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Plasma technologies improve plasma physics

"The science of plasma physics, and the technologies related to it, for which nearly all of the funding comes from fusion energy R&D budgets, has been prolific in the production of insights and techniques with wide applications in other fields of science and industry."
John P. Holdren, Harvard University

Near-term technological breakthroughs in fusion research depend upon advances in plasma technologies to enable both current and next generation plasma experiments to achieve their full potential. For next generation experiments now in the design phase, researchers must perform validating R&D addressing fabrication, performance, and operational safety, as well as affordability of major components and systems. Plasma technologies include

- **fueling**
- **plasma heating and current drive**
- **magnetics**
- **plasma-facing materials and components**

1MW, 110 Ghz gyrotron on DIII-D tokamak, General Atomics

Plasma fueling

The plasma fueling program element consists of technologies to accelerate cryogenic hydrogenic pellets, other advanced fueling systems such as compact toroid accelerators and high-Z impurity injection systems for disruption mitigation.

The goal of the plasma fueling program is to develop innovative fueling methods and systems to support near-term magnetic confinement experiments in the United States and abroad. These fueling systems must be capable of providing a reliable, flexible particle source for controlling core plasma density and density gradients. In a related area, the technologies applicable for fuel injection can be adapted to provide systems for disruption mitigation.

6- antenna mockup at Oak Ridge National Laboratory

Plasma heating and current drive

Electron cyclotron heating and current drive are important techniques for heating and controlling the plasma in confinement experiments in the United States, including the DIII-D tokamak, as well as internationally. The gyrotron is under intensive development to provide the megawatt power levels needed for electron cyclotron experiments. Within the VLT infrastructure, gyrotron research and development goals include increasing the reliability, increasing the unit power level up to the range of at least 1.5 to 2 MW, and increasing the efficiency to well over 50 percent. Research on gyrotrons has led to many valuable spinoffs including high frequency gyrotron amplifiers for radar, gyrotrons for industrial heating applications, and gyrotrons for spectroscopy.

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Ion cyclotron systems can provide radio frequency power for heating and driving current in fusion plasmas. The goals of radio frequency technology development for fusion are to make systems that can deliver more power per antenna,

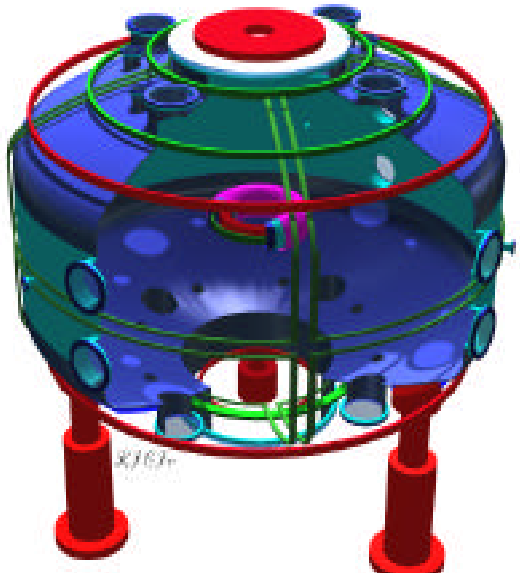
and that can operate reliably under a wide variety of plasma conditions. Researchers in the United States and abroad are collaborating in a radio frequency development program to design, develop, and test improved antennas and more robust systems. Results from fusion ion cyclotron technology development are also being applied in important non-fusion fields, such as improving ways to manufacture large semiconductor devices (e.g. computer chips), and in developing advanced high-efficiency ion rocket motors for possible interplanetary travel.

In the future, ion cyclotron systems combined with large antenna arrays can provide radio frequency power for heating and driving current in the plasma. The needs of the National Spherical Torus Experiment are prototypes of such systems.

Progress in high performance magnet development

Dramatic progress in the development of higher performance magnets is partly attributed to worldwide participation in magnetic fusion research. Even greater magnetic performance is envisioned with investments in emerging commercial high-temperature superconducting technology.

Within the framework of the Virtual Laboratory for Technology, fusion technologists are focused on more efficient, smaller and cost-effective experiments. Achieving the goal of more uniform and economical products requires lower cost magnet designs in concert with efficient manufacturing and quality assurance methods for large-scale production.



The Levitated Dipole Experiment (LDX)
A Science-Technology Partnership

The development of the Levitated Dipole Experiment superconductor is a good example of mutually beneficial efforts between fusion and high energy physics plasma technologists

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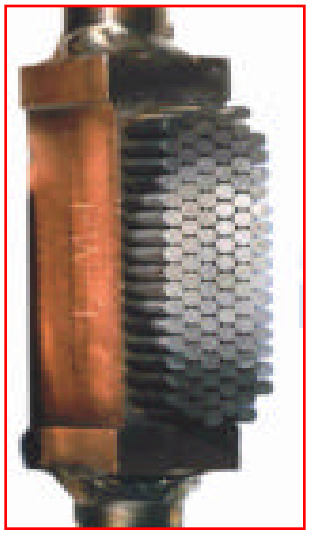
Plasma Facing Components

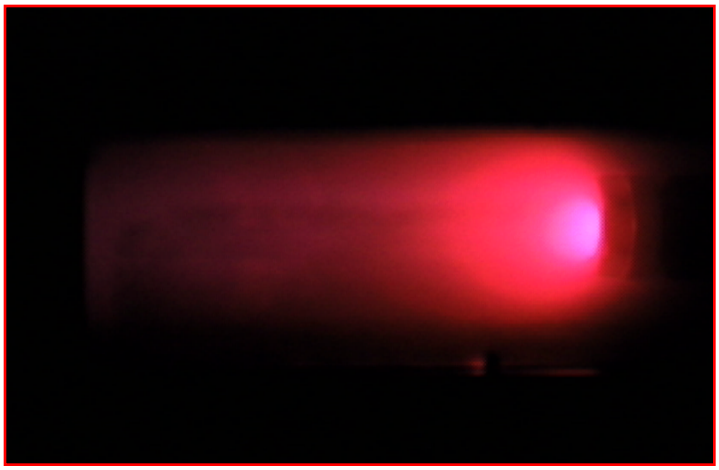


One of the key technology issues for fusion energy science is developing plasma-facing components that can actively remove the plasma thermal energy without contaminating the plasma. High atomic number refractory metals like tungsten have long been considered potential candidates for plasma facing materials. The challenge is finding reliable methods for joining the tungsten to a water-cooled copper heat sink, and accommodating the large thermal stresses under high heat flux. A tungsten armored plasma facing component was fabricated from tungsten rods joined to copper using a novel pressing technique. Several small-scale prototypes of this tungsten component have set new international records in heat loading.

Tungsten rod plasma facing component mockup, Sandia National Laboratories in collaboration with Boeing Corporation

Liquid lithium materials

Plasma interactions with liquid lithium materials are under investigation as part of the Office of Fusion Energy Sciences' Advanced Limiter-divertor Plasma-facing Systems (ALPS) program. This research may lead to a new generation of plasma flux handling systems based on liquid metal jets or streams. Properties of liquid metals such as lithium and gallium are investigated as to their erosion rates, oxide layer formation and control, hydrogen retention, chemical and physical sputtering processes, and thermal effects. These materials are subject to steady state hydrogenic and impurity plasma environments which deliver high heat flux (5 -10 MW/m^2) and particle flux ($\sim 10^{23}\ m^{-2}\ sec^{-1}$) which control the temperature of the liquid metal samples.



In this visible light image, liquid lithium contained in the sample holder is exposed to a high heat flux plasma at UC San Diego's PISCES facility. Thermal blooming of the liquid surface is occurring.

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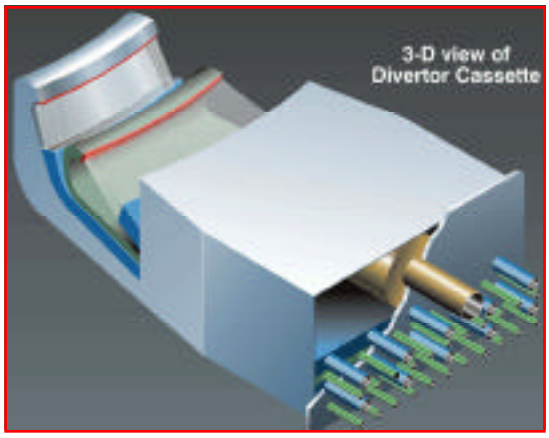
One of the most challenging areas for fusion power is the development of plasma-facing systems that can withstand high surface heat fluxes and neutron wall loads that at the same time exhibit desirable safety and environmental features.

Among the potentially attractive technologies for use in systems that operate in advanced, high power density physics regimes are liquid plasma-facing concepts, e.g., divertors. Liquid facing systems may potentially offer several advantages over conventional solid systems, including high power density capability, high erosion lifetime, no neutron damage concerns for liquids, active deuterium-tritium and helium pumping of the liquid surface, high temperature operation/high power conversion efficiency, and low coolant pressure operation.



The Advanced Liquid Plasma-facing Surface (ALPS) Project evaluates these systems for advanced fusion systems. The ALPS group includes broad representation from the U.S. plasma physics and fusion technology communities. Preliminary research is focused on identifying promising liquid plasma-facing surface concepts in divertor applications.

Divertor Material Evaluation System (DiMES)

The goal of the Divertor Material Evaluation System (DiMES) in DIII-D is to develop the scientific foundation of plasma facing materials by exposing fusion relevant materials to the well-diagnosed lower divertor of the DIII-D tokamak experiment. DiMES studies the basic process of erosion, deuterium retention, surface arcing and impurity transport of plasma facing materials in a divertor tokamak under different normal discharges and transient events. It supports ALPS and DIII-D programs by contributing to the scientific and technological foundations for wall conditioning, plasma facing solid and liquid materials. It also provides the fundamental plasma/wall interaction data of long pulse, and long burn and ignition devices and reactor designs."

The DiMES probe in the DIII-D ***tokamak provides essential data on plasma material interactions***