OVERVIEW OF LIGHT WATER/HYDROGEN-BASED LOW ENERGY NUCLEAR REACTIONS

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This paper reviews light water and hydrogen-based Low Energy Nuclear Reactions (LENRs) including the different methodologies used to study these reactions and the results obtained. Reports of excess heat production, transmutation reactions and nuclear radiation emission are cited. An aim of this review is to present a summary of the present status of light water LENR research and provide some insight into where this research is heading.

1 Introduction

This review focuses on the transmutation reactions and excess heat production in experiments using light water electrolysis or hydrogen gas/plasma loading undergoing Low Energy Nuclear Reactions (LENRs). Although most LENR ("cold fusion") research has focused on heavy water, a considerable number of experiments have used light water electrolysis or hydrogen gas loading. A few experiments have attempted to compare the results from light vs. heavy water [1-4], but these comparisons remain inconclusive.

There are a wide variety of cold fusion nuclear reactions. As illustrated in Figure 1, the original Pons-Fleishmann (P-F) reaction involved DD fusion, where unlike in hot fusion, the reaction channel is "interrupted" through deactivation of the excited He^4 reaction product by energy transfer to the host lattice, ultimately heating the lattice. Alternately, a number of researchers have reported transmutation reactions that involve interactions between deuterium (or hydrogen) directly with atoms in the host lattice, typically heavy metals. This branch of "cold fusion" is commonly termed LENR, although recently there has been a move to also term P-F type DD reactions as LENRs as well.

The observation of nuclear reactions between electrolyte and host metal atoms is quite unexpected due to the very large coulombic barrier involved (much larger than for D-D reactions). Consequently, one purpose of this review is to bring together much of the data accumulated on this striking new phenomenon. The readers are left to decide for themselves if the data is adequate to establish the case for such reactions and possibly to formulate new experiments that build on and extend this data base.

About 40 publications were included in this review (see references herein). This was intended to be representative but not exhaustive of the field. Researchers wishing to add information to the data base are invited to contact the authors.

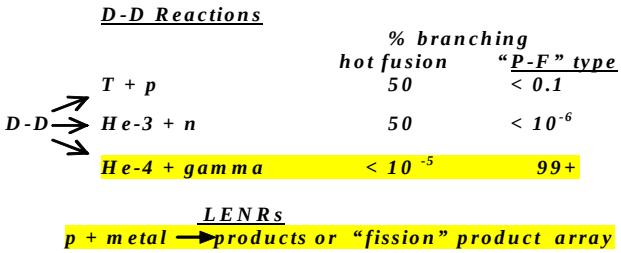

Figure 1. Comparison of LENR reactions and DD reactions occurring in hot and "cold" (Pons-Fleishmann type) fusion.

1.1. *Methodology*

A summary of various methods employed for this study is given in Table 1. A majority of the researchers cited used electrolysis to study LENR: Pd/Pt, Ni/Pt were commonly used electrodes. K_2CO_3 is a popular choice as an electrolyte, a trend perhaps started by the Mills and Kneizy's early experiments where extremely large reaction rates were reported. Gas loading is also frequently used while a few researchers have reported using a Glow Discharge (GD) plasma.

Table 1: Summary of various methods employed for light water/H_2 LENR studies (Data collected for this and following tables and figures use refs 1-35).

		Total
Electrolysis	Electrode	
	Pt/Pd	14
	Pt/Ni	5
	Pt/W	3
	Pt/Au	4
	Pt/Sn	1
	Pt/Re	1
	Pt/Ti	2
	Pt/Ag	1
	Pt/Pt	2
	Electrolyte	
	K2CO3	10
	H2SO4	3
	Na2CO3	5
	Li2SO4	4
	KOH	1
	Na2SO4	5
	CS2SO4	1
	H2O	2
GD Plasma		1
Gas Loading		5

1.2. *Early Studies at UIUC*

Earlier work by one of the authors (Miley) in collaboration with J. Patterson represents one of the more extensive studies of light water electrolysis relative to reaction products and excess heat. About 1000 microspheres (~0.5 cm^3 volume) were used in a packed-bed electrolysis cell. Thin films of Ni and/or Pd were coated on the beads to serve as the cathode. The electrolyte was 1-molar Li_2SO_4 light water electrolyte with a flow rate of ~11 ml/min through the packed bed. Voltages across the bed were held at ~2-3 V, with several mA of current, giving an electrical input power of approx. 0.06 W. Significant excess heat and a fission-like reaction product array were reported. A detailed description of the experiment can be found in the Miley, Patterson et al. paper [1].

1.3. *Reaction Product Analysis Method*

Reaction products have been analyzed using a variety of precision mass analysis techniques. For example, Miley, Patterson et al. used a combination of NAA, SIMS, Energy Dispersive X-ray (EDX) analysis and Auger Electron Spectroscopy (AES) [1]. Cirillo and Iorio used SEM to study transmutation products [9]. Arapi et al. used TOF-SIMS for product analysis [5]. Iwamura et al. used XPS extensively in their studies, although they concentrated on D_2 gas experiments (vs. H_2), so are not included in this survey per se [36].

2 Results

2.1. *Transmutation Products*

A quantitative measure of the yield of transmutation products (and isotopic shifts from natural distribution in key products) in 4 major atomic groups (6-18, 22-35, 44-54, 75-85) were obtained by Miley, Patterson et al. [1]. Others also have reported significant nuclear reaction products and isotopic shifts in light water LENRs. In some cases of the observed elements were from the Lanthanide Group, including Lu, Tb, Pr, Eu, Sm, Gd, Dy, Ho, Nd and Yb. It is widely accepted that these rare earth elements are less likely to be found as impurities, strengthening confidence in their results (although most researchers have tried to rule out mistakes due to impurities vs. the common “product” elements such as Fe, Cu, Ag, Zn, Au, etc via analysis of cell components, electrodes and electrolyte prior to LENR runs).

Isotopic shifts are another key feature often cited against mistaken identification of impurities as reaction products. Violante’s study showed that the ^{63}Cu /^{65}Cu isotopic ratio shifted [33]. In this Ni-hydride film work the most abundant copper isotope was ^{65}Cu with a shift from natural distribution by 1360%. Cirillo and Iorio found Re, Os, Au, Hf, Tl, Er, and Yb on the surface of the cathode, which was not present before the reactions [9]. Ohmori et al. reported finding Hg, Kr, Ni and Fe with anomalous compositions in Au electrodes during light water electrolysis [29]. In addition Si, Mg with other anomalous compositions were also detected in the precipitates separated from the Au electrode after

electrolysis at extremely high current densities. They found significant deviations from natural values. Minor product elements such as Os, W, and Ru in particular showed large deviation, whereas elements with larger yields like Pb and Ag rarely showed significant deviations.

Yamada et al. also reported a large increase of Cr, Fe, Cu and Ag in their experiment where Pd was loaded with hydrogen gas [35]. Arapi et al. found Be and Ni in heavy water while in light water LENR they report Li, Ba and Ni [5]. Dash et al. reported formation of Au and Ag in both light and heavy water LENR; however, the concentrations were somewhat higher in the heavy water experiments [10].

Table 2 summarizes the list of elements observed in light water by the number of times they were reported being produced in their research by different research groups. Fe and Cu were commonly observed. Rare earth elements were reported less frequently. Also note that a majority of the transmutated elements reported have changes in their isotopic composition from the natural abundance.

It is interesting that the frequency of observation of light water LENR elements is not significantly different from heavy water LENR (for the latter see Ref. 37).

Table 2: The total numbers of reports that state the elements were produced in their experiment.

Observation Frequency	Transmutation Elements
1	As,Ge, S, Hg, Kr
2	Cd, Rr, Au, Hf, Th, Er, Yb, B, V, Cs
3	Li, Ba, Al, Os, C, Si
4	Mg, Mn, Co, Pb
5	Ag, Cl, Ti
6	Ni, K
7	Ca, Cr, Zn
8	Cu
11	Fe

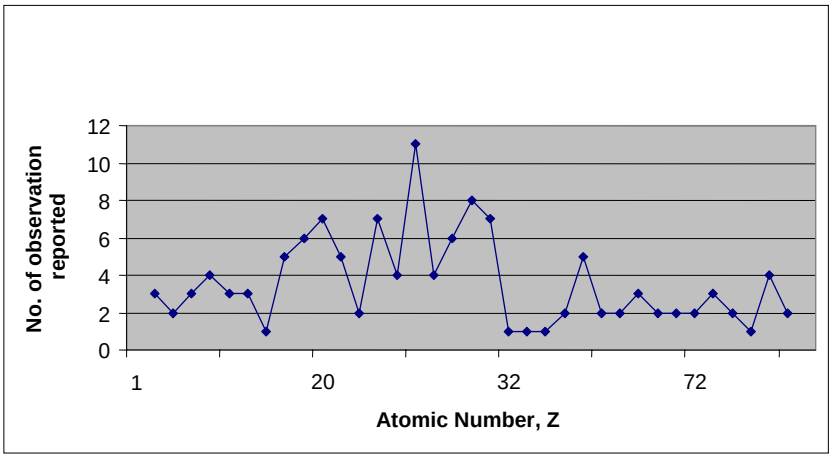

Figure 2. This graph shows the frequency of observation for various transmutated elements designated by atomic number.

One way to evaluate this data is to consider a confidence level of >6 observations. Then Ni, K, Ca, Cr, In, Cu and Fe meet the criteria (Figure 2). However, it can be argued that the potential impurity levels for some of the less frequently observed elements are very low, raising the signal/noise confidence level for those observations despite their less frequent observation.

2.2. *Radiation Emission*

Recent experiments using various methods of loading hydrogen have shown significant soft x-ray emission in certain specialized experiments for e.g. see Ref. 38. Also MeV energy charged particles have been reported. Alpha particles and protons have been identified with energies around 11.0-16.0 MeV and 1.7 MeV, respectively. During electrolysis of thin Pd-film cathodes on dielectric substrates as well as from Pd-black electrode surfaces. Only very weak x-ray emission was found in these experiments, the upper dose limit (corresponding to ~ 5.0 X-ray photon/s $\times cm^2$ with E_x=10 keV) [39]. While there is evidence for energetic charged particles and soft x-ray emission in these studies, it remains to be determined if the mechanism for this emission is directly related to the transmutation/heat effect or is associated with auxillary EM effects. In a unique experiment to explore possible radioactive waste disposal applications, Dash and Chicea reported that in light water experiment using U electrodes the intensity of the alpha, beta, gamma radioactivity of the electrodes increased after loading hydrogen [11]. The ^{235}U and ^{234}Th isotopic concentrations were also reported to have increased.

2.3. *Excess Heat*

Various researchers have reported excess heat generation suggesting that it is also one of the signatures of light water LENRs. Several such reports are mentioned here. Indeed, since the transmutation reactions involve +Q values, some excess heat should be expected. However, the magnitude of the excess heat vs. the input power remains an open question.

Cirillo and Iorio report a definitive excess energy in their light water experiment even after substracting out energy associated with chemical reactions; energy related to the heating-up and fusion of the tungsten; energy used in expanding gas and steam leaving the cell; energy lost by thermal and electromagnetic radiation; and loss of heat through the insulation [9].

Dash et al. have performed extensive light-water experiments and report that excess heat generated in their light water LENR experiment was only slightly lower than in “equivalent” heavy water experiment [10]. In their pioneering studies Mills & Kneizys reported 130 mW of excess heat [18]. Noninski repeated Mills and Kneizys light water Ni electrode experiment independently and reported 26 -160% excess energy compared to input energy [23]. Dufour et al. reported excess energy of 7 mW in their H_2 gas loading experiment, corresponding to ~25-30 % of the input energy [13]. Ohmori and

Enyo reported 907 mW of excess energy in a K_2CO_3, Sn electrode electrolysis experiment [32]. Fujii et al reported having excess energy of 7.8W in a Li_2SO_4, Pd/Ni electrode electrolysis experiment, which is more than 5% excess [14]. However this excess heat was always reproducible.

It is not conclusive whether using light water or heavy water produces more excess heat. Some research has reported that heavy water produced relatively larger excess heat and more transmutation products [7, 10], while some have indicated that in both cases the excess heat and reaction products were similar [31]. Direct comparison is complicated since many parameters are modified with an electrolyte substitution. Thus, much work is required before carrying out a meaningful comparison.

The excess energy for light water/H_2 LENR reported by various researchers tends to be either low (<10%) or high (>25%), with few reports of intermediate values (see Table 3, Figure 3). More quantitative analysis is required to understand if this "two tier" result has a basic cause.

Table 3: The range of Excess Energy various reports have achieved in their experiment.

Excess Energy (%)	Number Reported
0-5	2
6-10	2
11-15	0
16-20	0
21-25	1
26-30	3
31-35	0
35+	2

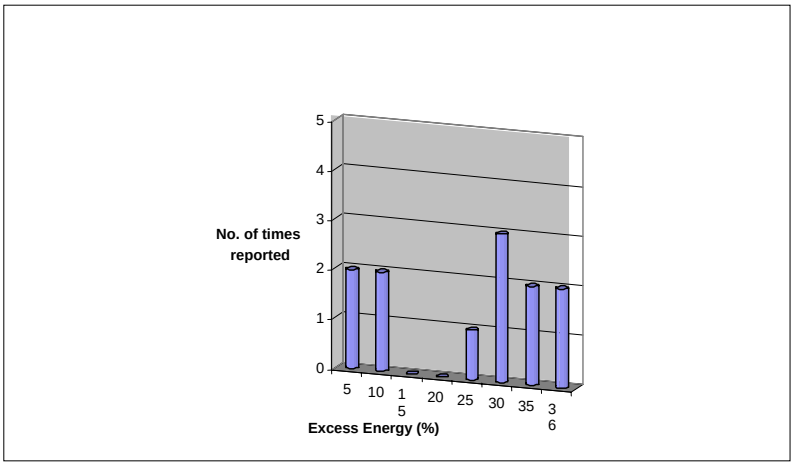

Figure 3. This graph shows the Table 3 data in a graphical presentation.

3 Historical Trends

A review of historical trends indicates that a majority of researchers have examined both the transmutation reactions and excess heat generation, strongly suggesting that they expect both phenomenon in light water LENR. However, considerable work has also continued to study these phenomenons separately. Table 4 shows that heavy activity occurred in the early 1990 period, and then decreased. However, starting in 2000 onwards, research in light water LENR again increased in activity.

This suggests that some time was required for researchers to digest the early work and become interested in devoting time to this new area of LENR.

Table 4: Survey of the year and the key signatures of LENR focused in the study.

Type of Study	Years			Total
	1990-1994	1995-1999	2000-2005	
Excess Heat & Transmutation	4	2	6	12
Excess Heat studied – Transmutation not studied	6	1	1	8
Transmutation studied – Excess Heat not studied		3	5	8
Excess heat studied – Transmutation not found			1	1
			Total	29

4 Theory

Many different theories have been proposed for the mechanism of reactions that takes place in LENR. However, a definitive match of theory and experiment has yet to be achieved. Thus the “best” theory remains unclear. In order to explain how the large coulombic barrier is overcome, many theories introduce a neutral particle in the reaction matrix. Some of the theories of this type include Neutron Cluster formation by Fisher [40], Free Neutron Reactions by Kozima [41], R-Matrix Theory by Chubb [42], Shrunken Hydrogen by Mills [43], Electron-Proton capture by Stoppini [44] and Proton/Deuteron Cluster by Dufour [45]. The challenge now is to sort out how any of these theories can explain the unique signatures of heat and varied transmutation products reported experimentally.

5 Conclusions

In view of the rather extensive data base for light water/hydrogen-based LENR, it is rather convincing that this phenomenon is real. Since the measurements are very tedious and demanding, some errors are no doubt contained throughout the database. (The authors did not feel qualified to rule out any seriously reported data by competent researchers). However, it seems highly unlikely that all of the data is erroneous. From a practical point of view, the issue remains whether or not there is any unique advantage of light water/hydrogen LENR vs. heavy water/deuteron LENR. Two applications are at issue for both: heat production and /or transmutation. However, the experiments surveyed here suggest that at this stage there is no clear evidence whether or not heavy water is

more favorable than light water for either application. Clearly many more comparative studies are essential to clarify this issue. Another aspect is that the heat reaction in these two cases appears to produce different reaction products. Thus, for wide applications involving public exposure the reaction products need to be carefully evaluated relative to environmental compatibility and radioactivity. This evaluation not only applies to the main reaction but possible parasitic ("side") reactions.

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References

1. G.H. Miley, G. Narne, M.J. Williams, J. A. Patterson, J. Nix, D. Cravens and H. Hora, *Progress in New Hydrogen Energy*, **2**, 629 (1997).
2. J. Dash, G. Noble and D. Diman, *Trans. of Fusion Technology*, **24**, 299 (1994).
3. J. Dash, G. Noble and D. Diman, "Surface Morphology and Microcomposition of Palladium Cathodes After Electrolysis in Acidified Light and Heavy Water: Correlation With Excess Heat", *ICCF 4*, Lahaina, Maui, (1994).
4. J. Dufour, J. Foos, J. P. Millot, and X. Dufour, *Fusion Technology*, **31,** 198 (1997).
5. A. Arapi, R. Ito, N. Sato, M. Itagaki, S. Narita and H. Yamada, "Experimental observation of the new elements production in the deuterated and/or hydride palladium electrodes, exposed to low energy DC glow discharge", *ICCF-9*, Tsinghua Univ., Beijing, China, May 19-24, (2002).
6. R.T. Bush, *Fusion Technology*, **22**, 301 (1992).
7. C.S. Cano, "Comparison of Heat Output and Microchemical Changes of Palladium Cathodes under Electrolysis in Acidified Light and Heavy Water", *MS Thesis*, Portland State University, (2002).
8. C.H. Castano, A.G. Lipson, S.O. Kim and G.H. Miley, "Calorimetric Measurements during Pd-Ni thin film–cathodes Electrolysis in Li_2SO_4/H_2O Solution", *Proc. of the ICCF-9*, Beijing, China, pp. 24-28, May 19-24 (2002).
9. D. Cirillo and V. Iorio, "Transmutation of metal at low energy in a confined plasma in water", *ICCF11*, Marseille, France, (2004).
10. J. Dash and G. Noble, *Intern'l. Symp. On Cold Fusion and Advanced Energy Sources*, Belarusian State University, Minsk, Belarus, May 24-26, (1994a).
11. J. Dash and D. Chicea, "*Changes In The Radioactivity, Topography, And Surface Composition Of Uranium After Hydrogen Loading By Aqueous Electrolysis"*, *ICCF-10,* Cambridge, MA, (2003).
12. M. Di Giulio, E. Filipppo, D. Manno and V. Nassisi, *Intrn'l J. Hydrogen Energy*, **27**, 527, (2002).

13. J. Dufour, J. Foos, and J.P. Millot. “Measurement of Excess Energy and Isotope Formation in the Palladium-Hydrogen System”, *ICCF-5*, Monte-Carlo, Monaco: IMRA Europe, Sophia Antipolis Cedex, France, (1995).
14. M. Fujii, S. Mitsushima, N. Kamiya and K.Ota, “Heat measurement during light water electrolysis using Pd/Ni rod cathodes”, *ICCF9*, Beijing, China, May 19-24, (2002).
15. T. Hanawa, “Z-ray Spectrometric Analysis of Carbon Arc products in Water,” *Proc. ICCF-8*, Italy, 147, (2000).
16. X.Z. Li, Y. Deng, Y.J. Yan, H.F. Huang, W.Z. Yu, and C.X. Li, *J. New Energy*, **6**, *1*, 80 (2001).
17. G.H. Miley, “Product characteristics and energetics in Thin-Film electrolysis experiments,” *Proc. ICCF-7*, Vancouver, Canada, 241, April 19-24, (1998).
18. R.L. Mills and S.P. Kneizys, *Fusion Technology*, **20**, 65 (1991).
19. R. Mills, M. Nansteel and P. Ray, *J. Plasma Physics*, **69**, 131 (2003).
20. R. Mills, J. He, Z. Chang, H. Zea, K. Akhtar, Y. Lu, C. Jiang and B. Dhandapani, “Catalysis of Atomic Hydrogen to Novel Hydrides as a n New Power Source”, *230th ACS National Meeting*, Washington D.C., Aug 28 – Sept 1, (2005).
21. D.W. Mo, Q.S. Cai, L.M. Wang and X.Z. Li, “The Confirmation of Nuclear Transmutation Phenomenon in a Gas Loading H/Pd System Using NAA,” *ICCF-7*, Vancouver, Canada, 105, April 19-24, (1998)
22. T. Mizuno, T. Ohmori and A. Akimoto “Generation of Heat and Products During Plasma Electrolysis”, *ICCF-10*, (2003).
23. V. Noninski, *Fusion Technology*, **21**, 163 (1992).
24. R. Notoya, Y. Noya and T. Ohnishi, *Fusion Technology*, **26**, 179 (1992).
25. R. Notoya, “Nuclear Products of cold Fusion Caused by Electrolysis in Alkali Metallic Ions Solutions,” *Proc. ICCF-5*, Monte-Carlo, Monaco, pp.531-538, April 9-13, (1995).
26. T. Ohmori and M. Enyo, *Fusion Technology*, **24**, 293 (1993).
27. T. Ohmori and M. Enyo, *J. New Energy*, **1,** 15 (1996).
28. T. Ohmori and T. Mizuno, “Observation of the Product Elements of Nuclear Transmutation Reaction on/in Several Metal Electrodes by the Cathodic Electrolysis in Light Water Solutions,” *ICCF-7*, Vancouver, Canada, p.109, April 19-24 (1998a).
29. T. Ohmori, T. Mizuno, Y. Nodasaka and M. Enyo *Fusion Technology*, **33**, 367 (1998).
30. T. Ohmori and T. Mizuno, “Strong Excess Energy Evolution, New Elements Production, and Electromagnetic Wave and/or Neutron Emission in the Light Water Electrolysis with a Tungsten Cathode,” *Proc. ICCF-7*, Vancouver, Canada, 279, (2000).
31. T. Ohmori, H. Yamada, S. Narita and T. Mizuno, “Excess Energy and Anomalous Concentration of ^{41}K Isotopes in Potassium formed on/in a Re Electrode during the Plasma Electrolysis in K_2CO_3/H_2O and K_2CO_3/D_2O Solutions,” *Proc. ICCf-9*, 284, May 19-24 (2002).
32. T. Ohmori and M. Enyo, *Fusion Technology*, **24**, 293 (1993).
33. V. Violante, E. Castagna, C. Sibilia, S. Paoloni, F. Sarto, “Analysis Of Ni-Hydride Thin Film After Surface Plasmons Generation By Laser Technique”, *ICCF 10*, (2003).

34. H. Yamada, S. Narita, Y. Fujii, T. Sato, S. Sasaki and T. Ohmori, "Production of Ba and several Anomalous Elements in Pd under light Water Electrolysis," *ICCF-9*, Beijing, China, 123, May 19-24 (2002).
35. H. Yamada, S. Narita, H. Onodera, H. Suzuki, N. Tanaka, T. Nyui and T. Ushirozawa, "Analysis By Time-Of-Flight Secondary Ion Mass Spectroscopy For Nuclear Products In Hydrogen Penetration Through Palladium", *ICCF10,* (2003).
36. Y. Iwamura, T. Itoh, M. Sakano, N. Yamazaki, S. Kuribayashi, Y. Terada, T. Ishikawa and J. Kasagi, "Observation of Low Energy Nuclear Reactions Induced By D2 Gas Permeation Through Pd Complexes*", ICCF- 9*, Beijing, China, (2002).
37. G.H. Miley and P.J. Shrestha, "Review of Transmutation Reactions in Solids", *Proc. ICCF10*, Cambridge, MA, Aug 24-29 (2003).
38. G.H. Miley, P.J. Shrestha and H. Hora, *Current Trends in International Nuclear Research,* (Ed.) E. Panarella, NRC Research Press, Ottawa, Canada (2003).
39. A.G. Lipson, A.B. Karabut, and A.S. Roussetsky, "*Anomalous enhancement of DD-reaction, alpha emission and X-ray generation in the high current pulsing deuterium glow-discharge with Ti-cathode at the voltages ranging from 0.8-2.5 kV", ICCF-9*, Beijing, China, (2002).
40. J.C. Fisher, "Theory of Low-Temperature Particle Showers," *ICCF-10*, (2003).
41. H. Kozima, "CF-Matter and the Cold Fusion Phenomenon," *ICCF-10*, (2003).
42. S.R. Chubb, "Framework for Understanding LENR Processes, Using Conventional Condensed Matter Physics," *ICCF-11*, Marseille, France, (2004).
43. Black Light Power Inc. Website, accessed on 11/10/2005, http://www.blacklightpower.com/techpapers.shtml
44. G. Stoppini, *Fusion Technology*, **34**, 81 (1998).
45. J. Dufour, J.H. Foos, and X.J.C. Dufour, *Infinite Energy*, **4,** 53 (1998).