Condensed Matter Nuclear Reactions in Nano-Materials

ARPA-E Workshop on Low-Energy Nuclear Reactions

October 21-22, 2021

With additional backup slides that weren't presented at the Workshop. Workshop presenters with additional details are in "[...]".

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V 2.0

Have We Found the Keys to the Kingdom?

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- Pd used as a hydrogen gas separator/purifier. *[Benyo]*
  - Has a unique electronic structure: $4d^{10}$ <> $4d^{9}5s^{1}$: *paramagnetic and ferromagnetic states*
- Pd will load H/D, *e.g*. PdD_x to x < .56, α >> β phase
  - Fleischmann and Pons used electrolysis to bulk load x > .9, *but takes days to weeks to load*
- McKubre has shown bulk PdD_x, *x > .86 for onset of LENR heat.* *[McKubre]*
- Szpak showed electrolytic Pd/D co-deposition *rapidly loads x≈ 1.0* *[Mosier-Boss]*
  - SEM analysis shows a size range from *nm to μm scales*
  - Miles and Barham: *watts thermal*
- Storms suggests *nm fissures* provide a nuclear active environment (NAE)
- Staker observed and created *Pd Super-Abundant Vacancies (SAV)* allowing high-densities of hydrogen isotopes
- DeChiaro modeled *itinerant ferromagnetism* and SAV
- Pianitelli, *Ni*, Takahashi, Celani and others have found *NiCu exhibit excess heat with hydrogen*

	Excess Heat	Duration	Mass	Material	W_t/g	Joules
• Arata:	10 W_t	12 weeks	3 g	Pd-black nanoparticles w/D_2	3.3	73 MJ
• Takahashi	226 W_t	several weeks *[5]*	505 g	CuNi nanoparticles w/H_2	0.45	683 MJ
• Ahern:	21 W_t	5 days	5 g	PdNi nanopowder w/D_2	4.2	9 MJ
• Celani:	18 W_t	5 hours	0.45 g	CuNi nanolayers w/H_2 or D_2	40.0	324 kJ

LENR requires multiple science and engineering disciplines.

Questions remain: Scaling, self-operating, reaction products, life-time, triggering, mechanisms.

Common Features of LENR-Active Nano-Materials

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- **Hydrogen isotope spillover**[1]
  - Three stages: adsorption, dissociation, absorption
  - Pd will do all three, Cu the first two[2], Ni absorbs H at > 200 ℃
- **Materials**
  - Pd, Pd_3Ni_7, Pd_1Ni_9, Cu_3Ni_7, $Cu_{55}Ni_{44}Mn_1$ often in ZrO_2
- **Structures**
  - Nano-scale structures, 2 – 20 nm
- **Fabrication**
  - Spin-cast powders[3] *[Narita]*
  - Multi-layers[4,5] *[Narita]*
  - Co-deposition[6] *[Mosier-Boss & Barham]*
  - Double cathode[7] *[Nagle & Narita & McKubre]*
- **Operation**
  - H_2 or D_2 gas or electrolytic loading and/or flux *[Benyo & McKubre]*

Less appreciated

The roles of magnetic order and disorder

- Bulk Ni Curie Point ≈ 354 ℃,
- Nanoparticle Curie Point T < bulk material
- Pd is paramagnetic
- ZrO_2 in contact with Pd strains the lattice *induces ferromagnetism*[8,9]
- *PdH and PdD are superconductors*[10]
- Superconductor $YBCOD_x$ is *LENR Active*[11]

Is LENR a topological phenomena?

Is magnetism a key?

Excess Heat

Pd, PdNi favors D_2
Ni, CuNi favors H_2
Oxides often present

Comparisons

10^4	eV/H	(Iwamura)[4]
$10^3 - 10^5$	eV/D	(Takahashi)[12]
4.88	eV/H	(oxidation: H_2O)

[1] *Spillover of Adsorbed Species, Studies in Surface Science and Catalysis,* **17**, ed. G.M. Pajon, S.J. Teichner and J. E. Germain (editors) Elsevier (1983).
[2] A. Crucq, *et al*., "Hydrogen Spillover from Ni to CuNi Alloys", *Studies in Surface Science and Catalysis*, **17**, (1983) 137-147.
[3] B. Ahern, "Program on Technology Innovation: Assessment of Novel Energy Production Mechanisms in a Nanoscale Metal Lattice", *EPRI Technical Report Update*, **1025575,** EPRI, Palo Alto, CA (2012).
[4] Y. Iwamura, "Heat generation experiment using nano-sized metal composite and hydrogen gas", *Cold Fusion: Advances in Condensed Matter Nuclear Science*, **Elsevier,** ed. Jean-Paul Biberian (2020) 157-165.
[5] F. Celani and C. Lorenzetti, "Electrically induced anomalous thermal phenomena in nanostructured wires", *Cold Fusion: Advances in Condensed Matter Nuclear Science*, **Elsevier**, ed. J-P (2020) 101-114.
[6] Y. Arata and Y-C. Zhang, "Observation of Anomalous Heat Release and Helium-4 Production from Highly Deuterated Palladium Fine Particles", *Jpn. J. Appl. Phys.* **38** Pt. 2, No. 7A, (1999) L 774–L 776
[7] US Patent # 8,419,919, "System and Method to Generate Particles", (April 16, 2013)
[8] L.F. Dechiaro, L. P. Forsley, and P.A. Mosier-Boss, "Strained Layer Ferromagnetism in Transition Metals and its Impact Upon Low Energy Nuclear Reactions", *JCMS,* **17**, (2015) pp. 1-26.
[9] D.L.R. Santos*, et al*, "Spin pumping and interlayer exchange coupling through palladium," *Phys. Rev. B* **88** (2013) 054423.
[10] US Patent # 7,033,568, "High Tc palladium hydride superconductor" (April 25, 2006).
[11] Lipson, A.G., *et al*., "Generation of the products of DD nuclear fusion in high-temperature superconductors YBa2Cu3O7-deltaDy near the superconducting phase transition." *Tech. Phys.*, **40** (1995) p. 839.
[12] Takahashi, *et al*., "Enhancement of Excess Thermal Power in Interaction of Nano-Metal and H(D)-Gas", *Proceedings of JCF20 of JCFRS,* preprint (2020).

Representative Nano-material *Anomalous Heat*

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Arata (nano-Pd black/D_2 double cathode)[1] *[Narita &Nagle]*

Material: 20 nm diameter, Pd black, 3 g

Triggering: Electrolytically loaded, [1 kbar D_2]

Excess Heat: 5 – 10 W, *continuous*

Duration: 12 weeks

Celani (CuNiMn & oxide nanolayers, D_2 or H_2)[3]

Material: Mod. Constantan [$Cu_{55}Ni_{44}Mn$] w/oxides, 0.45g[4]

Triggering: Thermal, 50 Hz A/C stimulation, 600 V, heating

Excess Heat: 18 W_t with 99.7 W Joule heating

Duration: 5 hours

Ahern (nano-$PdNiZrO_2/D_2$)[2]

Material: 10 nm diameter $PdNiZrO_2$ powder, 5 g

Triggering: Thermal, T > 360 °C. *[Ni Curie Point, 358 °C]*

Excess Heat: ~ 21 watts, *not repeated*

Duration: 5 days, terminated for evaluation

Takahashi[5,6] ($PdNiZrO_2$ & $CuNiZrO_2$ nanopowders) *[Narita]*

Material: $PdNi_{10}/ZrO_2$ (PNZ10)
Cu_3Ni_7/ZrO_2 (CNZ7) 505 g

Triggering: Thermal?

Excess Heat: PNZ10rr 186 W/kg[5] D_2
CNZ7rr 226 W/kg[5] H_2
reaction energy[5] (η-value) 10^3 to 10^5 eV/D

Duration: several weeks

[1] Y. Arata and Y-C. Zhang, "Observation of Anomalous Heat Release and Helium-4 Production from Highly Deuterated Palladium Fine Particles", *Japan J. Appl. Phys*. **38** Pt. 2, No. 7A, (1999) L 774–L 776
[2] B. Ahern, "Program on Technology Innovation: Assessment of Novel Energy Production Mechanisms in a Nanoscale Metal Lattice", EPRI Technical Report Update, 1025575, EPRI, Palo Alto, CA (2012).
[3] F. Celani and C. Lorenzetti, "Electrically induced anomalous thermal phenomena in nanostructured wires", *Cold Fusion: Advances in Condensed Matter Nuclear Science*, **Elsevier**, ed. J-P Biberian (2020) 101-114.
[4] Personal communications with Celani during and after the ARPA-E Workshop.
[5] A. Takahashi *et al*.," Latest Progress in Research on AHE and Circumstantial Nuclear Evidence by Interaction of Nano-Metal and H(D)-Gas", *JCMNS*, **33**, (2020) 14–32.
[6] A. Takahashi, *et al*., "Enhancement of Excess Thermal Power in Interaction of Nano-Metal and H(D)-Gas", *Proceedings of JCF20 of JCFRS*, preprint (2020).

Related Experiments With *Excess Power*

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Lead researcher/*[presenter]*		Nano-material	H/D Isotope	Country	Year
Ahern[1]		$PdNi/ZrO_2$, nanopowder	D_2	US	< 2012
Arata[2]	*[Narita, Nagle, McKubre]*	Pd black nanopowder, double cathode	D_2 from D_2O	Japan	< 1997
Barham	*[Barham]*	Fast Pd/D Co-deposition	D_2 from D_2O	US	< 2021
Beiting[3]		ZrO_2NiPd nanopowder	H_2	US	< 2017
Celani[4]		NiCuMn (Fe) oxide nano-layers	H_2, D_2	Italy	< 2014
Iwamura[5]	*[Narita]*	CuNi, nanolayers	H_2, D_2	Japan	< 2018
Kitamura[6]	*[Narita]*	Pd, ZrO_2 nanopowder	H_2, D_2	Japan	< 2009
Miles[7,8]	*[McKubre]*	Pd/D Co-deposition (ammonia complex)	D_2 from D_2O	US/Japan	< 1999
Snoswell[9]		Ni nanopowder	H_2?	Australia	< 2012
Storms[10]	*[Nagle]*	compressed Ni or Pd micropowders	H_2, D_2	US	< 2021
Swartz[11]	*[Nagle]*	PdNi-ZrO_2, $PdZrO_2$ nanopowder	D_2	US	< 2017
Takahashi[12]	*[Narita]*	PdNi-ZrO_2 and CuNi-ZrO_2 nanopowder	H_2, D_2	Japan	< 2013

1 B. Ahern, “Program on Technology Innovation: Assessment of Novel Energy Production Mechanisms in a Nanoscale Metal Lattice”, *EPRI Technical Report Update*, **1025575**, EPRI, Palo Alto, CA (2012).
2 Y. Arata and Y-C. Zhang, “Observation of Anomalous Heat Release and Helium-4 Production from Highly Deuterated Palladium Fine Particles”, *Jpn. J. App Phys*. **38** Pt. 2, No. 7A, (1999) L 774–L 776.
3 E. Beiting, “Investigation of the nickel-hydrogen anomalous heat effect,” *Aerospace Report* **No. ATR-2017-01760,** The Aerospace Corporation, El Segundo, CA (2017)
4 F. Celani, et al, “Progress Toward an Understanding of LENR–AHE Effects in Coated Constantan Wires in D2 Atmosphere: DC/AC Voltage Stimulation”*, JCMNS*, **33** (2020) 1-28.
5 Y. Iwamura, “Heat generation experiment using nano-sized metal composite and hydrogen gas”, *Cold Fusion: Advances in Condensed Matter Nuclear Science,* **Elsevier,** ed. Jean-Paul Biberian (2020) 157-165.
6 A. Kitamura, et. al., “Anomalous effects in charging of Pd powders with high density hydrogen isotopes”, *Phys Lett A.*, **373**(35), (2009) 3109-3112.
7 S. Szpak, P.A. Mosier-Boss, and M. H. Miles, “Calorimetry of the Pd + D Codeposition,” *Fusion Technology*, **36** (1999) 234-241.
8 M. H. Miles, “Co-deposition of Palladium and other Transition Metals in H2O and D2O Solutions”, *JCMNS*, **13** (2014) pp 401-410.
9 Communication between B. Ahern and M. Snoswell, discussing Quantum Sphere Corp. nano-nickel powders. See *EPRI Report* **1025575**, p. 4-7, ref [30].
10 E. Storms, “The Nature of the D+D Fusion Reaction in Palladium and Nickel”, *ICCF-23*, Xiamen, China, (June 9-11, 2021)
11 M. Swartz, “Oscillating Excess Power Gain and Magnetic Domains in NANOR®-type CF/LANR Components”, *JCMNS*, **22,** (2017) 35-46.
12 A. Takahashi *et al.*,” Latest Progress in Research on AHE and Circumstantial Nuclear Evidence by Interaction of Nano-Metal and H(D)-Gas”, *JCMNS,* **33,** (2020) 14–32.

Assessment of Needs

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- **Experimental Improvement** (*minimum sensitivity to detect rare products or swamped by background*)
  - High Temperature Calorimetry
    - *Range 30 C – 500 C, > 100 mW sensitivity*
  - Nuclear, HPGe, RF, IR, UV diagnostics, (> 5 sigma over background)
    - *in situ and adjacent to operating devices: watch out for cosmogenic muons and neutrons, natural BG radiation*
    - *Real-time energetic particle spectroscopy preferred: TOF if possible (gold standard for particle energy)*
    - *Witness materials with HPGe insitu, post HPGe monitoring and material assays*
  - Material assay and *limitations (interferences) Indicates the roles of various structures and materials, contaminants*
    - SEM/EDX: wide area FOV, qualitative surface structure, limited elemental sensitivity (parts per ten thousand)
    - ICP-MS: quantitative, isotope specific, but multi-ion (e.g. H_n^+, Ar feed gas) complexes, ppb-ppm
    - TOF-SIMS: isotope specific, qualitative, small FOV, ppb-ppm
    - NAA/PGNAA: quantitative, isotope specific, limited isotope detection, ppt-ppm
    - Alpha/Beta Liquid Scintillator Spectrometer: tritium, activation products, limited energy resolution, ppm
- **Patent Rights**
  - USPTO treats LENR heat as “perpetual motion”, hence, unpatentable, yet necessary for investment and commercialization
- **Licensing**
  - NRC and IAEA providence
  - Patents and patent interference
- **Health Physics Concerns**
  - Nanoparticles, especially non-encapsulated Ni-based nanopowder and their escape via seal and valve seat fouling
  - Self-generated B and EM fields
  - Bremsstrahlung radiation
  - Neutron radiation

Fundamentally, there is a need to run longer with simultaneous diagnostic measurements to correlate effects.

Preferred Experiments

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- **Diagnostics:**
  - **Nuclear:** HPGe x-ray/γ 10 keV – 3 MeV or LaBr3 or NaI(Tl) *[in decreasing energy resolution, but increasing detection (size) efficiency]*
    - CR-39, in situ (< 50 C), external *[Detect both charged particles and neutrons, speciation and energy resolution]*
    - Neutron scintillators for time resolved (< 200 nsec resolution) *[neutron counting and/or spectroscopy]*
    - Plastic/glass scintillators (*in situ ion counting)*, (< 20 nsec resolution) *[Detect charged particles]*
    - Silicon Barrier detectors (200 keV – 20+ MeV ion detection) *[Resolve charged particle energy and nuclear exit channel]*
  - **Optical:** Fiberoptic feedthrough for spectroscopy, digital camera *[Resolve spectra and spatial relationship of "hot" spots]*
  - **IR:** NIR, MIR 1 um – 12 um range, notch-filters *[Detect down-shifted bremsstrahlung, non-black-body radiation]*
  - **RF:** 100 kHz – 10 GHz, with H/V Stokes parameter polarization *[Detect magnetic effects]*
  - **Low temperature Calorimetry:** 25 C – 100+ °C, < 50 mW_t sensitivity *[suitable to aqueous electrolysis]*
  - **High temperature Calorimetry:** 100 C – 500+ °C, 200 mW_t sensitivity *[suitable to high temp gas operation]*
- **Experiments:**
  - **Electrolytic co-deposition with fractal surface nano-particles:**
    - $PdCl_2$, LiCl electrolyte with Pt, Ag, Au cathodes, e.g. patent[1] and Trackers STEM Protocol™
    - Operation > 100 °C, approaching 150 C, 15 bar
    - Slow, ramped up V/I for 2+ weeks *[determine effect lifetime by running longer]*
    - Fast, constant or ramped down, V/I, for 2 weeks *[determine effect lifetime by running* longer: Letts/Dahlgren/HIVER]
  - **Gas Cycling of nanopowders and nanolayers**:
    - nanopowders and nanolayers, H_2, D_2, HD, He, Ar
    - Operation > 200 °C, << 1 bar (often less than 100 torr)
  - **Double Cathode with nano-powders:**
    - nano-powders placed within sealed, electrolyzed Pd tubing for high loading
- **Triggers:**
  - **Low Energy**: thermal, RF, laser, gas cycling/flux
  - **High Energy**: neutron, e-beam, bremsstrahlung

[1] US Patent 8,419,919, "System and Method to Generate Particles" (April 16, 2013)

Possible ARPA-E Program Going Forward

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- **Drive towards LENR/Lattice Confinement Fusion (LCF) Scaling**
  - Self-sustaining operation
    - Establish LENR/LCF lifetime, power output/gm, available Delta T
    - Thermal or direct power conversion
  - Path to Commercialization: *Watts, kW or MW*?
  - Investigate multiple LENR/LCF-capable experiments: "*Lab rats*"
  - Develop predictive modeling of materials and nuclear effects
  - Setup cooperative teams: *share knowledge and findings*!
  - Publish results in "Tier 1" journals
    - Recognition by scientific and engineering communities
    - Acceptance by government agencies and universities
    - Harness private sector funding

Catch-22: *Government agencies won't recognize LENR unless Tier 1 journals publish results. These journals won't publish results unless LENR is recognized by these agencies.*[1]

- **Beyond ARPA-E Program**
  - Multi-agency supported LENR/LCF Program
  - Foreign entity participation
  - Develop university and student support to create the technology workforce
  - Deploy the technology

[1] P.A. Mosier-Boss, L.P. Forsley and F.E. Gordon, "How the Flawed Journal Review Process Impedes Paradigm Shifting Discoveries", *JCMNS*, **12** (2013) 1-12.

Backup Slides

Backup material wasn't presented at the ARPA-E Workshop. However, both Takahashi's and Iwamura's research were discussed by Narita in the Workshop.

Takahashi[1,2] : Nano-particle Anomalous Heat (AHE)

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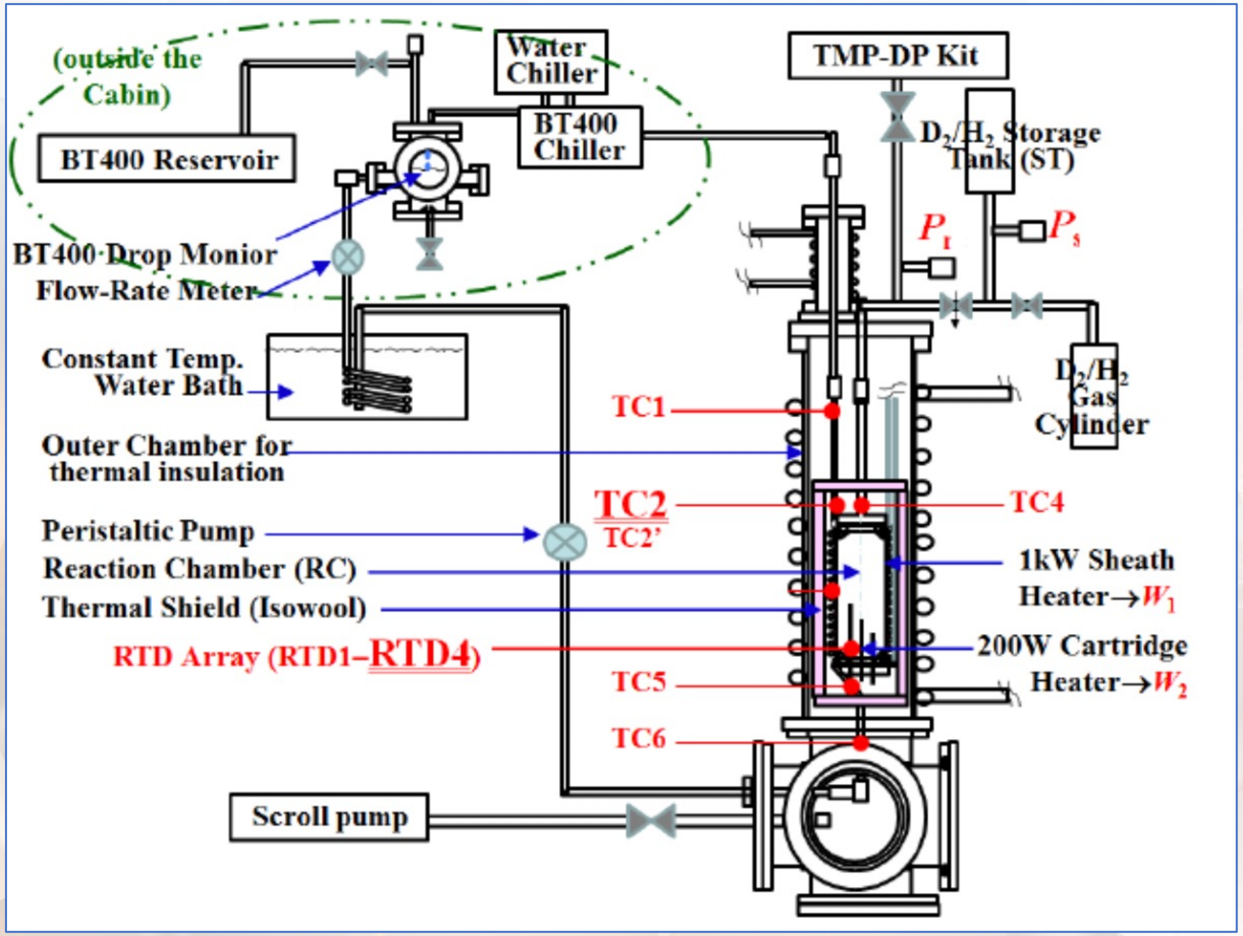


Kobe University C system AHE calorimetry Schematic, oil-flow-calorimeter system with flow-rate-monitors and dual heaters (W1,W2).

Observations

$PdNi_{10}/ZrO_2$ (PNZ10) Cu_3Ni_7/ZrO_2 (CNZ7) melt-spun, calcinated or recalcinated nano-powders.

Calorimetry[1]

80–400 W_{ex}/kg excess thermal repeatable for several weeks at elevated temperature ≈ 300 °C with re-calcined PNZ-type with D.

Specific reaction energy[2] (η-value) 10^3 to 10^5 eV/D.

50-140 W_{ex}/kg obtained by CNZ-type with H

50–70 W_{ex} > two weeks by 505 g CNZ7r (re-calcined)

Neutron Counting[1]

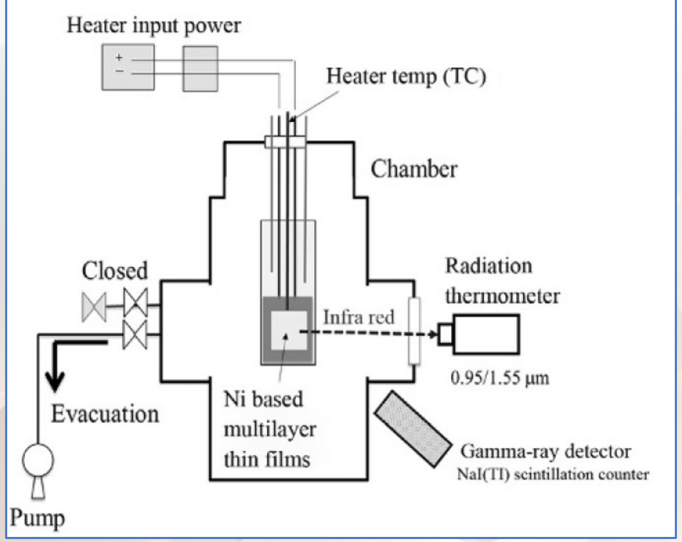
Neutron yield: 0.1 n/J: 1.0×10^{-13} of bare d–d fusion.

AHE is largely aneutronic!

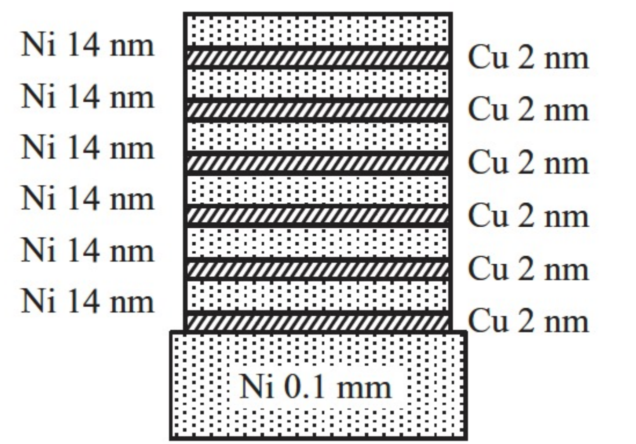
[1] A. Takahashi *et al.*," Latest Progress in Research on AHE and Circumstantial Nuclear Evidence by Interaction of Nano-Metal and H(D)-Gas", *JCMNS,* **33,** (2020) 14–32.

[2] A. Takahashi, *et al.*, "Enhancement of Excess Thermal Power in Interaction of Nano-Metal and H(D)-Gas", *Proceedings of JCF20 of JCFRS,* preprint (2020)..

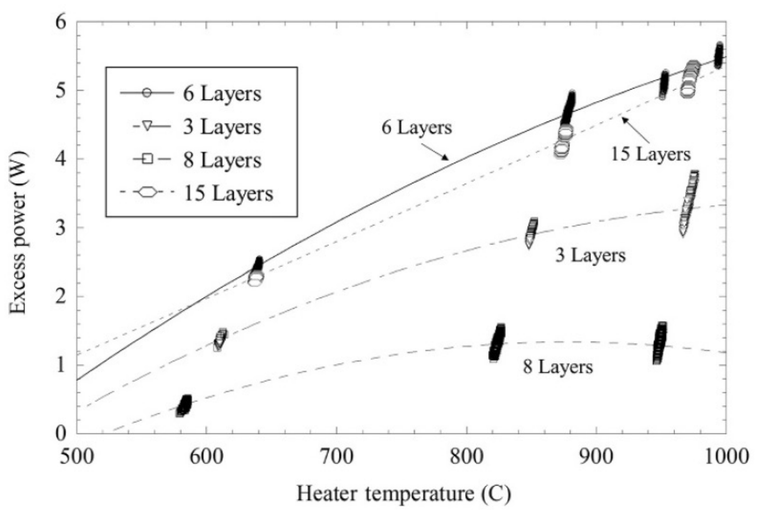
Iwamura[1]: Nano-metal Composite Anomalous Heat



Experiment



Six-layer nano-composite



$W_{t\ excess}$ vs temp

Released excess energy per hydrogen

	Six Layers (Cu 2nm, Ni 14nm)
Absorbed H [mol]	7.3×10^{-4}
Absorbed number of H	4.4×10^{20}
Total excess energy [J]	1.1×10^{6}
Excess energy per hydrogen [J/H-mol]	1.5×10^{9}
Excess energy per hydrogen[eV/H]	1.6×10^{4}

Total Excess: 1.1×10^6 J
Excess Energy: 1.6×10^4 eV/H

Comparisons

10^4 eV/H (Iwamura)
vs
$10^3 – 10^5$ eV/D (Takahashi)
vs
4.88 eV/H > H_2O (oxidation)

[1] Y. Iwamura, "Heat generation experiment using nano-sized metal composite and hydrogen gas", *Cold Fusion: Advances in Condensed Matter Nuclear Science,* **Elsevier,** ed. Jean-Paul Biberian (2020) 157-165.

Nano-material Anomalous Heat

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Ahern (2011, nanopowders) [1]

"…nanotextured nickel in the presence of hydrogen gas, tests of similar materials conducted under this EPRI research grant produced only milliwatt-scale thermal power releases… one experiment, a 21-watt release was observed but not replicated."

Reproducibility depended upon triggering by raising temperature above 360 °C. The excess heating rate output did not exceed 200 milliwatts.

…thermal power estimated to be 100 milliwatts per degree C of elevation above the value of the outer resistance thermal device (RTD)….10-nm nickel powder from Quantum Sphere Corp. The inner RTD was 208°C hotter than the outer RTD (533 °C versus 325 °C) …~ 21 watts from 5 grams of nanopowder… maintained for five days… terminated for evaluation.

Issue: Is heat produced by global collapse of magnetic order at Curie Point or are reactions initiated by the same? *It appears that the excess power over time exceeds the magnetic field collapse energy storage.*

Celani (< 2020, nanolayers)[2]

…the successful work of Brian Ahern with nickel-based powders and having close experience with similar systems, we speculated on the possibility of an unidentified "trigger"… AHE can be triggered and controlled electrically, opening the possibility for further scale up toward practical applications…we achieve 8–9W of AHE when using 80W of Joule heating of the Constantan [$Cu_{55}Ni_{44}Mn_1$] under AC stimulation (50 Hz, up to 600V).

Constantan wires producing the largest AHE were produced in the 1970s which contained about 0.5% iron, nearly absent in more recent Constantan lots. Holmlid reported the possible formation of ultradense states of atomic hydrogen and deuterium in iron-potassium catalysts.

Takahashi[3,4] (nanopowders) [*see Narita overview of Japanese research*]

$PdNi_{10}/ZrO_2$ (PNZ10) Cu_3Ni_7/ZrO_2 (CNZ7) melt-spun, calcinated or recalcinated nano-powders. 80–400 W/kg excess thermal W_{ex} repeatable for several weeks at elevated temperature ≈ 300 °C with re-calcined PNZ-type with D[3]. Specific reaction energy[4] (η-value) 10^3 to 10^5 eV/D. 50-140 W/kg W_{ex} obtained by CNZ-type with H and 50–70 W continued > two weeks by 505 g CNZ7r (re-calcined)

Neutron yield: 0.1 n/J: 1.0×10^{-13} of bare d–d fusion. *AHE is largely aneutronic!*

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[2] F. Celani and C. Lorenzetti, "Electrically induced anomalous thermal phenomena in nanostructured wires", *Cold Fusion: Advances in Condensed Matter Nuclear Science*, **Elsevier**, ed. Jean-Paul Biberian (2020) 101-114.

[3] A. Takahashi *et al*.," Latest Progress in Research on AHE and Circumstantial Nuclear Evidence by Interaction of Nano-Metal and H(D)-Gas", *JCMNS*, **33,** (2020) 14–32.

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