Fusion Energy Division

ANS Nuclear Grand Challenges
Descriptions of Fusion Grand Challenges
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1. Qualification of advanced materials that can withstand extreme nuclear fusion and fission environments (high temperature, radiation damage and transmutation, helium and hydrogen surface and bulk effects, and compatibility with advanced coolants).

   Advanced fission and fusion reactor designs offer many potential benefits but will require new materials to be successful. These advanced reactors have unique challenges that call for materials to resist corrosion when in prolonged contact with liquid salts or liquid metals, remain strong at elevated temperatures in a neutron field, maintain structural integrity when exposed to high fluxes of light ions and high heat flux, resist reaction in a loss of coolant event, and more. Materials must be developed and qualified for each of these areas so that they can be implemented in new reactors.

2. Safely and efficiently fuel, exhaust, breed, confine, extract, and separate tritium in unprecedented quantities.

   Tritium management in fusion and fission systems presents a persistent challenge to confine and avoid tritium permeation into undesirable locations. Fusion reactors pose additional challenges in tritium management. Only a fraction of tritium in the plasma will be "burnt up" and converted to helium. Cost effective, high throughput tritium re/processing capabilities need to be developed. In addition, burning plasma fusion reactors will require unprecedented quantities of tritium. As tritium is not found in nature, it must be bred. Scalable systems for breeding and extracting sufficient quantities have not been demonstrated. Since the fusion fuel cycle wholly depends on tritium availability, this is a critical area for the success of fusion energy.

3. Successfully demonstrate significant energy gain in a long pulse or steady-state burning plasma.

   The path to viable fusion power from a magnetically confined plasma source requires the creation of a burning plasma. In a burning plasma, the primary heating source comes from the fusion reaction itself. Furthermore, in order to begin to consider the economic viability of a fusion power plant, the reaction must have a significant energy gain, or “Q” factor (ratio of output power to input heating power), in a reaction that is sustained over a time frame of minutes or hours. Construction has begun for an international experiment that aims to achieve this (the ITER tokamak), and numerous privately funded smaller experiments have the potential to make leaps forward toward this goal.

4. Development of an experimentally validated integrated predictive simulation capability that will reduce risk in the design and operation of fusion energy systems.

   Accurate, predictive simulation capabilities are needed to provide input to virtually all aspects of the design, operation, and licensing of fusion energy systems. The design of fusion energy systems requires accounting for many strongly interactive multi-disciplinary physics and engineering components. Opportunities exist to take greater advantage of exascale computing to enable high fidelity integrated multi-disciplinary simulations to qualify the operating scenarios of the burning plasmas in fusion energy systems, optimize the design of these systems, and ensure their safe construction and operation.

5. Development of an appropriate safety and licensing process for future nuclear fusion facilities, with related criteria, including the qualification of materials and safety-important systems.

   A nuclear licensing process is required that is well-adapted to the specific safety and environmental challenges facing nuclear fusion facilities on the scale of a commercial power plant. In particular, criteria must be set and engineering codes and standards developed taking account of the environment in which fusion systems will operate. These criteria must then be satisfied by materials development and qualification together with the design of safety-critical systems, structures and components.

6. Construct and operate a high flux, high-energy (10 to 15 MeV) neutron source for research in fusion, fission, transmutation, and radio-isotope production applications.

   A high-flux, high-energy (10 to 15 MeV) neutron source is needed for testing, evaluating, and qualifying the performance and durability of various components and materials that could be used in fusion reactors, next-generation fission reactors, or sub-critical fast spectrum reactors driven by either a fusion-based neutron source, or an accelerator-based spallation neutron source. In addition, both hybrid fusion-fission reactors (HFFRs) and accelerator-driven systems (ADS) may be applied for the use of transmutation and destruction of minor actinides and long-lived fission productions, and also for the production of various industrial and medical radioisotopes (such as Mo-99). The performance characteristics of HFFR and ADS components under high neutron radiation fields need to be evaluated. A high-flux fast neutron source is needed to evaluate the radiation damage in structural components, particularly first-wall components in fusion reactors, and to serve as a test bed for evaluating various tritium-breeding blanket components and materials (including solid and liquid lithium-based compounds), and low activation materials.

7. Demonstration of an effective plasma exhaust system that can operate under nuclear conditions and maintain performance for a lifetime that avoids frequent replacement.

   The system to exhaust the products of the fusion reaction together with un-burnt fuel must perform in a harsh environment of charged particle flux and very high heat load (typically up to 20 MW/m^2). Current concepts would have limited lifetime (maximum 1-2 years), necessitating a lengthy plant shutdown for replacement, an operation to be performed fully by remote handling. This would have a severe impact on power plant availability and economics. A physics and engineering solution is needed for a viable fusion power plant.