Position Paper and Recommendations of the User Group at the Basic Plasma Science User Facility at UCLA

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I. Introduction

The Basic Plasma Science Facility at UCLA (BaPSF) is a unique and comprehensive research facility providing valuable support and frontier-level scientific opportunities for the plasma sciences. With its suite of plasma devices and extensive particle and wave generation capabilities, it covers a wide range of plasma conditions with excellent diagnostic capabilities that are typically not accessible elsewhere.

The purpose of this facility is expressly to explore under controlled and well-diagnosed conditions the fundamental processes that take place in plasmas ranging from naturally occurring space and geophysical plasmas to high-temperature fusion plasmas and to industrial and medical plasma applications. The facility is available to qualified national and international scientists working in collaboration with an expert BaPSF staff.

The core of the facility is the Large Plasma Device (LAPD). The LAPD is the finest basic plasma research device in the world. It is the culmination of many years of research into plasma sources and plasma confinement schemes. The machine produces a quiescent, 18 meter long plasma in which the ions can be strongly magnetized; the plasma diameter is fifty centimeters. The plasma source is reliable and durable; it permits continuous experimentation for several months. Highly reproducible plasmas are created whose density profiles can be controlled to provide a variety of conditions encountered in naturally occurring plasmas. An important element of the LAPD facility is its flexibility of operation. The broad range of operational conditions permit the investigation of a large class of different phenomena with relative ease.

In addition to the LAPD, the Enormous Toroidal Plasma Device (ETPD) is part of the facility, essentially a large former tokamak. What was once a tokamak has been converted into a 1 Hz pulsed plasma device employing a high-emission cathode. It has been brought into preliminary operational status and has the possibility of producing plasmas up to 100 m in length with the possibility of accessing high beta plasma regimes. This device has the potential of studying a wide range of natural and fusion-related plasma phenomena.

Finally, several other plasma sources and devices exist within the BaPSF that permit the study of low temperature plasma phenomena relevant to industrial applications and diagnostic development. These devices include a large-area, non-magnetized etching plasma and a mirror geometry plasma used for component and diagnostic testing as well as other plasma wave studies. These devices were devised as spin-offs of the technology developed to support the LAPD functionality, but have provided important scientific tools on their own account. Because of the great commercial value of such low temperature plasmas, there is a growing need for such research tools. It is worthwhile to note that while plasmas are widely used in various industrial applications, particularly those used in processing semiconductor materials, the systematic study of a well-diagnosed plasma processing system is a rarity. The BaPSF is well-posed to contribute valuable understanding of such plasma processes with its combination of plasma sources and superb diagnostic capability.

The facility has been well-used since its inception and is supported by a User Group and Scientific Council, who determine the make-up of research projects for the facility. The User Group met in the spring of this year to discuss research opportunities for the BaPSF and to formulate a list of potential facility improvements designed to enable realization of these opportunities. The following is a summary of the consensus of the BaPSF User Group.

II. Recommendations of the BaPSF User Group

Thte User Group identified three over-arching areas of study for which the BaPSF can serve an important role, which cover in large measure the entire field of plasma sciences. These will be described briefly in the following.

Space Plasma Science

The study of the near-Earth plasmas in the ionosphere and magnetosphere is crucial for maintaining the integrity of global communication and navigation systems. Moreover, the longevity of current space assets and the efficacy of space travel itself require a detailed understanding of the mechanisms that occur within the Earth-plasma system and its interaction with the solar wind. There are many topics under the general notion of space weather that require further study, such as the magnetic reconnection problem, for which the BaPSF has already played an important role. This mechanism by which magnetic field lines merge in the presence of dissipative processes in plasma is important in understanding the interaction of the solar wind with the Earth's magnetotail and is believed to be a crucial process in the energy balance and particle acceleration observed in the magnetosphere. While satellites have provided a wealth of direct information on such space plasma physics, BaPSF provides a platform for the detailed study of these processes that is unique in its scale and diagnostic capability and serves as an excellent complement to in-situ space data.

In addition, certain solar and interstellar plasmas can be studied with scaled conditions that are accessible to BaPSF parameters, including shocks, waves, both linear and nonlinear, and wave-particle interactions. One example is that of the anomalous heating of the solar corona by Alfven waves.   Here, the question arises as to why Alfven waves generated in the lower corona are observed to damp much more quickly than traditional plasma theory would indicate, providing significant energy input into the upper solar corona. LAPD would offer an excellent opportunity to reproduce, and diagnose, the physics of this process.

Another area of some practical interest is that of the radiation belts, which present a potentially life-threatening hazard to our space assets and to space travel itself. While it is well-known that wave-particle interactions generated by the solar wind tend to regulate the radiation belt populations, relatively little is known about the details of the processes involved. The LAPD provides a unique platform for reproducing, and measuring, the magnetic geometry and dynamics of the belt regions.

Fusion Sciences

Another area where BaPSF plays an important support role is in that of fusion science. For instance, the understanding of edge plasmas and plasma-wall interactions is of particular importance. The LAPD is large enough to create a plasma with distinct core and boundary regions with an unequaled diagnostic environment for studying boundary phenomena. Also, the device is large enough to support many plasma waves of relevance to fusion devices and is particularly well-suited to the study of important nonlinear wave processes and wave-particle interactions. For instance, many fusion devices exhibit nonlinear wave behavior produced by instabilities and in externally-driven plasma heating and current drive applications. The LAPD can provide a venue to to study these phenomena with diagnostic measurements not available in full-scale fusion devices. In addition, the LAPD is an excellent device for the study of turbulence and its effect on plasma properties, which remains a key question in fusion plasmas. Moreover, a particularly beneficial opportunity arises to be able to verify large-scale plasma simulations in a situation with relatively simple spatial geometry and comprehensive particle and wave diagnostic capabilities. Finally, the ETPD can provide a unique high-beta plasma environment for the study of this regime, which is difficult to achieve in current fusion experiments, but is anticipated to be highly relevant to future fusion reactors.

Low-temperature plasma science

The BaPSF can impact the broad area of low temperature plasmas with its diverse range of plasma sources and comprehensive suite of diagnostics. For instance, it is important to better understand deposition and etching phenomena in detail, which requires a comprehensive determination of particle distribution functions along with an understanding of the associated wave phenomena. The development of micro-probes and sensor arrays at BaPSF enables the study of such processes in unprecedented detail. Other possibilities that may be studied using the suite of plasma sources at the BaPSF include plasma medical applications such as those where plasmas can be used to deposit energy within tissue with extreme precision.

As another example of a low temperature plasma suited for study at the BaPSF is that of lightning, where the ETPD comes into play. This device is unique in the world for providing a plasma configuration where many mean-free-paths can be contained within a device that is capable of studying true runaway phenomena, thought to be important in lightning breakdown.

III. Capability Enhancements and Opportunities

At the current time, the BaPSF has been operating at the forefront of plasma science in a number of areas. However, in order to remain at the forefront and to enable the facility to move into new, less well understood plasma regimes, we recommend that certain upgrades to the facility be considered with the potential scientific benefits as described below.

1. magnet upgrade - lower collisionality plasma

The upgrade of the magnetic field in the LAPD would enhance the overall confinement, raise the electron temperature and lead to a lower collisionality plasma. This would enable the study of 3D reconnection and extend the reach of the plasma into the solar wind regime. This would enhance the ability to study particle heating and acceleration in both magnetospheric and solar coronal plasmas.

2. cathode upgrade to LaB_6 in LAPD

The upgrade of the current BaO cathode to LaB_6 will produce a denser and hotter plasma for access to new plasma regimes (see above) and will facilitate faster turn-around of machine modifications, leading to a significant increase of machine availability.

3. development of microprobes

Prelimininary work at the BaPSF has shown the viability of microprobes in measuring the particle distribution functions in exquisite detail. The further development of this technique and deployment in arrays would enable the measurement of wave-particle interactions and turbulence in space and fusion plasmas and enable the study of a wide range of phenomena in low temperature plasmas. Diagnostic development remains a key side benefit of plasma research at the BaPSF.

4. molecular ions/gases

The addition of specific new ion and molecular gas species into the BaPSF devices would enable the study of a broad range of new phenomena relevant to industrial plasma applications. Bringing the comprehensive diagnostic capability of BaPSF diagnostics and data acquisition systems to bear on such plasmas would have an immediate and profound impact on the field of plasma chemistry.

5. relativistic e-beam

The addition of a relativistic electron beam would add the important capability to make precise measurements of the wave-particle interactions associated with the radiation belts. The current LAPD infrastructure along with the addition of precision beam diagnostics would enable an unprecedented study of belt dynamics in the truest Earth-based plasma configuration to date.

6. ETPD

Bringing the ETPD into full operation would enable the study of a variety of plasma phenomena that have never been addressed elsewhere. In particular, the high-beta plasma regime could be studied regarding wave phenomena and particle transport in an environment permitting comprehensive diagnostics. The application to fusion plasmas is evident. In addition, plasma propulsion concepts could be studied, including the unresolved issue of plasma detachment from magnetized thrusters. As mentioned above, the study of lightning in this device is a unique opportunity, particularly with regard to the issue of whether runaway electrons play a key role in determining the threshold for lighning events. Moreover, the unique energy sources available at the BaPSF, which include high-power rf at a variety of frequencies as well as ion and electron beams, and the diagnostic access of the ETPD provide an excellent opportunity for the study of a wide range of shock phenomena.

IV. Summary

We assert that the BaPSF fills a special role in the field of plasma physics providing research opportunities for topics ranging from astrophysics to fusion to indusustrial plasmas. The diverse plasma operating regimes combined with excellent diagnostic capabilities and expert infrastructure support provide a superb environment for studying various plasma phenomena in unparalleled detail. Not to be underestimated is also the possibility of training students and enhancing skills of the plasma science workforce, which is an issue of increasing importance to the national effort in fusion, space science and industrial plasmas.

The BaPSF fills a niche in plasma parameter space that is unreproduced in most small-scale plasma laboratories, and underrepresented in large-scale research devices worldwide. Both the LAPD and the ETPD are unique in the size scale for the plasmas they produce, and the combination with a comprehensive diagnostic suite is unparalleled. As the dedicated User Group for this facility, we strongly urge the continued support of the BaPSF, and the enhancement of its research capabilities.