**CUWIP Tour**

- **Background and History of the Laboratory:** A discussion of PPPL's history from Project Matterhorn, a classified project in the 1950s to today as PPPL transitions to a multipurpose Laboratory and expands into areas like advanced computing and microelectronics
- **National Spherical Torus Experiment-Upgrade:** A virtual tour of the NSTX-U
- **Developing Fusion Energy as a Future Energy Source:** The possible future of fusion energy including a Fusion Pilot Power Plant and Permanent Magnet Stellarators
- **Low Temperature Plasma Laboratory:** A virtual tour of the Low Temperature Plasma Laboratory featuring a videotaped discussion with physicist Yevgeny Raitses, who leads the experiment.
- **Laboratory of the Future:** A discussion of PPPL's expanded mission and the Princeton Plasma Innovation Center, a new building that will have cutting-edge laboratories, offices, and collaboration spaces for research into microelectronics and other areas
- **Lithium Tokamak Experiment:** A virtual tour of the experiment which is exploring how lithium can be used to coat the inner wall of fusion devices with this liquid metal to improve the performance and the confinement of plasmas in fusion reactions.
- **Science Education Laboratory:** RGDX and Plasma Demos: Learn how you can create and manipulate a plasma in your living room through the Remote Glow Discharge Experiment. Then learn about plasma and fusion energy by watching live demonstrations of hands-on plasma experiments.

**PPPL History and Background**:

Magnetic fusion research at Princeton began in 1951 under the code name Project Matterhorn. Lyman Spitzer, Jr., professor of astronomy at Princeton University, had for many years been involved in the study of very hot rarefied gases in interstellar space. Inspired by the fascinating but highly exaggerated claims of fusion researchers in Argentina, Professor Spitzer conceived of a plasma being confined in a figure-eight-shaped tube by an externally generated magnetic field. He called this concept the "stellarator," and took this design before the Atomic Energy Commission in Washington. As a result of this meeting and a review of the invention by designated scientists throughout the nation, the stellarator proposal was funded and Princeton University's controlled fusion effort was born. In 1958, magnetic fusion research was declassified allowing all nations to share their results openly

- **The Tokamak Fusion Test Reactor** made headlines when it produced world records of fusion power in the 1980s and 90s.
- In 1994 TFTR produced a world record of 10.7 million watts of controlled fusion power, enough to meet the needs of more than 3,000 homes. (Although it was still using more power than it put out).

- Tokamaks are donut-shaped vessels used in most fusion energy experiments, including NSTX-U.
- Tokamaks were developed by the Russians and the word "tokamak" is a Russian term.

- Fusion energy (and ballet) were two of the only areas in which Russia and the U.S. collaborated during the Cold War.

- . TFTR was a massive experiment compared to NSTX. The test cell shows the size of TFTR.
- Power Supplies: NSTX & NSTX-U need a huge amount of power to operate.
- PPPL is one of three customers, along with the cities of Trenton & New Brunswick, on a trunk line from PSE&G.
- We also use massive motor generators beneath the ground when NSTX-U is operating.

**PPPL People:**
• 531 Full Time Equivalent Employees
• 7 Joint Faculty
• 36 Postdoctoral Researchers
• 24 Undergraduate Students
• 45 Graduate Students
• 318 Facility Users
• 28 Visiting Scientists

**National Spherical Torus Experiment-Upgrade**
The National Spherical Torus Experiment-Upgrade (NSTX-U) is a two-story tall spherical tokamak. Unlike most tokamaks it is a spherical tokamak, meaning it is shaped more like a cored apple than a doughnut. The spherical tokamak could be a more sustainable and affordable model of a fusion energy power plant. The NSTX-U will help scientists understand the unique ST plasma regime, to evaluate the ST's potential as a reduced-cost fusion concept, and to develop novel liquid metal power and particle exhaust solutions. The device operated from 10 years from 1999 to 2010. It closed for an upgrade in which a more powerful central magnet was installed for a higher magnetic field and current and a second neutral beam was installed for more power and current drive flexibility. The NSTX-U operated for a 10-week run in 2016 and closed down due to a number of technical problems, including the failure of a coil in the machine core. An extent of condition identified needed repairs to the facility. The NSTX-U Recovery Project is replacing key components of the facility including:

- Six inner poloidal magnets/field coils used to shape the plasma
- Coil support structures and O-rings
- Graphite tiles and bracketry that can better withstand heat flux
- Passive plate bracketry to allow full electromagnetic load
- A newly machined center stack casing with improved heating and cooling structures

**Fusion Pilot Power Plant**

A report earlier this year by a panel of the National Academies of Science, Engineering, and Medicine (NASEM) requested by the DOE and chaired by Richard J. Hawryluk, former associate director for fusion at PPPL, said the U.S. should invest in the research necessary to build a fusion pilot power plant by 2035 to 2040. The pilot plant would be a steppingstone to building a commercial fusion power plant by 2050.

**Stellarators:**

- The stellarator has twisted magnetic field coils built onto the vessel. The configuration was designed by a computer.
- Stellarators could solve the problem of disruptions in tokamaks caused by the induced current.
- But stellarators are not as flexible as tokamaks and they are difficult to build.
- The Wendelstein-7 X in Germany and the JT-60 in Japan are examples of stellarators.

**Permanent Magnet Stellarators**

Scientists at PPPL are researching how fusion devices called stellarators could be simplified using permanent magnets, the same kind of magnets that are used to attach children's artwork to refrigerators. Stellarators were first envisioned by PPPL founder Lyman Spitzer 70 years ago. While stellarators have some advantages over tokamaks because the complex, twist coils, provide a steady-state magnetic field. But their complexity makes them difficult and expensive to construct. Using permanent magnets could make stellarators less complex and costly and could provide a model for fusion power plants of the future.

**Lithium Tokamak Experiment-Beta**

The Lithium Tokamak Experiment-Beta (LTX-ß) is an upgraded version of the Lithium Tokamak Experiment that produced its first plasma in September 2008. The three-year upgrade, completed in 2020, included a powerful neutral beam injector that doubled the magnetic field, as well as a twin evaporation system to fully coat liquid lithium on all the plasma-facing surfaces. PPPL researchers believe that doubled LTX-ß may herald a new regime of plasma performance with improved stability, lower impurity levels, better particle and temperature control, and more efficient operation that could ultimately lead to smaller and more affordable fusion devices.

**Low Temperature Plasma Laboratory**

Low-temperature plasmas LTP) are used in a broad array of advanced technologies that have major economic impact in the U.S. and internationally. PPPL researchers have pioneered research into low temperature plasmas. PPPL and Princeton University are leading the Princeton Collaborative Research Facility on Low-Temperature Plasma (PCRF), which will focus on research into low-temperature plasmas and their applications into modern applications such as material synthesis and processing. The Princeton Plasma Innovation Center will provide advanced laboratories and collaboration and workspaces for this effort.

**Princeton Plasma Innovation Center and the Laboratory of the Future**
The Laboratory of the future will need to be supported by modern, cutting-edge facilities and infrastructure. The Princeton Plasma Innovation Center will have laboratories, offices and collaboration space, to support PPPL's expanded mission focusing on research for industries of the future such as nanotechnology and quantum computing.

**Science Education Laboratory**

**RGDX**
PPPL's Remote Glow Discharge Experiment allows users from all over the world to learn about plasma physics through a hands-on, online experiment.

**Plasma Demonstrations**