# Self-Stimulating Fire

The work carried out by A-Z during the 2002 to 2006 period has set the stage for development of cold fusion heaters. It may be that A-Z's 2004 use of direct gas absorption into metal oxide nanometal composites will prove the best route to commercialization. This process would belong to the slow burn category. However, the estimated heat output thus far achieved by gas loading is relatively low. It may be that a better route to early practicality would be to make use of the full range of technical understanding that has been accumulated by the global community over the last 18 years. Key learnings are listed below. They suggest a competing approach which involves developing closed loop heaters that combine deuterium fluxing, high deuterium chemical potential, and oxide-nanometal interfaces.

One of the important discoveries that came out of past excess heat experiments using bulk Pd cathodes was a formulation by McKubre *et al.* of an empirical law relating fusion heat generation to operating parameters which were measured during F-P type electrolysis. This formula was used to model the electrochemical experiments carried out by the SRI team. It involves the product of 3 factors: deuterium concentration above a threshold value, current density above a threshold value, and the in and out deuterium flow through the full surface of the cathode during operation of the electrolysis cell. Net inflow and outflow flux were found to be equally effective. The McKubre formula is

$$P = M\,(x-x_o)\,(I-I_o)^2\,\left|dx/dt\right| \text{ Watts}$$

where P is generated heat power in Watts, M is a data-fitting constant, x is deuterium concentration in the metal electrolysis cathode defined by D/Pd ratio, $x_o$ is a threshold ratio which must be exceeded for production of measurable fusion heat, which is typically about 0.85, I is palladium metal cathode current density in Amperes/cm$^2$, $I_o$ is the threshold cathode current density at which measurable heat first appears, and $\left|dx/dt\right|$ is a deuterium fluxing term which measures the net flow of deuterium into or out of the palladium metal cathode. The remarkable thing about this equation is that it fits the data and doesn't care whether the fluxing term is positive or negative. In either case there is a flow of deuterons inside the Pd metal. When fluxing is present, deuterons are moving through the metal. As we shall see below, there is other evidence that deuterium fluxing is an important ingredient affecting fusion rate, and there is some theoretical justification for why fluxing should be important.

The McKubre equation was fit to the data shown in Figure 7 of the Summary Document which was written for the DOE Review. The fit was discussed on pages 5 and 6 of the Summary Document. The equation provided a good fit to two multi-day "bursts" of cold fusion heat which occurred during the much longer M-4 SRI experiment. The M-4 study was the one that produced convincing evidence for $^4$He production at 23.8 MeV per helium atom inside a hermetically sealed cold fusion apparatus

A second important discovery was made by Iwamura *et al.*, who explored the production of heat by electrolysis-driven deuterium permeation flow through a palladium reactor plate. The reactor plate contained 5 pairs of sputtered-implantedCaO and Pd layers. Their excess heat observations were reported at ICCF7. In a 1999 paper the Iwamura team listed 5 runs, in which fusion heat at times exceeded 1 Watt. No heat was observed with permeation plates not containing internal CaO-Pd sputtered layers. Because CaO is an ionic crystal with a highly negative free energy like that of $ZrO_2$ (both are very chemically stable), the oxide layers are expected to be in the form of small crystals, while the sputtered Pd is likely to have been initially disordered. There would seem to be a similarity between the Iwamura interfaces and those present in the Yamaura-fabricated $ZrO_2$-nanoPd composites. In the Iwamura studies the deuterium permeation flow was driven by heavy water electrolysis in which the front surface of permeation plate served as the electrolysis cell cathode. Gas was continuously pumped away from the back surface of Iwamura's permeation plate, thereby maintaining a pressure drop during operation. It seems highly likely that the D/Pd ratios in Iwamura's plates were significantly below the threshold value $x_o$ appearing in the McKubre empirical equation. Permeation implies a high rate of deuterium fluxing (flow), which may have compensated for Iwamura's relatively low D/Pd ratio. These observations of excess heat support the view that deuterium fluxing is important factor in heat generation.

F-P type electrolysis uses overvoltage electrolysis of heavy water to create a non-equilibrium deuterium chemical potential inside a Pd-metal cathode. However, a high deuterium chemical potential can be achieved without incurring the energy cost of dissociating heavy water if one uses a fuel cell type of solid electrolyte cell. The feedstock for fuel cells is deuterium gas, which replaces the heavy water used by F-P. A high deuterium chemical potential in Pd metal was demonstrated by Biberian in a fuel cell study described in *Proc. ICCF11*. It is easy to envision the use of solid electrolyte fuel cells on both input and output surfaces of a permeation type plate reactor. The operator could change the balance between deuterium fluxing rate and front surface deuterium chemical potential, while achieving high values of both. Closed-loop operation of a fuel cell-driven, closed-loop system would greatly reduce the parasitic power loss that occurs with heavy water electrolysis cell operation. The author thinks that this approach is a candidate for practical cold fusion heat production.

A-Z made an important step towards commercial cold fusion room heaters when they published the hydrogen absorption characteristics of $ZrO_2$-nanoNi and $ZrO_2$-nanoNi,Pd composites, starting from Zr,Ni and Zr,Ni,Pd alloys. These composite materials presumably had been manufactured at the Institute for Materials Science at Tohoku University. A-Z reported on their $H_2$ absorption properties in *Proceedings of ICCF10* in 2003. The $ZrO_2$ + nanoNi composite was as good an $H_2$ absorber as $ZrO_2$ + nanoPd, whereas the $ZrO_2$ + nanoNi,Pd alloy composite, which contained a 0.18 Pd/Ni atom ratio, absorbed twice as much gas. To my knowledge none of these composites have been tested in a DS-cathode electrolysis cell for generation of fusion heat. If the heat production from deuterided $ZrO_2$ + nanoNi composite is as good as that from $ZrO_2$ + nanoPd composite, the cost problem associated with use of palladium goes away. Since the oxide-nanometal composites have not shown an aging problem, there would then seem to be no serious barrier to cold fusion heater development.