# TRITIUM FOR FUSION

## CREATING A TRITIUM SUPPLY CHAIN TO ACCELERATE THE DEVELOPMENT OF FUSION ENERGY AND TO ADVANCE THE UNDERSTANDING OF THE EFFECTS OF TRITIUM ON INTEGRATED MATERIALS SYSTEMS

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT of ENERGY

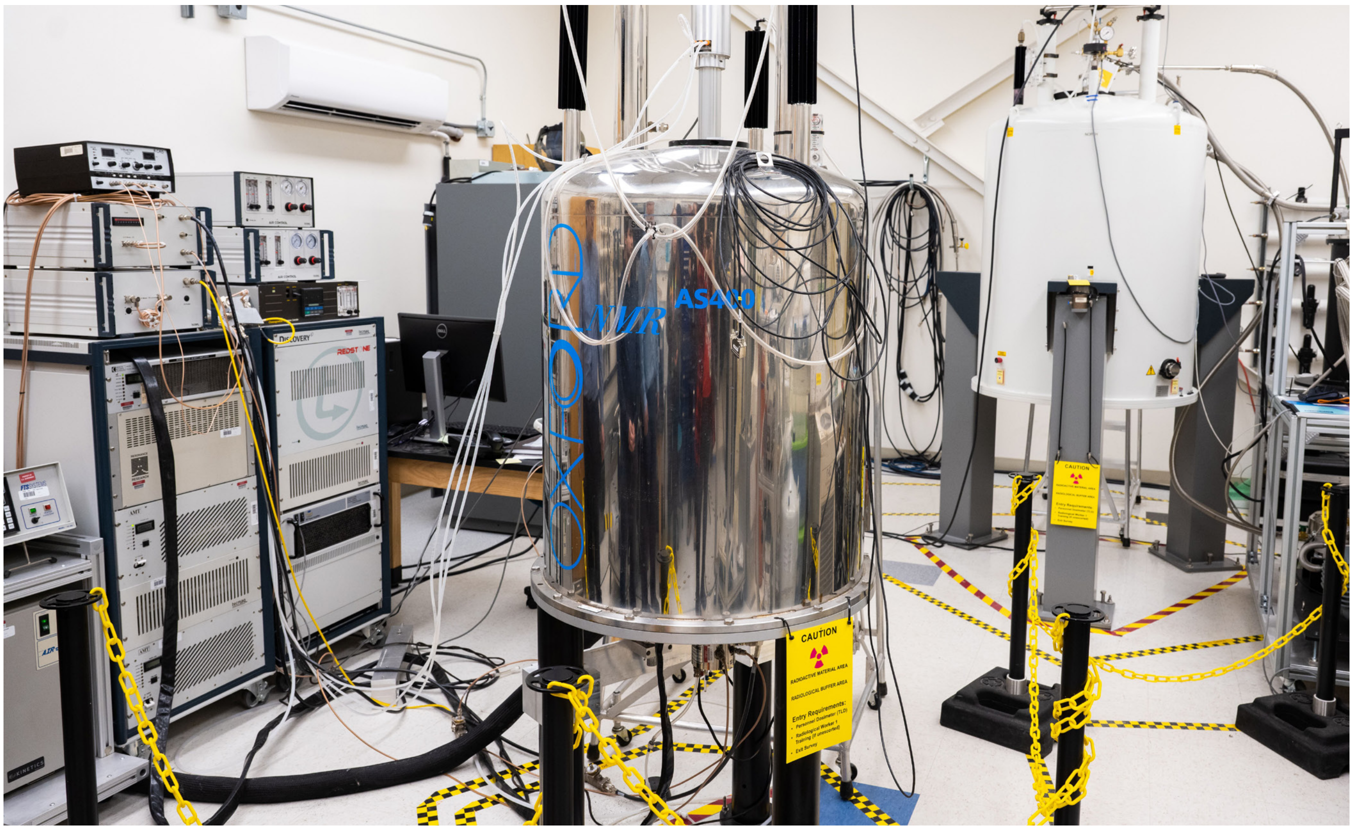
To create the burning plasmas for fusion energy, scientists need to start with a fuel source. Tritium—an isotope of hydrogen—is a promising fuel for fusion energy-based power.

At Pacific Northwest National Laboratory (PNNL), researchers are using their expertise in producing tritium to serve as the starting fuel for fusion power plants. We also focus on understanding the impacts of tritium on component materials that need to withstand these extreme environments.

## WORKING WITH AND HANDLING TRITIUM IN THE RADIOCHEMICAL PROCESSING LABORATORY:

PNNL's Tritium Technology Program (TTP) post-irradiation examination (PIE) capability focuses on the evaluation of irradiated target materials to further the understanding of tritium behavior, tritium permeation, as well as tritium production for National Nuclear Security Administration (NNSA) Defense Programs.

We have five laboratory spaces dedicated to tritium handling within our Radiochemical Processing Laboratory (RPL). Activities within these spaces include large-scale tritium handling up to the facility limit of ~16 grams; intermediate-scale analyses of liquid and gas samples for analytical chemistry, high-resolution gas mass spectrometry, and high-sensitivity noble gas analysis; and small-scale efforts for "non-rad" manipulation. Notably, the RPL is the only complex in the nation that is equipped to work with high levels of tri-




*PNNL scientists use the Radiological Nuclear Magnetic Resonance (NMR) Spectroscopy Laboratory to conduct research on nuclear materials. The work focuses on light elements, including tritium and lithium-6, which are at the center of many of the nation's top research priorities in energy, national security, and environmental remediation.*

tium in fume hoods. Our stringent radiological controls and containment capabilities, along with our rigorously trained staff, make the RPL the premier location for tritium research.

## LOADING SAMPLES WITH HYDROGEN ISOTOPES:

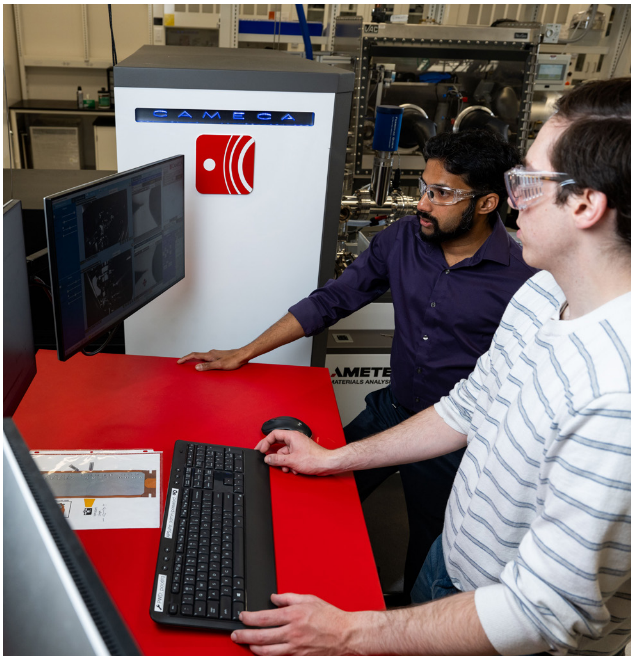
Tritium's radioactivity necessitates special handling procedures while working with the material. The non radioactive hydrogen isotopes, protium and deuterium, can be used as surrogates for tritium in several experimental contexts. For example, our researchers frequently load samples with deuterium to study material hydriding processes and prepare samples for subsequent hydrogen mobility tests. The deuterium is radiologically stable and chemically distinguishable from the naturally occurring protium in the atmosphere.

## HYDROGEN PERMEATION MEASUREMENT AND MICROSTRUCTURAL CHARACTERIZATION CAPABILITIES:

Managing tritium gas permeation is a major issue in future fusion energy systems. Our hydrogen permeation measurement capabilities study the movement of deuterium as an analogue of tritium to better understand the isotopes' behavior. Our testing capabilities include permeability, diffusivity, and solubility measurements of materials including high-entropy alloys, ceramics, and composites, and surface characterization techniques including scanning and aberration-corrected transmission electron microscopy, X-ray diffraction, and X-ray photoelectron spectroscopy.

## MICROSCOPY OF TRITIATED SAMPLES AND THEIR SURROGATES:

Our staff are trained to handle, prepare, and characterize tritiated and irradiated samples. We apply advanced microstructural characterization techniques to irradiated samples in dedicated spaces. Our microscopy techniques provide a wealth of information on tritiated materials, showcasing incredibly small defects at a high density. These techniques provide a qualitative view of microstructural differences. Coupling




*PNNL scientists use atom probe tomography to combine atomic-scale experiments with theory, creating a tool to design complex metal alloys that withstand extreme environments.*

them with sample montaging and segmentation for analysis of position-dependent void swelling provides quantitative information.

## ATOM PROBE TOMOGRAPHY AND MICROMECHANICAL TESTING OF TRITIUM BEARING MATERIALS:

Tritium-producing burnable absorber rods (TPBARs) are designed to produce tritium when irradiated in commercial nuclear reactors. PNNL is the design authority for the NNSA for these rods. Research in this area includes atom probe tomography with in situ gas exposure capability and correlating microstructure and micromechanical properties of the internal getter components, analyzing the effect of impurities on gaseous transport through nickel plating on the getters, and tritium diffusion and trapping in the microstructure of TPBAR components. The aspects of this research will inform materials development for the components of tritium fuel cycle for fusion reactors.

## AI FOR TRITIUM SCIENCE:

Our researchers apply state-of-the-art artificial intelligence technologies to help solve difficult problems in fusion energy. For example, our scientists have leveraged machine learning to model the interatomic potentials of lithium aluminate pellets with tritium and helium. We have also used large language models to propose pellet dopant substitutions to optimize tritium production and stability.

## SOLID AND MOLTEN-SALT BREEDERS FOR FUSION:

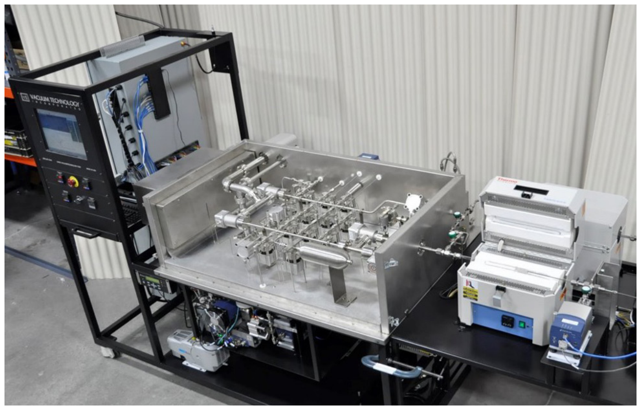
Many fusion reactor concepts incorporate a breeding blanket in their design, which produces tritium as part of the fusion energy cycle. This blanket is typically a solid ceramic, liquid metal, or molten salt. Our researchers are designing solid breeder materials for use in fusion reactors, such as the DEMO reactor being developed by the European Union and Japan. Balancing fabrication costs with material performance and longevity remains a formidable task. Additionally, our experience working with the irradiated lithium aluminate pellets used in TPBARs can be translated to other solid ceramic breeder materials.

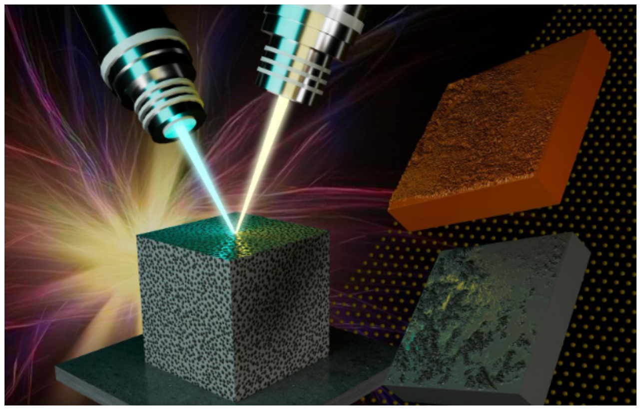
PNNL has experience working with molten salts for several programs within the Department of Energy Office of Nuclear Energy. This includes fabricating and processing FLiBe. These capabilities can also be translated to molten salt research relative to fusion energy breeding blankets.

The FLiBe molten salt, which is made from a mixture of lithium fluoride as a tritium breeder and beryllium fluoride as a neutron multiplier, requires special handling for safe manipulation and characterization. PNNL scientists are developing safety protocols essential for supporting FLiBe research.

## FUSION INNOVATION RESEARCH ENGINE:

As part of the Department of Energy's "Bold Decadal Vision for Commercial Fusion Energy," the Fusion Innovation Research Engine (FIRE) collaboratives were launched in 2024. PNNL participates in FIRE through the "Accelerating Fusion Blanket Development through Nuclear Blanket Testing (BNT)" project. This project aims to de-risk tritium breeder blanket concepts by creating capabilities and infrastructure to perform neutron irradiation of blanket components coupled with predictive modeling and simulation tools. Our researchers support this project by leveraging their expertise in the design, fabrication, operation, and interpretation of neutron irradiation experiments, which were performed within the Tritium Technology Program (TTP) at PNNL.





***Top:*** *This multi use, ultra-high vacuum gettering and permeation test capability at PNNL has multiple detectors for accurate measurements of hydrogen isotope diffusivity, solubility, and permeation rates. With a sensitivity that is 1,000 times greater than conventional test platforms, PNNL can use it to measure the permeation reduction factor up to 100,000.*

***Bottom:*** *PNNL researchers have developed a novel multi-projection scanning transmission electron microscopy technique to evaluate damage in tungsten heavy alloys.*

## MORE INFORMATION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