split cell in gas/liquid configurations (i.e., one side of the slug is in contact with gas, while the other side is in contact with liquid). First, we ran a N₂/H₂O control, where we laser heated a Pd slug on the N₂ side with the backside in contact in H₂O. As expected, we observed a plateau in temperature around 100°C (the measured ΔT was ~70°C with a T_0 of ~30°C) i.e., the Pd|H₂O system does not exceed the H₂O boiling point (**Fig. 28**). Out of due diligence, we ran an experiment with a loaded PdH slug and O₂/H₂O in the split cell. When laser heating in O₂, we observed a minor increase in peak temperature (still around 100°C) and did not thermal runaway (**Fig. 29**). This proves H₂/O₂ recombination is not responsible for the '89 LLNL thermal runaway.

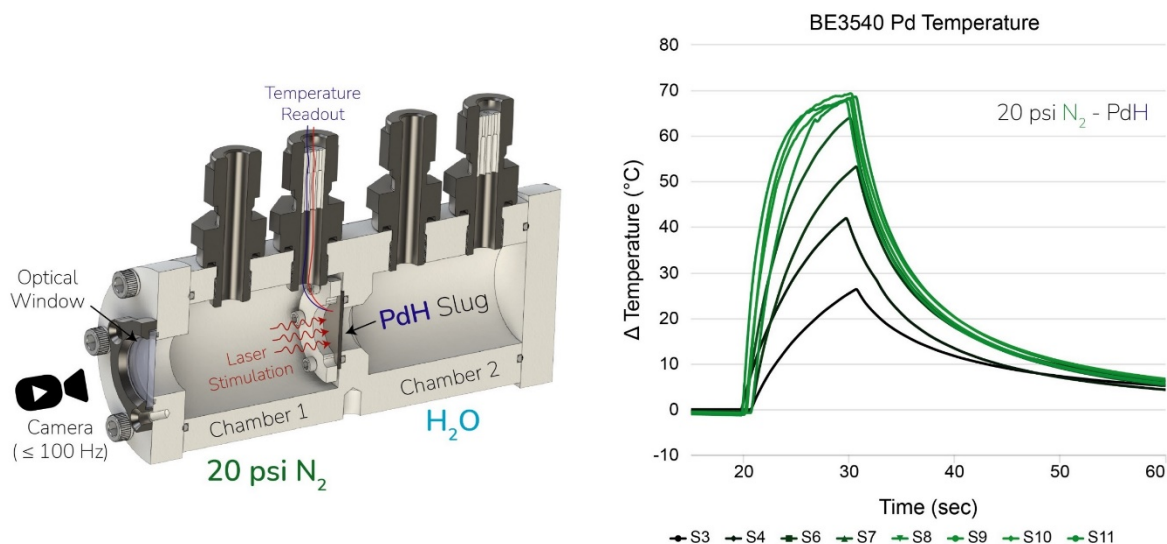


Fig. 28: Using a split-cell, we show that a Pd slug in contact with H₂O does not exceed 100°C (the ΔT plateaus near 70°C with a T_0 of ~30°C).

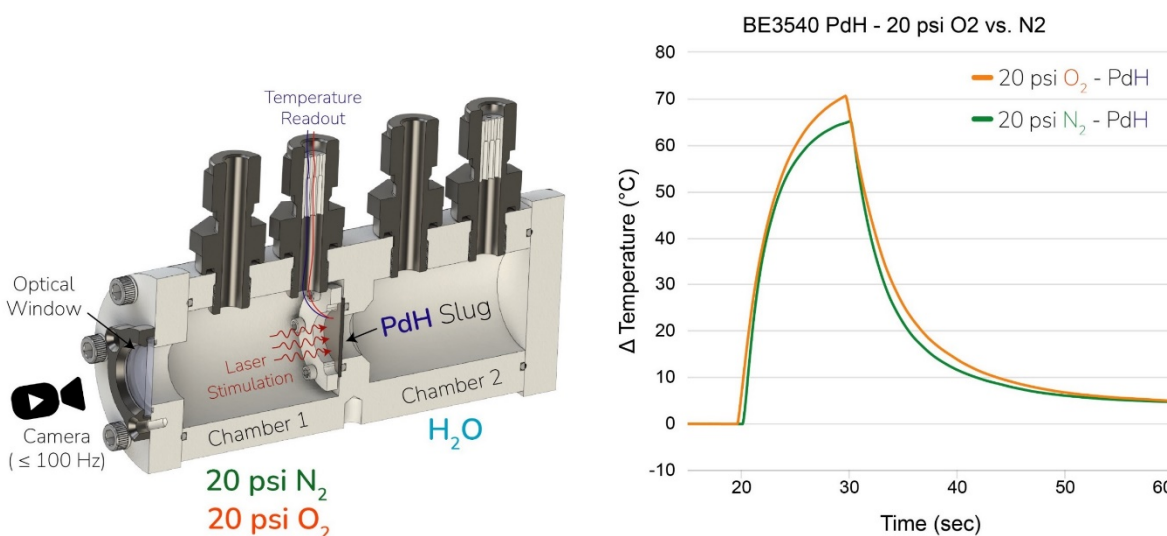


Fig. 29: Using a split-cell, we show that O₂ (which undergoes H₂/O₂ recombination) produces slightly higher temperatures than an N₂ control, but the peak temperature remains around 100°C ($\Delta T = 70^\circ\text{C}$ with a T_0 of ~30°C) and no thermal runaway is observed.

Given our control experiments, specifically those with laser-heating Pd in contact with water, it became challenging to understand how classical mechanisms could enable a Pd cathode to incandescently glow in water, reaching temperatures $>1000^\circ\text{C}$: the power output would need to be significant. To put rough numbers to the required power output, we calculated the energy density

required to heat the surface of a 6mm cylinder in water to 1000°C (i.e., glowing “white hot” as observed in the ’89 LLNL experiment) using COMSOL. The heating is assumed to occur in a 15 μm annulus at the surface. We found minimum energy density to glow white-hot is 2.9 kJ/cm³ (i.e., instantaneous) and 407 kJ/cm³ is required for glow for 1 second (**Table 3**). A 6mm diameter, 30mm long Pd cathode has volume of 0.85 cm³ and 8.2×10^{15} surface atoms, which is $\sim 10^{-8}$ mol. If we assume chemical reactions are occurring only with surface atoms and take an upper bound of 1000 kJ/mol for a reaction⁴⁷, we could instantaneously produce 10^{-5} kJ, which is orders of magnitude below the 2.5 kJ required for the cathode to instantaneously glow. If not just the immediate surface, but the aforementioned annulus of 15 μm , reacts, then 10^{-3} moles are involved, producing 1 kJ, near the required value.

Duration (sec)	Required Energy Density (kJ/cm ³)
0.000	2.9
0.001	35.6
0.010	104
0.100	267
1.000	407

Table 3: The energy density required to heat a 15 μm annulus at the surface of a 6mm cylinder in water to 1000°C.

While chemical reactions are highly unlikely to produce a glowing cathode in water, a nuclear explanation presents challenges as well. There is certainly plenty of energy available; highly loaded PdD can (if all deuterons react) produce over 10^8 kJ/cm³; so only a tiny fraction of the available deuterons must react.

However, even if we assume a nuclear explanation, certain observations from the ’89 LLNL experiment seem to be at odds: the cathode glowed for seconds *and* the beaker shattered *and* only the cathode surface melted. Thermal diffusivity in the Pd cathode is significantly faster than in water so, for seconds-long heating durations, the cathode is nearly in thermal-equilibrium. So, if the cathode surface melted, and glowed for seconds, much of the bulk should have as well⁴⁸. Moreover, for the beaker to shatter from a shock wave, there must have been rapid heating (e.g., < millisecond); but the cathode was observed to glow for seconds.

Two observations (that only the surface melted, and that the beaker shattered) seemingly require very short, sub-millisecond, heating durations, and are at odds with the observation of seconds-long glowing. It’s possible that the glowing didn’t actually last for seconds, but was simply perceived to do so due to human physiology. But, while a sub-millisecond heat pulse might explain

⁴⁷ The highly exothermic thermite reaction of Fe₂O₃ and Al produces ~ 850 kJ/mol.

⁴⁸ The timescales of atomic diffusion matter, but it’s hard to envision surface reformation without the bulk failing to some extent.

both the surface-deep heating and the beaker shattering, it leaves us having to understand how nuclear events across a large surface region are time-synchronized so tightly.

Perhaps a glowing cathode in direct contact with water is too simple of a picture. What if we had a scenario where the liquid surrounding the cathode locally boils, creating a vapor environment and reducing the power required to heat?

LLNL : Plasma Electrolysis

Plasma electrolysis⁴⁹ is a nontypical electrochemical process that uses electric current to produce a plasma from an electrolyte solution. At high enough voltages, electrolyte solution around the cathode can heat up and vaporize, forming a vapor envelope. Within this vapor layer, the high temperatures and electric field can cause the molecules to ionize, creating a plasma, which is typically visible as a glowing region around the cathode (**Fig. 30**). The specific conditions under which plasma forms depends on a range of factors including the composition of the electrolyte solution and electrodes, the anode/cathode geometry, and the applied current and voltage.

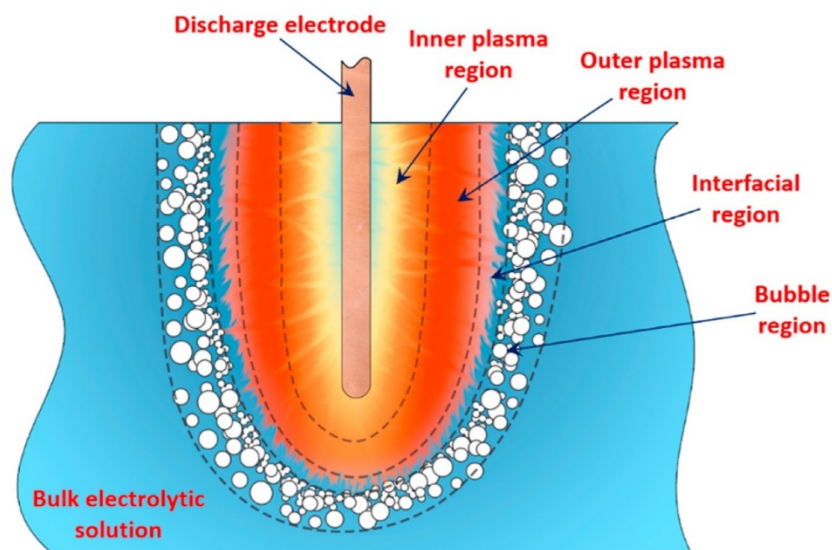


Fig. 30: Plasma electrolysis can occur in electrochemical cells when high enough voltages are applied. Figure taken from S. Besspalko⁵⁰.

⁴⁹ Plasma electrolysis is also referred to as plasma-driven solution electrolysis (PDSE) and contact glow-discharge electrolysis (CGDE).

⁵⁰ Besspalko, S., Mizeraczyk J., *Energies*, **15**, 7508 (2022).

Fundamental to generating plasma electrolysis is a sufficient power supply. We developed two, independent apparatuses with different power supplies (**Fig. 31**). One setup used an 80 V, 62 A, 5 kW power supply (Magna Power Electronics TSA80-62), while the other used a higher voltage 230 V, 20 A, 1.5 kW power supply (NI RMX-4126). Importantly, these power supplies are common and it's plausible that units with similar specifications were in the '89 lab at LLNL. We replicated the '89 LLNL setup (e.g., cathode geometry, current density range, quartz cell, etc.) and followed Wood's protocol: cranking up the current to induce vigorous bubbling. Doing so, we observed plasma electrolysis as low as 30-40 V with initiation current densities $< 3 \text{ A/cm}^2$ and much lower sustainer currents. At voltages $< 80 \text{ V}$, current densities $< 3 \text{ A/cm}^2$, and 0.5M LiOH in H_2O , we observed both sustained glow discharge (**Fig. 32**) and intermittent glow discharge (**Fig. 33**). At a set voltage and current density, we found that the cathode/anode geometry was important to reproducibly observe plasma electrolysis (this matches Wood's recollection, where the cathode/anode geometry was inconsistent in his replications and no additional runaways were observed).



Fig. 31: Power supplies used in '89 LLNL replication experiments.

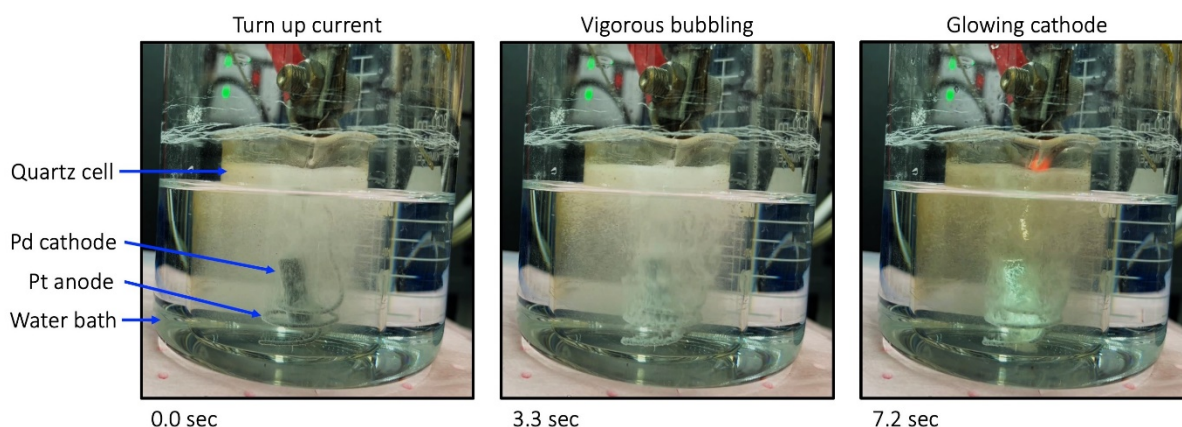


Fig. 32: Sustained glow discharge is observed as low as 30-40 V and $< 3 \text{ A/cm}^2$ in 0.5M LiOH in H_2O .

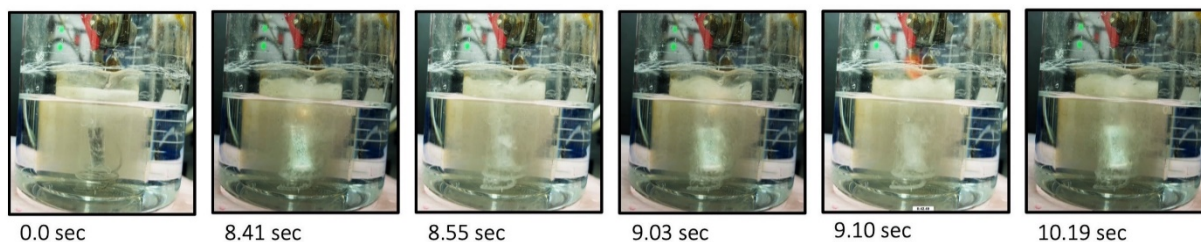


Fig. 33: At times, intermittent glow discharge is observed as low as 30-40 V and $< 3 \text{ A/cm}^2$ in 0.5M LiOH in H_2O .

After observing plasma electrolysis at lower voltages (e.g., 30-40 V), we used a higher voltage supply to probe up to 230 V (using 0.25M LiOH/LiOD in $\text{H}_2\text{O}/\text{D}_2\text{O}$, respectively). At higher voltages, the plasma electrolysis is exceedingly violent, quickly increasing the water temperature to nearly 100°C and heating the cathode to a glowing white-hot state (**Fig. 34**). Importantly, during plasma electrolysis, the current density is $< 800 \text{ mA/cm}^2$, which matches the conditions from the '89 LLNL experiment (**Fig. 35**). Furthermore, our Pd cathodes often had melted surfaces, again matching the '89 LLNL description. Moreover, the plasma electrolysis is coupled with loud “flashes and bangs”, which we attribute to H_2 / O_2 combustion. The Faradaic efficiency in plasma electrolysis is dozens of times higher than normal electrolysis, producing orders of magnitude more hydrogen⁵¹. When the H_2 and O_2 produced from the electrolysis are in proximity to the plasma, sparks form and combust the H_2 / O_2 . To prove plasma electrolysis is unrelated to loaded Pd cathodes, we ran Pt/Pt controls and observed qualitatively the same plasma electrolysis and H_2 / O_2 combustions.

⁵¹ Susanta K. Sen Gupta, *Plasma Sources Sci. Technol.*, **24** 063001 (2015).

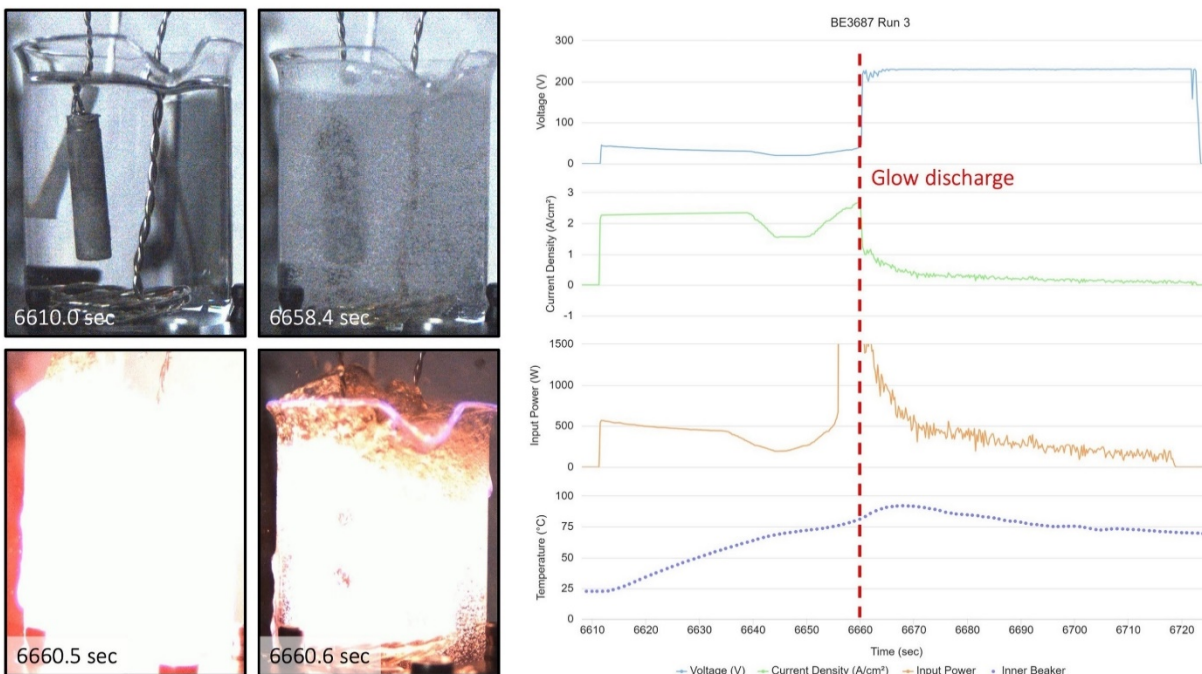


Fig. 34: In both 0.25M LiOH and LiOD, increasing current density produces vigorous bubbling after which violent plasma electrolysis is observed at 230 V, < 3 mA/cm².

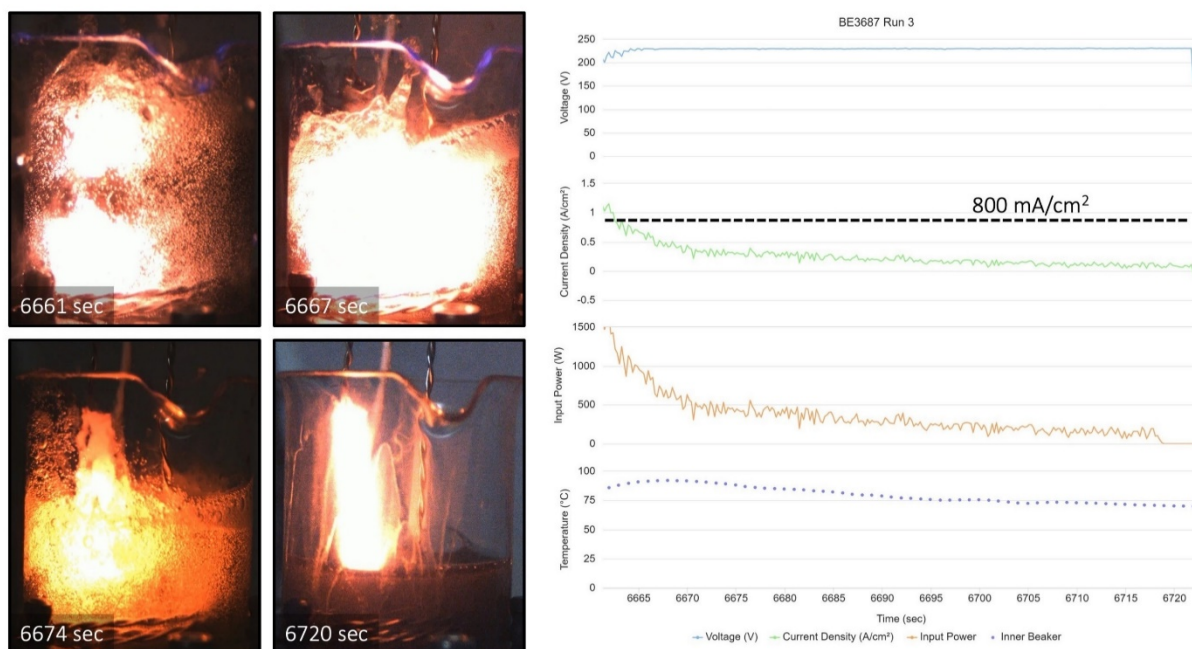


Fig. 35: In both 0.25M LiOH and LiOD, violent electrolysis occurs < 800 mA/cm², matching the observations in the '89 LLNL experiment. The plasma electrolysis is accompanied by loud H₂ /

O₂ combustions (as seen at 6667 sec). The water level is reduced due to splashing, revealing a white-hot Pd cathode even after the voltage and current are turned off at 6720 sec.

While the H₂ / O₂ combustions are most likely responsible for the shattered cell in the '89 LLNL experiment, it's important to highlight the shattered-cell observation is not scientifically testable. Without knowing the exact state of the glass used in the '89 experiment, we cannot meaningfully test theories for glass failures. The strength of glass is highly dependent on external factors (e.g., crack propagation occurs at significantly lower stresses with the presence of water and under heating⁵²), pre-existing conditions (e.g., repeated, cyclic heating leads to increased defects⁵³), and composition⁵⁴. At a photovoltaic module reliability workshop at NREL⁵⁵ (National Renewable Energy Laboratory), C. Barry discussed “why glass sometimes breaks.” Their data on glass failure showed a >3x spread in failure stress and was summarized well: “Will my glass break? Nobody knows for sure. You can't tell how strong it is, until it was.”

Keeping the non-testability of the '89 shattered cell in mind, we built an apparatus to test H₂ / O₂ combustions in water in *unused* (i.e., as delivered from the vendor) quartz cells (**Fig. 36**). The apparatus was remotely controlled and mixed O₂ + 2H₂ in a small, isolated volume. To ignite the gas mixture, we used a modified spark plug, which applies a high voltage transient and breaks down the gas between two electrodes. We tested as low as 2 mL of an O₂ + 2H₂ mixture in direct contact with 50 mL quartz beakers (1.5mm average wall thickness, with 1.5-2.3mm thickness at the base) and observed catastrophic glass failures in all cases. Depending on the volume of O₂ + 2H₂, the shard size distributions varied, ranging from a few large shards to dust. To simulate a scenario of a H₂ / O₂ combustion in the water (i.e., it's not in contact with the glass), we mixed O₂ + 2H₂ in a thin latex balloon suspended in water. We found that up to 3 mL of an O₂ + 2H₂ mixture was unable to break the quartz. Moving the thin latex balloon in-contact with the quartz wall (while still suspended in water) did catastrophically break the quartz (**Fig. 37**). So, we concluded that a combustible < 3mL O₂ + 2H₂ mixture must be in contact with glass to induce fracture.

It's important to highlight that Mizuno ran plasma electrolysis experiments between 2000 – 2005 and observed *one* catastrophic explosion⁵⁶; however, this had nothing to do with loaded Pd cathodes as Mizuno used a Pt anode and W cathode, neither of which load with deuterium.

⁵² S.J. Grutzik et. al, *Journal of Non-Crystalline Solids: X*, 16, 100134 (2022).

⁵³ W. Feng et. al, *Corrosion and Materials Degradation*, 2(3), 412-446 (2021).

⁵⁴ G. Rene, *Journal of Non-Crystalline Solids*, 316(1), 1-11 (2003).

⁵⁵ C. Barry, *Photovoltaic Specialists Conference* (2009).

⁵⁶ T. Mizuno, *The 12th International Conference on Condensed Matter Nuclear Science* (2005).

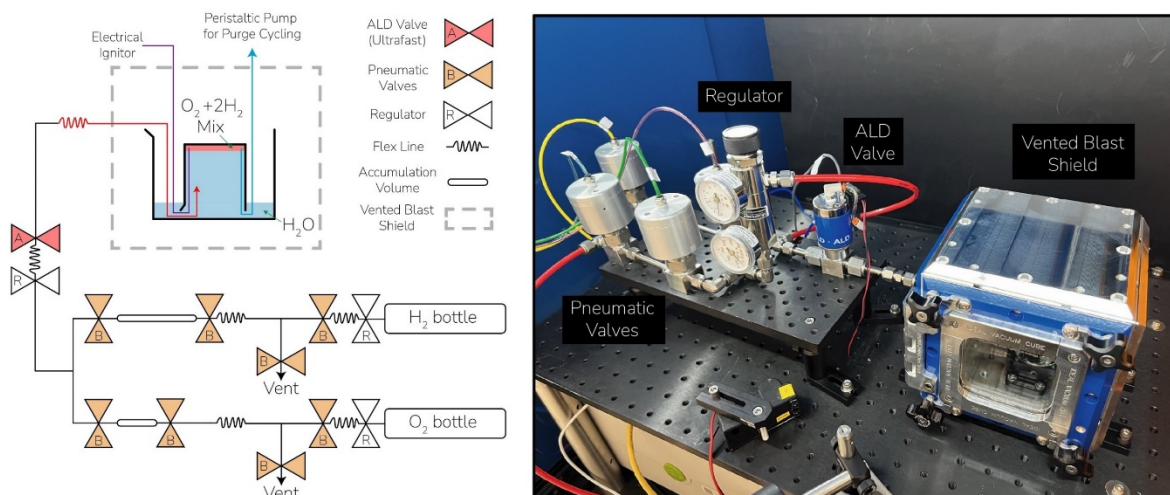


Fig. 36: Apparatus used to study H₂ / O₂ combustions in water.

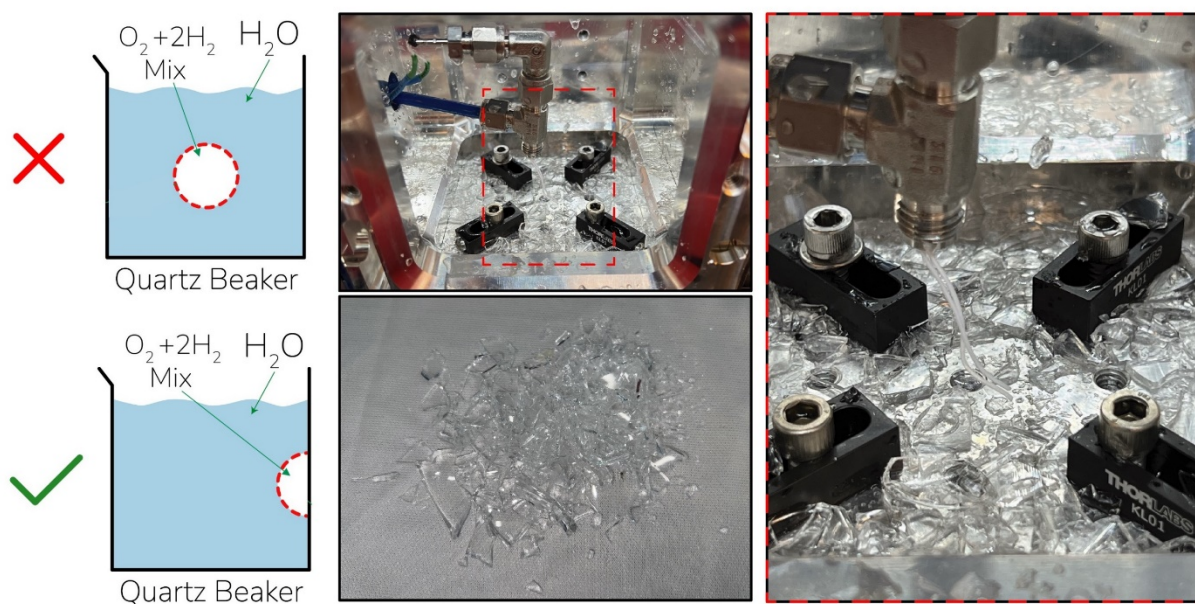


Fig. 37: As long as a combustible O₂ + 2H₂ mixture is in-contact with the quartz cell wall, the cell catastrophically fails.

In summary, we've reproducibly explained (in qualitative terms) the key observations of the '89 LLNL experiments: "cranking up" the current density in current control leads to "vigorous bubbling" and subsequently a "glowing cathode" that undergoes a color change from "red to white"

hot” after which a “flash and bang” occurs, shattering the cell⁵⁷ and leaving a melted Pd cathode surface (**Fig. 38**). We argue that the voltage of the “unknown power supply” is the key to the ’89 LLNL experiment: if capable of >30 V at the 800 mA/cm² current density believed to have been used, then plasma electrolysis and H₂/O₂ combustions can occur and explain the observations.

Hopefully, the ongoing Callisto electrochemical loading replications of the ’89 LLNL experiment will demonstrate LENR. In that event, then it is reasonable to assume that the ’89 LLNL experiments were also due to LENR. However, if they do not, then the one-off nature of the ’89 LLNL experiment (and the lack of any quantitative data records from it), means that we will never actually know the cause of the LLNL results. LENR is one possible explanation of those results. But, given the Callisto experiments, we believe that LENR is no longer the only possible explanation. Hence, the existence of the ’89 LLNL results is not sufficient to establish the existence of LENR “beyond a reasonable doubt”.

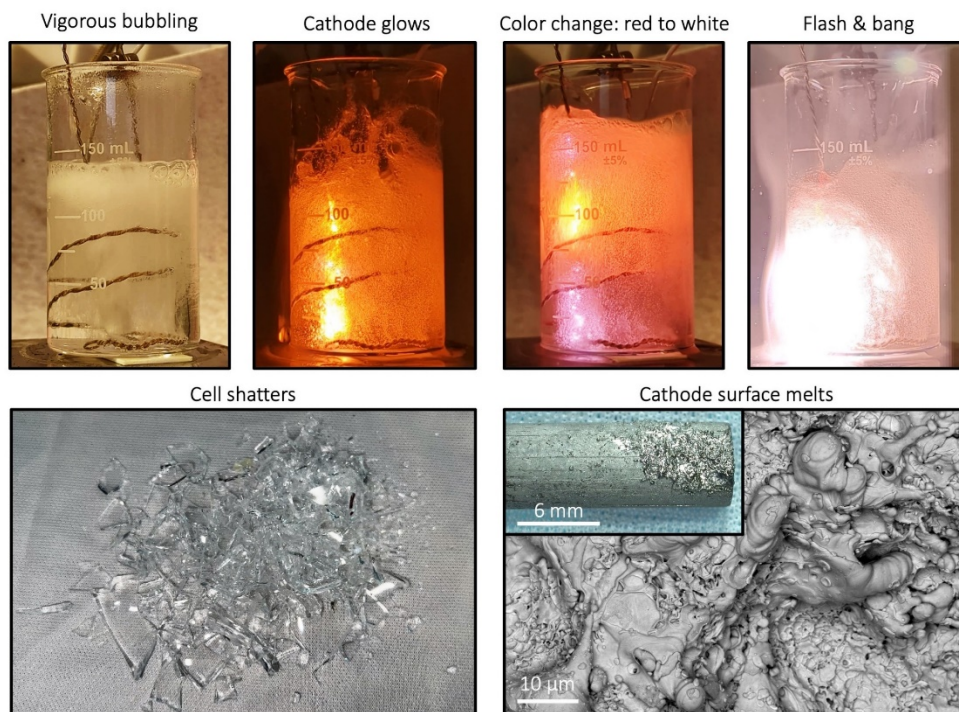


Fig. 38: The key observations from the ’89 LLNL experiment have been qualitatively reproduced and explained by plasma electrolysis and H₂/O₂ combustions.

⁵⁷ All cell shattering experiments were done in the controlled H₂ / O₂ combustion apparatus.