Review Committee Evaluation of the Lawrenceville Plasma Physics Focus Fusion Program

November 28, 2013.

Executive Summary

The independent LPP technology review committee was pleasantly surprised by the efforts and progress made by LPP in its development of the Dense Plasma Focus (DPF) fusion power concept. While recent progress has been notable, significant physics issues as well as a number of engineering challenges remain to be addressed before the practical viability of the concept can be fully evaluated. The committee found that LPP has identified some major physics challenges to achieving aneutronic fusion with a DPF and formulated a near term program to address them.

I. Introduction

At the request of one of the Lawrenceville Plasma Physics (LPP) investors, an expert review committee was assembled to review and evaluate the LPP program on the Dense Plasma Focus (DPF) fusion power concept. The committee was chaired by Dr. Robert L. Hirsch, formerly a fusion researcher and head of the federal fusion research program, Dr. Stephen O. Dean, former fusion researcher, former federal fusion program manager, and current President of Fusion Power Associates, Professor Gerald Kulcinski, fusion researcher and Associate Dean of Research at the University of Wisconsin, and Professor Dennis Papadopoulos, plasma physics and astrophysics researcher at the University of Maryland. Additional biographical background is provided in the Appendix.

The members of the committee have no financial association with the LPP program and agreed to participate in this review with the understanding that the committee would have complete freedom to express its opinions as it saw fit.

II. The Committee Review

The committee assembled at the LPP facility in Middlesex, New Jersey, for a one-day briefing and tour on November 18, 2013. On November 19, the committee met in executive session to discuss the LPP program and related DPF technical issues. Thereafter, Dr. Hirsch drafted this report, which the committee modified as it saw fit, resulting in this final report, which the full committee endorses.

III. The Dense Plasma Focus Concept (DPF).

For the purposes of this report, we quote the DPF description in Wikipedia:

“A dense plasma focus (DPF) is a machine that produces, by electromagnetic acceleration and compression, a short-lived plasma that is hot and dense enough to cause nuclear fusion and the emission of X-rays. The electromagnetic compression of the plasma is called a *pinch*. It was invented in the early 1960s by J.W. Mather and also independently by N.V. Filippov in 1954.”

The reader is directed to the technical literature and the Internet for detailed descriptions of the concept, related physics, and technical progress. Because of limits on space and time, the following discussion assumes that the reader is familiar with the technical aspects of DPF physics and technology.

IV. LPP Thinking and Results From Its DPF Research

The LPP effort is led by Mr. Eric Lerner, and conducted by a relatively small research team. Mr. Lerner has published his results in peer-reviewed scientific journals and openly exchanged information with other researchers in DPF research and related areas of physics. The LPP program is primarily guided by Mr. Lerner’s thinking.

The LPP program focuses on developing the DPF concept for use with the pB^{11} fusion fuel cycle. This cycle has the potential for producing fusion energy with low neutron emissions, thereby minimizing undesirable radiation hazards and radioactive materials. The committee supports this goal, due to its superior environmental characteristics and potential for high electric conversion efficiency.

As indicated, the operation of a DPF involves a brief electrical discharge that creates a gaseous plasma, which through acceleration and compression, often results in a high density (10^{22} ions/cm^3 though the current LPP DFF density is about 100 times lower), few micron size, energetic (>150 keV), strongly magnetized (10^6 Tesla) plasmoid, which could in principle release potentially useful quantities of fusion energy from fusion fuels in the very short period of time that a DPF maintains its integrity. By rapidly and repeatedly pulsing such a device, significant quantities of energy to both drive the DPF and provide useful, environmentally attractive electric power for practical use might be produced. The committee accepts that such an approach is in principle plausible, but its practical viability remains to be established.

As the committee understands the background, LPP’s choice of the DPF concept was based on Mr. Lerner’s belief that previous DPF limitations might be overcome with a different formulation of related physics theory and by using an expanded array of plasma diagnostics to better understand the fundamental physics of important phenomena occurring in DPF discharges. A related research program could conceivably lead to a practical source of electric power.[1]

Highlights of the LPP"s program, based on a theoretical model developed by Mr. Lerner are as follows:

1. The concept should **operate more effectively with heavier elements**, such as boron.
2. Scaling to effective operation is towards **smaller sizes**.
3. The so-called **Quantum Magnetic Field effect,** postulated in astrophysical plasmas but not verified in laboratory experiments, will reduce energy transfer from hot ions to electrons thereby preventing catastrophic energy loss due to bremsstrahlung emission by hot electrons.
4. Lerner's theoretical model predicts that reduction of bremsstrahlung loss and reabsorption of synchrotron radiation by the dense and opaque plasma focus could allow the pB^{11} DPF pinch to reach **ignition**.[2]
5. After the pinch disassembles, Lerner believes that **plasma ions will be exhausted along the axis of the device**, carrying roughly two-thirds of the plasma energy, allowing efficient direct energy conversion to electric power.
6. Based on his theoretical model, **a weak axial magnetic field** might enhance the beneficial formation of the pinch plasma.

The committee's views on these points are as follows:

1. **DPF operates more effectively with heavier elements.** *This prediction from the model remains to be verified. In the near future LPP has a credible plan to test this theory using Nitrogen as a stand-in for Boron. This appears possible, and, if proven, would be a distinctive characteristic of the DPF.*

2. **DPF wants to scale to smaller sizes.** *This prediction of the model also needs experimental validation. This appears possible, and, if demonstrated, is a positive, distinctive characteristic of the DPF. Smaller size scaling would be unique among fusion concepts and would mean that program development might proceed rapidly. On the other hand, in a power producing device, small size might lead to difficult device cooling, an issue that cannot be evaluated at this time.*

3. The Quantum Magnetic Field Effect will keep electron temperatures lower than the ion temperatures. *This effect has never been seen in*

[1] There are other potential applications of DPFs that might yield near-term applications other than fusion power, but LPP was not pursuing those applications at the time of the committee review.
[2] Fusion ignition is the point at which a nuclear fusion reaction becomes self-sustaining, i.e., does not require additional energy input.

laboratory experiments. Its demonstration represents a major challenge since it requires much higher densities and much higher self-generated magnetic fields. Lower electron temperatures are essential for this or any pB^{11} concept, because electron temperatures near ion temperatures would result in radiation losses that would prohibit net power production.

4. **Ignition with pB^{11} may be possible**. *While conceivable, ignition in pB^{11} has to our knowledge not been previously considered possible in other pB11 fusion concepts. If achievable, it would provide a distinct advantage for the DPF pB^{11} approach to fusion power.*

5. **Plasma ions will be exhausted along the axis of the device.** *If true, beam ion exhaust holds considerable potential for direct energy conversion, a distinct advantage, assuming relative engineering simplicity is viable.*

6. **A weak axial magnetic field may help pinch formation.** *LPP presented plausible arguments and data to the committee on this proposition. If true, it could represent a means of enhancing operation of a DPF system.*

V. Other Issues

1. **Plasma densities in the current experiment:** LPP personnel and the committee believe that the plasma densities in the existing DPF experiment are too low by over a factor of 10,000 to be practical for a pB11 fusion power system. Since observed densities at LPP are currently lower by about a factor of 10-100 than in many other DPF experiments, there does not appear to be a fundamental barrier to achieving higher densities than currently observed in the LPP device. LPP personnel believe that the reason for current low plasma densities is the high impurity content of current plasmas and that a change in device electrode material is a potential solution. LPP proposes to fabricate their anode out of tungsten to dramatically reduce impurities and increase plasma densities. This approach seems reasonable to the committee. Densities must be increased even further by demonstrating the effect of using a heavier element (like the Nitrogen proposed) and eventually reaching the higher densities required for the quantum magnetic field effect.

2. **Impurities in the current experiment:** Both LPP and the committee recognize that impurity concentrations must be dramatically reduced. See comments above.

3. **The LPP program:** The current LPP program is grossly underfunded and appears to be living hand-to-mouth. In spite of the issues and uncertainties outlined in this report, the committee feels that the promise of the LPP DPF approach to fusion power has considerable merit and that

a much higher level of investment is warranted, based on their considerable progress to date. Enhanced support should largely be used for additional experimental and theoretical efforts as well as for additional diagnostics and a larger experimental facility to accommodate additional diagnostics.

4. **Developing the DPF to a viable, economic, environmentally attractive fusion power reactor:** If the physics issues outlined herein can be satisfactorily resolved, it is conceivable that the DPF concept could be developed into a viable, economic, and environmentally attractive electric power source for not only civilian power but also for military purposes. LPP's projection of very small (about 5MW) units would be an advantage relative to most other fusion concepts. To date, LPP personnel have not given extensive consideration to the engineering of a DPF power reactor. This is appropriate in the committee's opinion, because without the successful resolution of existing issues, a DPF reactor will not be possible. Having said that, the committee does not see any fundamental roadblock to power system viability.

VI. Conclusions

The committee was pleasantly surprised at the innovative thinking and experimental results achieved thus far by Mr. Lerner and his team at LPP. We commend him for developing a theoretical model to guide the effort. In the committee's view, their approach to fusion power based on their DPF findings to date is worthy of a considerable expansion of effort.

While a number of near-term physics issues remain to be resolved, it is likely that with adequate financial support, these matters could be addressed in a relatively short period of time, e.g., a few years. Further effort in this area is definitely justified.

Appendix

LPP Fusion Review Committee – Selected Career Highlights

Dr. Robert L. Hirsch, Committee Chairman

- Senior Energy Advisor, Management Information Services, Inc. (MISI) and consultant in energy technologies. 2007-present
- Director fusion research, USAEC & ERDA, 1972-1976
- Staff member, USAEC fusion program, 1968-1972
- Contributor to the fusion research literature

Dr. Stephen O. Dean

- President, Fusion Power Associates, 1979-present
- Served on DOE Fusion Energy Advisory Committee, Chaired review panel on Alternate Concepts
- Served on Secretary of Energy, Energy R&D Task Force
- Editor, J. of Fusion Energy, Springer Publications, Inc.
- Director, Magnetic Confinement Systems, AEC/ERDA/DOE 1972-79

Prof. Gerald L. Kulcinski

- Associate Dean for Research, College of Engineering, University of Wisconsin-Madison; Grainger Professor of Nuclear Engineering; Director of the Fusion Technology Institute.

- Technical Program Chair, ANS Topical Meeting on Fusion Technology, 1976, member of the Board of Directors (1987-90), chair of the Honors and Awards, Fusion Division, 1997-2004; General Chairman of the 16th ANS Topical meeting on Fusion Technology (2004).

- A U.S. delegate to the International Tokamak Reactor (INTOR) Project, Vienna, Austria,1979 - 1981, and member of the INTOR advisory panel.

- Associate Editor of Fusion Engineering and Design, 1983-2003.

Prof. Dennis Papadopoulos

- Professor of Physics, Departments of Physics and Astronomy, University of Maryland, 1979 – present
- Senior scientist and division consultant, Plasma Physics Division, Naval Research Laboratory - 1969-1979

- Science Advisor, Applied Physics Division, Office of Fusion Energy, DOE, 1978
- Currently PI, Multi-University Research Initiative on the "Fundamental Physics Issues on Radiation Belt Dynamics and Remediation"