Clear and simple evidence of correlations among Open Voltage values and AHE in Constantan wires, DC operations under H_2 gas, after long time conditioning at 70 and 100 W of input power.

#Francesco Celani[1,2,4], C. Lorenzetti[1], G. Vassallo[1,2,3,4], E. Purchi[1], S. Fiorilla[1], S. Cupellini[1],

M. Nakamura[1], P. Cerreoni[1], R. Burri[1], P. Boccanera[1], A. Spallone[1,2,4], E. F. Marano[1].

(1) ISCMNS_L1: Intern. Soc. of Condensed Matter Nucl. Science_Via Cavour 26, 03013 Ferentino (FR)-Italy;

(2) EU Project H2020: CleanHME-European Union, grant #951974;

(3) DIDI, University of Palermo, 90128 Palermo (PA)-Italy;

(4) Istituto Nazionale di Fisica Nucleare, Via E. Fermi 56, 00044 Frascati (RM)-Italy.

franzcelani@libero.it INFN-LNF, Via E. Fermi 56, 00044 Frascati (RM)-Italy

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OUTLINE

- **Introduction.**
  a) **Sketch of reactor core: coiled constantan coil, with long and thin wire coated by Low Work Function (LWF) materials. Counter-electrode geometry (Fig. 1).**
  b) **Hybrid glassy-Quartz/Alumina sheath, large surface area, LWF materials coated (Fig. 2).**
  c) ***Richardson* equation and plot (i.e. electron emission at low pressures, Fig. 3).**
  d) ***Paschen* plot (i.e. gas ionization regimes, at mild pressures, Fig. 4).**
  e) **Sketch, with photo, of reactor assembly and drawing with key aspects, (Fig. 5, 6).**
- **Probable pre-activation procedures.**
- **Current, very simple, measurement procedures.**
- **Results.**
- **Comments.**
- **Conclusions with future work.**
- **Acknowledgments and Disclaimer.**

Introduction (with key background information)

- **Very recently, in the framework of AHE stimulation in Costantan-H_2 gas system at high temperatures and mild pressure, we compared the values of Anomalous Heat Effects (AHE), if any, after keeping the core of the reactor now operating at INFN-LNF, under enough-long time (38 hours) DC pre-operations at 4 different values of input powers: 70 W, 100, 120, 130 W.**

- **Further tests were performed using Ar/H_2 atmosphere (83/17 ratio), with an initial total pressure of 4.2 bar, *before* using the "Reference" H_2 atmosphere at 4.8 bar.**
  The test with Ar/H_2 atmosphere, because gave intrinsically very different values of temperatures internal and external to the reactor in respect to pure H_2 atmosphere, *as theoretically expected*, were crucial to keep us confident to exclude possible artefacts in the measurements using the "self-calibration approach" by the Reference experiment (identified as #0, see later).

- **Evaluations of AHE were made by *simple thermometry measurements*, external to the reactor wall, using as *Reference the same core, with the same gas at similar pressures (>>1 bar)*, that got different activation cycles. Moreover, also the inside-core temperatures are measured, as general-purpose cross-test of self-consistency of experimental results. The reasons to choose just thermometry, instead of usual calorimetry, is the shorter time needed to get temperature equilibrium: <30 m instead of 4-6 hours by using our air flow calorimeter, operative from several years at INFN-LNF. So, in the explorative phase of research, it is efficient/mandatory to save time. *At the end of explorative experimentation, the most important measurements will be repeated by calorimetry: to be completely sure that no strange instrumental or set-up artefacts could be happened.***

- **The core is our "standard" geometrical configuration of thin wire (based on Constantan, an alloy of Cu_55-Ni_44-Mn_1), diameter 200 μm, length 158 cm, coaxially coiled around a Fe counter electrode used also as main mechanical support. The recent geometry is a SIMPLIFIED version of what presented at ICCF23 (Fig. 1, 2), without IR reflector and local thermal screening.**

- **The Constantan wire's surface is made spongy (by proper oxidation cycles-in open-air at high temperatures, up to 800 °C): Joule heating with current density up to 9 kA/cm^2 (for short times) and coated (several times) by a specific solution of materials (like Sr, K) characterised to have a Low Work Function (LWF) values for electron emission, (i.e. Richardson equation, Fig. 3), *once properly activated.* Moreover, Fe and (partially) Mn are added to LWF because both behave as local hydrogen reservoir at high temperatures and anti-sintering effects at the submicrometric Constantan surfaces: we need to keep "nano-dimensionality", even under high temperatures conditions.**

- **As further characteristic, the *specific glassy sheaths*, used for electrical insulation purposes, apart to be embedded by LWF and Fe-Mn solutions, have the peculiarity to absorb selectively Atomic Hydrogen (H) at high temperatures (as discovered, by chance, by *Irving Langmuir* on 1928). The sheaths used are made by thin wires, quite rough surface, of only 5 μm diameter each: the effective surface area of the "bounded" sheath, apparent diameter of 1.5 mm and internal hole of 0.5 mm, is in the range of several m^2 for each linear meter. Such sheaths are produced by SIGI-Favier (Italy-France Company).**

- ***The H production, from molecular H_2, is strongly enhanced by Constantan that is the best alloy to facilitate such dissociation, providing over 3 eV, in comparison with the well-known (and very expensive) Pd (0.424 eV).***

- **In respect to aging effects at the spongy surface of Constantan wire, at the beginning very catalytic after initial activation procedures, we found the also the application of high voltage pulses (up to 1000 V, duration some μs), even under mild pressures (few bar) is able to reactivate, at least, the aged surfaces. We think that the complex phenomena, to be further investigated, are due both to Paschen regime (Fig.4) and DBD (Dielectric Barrier Discharge) effects. The pulses were applied, with proper timing on each pulse, both longitudinally (voltage drop along the wire up to 400 V, current up to 12 A, power density up to 10 kV*A/g, time duration from 2.5 up to 10 μs), and transversally by the Fe counter electrode (up to 1000 V, peak current << 1 A).**

More details, on wire preparation and geometrical configuration, were published in several of our papers, since ICCF22 Conference (September 2019, Assisi), up to the most recent

Invited Paper at ICCF23 (June 2021, Xiamen University, China)

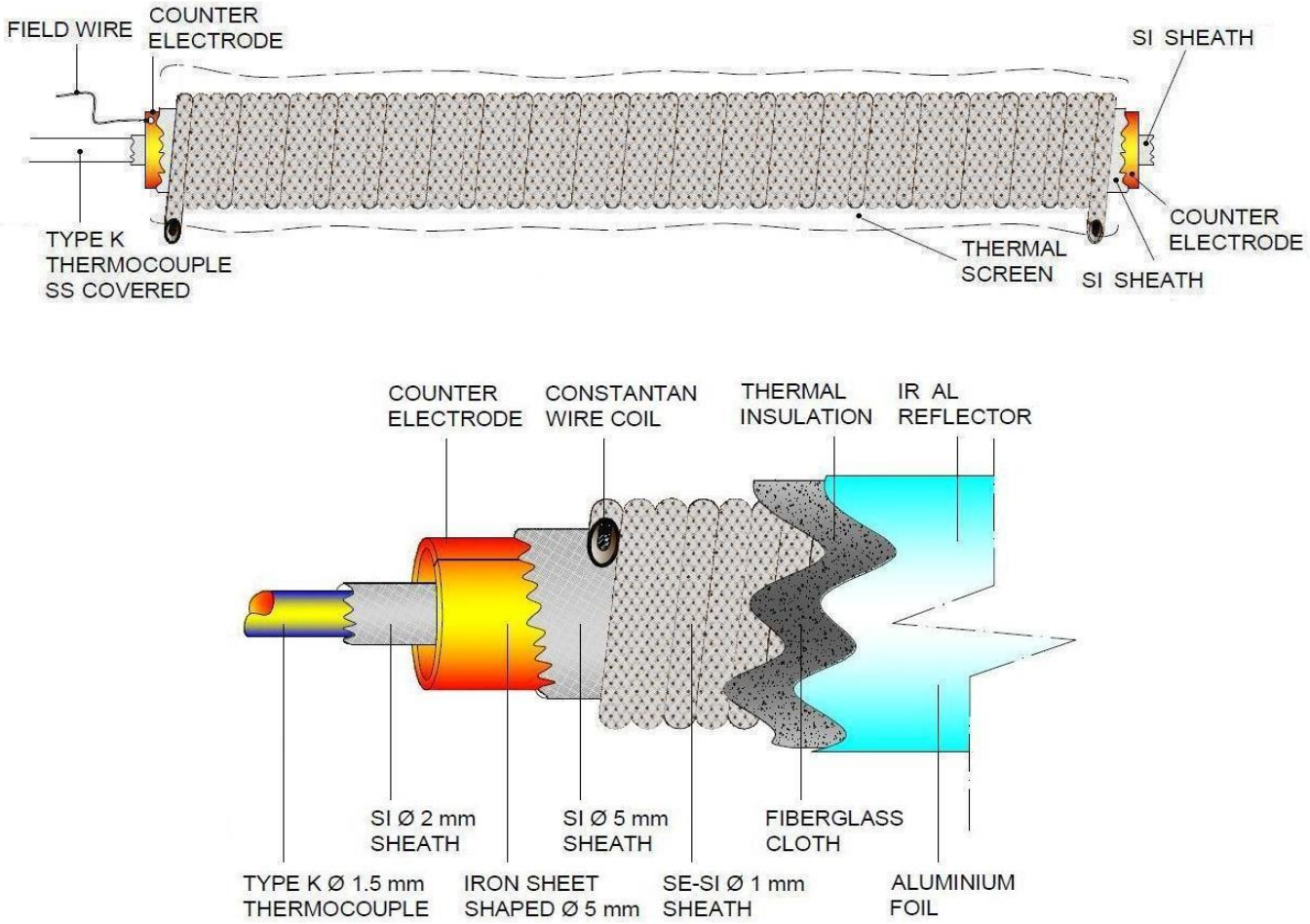


Fig. 1. Scheme of the coaxial coil with its inner Fe counter-electrode. A coil, wirw length of 158 cm, had usually 75 turns; recently reduced to about 50 because HV insulation problematics. The present core, in respect to ICCF23 version, is a simplified version without IR screening (by Al foil) and thermal insulation.

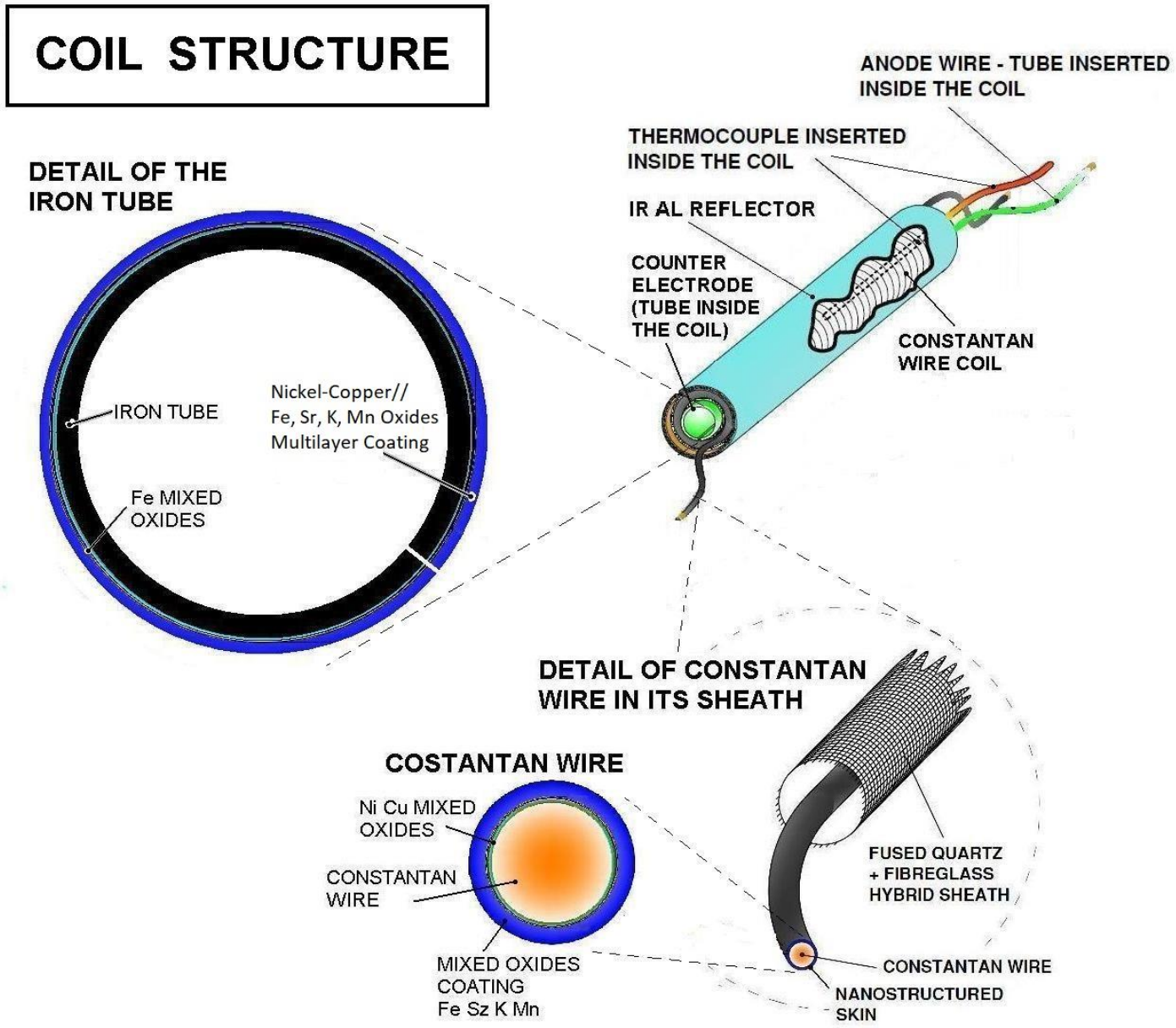


Fig.2. Overview of the coil assembly: multilayer coating of LWF oxides; high temperature insulating hybrid glass-(AlO_2-SiO_2) porous sheaths; external IR reflector. The set-up used in the present work is without IR screening.

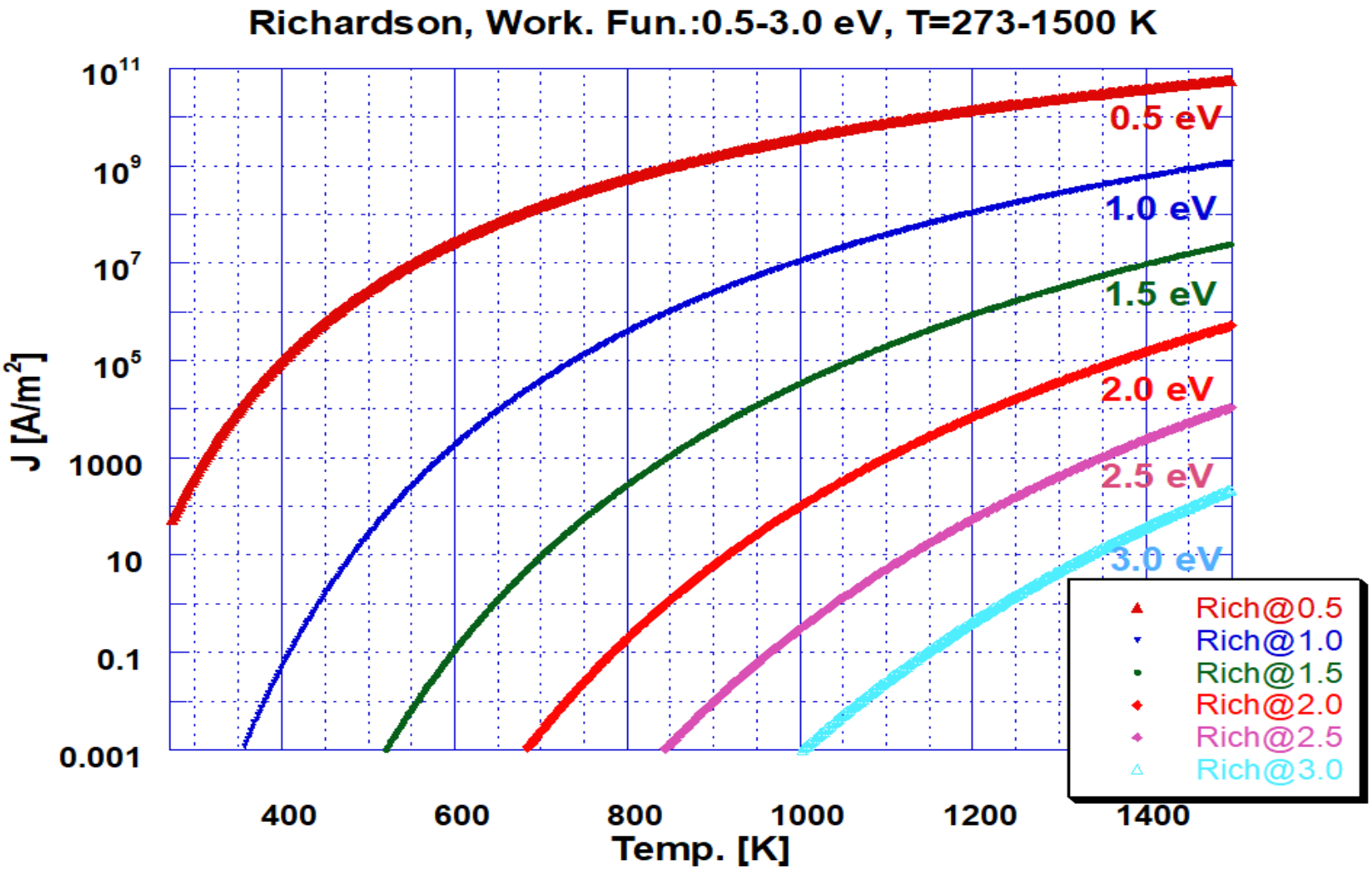


Fig.3. Calculated dependence of density of electron emission J (A/m^2) versus Temperature (273-1500 K) and Work Function (0.5—3.0 eV) as main parameter, according to the Richardson's law.

Electrons are emitted following the Richardson law for the thermionic emission at reduced pressure:

$$J = AT^2 e^{-\frac{W}{kT}}$$

Where:

- J is the current density emitted (A/m^2);
- T is the emitter temperature (K);
- W is the work function (eV);
- k is the Boltzmann constant, $1.38*10^{-23}$ (J/K);
- A is a constant (in the simplest form of the law: $1.20173*10^6$ A*m).

- From the formula it is evident the need to have values of *W as low as possible* to avoid operating temperatures excessively large (over 1000 °C). In our experiments we used mainly SrO, K doped, to have a value of W close to 2 eV. All the wire pretreatments (i.e. surface oxidation→reductions to get submicrometric sponge-like surfaces, i.e. large effective area) and final chemical coatings (multilayers procedure), are home-made.

1) Child -Langmuir law.

The electrons that “boil-off” at the surface of hot material, at *low gas pressures*, can be expelled when a counter electrode with a certain voltage is positioned at a sufficiently close distance from the material surface. The current intensity depends as $V^{1.5}$.

In detail:

$$J = B * S * \frac{V^{1.5}}{d^2}$$

Where:

- J is the current density,
- B is a constant,
- S is Anode surface,
- V is voltage among Anode and Cathode,
- d is Anode-Cathode distance.

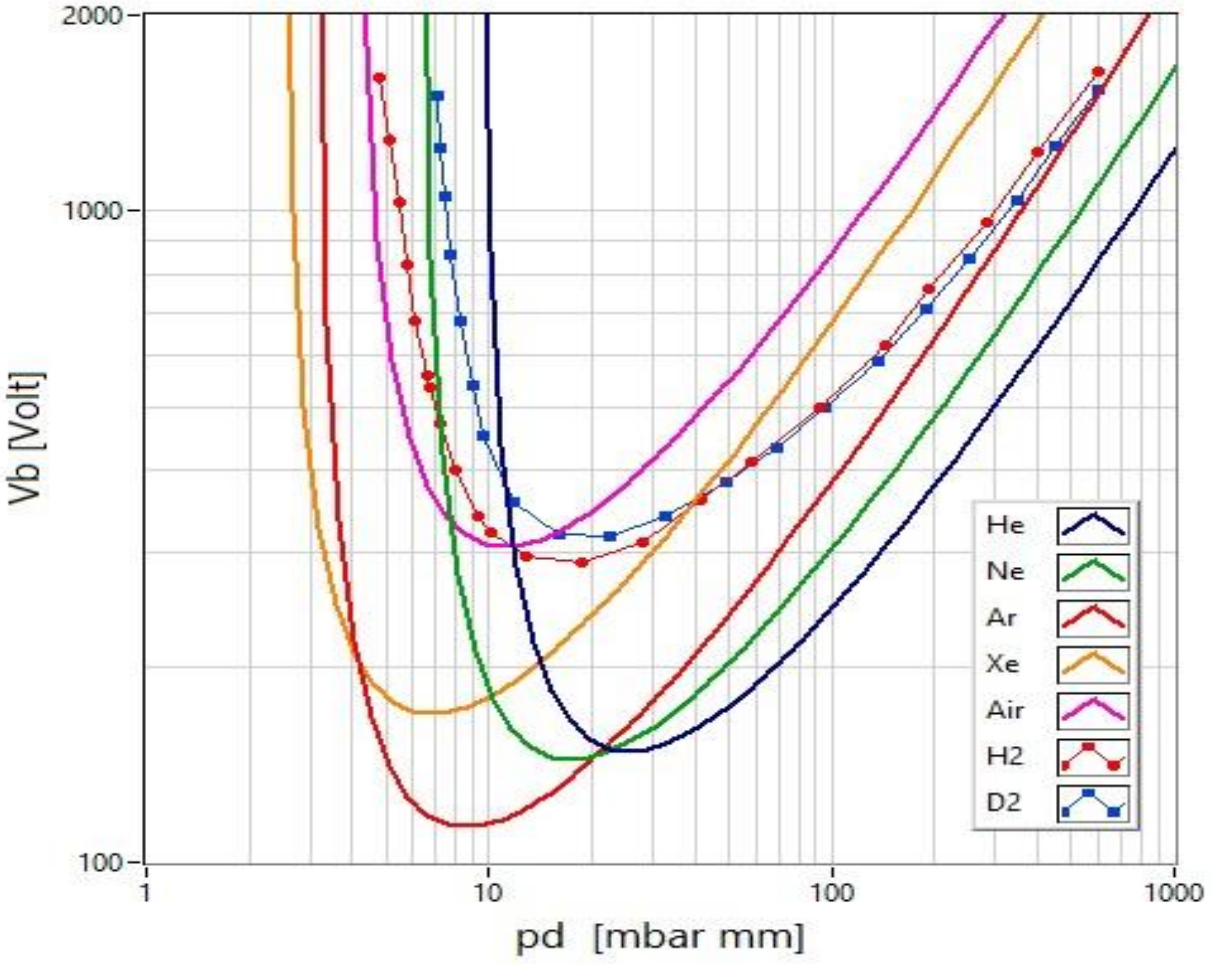


Figure 4. Paschen curve. Direct current breakdown tension (Vb) of several gases versus pressure and distance between electrodes (p*d). The addition of Ar to H_2 or D_2 clearly enables discharges at lower voltages. He could be useful at higher values of p*d. We made test with both noble gas (i.e. He, Ar), pure or mixed with mainly H_2. Mixtures with D_2 were also made but quite difficult to be fully understood.

Photo of real reactor and overview of connections

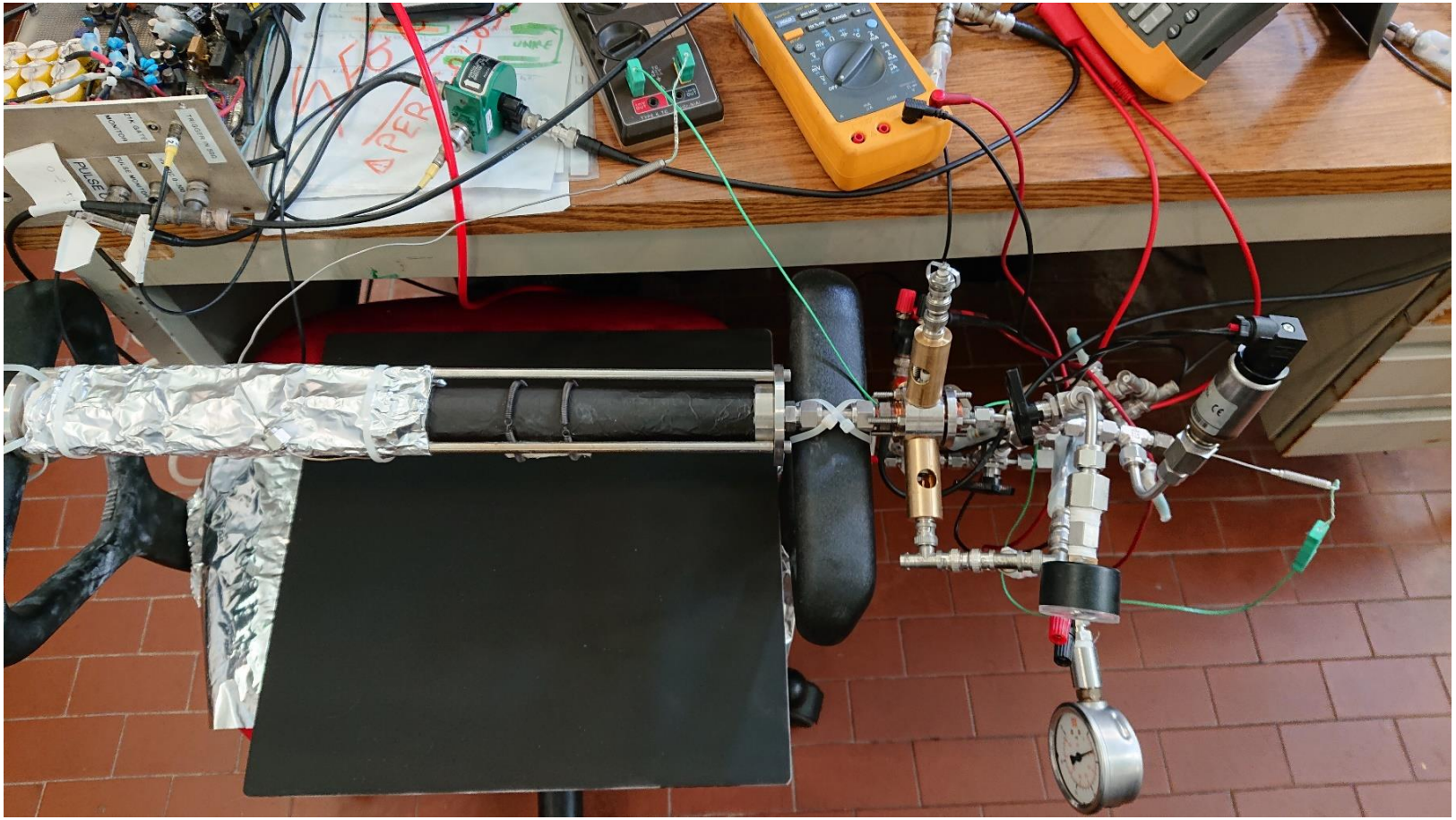


Fig 5A. Photo of the reactor in the most recent open-air set-up. In order to reduce thermal back irradiation, there is a large and tick Al plate, blacked (paint with 95% emissivity), used as heat dissipator. The "ambient" temperature, used in the calculation about AHE, takes in proper accounts also the plate temperature.

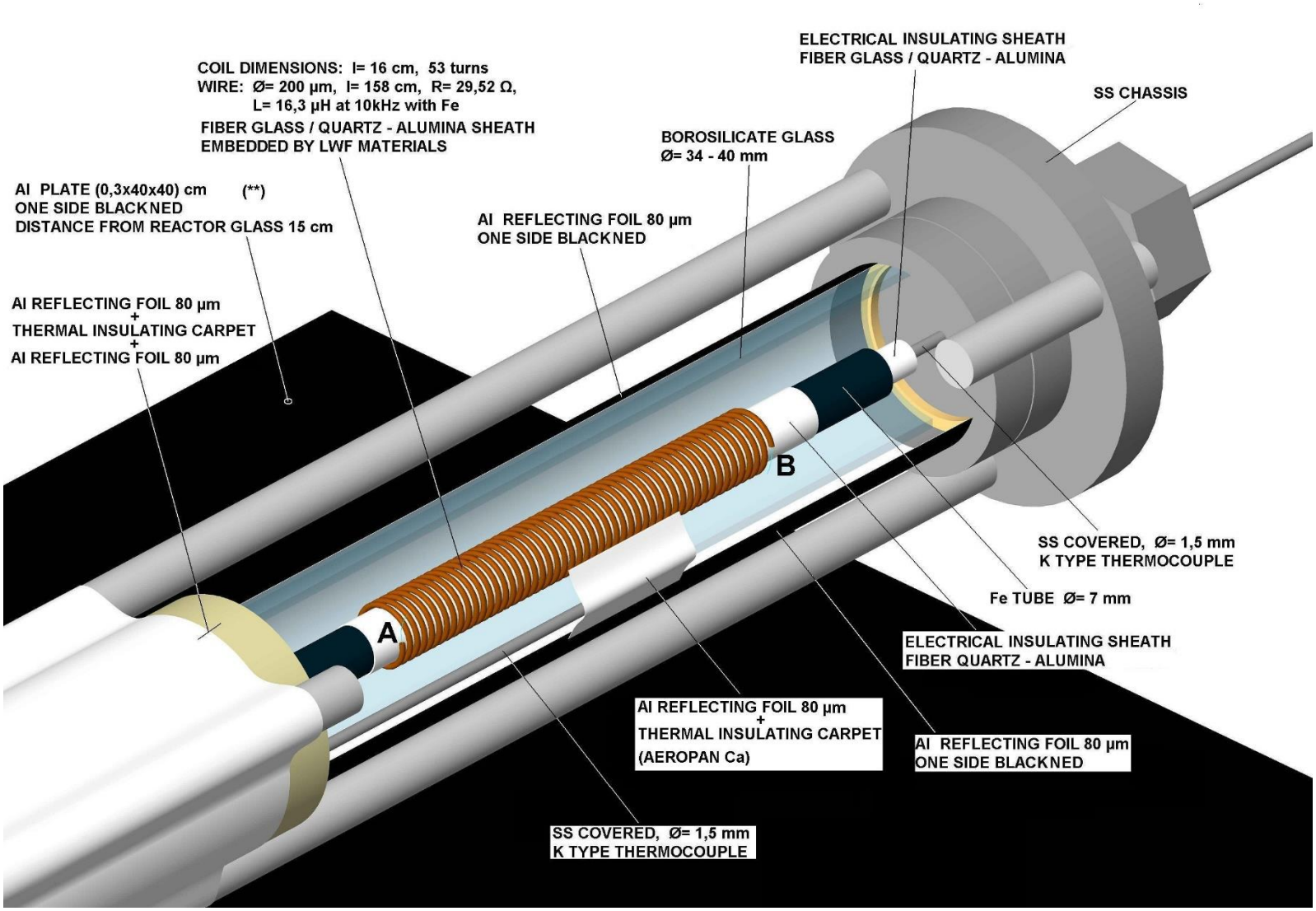


Fig. 5B. Schematic of the reactor assembly with key elements detailed.

Probable activation procedures.

- **At the moment we *think the pre-activation procedures*, after open-air wire preparation and the usual, in situ, several cycles of vacuum and H_2 interaction at high temperatures and pressures (about 500 °C, 3-5 bar of pressure), had at least, *new further steps* in the present experiment.**
  They could be significative for "conditioning/activating" the wire and to get the recent characteristic of "easy" AHE production, even after long time of operating conditions "*apparently unable*" to produce significant amounts of AHE or even left at RT but under H_2 gas (few bar of pressure).
  They were as following:

  a) **High power "standard" (in our new experiments) pulsed stimulation, up to 10 kV*A/g of materials, for time lasting up to 40 h, pulse duration of 10 μs, repetition rate up to 2.5 kHz, i.e. mean power up to *90 W*. Gas H_2 at 4-5 bar of pressure. Mean coil temperature >500 °C, larger locally during pulsing period because skin effect due to: a) higher frequency components of the pulse; b) magnetic material of the coating mixture.**

  b) **The recent type of pulsing procedures, at higher repetition rate (from 2.5 to 5 and 10 kHz) and shorter time duration (from 10 μs down to 5 and 2.5 μs), even if the total time of test (few hours at each operating point) was lower in respect to the "standard one". They were, very shortly, discussed in our presentation#1 at this Workshop, although the pulser (home-made) used, was damaged after short time of operations and we are now waiting to get the spare part needed to repair it.**

New results, key aspects

- **The first step was to increase the inner core temperature up to about 650 °C, even with the planned maximum power applied of about 110--120 W, with largest values for short time (10-15 m only). We experienced that such step could be useful to have a "fresh re-activation" of LWF materials and /or of the bulk, just because quite large current density (electromigration of "proper" impurities??).**
  a) **We adopted the simple procedure to increase the internal temperature just by reducing the thermal conductivity of the gas. In short, we added large amounts of thermal insulating and chemically inert gas, like Ar. Moreover, its cost is very low. According to previous test in similar conditions, a ratio of Ar/H_2 at about 80/20 was proper: in the specific experiment was 83/17.**
  b) **The overall pressure was planned to be of the order of 4 bar in order to avoid, in these tests, to "enter" into the Paschen regime (shown in Fig. 4) that, at the moment, we are not able to control if we would use, for any reasons, pulsed conditions (up to 1000 V peak): we experienced several catastrophic failures of the wires because, uncontrolled, localised hot-spot of energy. We think that the geometrical control of the coil construction, i.e. the anode-cathode distance (2-3 mm), is not enough accurate/regular for our purposes.**

- **After making calibration of the system up to the maximum power planned (110 W), we decreased the power with steps of (about) 10 W, with the end point at zero value. Moreover, to have some reference values at very low power we added, to the planned value of 10 W, another intermediate value of 5 W, before reaching 0 W.**

- **For each measurement we recorded:**
  a) **Voltage drop along the wire, one side grounded;**
  b) **DC current flowing;**
  c) **Temperatures: Internal at the coil; external glass wall (covered by Al foil and black darkened); ambient (at the large Al plate, black darkened, as shown in Fig. 5A);**
  d) **The Open Circuit Voltage (OCV), if any, just after the moment of the abrupt interruption of the large current powering the wire. The measurement is performed manually, with a time delay <1 s after the interruption. The voltage measured is in the range of few-some mV.**

- **In the past, since the beginning of the use of Constantan wires (i.e. 2011-2012) we observed some times that some "*spontaneous voltage", i.e. OCV*, come from the wire at the moment of switching off. Moreover, such voltage happened to be positively related to the amount of AHE. Although we made some dedicated tests, at International level (e.g. jointly with Mathieu Valat and Bob Greeiner, membership of the *Martin Fleischman Memorial project*), to evaluate the effect and try to find a way to "control" it, the results of the efforts were not fully satisfactory. We had to accept the fact that the effect, although real and quite important, was out of our control about "generation on demand".**

Procedure of measurements

- **Given the wire diameter (200 μm), i.e. cross-section area $3.14*10^{-4}$ cm^2, geometrical construction of the reactor and its core, gas (H_2) and its pressure (4.8 bar at RT), the measured temperatures of inner core are respectively about 404 °C (at 70 W) and 504 °C (at 100 W) for the "*reference*" measurements at the beginning of the 5 experiments. The current density J flowing inside the wire are respectively 5063 and 6000 A/cm^2.**

- **After the explorative cycle by Ar/H2 gas mixture, as previously described, the sequence of operations was *very simple*, as following:**

a) **Make vacuum (simple 2-stages RP) to the system, applying some current to get an internal core temperature of 400-500 °C, allowing also some H_2 previously stored inside the system/core, to be evacuated.**
b) **After cooling to RT, add H_2 at proper pressure (4.8 bar) and clean the system by 2 cycles of H_2→Vacuum→H_2. In the mean-time, wait several tens of minutes, at high temperatures (about 500 °C) to allow possible water (produced because H_2 recombined with O_2) to be fully evacuated during vacuum regime.**
c) **After refilling H_2 at RT, apply, quickly, the largest power compatible with the system under full safety conditions: e.g. 110 W, current about 1.98 A ($J=6300$ $A/cm^{2)}$; inner core temperature (in our geometrical configurations) reached 533 °C. About the maximum power value of 110 W, later we realised that it can be increased safely.**

d) Wait for thermal stabilization (about 20 m in our system) at high power. Because longer equilibrium time for the first measurement (starting from RT), we waited 60 m to get reliable data and to note several cross-reference aspects. Anyway, in the first test, after 30 m from the beginning, the temperatures, both internal and external, were stable, as previously experienced.

e) Once thermal equilibrium was reached, note all the proper conditions and ABRUPTLY disconnect the DC power supply. Measure, *immediately* (<1 s), the spontaneous voltage, from us named Open Circuit Voltage (OCV), at the ends of the Constant wire (one side grounded): mV range. This is the *control/correlation parameter* in such specific tests. A schematic drawing of the procedure, enriched by some further details, is shown in Fig. 6.

f) Give again power reducing the intensity, steps of 10 W, up to the minimum of 10 W. For each step wait 30 m to get full equilibrium. Moreover, lowest measurements are made also at 5 W and 0 W, as performed under Ar/H2 experiments. Collect all the intermediate values, after waiting at least 30 m for thermal stabilization. Such are the Reference points, to be used as ZERO AHE (i.e. Ref.#0) for the supposed active regimes in the next steps. In short, we forced the first set of measurements to be the ZERO of the system, even if some AHE could happen. In other words, the interpretation of all the results with the active cycles are conservative.

g) Apply high power, e.g. 70 W for long time (38 hours)➔ Exp.#1.

h) Repeat the procedure of e) and f) (only first section), increasing, at the first measurement, the maximum reference values (i.e. 110 W).

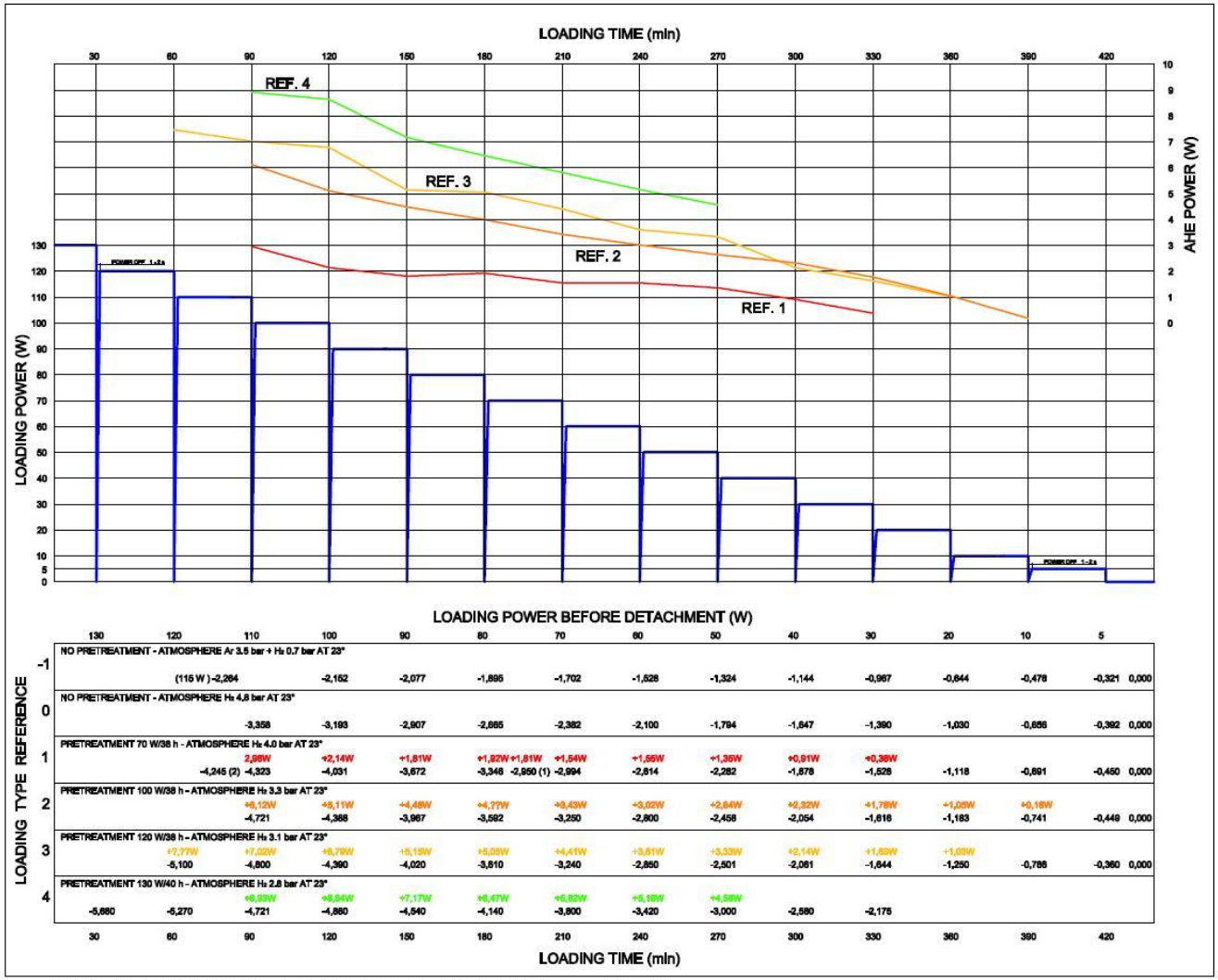
i) Repeat the procedure of g), i.e. 38 hours applying 100 W➔ Exp.#2.

j) Repeat the procedure of h)-

k) Repeat the of h), applying 120 W➔Exp.#3.

l) **Repeat the of h), applying 130 W➔Exp.#4. It gave, at the moment, the best result with AHE over 12 W.**

Because we didn’t made at the beginning of the procedure calibrations at power level over 110 W, the AHE values at such conditioning procedure were extrapolated: quite reliable 2° order of fitting.



SYSTEM RESPONSE TABLE: VOLTAGE (mV) AND AHE (Only positive W)

Fig. 6. Schematic of the time sequence to make measurements. Usually are made >12 measurements for each conditioning power (time about 38 h each). *Plot to be completed with latest experiments performed*.

Experimental results

- **It was clearly observed that the AHE values are related to the OCV values, moreover inter-related to values of the high-power pre-treatments. Both values increased when the "conditioning time at high power" was the largest. Measured over 12 W of AHE, in steady conditions with 130 W of pre-conditioning..**

- **We note that there is a general increasing of the temperatures, due to the conditioning procedure, both internal (the core) and external, the last used as the measurement parameter to evaluate the AHE. As a consequence, even if the procedure is very simple, i.e. only thermometry (because the need to perform several measurements in limited amounts of time), the probability of wrong results is unlike.**

- **Such effect clearly showed that the Constantan-H_2 system has some "memory effect" about "conditioning" of the wire in the whole, i.e. bulk and surface. The effect seems to last, at least, several hours.**

- **We guess that the return to steady-state conditions, after some out-of-equilibrium forced situation, is the most probable source of AHE, i.e. the *flux* of H_2 stored into the inner lattice and/or at the sub-micrometric locations at the surface. Moreover, we can't exclude that the previous, very long time (weeks) treatments at very high peak power, up to 10 kV*A /g of Constantan used in these tests, facilitated the absorption of H_2 even not under so extreme situations.**

- **The effect of "conditioning" by high power is similar to what we observed in previous experiments after pulsed (few microseconds durations, several kHz of repetition rate) high power conditions (current density up to 35 kA/cm^2) for shorter times (typically 30 minutes), as presented also at ICCF23. The results shown at such Conference "inspired" us to found a systematic procedure to get "memory effect".**
- **Some of the key results are shown in Fig. 7, 8, 9, 10, 11. Some of the figures are simplified to allow an easier understanding.**

In the present procedure the main advantage is an extremely simple experimental set-up, easy to be reproduced, (we hope) worldwide, from other Scientists involved in the LENR-AHE field.

Moreover, the AHE evaluation in DC conditions is easier understood/evaluated in respect to our more complex calculations under pulsed conditions.

Anyway, and in addition, with pulsed conditions

we can reach values of AHE larger in respect to DC polarization.

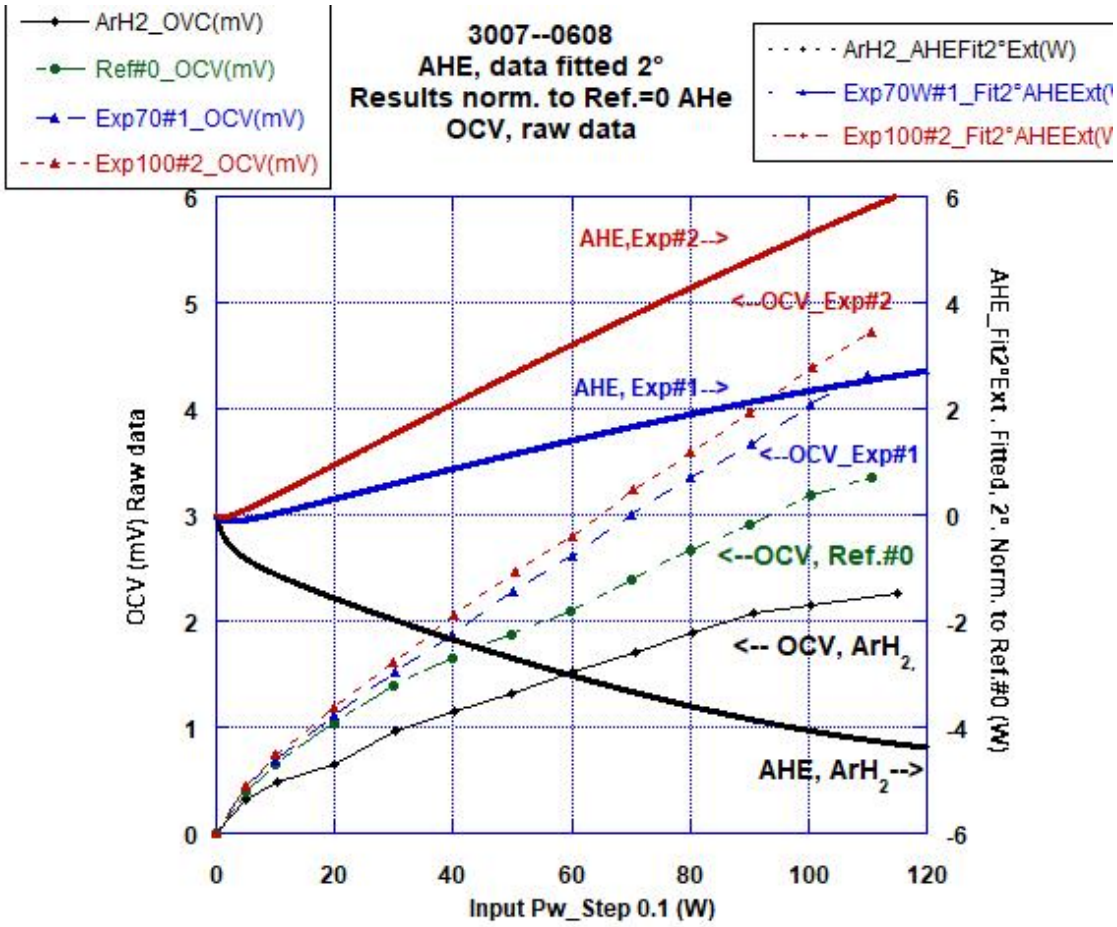


Fig. 7. Main experimental result. Data regarding OCV are raw. The data about AHE got simple mathematical "treatment": before fitted (2° order, R>0.999) and later normalized to the value of Ref.#0 measurement, imposed to be zero. As further comparison, were reported also the data using the Ar/H_2 mixture. *The correlations among the values of OCV and AHE are self-evident*: the largest value of AHE corresponds to largest value of AHE (i.e. Exp.#2); vice-versa the lowest value is related to Ar/H2 mixture.

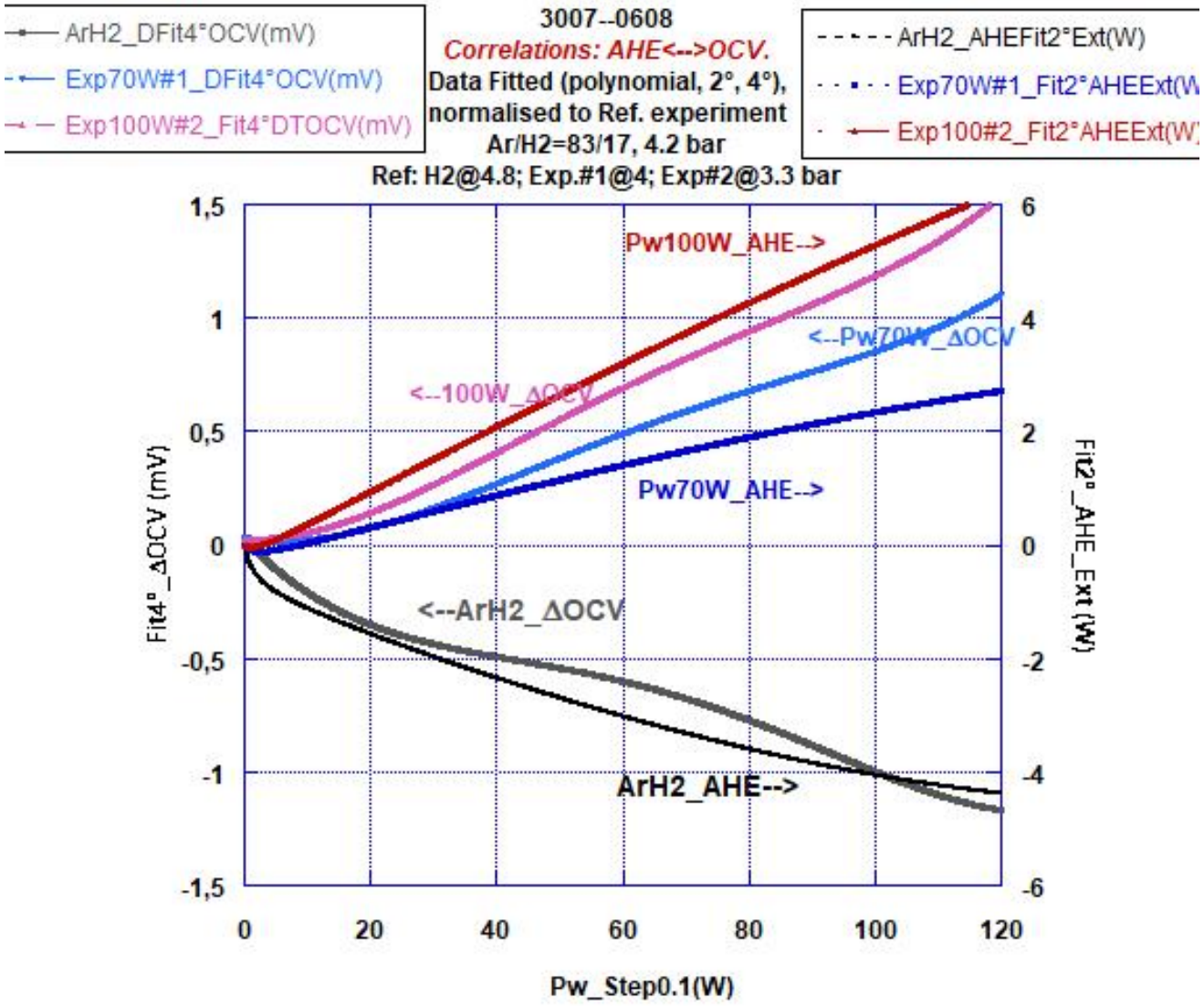


Fig. 8. Data similar to Fig. 7: for a faster understanding of correlations, normalised also the value of OCV and, after 4° fitting (R>0.999) subtracted to each experiment: added also Ar/H_2, apart Exp.#1, Exp.#2.

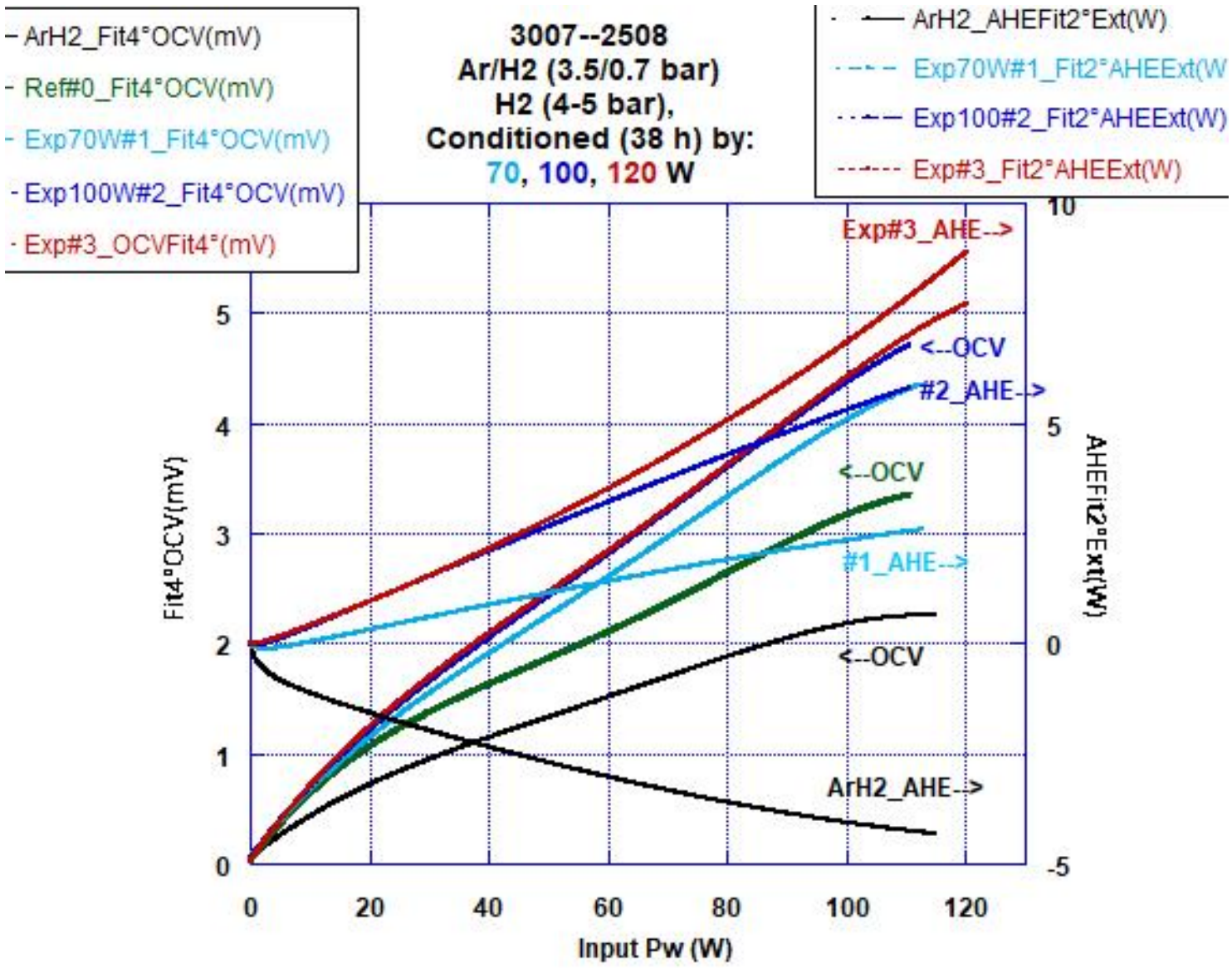


Fig. 9. Data similar to Fig. 7 but added measurement with conditioning at 120 W.

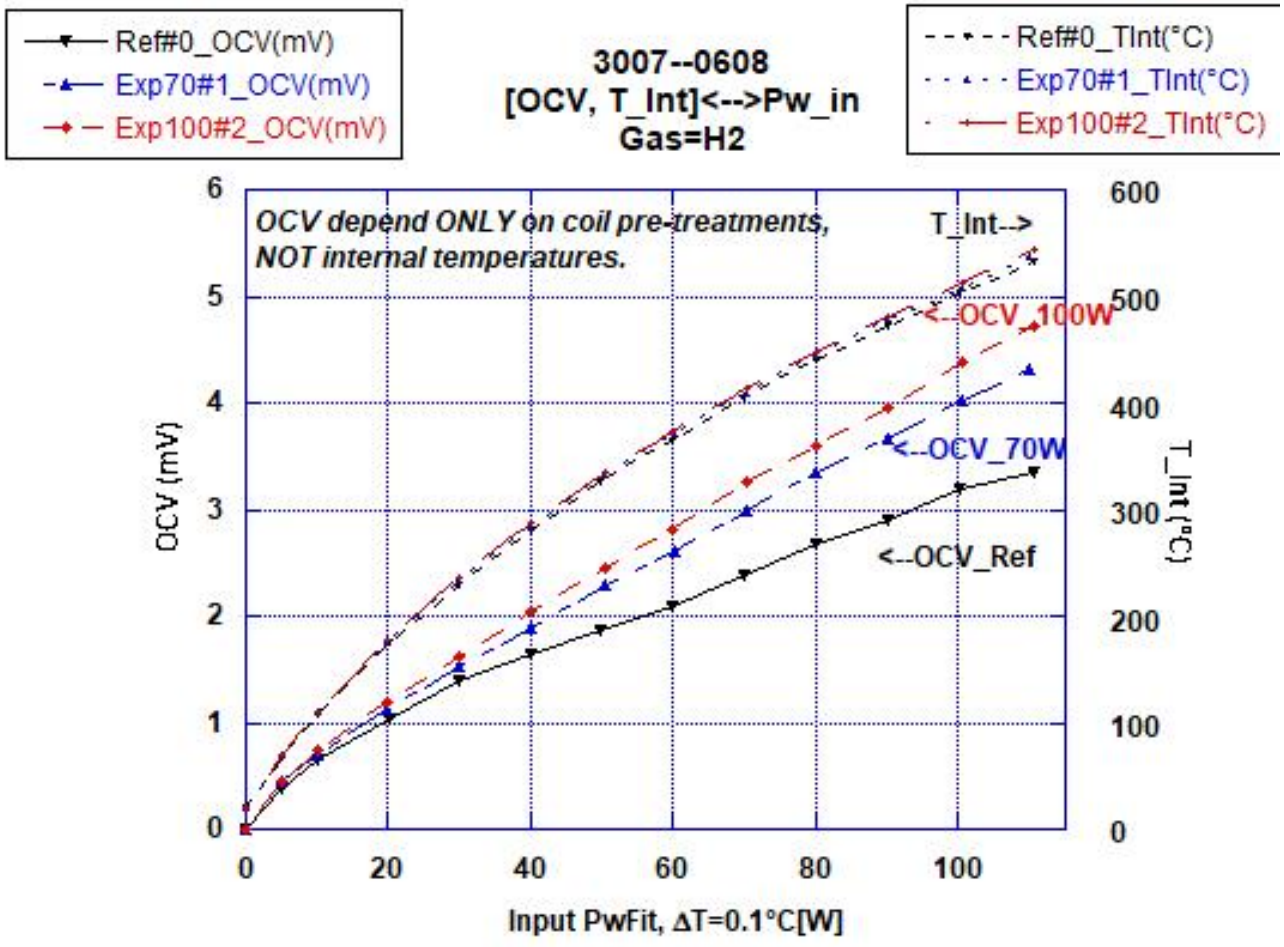


Fig. 10. In the sake of deeper understanding of OCV values, it is shown that their values are NOT related mainly to the coil temperature, quite similar each-others (obviously the highest on Exp-#2 and lowest on Ref.#0), but to the specific "conditioning" of the wire. In the case of Ar/H_2 gas, the internal core temperature is the largest (about 650 °C), but the OCV is the lowest. Such results suggested us that the H2 concentration at surface could play an important role.

A summary of models and earlier reports compatible with our observations

"Standing on the shoulders of giants"

Our most recent findings show that AHE correlates with the occurrence of thermionic effects or with an unusually high surface ionization (likely mediated by the use of low work function materials). We must however pay tribute to several other Researchers that have performed experiments with similar materials though starting from a variety of possible reaction models:

- **Our correlation with thermionics and surface ionization phenomena may point toward the role of the hydride ions (H^-). This possibility was already investigated by *Francesco Piantelli* (Univ. Pisa, Italy) and his Collaborators [1]. Piantelli reports that H^- ions may be captured by certain atoms, leading to a succession of (nuclear) reactions that are the cause of AHE.**

- **Also, our work with low work-function coatings takes inspiration from the pioneering research of *Yasuhiro Iwamura* (Mitsubishi Heavy Industries, Univ. Tohoku; Japan). Already in the nineties he reported experiments with multilayer structures comprised of calcium oxide (CaO). It is worth to mention that he interprets the effect of CaO and similar compounds in the framework of an electron induced nuclear reactions model [2] [3] [4] [5].**

- **Commonalities, exists also among our work and the reports of *Jacques Dufour*, (Shell Company, later Independent Researcher, France) especially on the role of low work-function oxides [6]. Dufour explains AHE occurrence with the Enthalpy of an allegedly new class of chemical reactions between a shrunken hydrogen atom and nickel among other elements.**

- **Some analogies exist also with the work of *Randell Mills*, (Black Light Power, USA) and his well-know "hydrino" hypothesis. Mills believes that AHE is due to the formation of a hydrogen atom with a shrunken orbital corresponding to a lowest energy state than the ground state [7].**

- **Among others, the effect of current and voltage pulses to activate the AHE phenomena was also recognized by *Brian Ahern* (EPRI, DARPA; USA), [8]**

- **In previous reports we have stressed the importance of a flux of active species for AHE occurrence. This confirms in full the previous of work (since December 1989) of *Gustave Carl Fralick* (NASA, USA) [9] and *Leslie Case* (Independent Researcher, USA) [10], among many others (like M. Mac Kubre and his Collaborators at SRI-USA).**

- **Finally, yet importantly, we are intrigued by the findings of *Leif-Holmlid* (Univ. Gothenburg, Sweden) on the possible nuclear reactions mediated by condensed clusters of Rydberg hydrogen or deuterium atoms [11] [12]. In fact, we must certainly recognize similarities among his alkali promoted catalysts and our coatings of mixed oxides (comprised of Low Work Function materials).**

- **At the end, we just recall that from the beginning of Cold Fusion experiments (April 1989), *We* observed that any kind of un-explicable effects happened *only during non-equilibrium situation*, perhaps flux of active gas involved. Our observation, reported in our paper at the Workshop, was quoted even by Nature (April 1989): some of their Reporter attended the *First Cold Fusion Workshop* (April 1989, organised by Prof. Antonino Zichichi at the "Ettore Majorana Centre of Scientific Culture" located in Erice-Italy). From that time, up to now, almost all our experimental activities were devoted to induce *non-equilibrium situations* to the system, minimizing the extra-energy added.**

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Conclusions

- **For what we can know, it is the first time that, in the long "history" of Cold Fusion-LENR experiments, 2 important parameters were clearly intercorrelated along a large interval of input power (2 order of magnitude) and quite large number of experimental "points" (over 70).**

*****All the data were in agreements each-other***.**

- **We planned further test in order to reconfirm the data and increase the absolute value of AHE. Obviously, we will make experiments with Deuterium gas, to check if exists some isotopic effect.**

- **Up to now we didn't reach the maximum DC current (about 2.5 A) allowed by our 200 μm wire under Hydrogen atmosphere: because the AHE increases increasing the temperature, we are confident that even larger values of both AHE and OCV could be easily reached.**

- ***In other words, we feel (hope!!) that the very long time (since almost the beginning, i.e. June 1989) of doubts, about the Scientific realty of Cold Fusion-LENR AHE, are ended.***

- ***Now we have to concentrate mainly on Technological aspects, i.e. to develop proper procedures able to increase the AHE and test the long-time stability for practical applications.***

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Since 2017 we initiated also a multiple collaboration with **NEMC** and **SIGI-Favier** (Italy-France), to design an original hybrid sheath obtained by crossing Glass and Alumina–Quartz fibres. The sheaths are used for the electric insulation of the wires. These original sheaths can continuously operate up to 1200 °C and, thanks to a tailored geometry, may adsorb significant amounts of Atomic Hydrogen[1]. Moreover, the sheaths are porous, holes of micrometric dimension: *one of the key aspects of our experimental set-up.*

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Disclaimer

The work reported in this document is under the fully responsibility of the Authors and didn't represent necessary the opinion of whole CleanHME International project.

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