DRAFT 3/12/2013

Report of the FESAC Subcommittee on the Prioritization of Proposed Scientific User Facilities for the Office of Science

Written in Response to Dr. William Brinkman's charge letter to the Office of Science Federal Advisory Committees
December 20, 2012

March 15, 2013

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1. Introduction

On December 20, 2012, Dr. William Brinkman, Director of the DOE Office of Science (SC), charged his six Federal Advisory Committees to help with the task of prioritizing proposed SC scientific user facilities. Specifically, each committee was tasked to: (1) review a list of existing and proposed new and upgraded facilities provided by the respective SC Associate Director, subtracting from or adding to the list as the committee felt appropriate; (2) consider new facilities or upgrades that require a minimum investment of $100M; (3) assess the ability of each facility to contribute to world-leading science in the next decade (2014-2024), placing each facility in one of four categories: (a) absolutely central, (b) important, (c) lower priority, or (d) don't know enough yet; and (4) assess the readiness for construction for each proposed new facility or upgrade, placing each facility in one of three categories: (a) ready to initiate construction, (b) significant scientific/engineering challenges to resolve before initiating construction, and (c) mission and technical requirements not yet fully defined. To meet the very compressed timetable set by SC, final committee reports (in the form of a "letter") were to be transmitted to Dr. Brinkman by March 22, 2013. SC would then use these reports, and additional input from other stakeholders, to create a prioritized list of major facilities for the next decade. The full charge letter may be found in Appendix A.

With concurrence from the SC Office of Fusion Energy Sciences (FES), the FESAC Chair formed a Subcommittee of technical and project experts knowledgeable of FES mission, vision, and portfolio. Subcommittee members are listed in Appendix B. The Subcommittee held two in-person meetings in Gaithersburg MD on February 1 and March 2-3, and convened six 2- or 3-hour conference calls on January 25, February 8, 15, 22, and March 8, 15. FES personnel attended both in-person meetings. Meeting agendas may be found in Appendix C.

Conflict of interest (COI) procedures were established early on and rigorously followed. DOE General Council participated at the first in-person meeting, providing guidance, discussing practical scenarios, and answering Subcommittee questions. Subcommittee members declared direct and potential COI prior to any assessments. Anyone with a direct COI for an existing or proposed facility, including those put forward by FES, the broader community, or the Subcommittee itself, was recused from all discussions and voting associated with that facility. Recusal meant, "leaving the room" (physically at meetings, and hanging up during a conference call).

2. Executive Summary

Research in fusion and plasma science supported by the Office of Fusion Energy Sciences (FES) is very diverse, ranging from the enormous intellectual and technical challenge of bringing the power of stars to earth, to discovering, predicting, and controlling the complexity of plasmas—the fourth state of matter. Four strategic goals frame the breadth of the FES portfolio:

- *Advance the **fundamental science of magnetically confined plasmas** to develop the predictive capability needed for a sustainable fusion energy source;*
- *Pursue scientific opportunities and grand challenges in **high energy density plasma science** to explore the feasibility of the inertial confinement approach as a fusion energy source, to better understand our universe, and to enhance national security and economic competitiveness;*
- *Support the development of the scientific understanding required to design and deploy the **materials needed to support a burning plasma environment**; and*
- *Increase the **fundamental understanding of basic plasma science**, including both burning plasma and low temperature plasma science and engineering, to enhance economic competiveness and to create opportunities for a broader range of science-based applications.*

The Subcommittee considered a wide array of proposed new and upgraded facilities that could create opportunities to enhance or establish U.S. leadership in plasma and fusion science in the context of these four strategic goals. The research needs and opportunities that frame the requirements for these facilities are documented in a thorough set of studies and reports that have been completed in recent years, including *Frontiers in High Energy Density Physics: The X-Games of Contemporary Science* (NRC, 2003); *Scientific Challenges, Opportunities, and Priorities for the U.S. Fusion Energy Sciences Program* (April 2005); *Priorities, Gaps and Opportunities: Towards A Long-Range Strategic Plan for Magnetic Fusion Energy* (FESAC, 2007)*; Plasma Science: Advancing Knowledge in the National Interest* (NRC, 2007); *Report of the FESAC Toroidal Alternates Panel* (2008); *Report of the Research Needs Workshop (ReNeW) for Magnetic Fusion Energy Sciences* (FES, 2009); *Advancing the Science of High Energy Density Laboratory Plasmas* (FESAC, 2009); *Basic Research Needs for High Energy Density Laboratory Physics* (DOE-SC, 2009); *Research Opportunities in Plasma Astrophysics* (PPPL, 2010); *Materials Science and Technology Research Opportunities Now and in the ITER Era: A Focused Vision on Compelling Fusion Nuclear Science Challenges* (FESAC, 2012); *Priorities of the Magnetic Fusion Energy Science Program* (FESAC, 2013); and *An Assessment of the Prospects for Inertial Fusion Energy* (NRC, 2013).

As described in Step 1 of the charge letter from Dr. Brinkman, FES provided FESAC four suggested new and upgraded facilities: 1. Fusion Materials Initiative; 2. Quasi-axisymmetric Research Experiment (QUASAR); 3. Fusion Nuclear Science Facility (FNSF); 4. Upgrade of the DIII-D National Fusion Facility. These facilities address research in two of the four strategic goal areas listed above. To gain a broader perspective on potential facility opportunities, the Subcommittee issued a call for white papers from the scientific community (Appendix D). This solicitation resulted in 37 white papers

(Appendix E[1]) describing new facility opportunities that could advance research in support of all four FES strategic goals. The white papers were evaluated by the Subcommittee using a set of criteria for world-leading science and readiness based on the guidelines in the charge letter from Dr. Brinkman. This provided extremely valuable input to the process. However, the Subcommittee's decisions on the recommended facilities listed in Table 1 were framed by the composite information in the planning documents listed above, the proposed new and upgraded facilities received from FES, together with the white papers.

In addition to the four proposed new and upgraded facilities, FES provided FESAC descriptions of the existing tokamak facilities: the DIII-D National Fusion Facility, located at General Atomics, and the Upgraded National Spherical Torus Experiment (NSTX-U), located at Princeton Plasma Physics Laboratory. FES did not include the Alcator C-Mod tokamak facility located at MIT, since this facility is proposed to cease operation as described in the President's FY 2013 budget proposal. To support a process of parallel and uniform evaluation of existing and proposed new and upgraded facilities, the Subcommittee solicited white papers from the program leaders of DIII-D, NSTX-U, and Alcator C-Mod (also listed in Appendix E).

It is important to observe that the ITER facility under construction in France was not included in the lists of facilities received from FES. The reason for this is explained in a supplemental letter from Dr. Edmund Synakowski, Associate Director, FES to Dr. Martin Greenwald, Chair, FESAC that provided additional guidance (Appendix F). To quote Dr. Synakowski, "As we all appreciate, ITER is unique not only in the world-leading science it is expected to accomplish, but in how it is being conducted under an international agreement with seven Members. As a consequence, SC leadership has determined that ITER is not to be considered in this exercise." The Subcommittee interpreted this as strong DOE support for the burning plasma science enabled by ITER that defines the present frontier in fusion research using magnetically confined plasmas. An assessment of ITER is therefore not included in this report.

The charge letter from Dr. Brinkman states that only facilities whose cost exceeds $100M should be considered in this process. However, the supplemental letter from Dr. Synakowski provided guidance that facilities with cost below $100M could be considered for FES, although "the $20M level is probably too low." Despite this extra freedom, facility cost was a substantial filter that eliminated from consideration important options identified in the planning documents noted above, the white papers, and even some of the suggested facilities received from FES. This is true in all four of FES's strategic goal areas, but it is particularly stark for materials for the burning plasma environment and basic plasma science, where low-cost facilities could have tremendous impact. As such, not identifying or putting forth a particular facility in this report should not be equated with it lacking potential for world-leading science.

The Subcommittee recommends the five new and upgraded facilities listed in Table 1. Two-page descriptions for each of these and the existing facilities follow. The Subcommittee strove to identify strong options representing each of the strategic goals for FES, using the numerous available research planning reports as the technical basis for defining facility requirements. Each two-page description describes the facility's mission,

[1]The white papers are available to the public at http://burningplasma.org/fsff-whitepapers.html

its ability to enable world-leading science, and its connections to the research planning reports. For readiness, "ready for construction" was interpreted as roughly equivalent to "ready for Critical Decision 0 (CD-0)" in standard terminology for project management as implemented by the DOE Office of Science.

Table 1: Recommended facilities for the next decade (2014-2024). Each facility is categorized for world-leading science as: (a) absolutely central; (b) important; (c) lower priority; and (d) don't know enough yet. The readiness of the proposed new and upgraded facilities is categorized as: (a) ready to initiate construction; (b) significant scientific/engineering challenges to resolve before initiating construction; and (c) mission and technical requirements not yet fully defined.

Facility	Science	Readiness
DIII-D National Fusion Facility	a	(existing)
Upgraded National Spherical Torus Experiment (NSTX-U)	a	(existing)
Fusion Materials Irradiation Facility	a	a
Fusion Nuclear Science Facility (FNSF)	a	b
Multi-Petawatt Science Facility	b	b
Quasi-Symmetric Stellarator Experiment	a	b
Upgrade to the DIII-D National Fusion Facility	b	a

As requested by the charge letter from Dr. Brinkman, the Subcommittee also categorized the existing facilities. The DIII-D National Fusion Facility and the Upgraded National Spherical Tokamak Experiment (NSTX-U) are premier facilities in worldwide fusion research, critical to support the U.S.'s involvement in ITER and to develop the knowledge base for future steps such as a Fusion Nuclear Science Facility. The NSTX-U experiment is mid-way through an upgrade project that will bring substantial new capabilities in exploring and developing the tokamak at low aspect ratio. The Subcommittee therefore categorizes these facilities as "absolutely central."

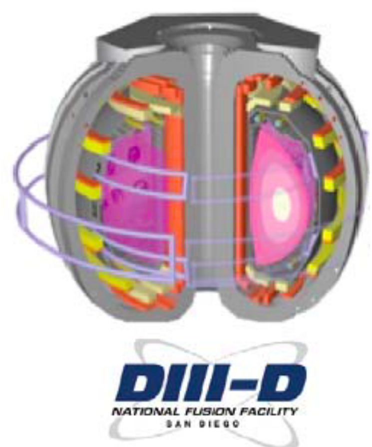
The future of the Alcator C-Mod facility is presently uncertain. The recently completed *Report of the FESAC Subcommittee on the Priorities of the Magnetic Fusion Energy Science Program*, chaired by Dr. Robert Rosner, recommended that if FES funding at the FY 2012 becomes available, then "roughly one-third of the restored funds, $12M per year should be deployed for a three to five year period of operation of C-Mod to resolve high-priority topics on ITER-relevant boundary and divertor physics, and might include upgrades as required to accomplish these goals." The Subcommittee concurs with this assessment and recommendation.

3. Existing Facilities

3.1 DIII-D National Fusion Facility

The mission of DIII-D is to establish the scientific basis for the optimization of the tokamak approach to fusion energy production, specifically to address critical topics regarding: 1) resolving burning plasma physics issues critical to the success of ITER; 2) developing the physics basis for steady-state tokamak operation required for efficient power production, 3) addressing key issues that will form the technical basis for a Fusion Nuclear Science Facility (FNSF) and 4) advancing the fundamental understanding and predictive capability of fusion science on a broad front.

Facility description



The DIII-D National Fusion Facility is the largest fusion research experiment in the U.S. DIII-D has considerable experimental flexibility and extensive world-class diagnostic instrumentation. This provides scientists worldwide with an experimental platform to push performance boundaries, resolve specific challenges for ITER and future devices, and advance the knowledge of fusion plasmas on a broad front. Capabilities of DIII-D include a highly flexible field-shaping coil system to produce a wide variety of plasma shapes, a broad range of auxiliary heating and current drive systems, coil sets both inside and outside the vacuum vessel which are used to correct magnetic error fields and study the plasma response to perturbing magnetic fields, over 50 state-of-the-art diagnostic systems to examine plasma parameters, and an advanced digital control system for feedback control of the plasma. These capabilities, together with a broad international team and close cooperation with theory and simulation provide an excellent facility for educating and training the next generation of fusion scientists.

Enabling world-leading science
(a) absolutely central

The existing DIII-D facility is a world-class fusion research device with several unique capabilities enabled by a comprehensive diagnostic set, close liaison with theory through model validation, and a high degree of device flexibility. These capabilities have led to numerous advances in the tokamak concept over the past two decades including the importance of non-circular shaping, sustained operation above the intrinsic free-boundary stability limit, and the suppression of damaging boundary plasma instabilities using non-axisymmetric magnetic coils.

With its existing capabilities, DIII-D is positioned to provide key scientific studies to explore the physics of performance-limiting phenomena in its present operating regimes:

- **Reducing the risk of sudden plasma termination –** Active heating and current drive tools enable the suppression of instabilities that may otherwise grow uncontrollably and terminate the plasma confinement, an event called a disruption. Disruptions are of significant concern in ITER because of the damage they may cause to internal components. DIII-D will develop individual elements of a disruption avoidance and mitigation strategy at performance levels consistent with the ITER baseline scenario.

- **Quantifying turbulence-driven energy, particle, and momentum transport –** Utilizing DIII-D's extensive diagnostic set and variable ion/electron heating and torque input, the role of turbulence in setting the transport characteristics of candidate ITER high confinement regimes will be explored. Perturbative transport studies will continue to test fundamental turbulence models, while the discrepancy of core transport to boundary transport models will be addressed.
- **Exploring steady-state options –** Flexible heating/current drive tools will help develop the physics basis of steady-state operation in tokamaks. Studies will investigate transport and stability properties and explore the potential for self-consistent solutions that do not use the inductive electric field typically employed in tokamaks.
- **Improving understanding of 3D field interactions with tokamak plasmas –** DIII-D's existing coil arrays will be used to apply rotating magnetic fields with variable spectra to correct error fields, control plasma stability, and probe the plasma response particularly towards eliminating damaging boundary instabilities called Edge Localized Modes (ELMs).
- **Advancing the physics of the boundary pedestal –** Existing diagnostics will enable tests of theory-based models of the steep gradient regions of the boundary plasma.

Facility's connection to FES planning documentation

DIII-D's existing capabilities will enable a range of research that will address many needs, gaps, and opportunities identified by recent FESAC reports. In general, DIII-D research enables the understanding and prediction for magnetically confined burning plasmas. Areas in which DIII-D will play world-leading roles, as identified in the ReNeW community-wide assessment of research needs, are given here as examples. Under Thrust 2 to *"Control Transient Events in Burning Plasmas"* the DIII-D 3D coil capabilities and disruption mitigation/diagnostic sets will enable researchers to contribute to the physics basis for ELM control and disruption mitigation design decisions on ITER. Under Thrust 4 to *"Qualify Operational Scenarios..for ITER"* a flexible heating/current drive set, multiple instability control tools, and the ability to operate at ITER-like torque and collisionality at moderate pressure provide the capability to access requirements to the ITER baseline scenario. Under Thrust 5 to "*Expand the limits for controlling and sustaining fusion plasmas"* DIII-D is a world leader in steady-state tokamak research and the existing capabilities will enable continued development of its physics basis. Under Thrust 6 to "*Develop predictive models for fusion plasmas"* the extensive diagnostic set of DIII-D enables tests of theory and simulation of turbulent transport, edge pedestal physics, disruption mitigation, fast particle physics and edge plasma physics. Under Thrust 9 to "*Unfold the physics of the boundary plasma layer"* DIII-D's extensive diagnostic set and ability to assess a variety of divertor/boundary configurations will allow researchers to develop an improved physics basis of scrape-off layer (SOL) heat/particle flow and geometric effects at moderate power density values.

3.2 Upgraded National Spherical Torus Experiment

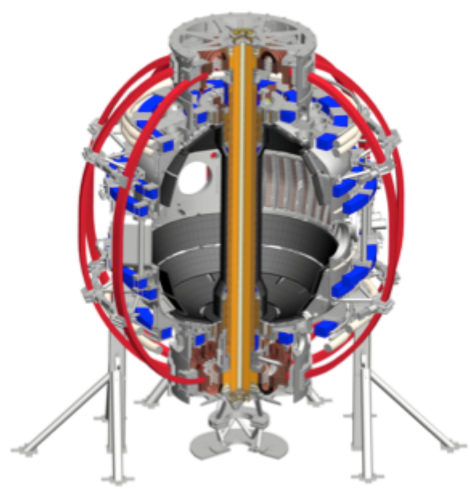
The National Spherical Torus Experiment (NSTX) is undergoing a major upgrade (NSTX-U) that will double its range of key parameters including the magnetic field strength, plasma current, and heating power. It will have unique capabilities in the world's tokamak portfolio in its development of new solutions to the plasma-material interface. With these enhancements NSTX-U is positioned to make major scientific contributions to:

1) advance the understanding of toroidal confinement physics for ITER and beyond,
2) understand and develop novel solutions to the plasma-material interface challenge, and
3) establish the physics basis for the low aspect ratio tokamak as a candidate for a Fusion Nuclear Science Facility (FNSF).

Underlying all these missions is access to a unique plasma physics parameter regime of high normalized pressure, (high β) combined with reduced inter-particle collision frequency (ν^*), to address fundamental questions about plasma stability and turbulent transport and greatly extend the understanding of toroidal plasma science.

Facility description

The NSTX-U explores magnetically confined plasmas in a tokamak configuration with a small ratio of the major radius to the minor radius compared to conventional aspect ratio tokamaks like ITER. It is one of only two medium-sized experiments in the world that operate in this low aspect ratio regime. The upgrade doubles the toroidal magnetic field to 1 Tesla, doubles the plasma current to 2 million amperes, doubles the neutral beam heating power to 14 MW, and greatly increases the pulse-length from 1 s to 7 s. These facility enhancements will provide access to reduced particle collisionality (higher plasma temperature) allowing the study of plasma transport and stability much closer to the conditions required for FNSF. The new second neutral beam system is aimed tangentially to increase the current drive efficiency for greatly enhanced plasma control that should enable access to fully non-inductive operation. This is essential for steady-state operation of a tokamak-based FNSF to provide continuous operation and high neutron fluence. NSTX-U will also explore advanced high-flux-expansion "snowflake" divertors, as well as liquid lithium as potential divertor power and particle control solutions for FNSF and beyond.



NSTX-U

Enabling world-leading science
(a) absolutely central

Contributions critical to ITER: The unique operating regime of NSTX-U allows it to, access directly regimes of interest for ITER. One such area is energetic particle physics, where the new heating systems in NSTX-U will provide expanded ability to vary the velocity and spatial distribution of energetic ions in the plasma. This physics is critical in the burning plasma or FNSF regimes where fusion reactions create high-energy alpha particles. Other specific areas of potentially strong contributions include radiative divertor solutions to the ITER-relevant heat fluxes, and impurity transport using multiple conditioning and PFC scenarios to enable control techniques to be developed in impurity-seeded ITER plasmas. The NSTX-U development of its Massive Gas Injection system for disruption mitigation may influence the design of a system for ITER.

Developing new solutions for the plasma-material interface: The increased heating power and compact geometry of NSTX-U will produce very high exhaust power densities prototypical of fusion reactors, requiring the development of solutions to handle these power levels at the Plasma-Material Interface (PMI). NSTX-U will explore novel solutions to the power exhaust challenge by testing extreme expansion of the magnetic field lines in a "snowflake" divertor configuration, and by testing liquid metal plasma facing components to mitigate the erosion and melting problems associated with solid materials. ***The ability to explore very high exhaust power density, high magnetic expansion, and liquid metals in the same device is unique in the world fusion program.***

Establishing the physics basis for a Fusion Nuclear Science Facility (FNSF): With access to the highest magnetic field and heating and current drive power of any low aspect ratio tokamak, NSTX-U will be the leading device in the world program to assess the viability of this regime for FNSF applications. The operating range of NSTX-U overlaps or connects to that of an envisioned FNSF based on low aspect ratio in the critical performance metrics of non-inductive current sustainment, improved energy confinement, normalized beta, and power flux density. The capabilities of NSTX-U extend beyond those of the MAST device (Culham Laboratory, UK), even after its planned upgrade in 2015.

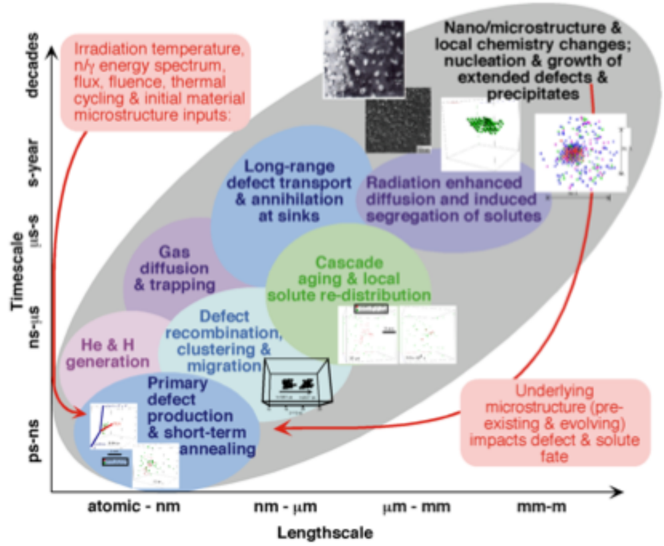
Facility's connection to FES planning documentation

The critical need to understand and predict the performance of burning plasmas has been repeatedly cited in DOE planning documents, NSTX-U is closely aligned and can contribute to the three FESAC Priorities, Gaps and Opportunities Report (2007) themes: 1) "Creating Predictable High-performance Steady-state Burning Plasmas," 2) "Taming the Plasma Material Interface," and 3) "Harnessing Fusion Power," The NSTX-U research objectives are completely supportive of the four High Priority ST Issues listed in the FESAC Toroidal Alternatives Panel Report (November 2008): 1) "Start-Up and Ramp-Up," 2) "First-Wall Heat Flux," 3) "Electron Transport," and 4) "Magnets" In the recent FESAC Subcommittee report on "Priorities of the Magnetic Fusion Energy Science Program" (January 2013), five high priority thrusts for the U.S. Fusion Program were identified. The four non-stellarator priorities, are in line with NSTX-U capabilities; Thrust 2 "Control transient events in burning plasmas," Thrust 6 "Develop predictive models for fusion plasmas, supported by theory and challenged with experimental measurement," Thrust 9 "Unfold physics of boundary layers," and Thrust 10 "Decode and advance the science and technology of plasma-surface interactions."

4. Proposed Facilities & Upgrades

4.1 Fusion Materials Irradiation Facility

The Fusion Materials Irradiation Facility will transform nuclear material science and address critical gaps in irradiation capability needed to qualify materials for future science missions. Fusion reactor materials must tolerate an extraordinarily demanding environment of high temperature, chemical interaction, time-dependent thermal and mechanical loading, and—most significantly—14 MeV neutrons from DT fusion reactions. These high-energy neutrons produce atomic displacement damage that ultimately equates to displacing every atom in the material up to 150 times during its expected service life. Fusion neutrons also drive changes in chemical composition by transmutation reactions and introduce damaging concentrations of reactive and insoluble gases. Materials development and performance is a long-standing feasibility issue, as well as a critical factor in realizing the environmental and safety potential of fusion. To address this significant challenge and to open new frontiers in materials science requires the development of facilities that more accurately simulate fusion relevant conditions. There are no laboratories in the world today that can reproduce the high-energy neutron flux conditions required. This facility is targeted to close the gap, creating a world-nexus for exploring multi-disciplinary radiation materials science.



A Grand Challenge in multi-scale science: Fusion neutron damage effects, occurring on the atomic level in picoseconds, ultimately determine bulk behavior and long-term survival.

Facility description

While scientific progress in the near term can be made using nuclear fission reactors and ion beam irradiation facilities, such advances will be incremental at best. These facilities lack the volume, flux and spectral characteristics to perform experiments on materials and subcomponents in an environment that can effectively simulate fusion conditions and get results on reasonable time scales. Ultimately, significant progress requires a test platform with neutron flux equivalent to that expected on the first wall of a DT fusion power reactor including:

1. High-flux irradiation volume >0.4 liter [with equivalent 14 MeV neutron flux >2 MW/m^2 (10^{18} $n/m^2/s$)] to test specimens of adequate size and number.
2 Atomic displacement damage >20 dpa/year so that degradation from effects such as volumetric swelling, irradiation-enhanced creep, phase instabilities, helium embrittlement, and solid trans-mutation will be observed in reasonable time.

3. Medium- and low-flux irradiation volumes to test sub-component assemblies and partially-integrated experiments for synergistic effects of irradiation on thermo-mechanical and corrosion properties.
4. Availability >70% to provide exposures >10 MW-year/m^2 in a reasonable time frame (less than a few years), accessing relevant temperature ranges with control of +/-5%.
5. Flux gradients < 20% per cm to provide consistent exposures over the volume.

Enabling world-leading science
(a) absolutely central

Burning plasma facilities for fusion nuclear science are still in the conceptual development phase and we lack many materials-related details to provide high confidence in their design. Because of this, it is advantageous (and necessary) to take a deeply scientific path toward understanding material behavior in the presence of burning fusion plasma systems. The conditions of radiation damage, thermal heat flux, and high-energy particle bombardment are the most extreme that exist on earth. This is truly the frontier for material science. Success in these efforts will spread beyond fusion-related needs and feed into a broad range of capabilities in material nanostructure, predictive behavior, and perhaps custom engineered material properties. Specific scientific questions that could be explored in such a facility include:

1. Is there a practical limit to the maximum amount of accumulated transmutation-produced gases that can be tolerated in materials, considering effects on deformation and fracture behavior, irradiation-induced swelling and creep, and high-temperature creep rupture lifetime?
2. How do we extrapolate single-effect 14 MeV neutron degradation phenomena to the synergistic fusion nuclear degradation environment?
3. How can materials be tailored at the microstructural level to mitigate the neutron degradation processes while maintaining high performance macroscopic properties, and margins of safety?
4. How does the neutron-induced damage and transmutation production, coupled with high thermal and mechanical loads, affect other processes such as tritium permeation and trapping, the evolution of plasma facing materials, tritium breeder material composition, and corrosion mechanisms at material interfaces?
5. Can quantitative, multi-scale, predictive physical models describing neutron-induced damage that spans spatial and temporal scales greater than nine orders of magnitude, be developed to describe the material evolutions in the fusion environment?

Higher goals for a fusion materials facility and an associated modeling program are to: 1) *predict* with high confidence how a particular material will perform under the conditions it is exposed to, and 2) to *design* new materials to perform as required. This requires leading-edge science and unprecedented engagement with theory, experiment, and simulation to understand the most basic principles that underpin the full range of multi-scale material properties and interactions with external stimuli. Since the fusion neutron flux, and other conditions, vary significantly throughout the system, from the first wall to the neutron shield (~ 1 m), it is necessary to optimize materials for their specific location. Developments of this magnitude will provide the materials knowledge base for many harsh-environment applications. This facility will attract a broad multi-disciplinary user base: the international fusion materials community plus researchers studying applications beyond plasma and fusion science, e.g., fast-modular and next-generation-fission reactors, medical isotope production, and single-event upset effects in high-altitude avionics.

Facility's connection to FES planning documentation

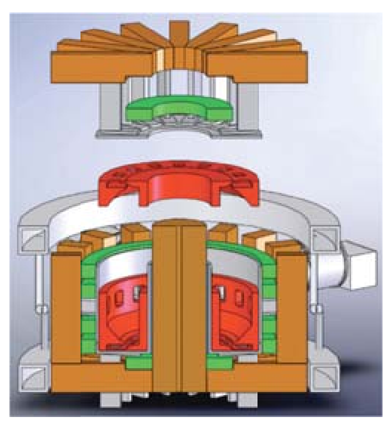
Facility requirements and candidate designs to provide fusion-relevant materials science is well covered in numerous reports: *Scientific Challenges, Opportunities, and Priorities for the US Fusion Energy Sciences Program* (2005); *Priorities, Gaps, and Opportunities: Towards A Long-Range Strategic Plan for Magnetic Fusion Energy* (2007); *Research Needs for Magnetic Fusion Energy* (2010); *Opportunities for Fusion Materials Science and Technology Research Now and During the ITER Era* (2012); and *Fusion Nuclear Science Pathways Assessment* (2012).

Readiness
(a) ready to initiate construction

There are at least two specific designs described in the planning documentation that have advanced to a CD-1 level. This provides high confidence that technical challenges and costs are understood in sufficient detail to initiate a selection process and construction. Cost-effective construction options exist, leveraging current and planned facilities elsewhere within the DOE (BES, HEP, and NNSA). Estimated total project cost: $100M to $200M; annual operation cost: ~$20M.

4.2 Fusion Nuclear Science Facility (FNSF)

The FNSF will provide the first-ever access to the integrated controlled thermonuclear fusion environment, which is characterized by strong couplings among high temperature plasma properties, plasma-material interactions, fusion neutron science and extreme material alterations and damage. The FNSF will be a world-leading research tool for establishing the scientific basis for fusion energy by addressing three critical challenges: 1) developing solutions to the strong interactions between the hot plasma edge and the walls surrounding the plasma; 2) confronting the nuclear degradation of materials and structures; and 3) harnessing fusion power via heat extraction and breeding of fusion fuel. With its lower fusion gain, higher fluence and heat flux, and steady-state operation, the FNSF complements the ITER mission, which will explore the world's first magnetically confined burning plasma. Together, FNSF and ITER will position the U.S. scientific community on the doorstep of exploiting the energy source of the stars here on earth.



Facility description

The FNSF is a minimally sized toroidal magnetic fusion device that will produce a fusion neutron flux prototypical of fusion reactors, in a size smaller than a power plant and over long durations sufficient to understand the numerous multi-physics processes in the structures that surround the plasma. The steady-state plasma current will be provided by self-generated processes and some degree of external drive. The 14 MeV neutron flux emerging from the plasma will ultimately reach > 1-2 MW/m^2, with plasma facing component lifetimes long enough for sustained operation at high neutron exposures. Required tritium fuel will be bred from lithium in the region that surrounds the plasma. This region will simultaneously absorb the power in the form of energetic neutrons and hold the materials temperatures in the operating ranges allowed by continually advancing materials properties. It includes mechanical, thermal, chemical, and nuclear features, which vary through its depth and which will be, up to that point, unexplored. This facility will evolve via a staged approach to provide increasingly higher fusion neutron production and allow testing and improvements of plasma performance, materials, and blanket system designs as its capabilities progress. Rapid changeover of components and experimental flexibility will be supported by use of demountable coils (see figure) and modular replacement of internal components via remote handling in the nuclear phase.

Enabling world-leading science
(a) absolutely central

Exciting opportunities for discovery science will arise as the interactions between the plasma and nuclear components of the fusion problem are confronted together for the first time in the world, and each stage of the FNSF program will offer world-leading science as they progress increasingly closer to a fusion reactor environment.

The first, non-nuclear, stage will explore the complex and integrated plasma-wall interactions encountered in maintaining a high-performance plasma for weeks (>10^4 times longer than present experiments) with pressures up to 7 atmospheres—the achievement of which would itself establish clear US world leadership. Under the long-duration and intense plasma bombardment of plasma-facing components, the surface properties of components are expected to change dramatically as material is eroded, re-deposited, and transported by the plasma to different regions of the chamber. This could lead to changes in interactions with the hot plasma boundary and strongly influence the core plasma behavior. Thus, processes that could substantially change the achievable fusion power in reactors will be studied systematically in FNSF even in this first stage.

Subsequent stages of FNSF operation will introduce tritium fuel to provide increasingly higher fusion neutron exposure and thereby offer access to world-leading studies of fusion nuclear processes integrated with a sustained high-performance plasma core. Operation at high fusion neutron fluence will provide new studies of material alteration through nuclear displacement/transmutation leading to void formation, creep, swelling, and embrittlement at component scales far larger than previously studied. Material changes of plasma facing components from neutron irradiation will impact material surface properties, and thus coupling to the edge and core plasma. Surface material changes will also impact how fusion fuel is retained in the surrounding walls and thereby influence the edge plasma and fueling requirements. Liquid metal flow dynamics, corrosion, tritium breeding, tritium permeation and recovery, and eutectic chemistry in a highly inhomogeneous environment will be studied in a steady-state fusion-relevant environment for the first time. The environmental and safety potential of fusion would emerge from the experiments and facility operations of the FNSF.

Facility's connection to FES planning documentation

The need to advance fusion nuclear science in the U.S. fusion program was described in:

FESAC report "Scientific Challenges, Opportunities, and Priorities for the US Fusion Energy Sciences Program (2005)"; FESAC report "Priorities, Gaps, and Opportunities: Towards A Long-Range Strategic Plan for Magnetic Fusion Energy (2007)"; Research needs workshop report "Research Needs for Magnetic Fusion Energy (2010)"; Report Fusion Nuclear Science Pathways Assessment (2012); DOE-sponsored review report on the technical plan for the U.S. ITER test blanket module program (2006); International workshop report on Magnetic Fusion Energy Roadmapping in the ITER Era (Nuclear Fusion, March 2012); FESAC report "Opportunities for Fusion Materials Science and Technology Research Now and During the ITER Era" (2012).

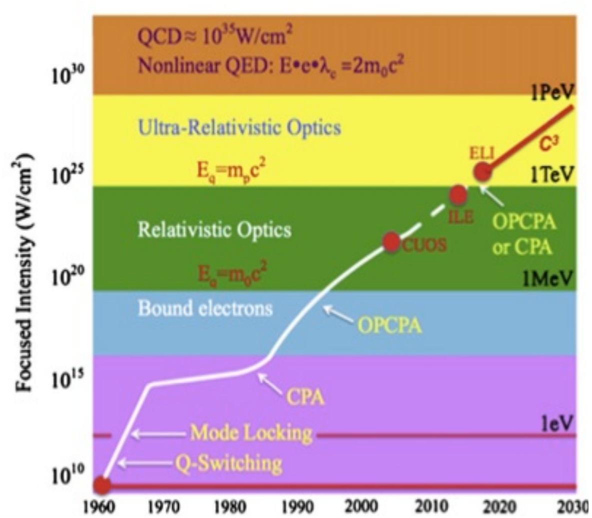
Readiness

(b) significant scientific/engineering challenges to resolve before initiating construction

Detailed specifications and design of the facility are in the beginning stages, but no fundamental impediment to initial operation of an FNSF facility is evident, assuming a staged development towards full nuclear capability. Work on ITER and existing U.S. and international experiments will advance the development of the control tools and actuators that will be required to operate FNSF at maximum performance. Challenges include tests of plasma-material interactions to identify initial wall designs, operational scenarios, development of the required steady-state auxiliary heating and current drive systems, and nuclear-capable control diagnostics and tools. Supporting materials research and engineering development in dedicated test facilities will be conducted to retire these issues in the early phases of the facility design and construction cycle. Estimated total project cost: $1B to $4B.

4.3 Multi-Petawatt Science Facility

A Multi-Petawatt Science Facility will give access to the highest focused-laser power intensities on earth. Achieving this capability will push fundamental laser-matter interactions beyond the existing relativistic-electron regime to conditions where self-emission of electromagnetic radiation influence electron dynamics, protons become relativistic, the structure of the quantum vacuum starts to reveal itself, and where matter and antimatter appear through processes involving extremely intense low-energy photons. Operation at this intensity frontier will feature one or more short-pulse lasers and advanced diagnostics to access new regimes of intense laser interactions with matter. Initiating a national process now to design and construct this capability will recapture U.S. leadership that is giving way to



Laser-focused intensity vs. years, from Mourou, Fisch, Malkin, *et al.*, *Optics Comm*, **285**, 720 (2012).

strong programs in Europe. This facility would build upon existing U.S. expertise in high-energy laser technology while leveraging existing facilities and unique diagnostics to transform the science of high energy density laboratory plasmas (HEDLP), high energy physics, relativistic atomic physics, and nuclear-physics.

Lasers planned for the Extreme Light Infrastructure*

Country	Facility focus	Power (PW)	Pulse energy (J)	Pulse width (fs)	Rep rate (Hz)
Romania	Nuclear physics	10 (×2)	200	20	0.1
Hungary	Attosecond physics	1	5	5	1000
		20	400	20	0.1
Czech Republic	Secondary beam radiation, high-energy particles	1	10	10	10
		5	50	10	10
		10 (×2)	200	20	0.1
To be determined	High intensity	10 beams of 10–20 PW each, phased and combined to create total power of 100–200 PW			

*Laser parameters still subject to change.

Representative laser facilities planned for the EU ELI

Facility description

We are interested in physical processes that occur at intensities above 10^{23} W/cm^2 and at power levels greater than 10 PW. This sets the minimum requirements for the large, expensive laser(s) that form the basis for the facility. Advances in existing laser technology can meet these intensities at the minimum level. Pushing capabilities to greater than 10^{24} W/cm^2 and 100 PW requires laser development and combining multiple beams. Additional, optical lasers and/or free-electron lasers (FELs), provide for heating and diagnosing experiments. Other diagnostics need to correspond to the particular physics areas including HEDLP, nuclear physics, and high-energy physics. The target chamber needs to be flexible with many ports to be adaptable to a wide range of laser input and diagnostics locations.

Specific facility requirements include:

1. High intensity main beam minimum requirements: (a) a minimum of two to enable important pump-probe experiments and access certain important regimes via beam interaction, (b) intensity greater than 10^{23} W/cm^2, with a development path to 10^{24} W/cm^2 and above, (c) a total focused power reaching 10-100 PW, (d) wavelength nominally the optical range, 0.5-1.0 µm, (e) on target energy 0.1-1.0 kJ per beam, (f) short optical pulse length, 10-100 fs, and (g) a reasonable repetition rate, ~ 0.001- 0.1 Hz.
2. Diagnostic and heating beams: (a) required optical heating beam, 0.5 µm, 1 kJ, ~ 1 ns, (b) required short pulse optical beam, 1.0 µm, 0.1 kJ, ~ 1 ps, (c) highly desired free-electron laser (FEL), 1 – 10 keV, ~ 100 J.
3. A flexible target chamber to field many kinds of experiments and allow a broad range of diagnostic opportunities for a wide range of science disciplines to participate.
4. Management model based on DOE/OS User Facility guidelines.

Enabling world-leading science
(b) important

The study of high energy density laboratory plasmas (HEDLP) captures the science of outer space and of inner Earth. It underpins studies of inertial fusion energy and compact particle accelerators. It is the science of high pressure and high-density matter at both high and low temperature. Because matter at high energy density is hard to create and very dynamic in the laboratory, most aspects of HEDLP require frontier experimental facilities and combine multi-scale computer simulations to advance our understanding. Large laser facilities are used to study HED materials and plasmas, but the number of researchers who have access to them is limited. At today's facilities, the rate of experimentation is too slow for many promising areas of study, compromising the development of important scientific applications. Both of these issues severely constrain the breadth of scientific involvement and the diversity of techniques arrayed to advance high energy density plasma science.

Foreign competition is building the Extreme Light Infrastructure (ELI), which consists of a spectrum of European facilities. These facilities will provide researchers with state of the art tools for the next decade or longer. Although U.S. researchers will try and get time on these facilities to pursue these new regimes, the Multi-Petawatt Science Facility will allow U.S. scientists unprecedented access to extreme states of matter and provide U.S. scientists world-leading access to explore relativistic HED plasma and intense beam physics, nonlinear plasma optics, high energy density hydrodynamics, radiation-dominated plasma dynamics and material properties, and IFE and compact accelerators. Interest in this facility is broad and includes several Office of Science Program Offices (FES, BES, HEP, NP) and NNSA.

Specific scientific areas that can be explored include: (1) astrophysics and the origin of cosmic rays: the role of collisionless shocks in amplifying magnetic fields and accelerating charged particles, (2) quantum electrodynamics, (3) high energy physics, (4) resonant and non-resonant laser-nucleus coupling, (5) inertial fusion energy and fast ignition via electron- or ion-beam generation, (6) particle acceleration and ultra-compact therapeutic radiation treatment, (7) novel radiation sources, (8) free-electron dynamics in an intense electromagnetic field, (9) relativistic atomic physics, (10) electron drag and radiation-reaction, (11) vacuum-polarization: the interaction of light *with* the background vacuum, and (12) anti-matter through pair production: electron/positron, muon/anti-muon and pion/anti-pion.

Facility's connection to FES planning documentation

The need to advance HEDLP science has been called out in multiple planning documents, including:

- *Frontiers in High Energy Density Physics: The X-Games of Contemporary Science*, NRC (2003).
- *Physics 2010: Plasma Science, Advancing Knowledge In The National Interest*, NRC (2007).
- *Advancing The Science Of High Energy Density Laboratory Plasmas*, FESAC (2009).
- *Research Opportunities in Plasma Astrophysics*, P. Wiesner, Ed., 2010.
- *Basic Research Needs for High Energy Density Laboratory Physics (ReNeW)*, R. Rosner and D. Hammer, 2010.

Readiness

(b) significant scientific/engineering challenges to resolve before initiating construction

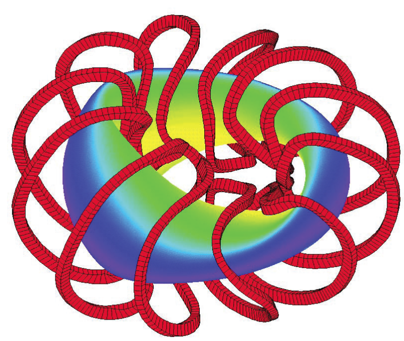
While some facility options might be ready to initiate construction, the HEDLP community needs to converge on priorities as noted above. Also, inter-agency and intra-office ownership and governance discussions (*e.g.*, between FES and BES, HEP, NNSA, NSF) will be useful and necessary when selecting a preferred option. Estimated total project cost: $100M to $200M; annual operation cost: ~$20M.

4.4 Quasi-symmetric Stellarator Facility

A new facility will evaluate a pathway toward producing steady, quiescent magnetically-confined fusion plasmas by scientific optimization of the underlying toroidal magnetic field geometry. The understanding and implementation of novel magnetic field configurations has been repeatedly shown to improve the performance of high-temperature toroidal plasmas over the last decades. As the fusion science research approaches the generation of nuclear-heated plasmas in the ITER tokamak, the necessity of controlling the behavior of the high temperature plasma to prevent virulent discharge-terminating instabilities known as disruptions is recognized as a challenge of the highest priority. There ultimately exists a further need to produce such fusion plasmas steadily, for weeks on end. Because of its imposed magnetic field geometry, a class of toroidal magnetic confinement devices generically known as stellarators are inherently suited, by design, to confine macroscopically quiescent plasmas in steady-state, i.e., without the need of a significant electric current (the source of free energy for these instabilities) flowing through the plasma itself. Should the quality of plasma performance in stellarators optimized for confinement prove adequate to support the high-pressure plasma required for fusion while simultaneously maintaining the plasma in a disruption-free steady state, the field of options for a successful path to fusion energy is significantly enhanced.

Facility description

The remarkable scientific advance that motivates increased interest in stellarators for fusion is the finding of so-called **quasi-symmetric** magnetic field configurations for stellarators in which the plasma confinement is predicted to be as good or better than in tokamaks. Despite the fact that the shape of the symmetrically-optimized stellarator plasma retains clear three-dimensional features (see the accompanying representation of a quasi-symmetric stellarator plasma enclosed by its magnet coils), several distinct types of quasi-symmetry have been identified theoretically, and one type has been experimentally tested with success at an exploratory level in a US device.



The quasi-symmetric facility will have adequate size and magnetic field strength for good plasma confinement. It will have sufficient heating power to test for pressure-limiting behavior in the important regime of low ion collisionality. For reduced cost, the device will utilize copper magnet coils to produce plasmas limited to duration of several seconds, sufficiently long to achieve nearly-constant plasma parameters in the plasma core and boundary to test the susceptibility to disruptions of high-performance stellarator plasmas with equilibrated self-driven current.

Enabling world-leading science

(a) absolutely central

The innovative application of symmetrizing principles to otherwise three-dimensional magnetic "bottles" for confining plasmas is a potentially powerful advance in plasma physics. The time is ripe to pursue a comprehensive approach to quasi-symmetric stellarators to exploit their projected benefits and deal with their presently-understood challenges in more integrated, high-performance plasma experiments. Specifically, studies on a new facility will, if successful:

- demonstrate the absence of disruptions in all scenarios of interest, including the high-pressure regime relevant to fusion applications;
- demonstrate the improvement in magnetic confinement of both thermal and energetic particles resulting from the use of quasi-symmetric stellarator fields;
- explore the challenge of exhausting the power and particle outflow from the hot plasma in the complex three-dimensional geometry of the stellarator;
- determine means of controlling or reducing impurity ion inflow that could lead to plasma contamination and cooling; and
- investigate the importance of controlled plasma flow on plasma confinement that is predominantly regulated by microscopic turbulence.

The exploration of plasmas in a symmetric geometry related to but quite distinct from that of an axisymmetric tokamak leads to a deeper and more mature scientific understanding of toroidal magnetic confinement. The operation of new, large international stellarator facilities in the ITER era demonstrates the perceived importance of stellarator benefits to fusion research, but the exploration of quasi-symmetry, even at a overall scale of performance below that of the foreign devices, is a unique hallmark of US-led science in this proposed facility. If the pursuit of quasi-symmetric stellarators bears out its scientific promise as outlined above, a plausible next step will be to explore truly steady-state plasmas in higher performance stellarators.

Facility's connection to FES planning documentation

The critical need to eliminate major disruptions in toroidal plasmas has been repeatedly cited in fusion community planning documents, including the *Priorities, Gaps, and Opportunities* report of 2007 and the ReNeW report of 2009. More recently, the 2012 FESAC report , *Materials Science and Technology Research Opportunities Now and in the ITER Era*, states "(a)lthough present tokamaks, and ITER, are designed to accommodate disruptions through structural engineering without significant damage, [projected next-step devices in fusion research] cannot likely accommodate this due its impact on the power extraction and tritium breeding requirements. Aggressive elimination or amelioration of disruptions in the present US tokamaks is a high priority." The 2013 FESAC report, *Priorities of the Magnetic Fusion Energy Program*, cites the specific science thrust from ReNeW to "optimize steady-state, disruption-free toroidal confinement using 3-D magnetic shaping emphasizing quasi-symmetric principles" as one of the highest priorities of the US fusion program, and specifically recommends the design and construction of an optimized stellarator facility during the next decade.

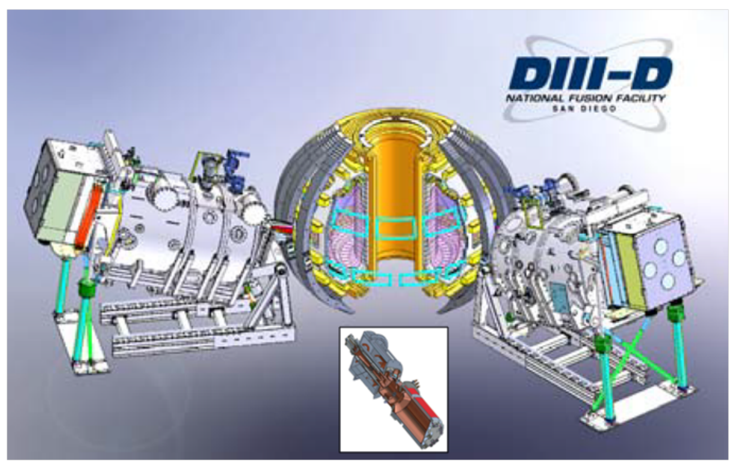
Readiness

(b) significant scientific/engineering challenges to resolve before initiating construction

Due to sustained activity in the US over the last decade, well-developed computational tools for designing optimized quasi-symmetric stellarators to address their physics targets are in place. A facility is needed to experimentally evaluate the merits of quasi-symmetric confinement, and to validate these theoretical tools for further use. Consistent with recommendations of the ReNeW report, several similarly-sized facilities with distinct types of quasi-symmetry (with different risk/benefit trade-offs) have been identified as candidates for construction. The facilities are in different states of planning and overall technical readiness, and further scientific/engineering development is needed in the aggregate. Estimated total project cost: $130M to $180M; annual operation cost $15M to $50M.

4.5 Upgrade to the DIII-D National Fusion Facility

The mission of the research program on the DIII-D National Fusion Facility is to establish the scientific basis for the optimization of the tokamak approach to magnetic fusion energy production. Research on the DIII-D facility provides leading contributions to fusion science by 1) providing solutions to physics and operational issues critical to the success of ITER; 2) developing the physics basis for steady-state operation required for efficient power production; 3) contributing substantially to the technical basis for a Fusion Nuclear Science Facility (FNSF); and 4) advancing fundamental understanding and predictive capability. The upgrade of the DIII-D facility will enable the U.S program to retain world leadership in these fusion science research areas by enabling access to new operational and parameter regimes.



Facility description

The DIII-D National Fusion Facility is the U.S.'s largest and most-capable magnetic fusion research experiment. Capabilities of DIII-D include a highly flexible magnetic field coil system, a broad range of auxiliary heating and current drive systems, over 50 state-of-the-art diagnostic systems to measure plasma parameters, and an advanced digital control system for feedback control of the plasma. The upgrade of the DIII-D heating, current drive, and 3D shaping systems embodied in DIII-D Upgrade will significantly expand the technical reach of the facility to maintain world-leadership in the ability to study plasma conditions prototypical of burning plasmas, to sustain high-performance plasmas for long-pulses that extrapolate to steady-state, to discover the underlying dynamics of plasma performance-limiting phenomena, and validate state-of-the-art simulations of magnetic fusion plasmas.

Enabling world-leading science
(b) important

Research at the DIII-D Upgrade facility will contribute strongly to world-leading science by providing the capability to:

- *Explore the physics of the burning plasma state* through an increase in electron cyclotron heating power to 15 MW for dominant electron heating at low injected torque, and upgrades to diagnostics.
- *Investigate the conditions required for steady-state operation* through broadened current distributions using increased off axis neutral beam power (10MW) with increased beam energy and pulse length (24MW for 6 seconds), and 15MW electron cyclotron current drive.
- *Develop the three-dimensional (3D) optimization of the tokamak concept* to improve edge stability, rotation and core mode control, through the implementation of additional perturbation coils with higher resolution in the toroidal direction, additional flexibility in the poloidal direction, and improved power supplies.
- *Resolve the disruption problem for the tokamak* through advanced stability control (3D and electron cyclotron heating upgrades), new plasma quench mitigation systems, and innovative diagnostic measurements.

The DIII-D Upgrade will provide unparalleled capability in the world program to explore and optimize core and edge plasma performance limits under constraints expected in future devices such as ITER and FNSF. The additional electron cyclotron heating and off-axis neutral beam heating and current drive in DIII-D Upgrade are expected to enable access and control of a range of current profiles with high-beta and fully non-inductive operation for FNSF and DEMO applications.

Facility's connection to FES planning documentation

The need to advance tokamak fusion science within the U.S. fusion program, support the ITER project, and establish the technical basis for a future fusion nuclear science facility or demonstration power plant has been described in the Fusion Energy Sciences Advisory Committee (FESAC) reports *Scientific Challenges, Opportunities, and Priorities for the US Fusion Energy Sciences Program* (April 2005) and *Priorities, Gaps, and Opportunities: Towards A Long-Range Strategic Plan for Magnetic Fusion Energy* (October 2007). It was further described in the report *Research Needs for Magnetic Fusion Energy* (2010), which resulted from a community exercise that culminated in a research needs workshop (ReNeW) (June 2009). The role of the DIII-D facility was mentioned extensively in these documents and addressed specifically in the FESAC report *Characteristics and Contributions of the Three Major United States Toroidal Magnetic Fusion Facilities* (August 2005). The facility upgrades embodied in DIII-D Upgrade will provide the U.S. with world-leading capabilities in 2 of 4 of the tokamak-specific ReNeW Thrusts identified as highest near-term priority research areas in the recent FESAC report *Priorities of the Magnetic Fusion Energy Science Program* (January 2013) (i.e., Thrusts 2 and 6) and will provide leading capabilities in the remaining 2 highest priority thrusts (i.e., Thrusts 9 and 10).

Readiness
(a) ready to initiate construction

Conceptual designs of each of the aforementioned upgrades have been developed, with no technical barriers to realizable implementation identified. Significant experience already exists in the construction and implementation of all of these upgrades, and previous facility improvements of the scope envisioned with these upgrades have been implemented successfully. Estimated total project cost: $70M to $150M.

Appendix A: Charge Letter

Department of Energy
Office of Science
Washington, DC 20585

Office of the Director

December 20, 2012

To: Chairs of the Office of Science Federal Advisory Committees:
Professor Roscoe C. Giles, ASCAC
Professor John C. Hemminger, BESAC
Professor Gary Stacey, BERAC
Professor Martin Greenwald, FESAC
Professor Andrew J. Lankford, HEPAP
Dr. Donald Geesaman, NSAC

From: W. F. Brinkman
Director, Office of Science

I am writing to present a new charge to each of the Office of Science Federal Advisory Committees. I would like each Advisory Committee to help us with an important task—the prioritization of proposed scientific user facilities for the Office of Science. To meet a very compressed timetable, **we will need your final report by March 22, 2013**.

This charge derives from Administration efforts to improve the efficiency, effectiveness, and accountability of government programs and requirements of the Government Performance and Results Modernization Act of 2010. In order to improve the agency's performance, and in compliance with this Act, DOE has established several Priority Goals, including the following goal for the Office of Science:

> *Goal Statement: Prioritization of scientific facilities to ensure optimal benefit from Federal investments. By September 30, 2013, formulate a 10-year prioritization of scientific facilities across the Office of Science based on (1) the ability of the facility to contribute to world-leading science, (2) the readiness of the facility for construction, and (3) an estimated construction and operations cost of the facility.*

To accomplish this goal, DOE will undertake the following steps. We will need your help with step #2, as described below.

1. *The DOE/SC Associate Directors will create a list of proposed new scientific user facilities or major upgrades to existing scientific user facilities that could contribute to world leading science in their respective programs from 2014 to*

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2024 (the timeframe covered by this goal).

This step is complete. The Associate Directors have developed material describing the nature of a number of proposed new or upgraded facilities, the scientific justification for the facility or upgrade, and the various inputs from the scientific community that provided motivation for the proposal. Additionally, the Associate Directors have provided assessments of their existing scientific user facilities to contribute to world-leading science through 2024. The Associate Directors will be in touch with their respective FACA chairs shortly to submit this material directly to you.

2. *The information developed by the DOE/SC Associate Directors will be used by the DOE/SC as the basis for engagement with the DOE/SC Federal Advisory Committees and others to seek advice and input on new or upgraded scientific user facilities necessary to position the DOE/SC at the forefront of scientific discovery. The Federal Advisory Committees will seek additional outside input as necessary. In particular, for programs that have a significant existing or potential user base outside of the DOE/SC, the Federal Advisory Committees will be encouraged to seek input from the broader scientific community and existing facility user committees.*

In order for your Advisory Committee to execute step #2, I suggest that you empanel a subcommittee to review the list of existing and proposed facilities provided to you by the program Associate Director, subtracting from or adding to the list as you feel appropriate. To address the concerns of the broad facilities user community, the subcommittees should include representatives of the broad, multi-disciplinary community that stands to benefit from these facilities, including representatives whose research is supported by other Federal agencies. In its deliberations, the subcommittees should reference relevant planning documents and decadal studies. If you wish to add facilities or upgrades, please consider only those that require a minimum investment of $100 million. More detailed instructions for the report are given below.

3. *Finally, with input from the DOE/SC Federal Advisory Committees and other stakeholders, the DOE/SC Director will prioritize the proposed new scientific user facilities and major upgrades across scientific disciplines according to his/her assessment of the scientific promise, the readiness of the facility to proceed to construction, and the cost of construction and operation. In making this prioritization, the DOE/SC Director will consider the resource needs for research support and for robust operation of existing facilities and will engage leaders of other relevant agencies and the Administration to ensure priorities are coordinated with related investments by other agencies and reflect cross-agency needs where appropriate.*

Please provide me with a short letter report that assigns each of the facilities to a category and provides a short justification for that categorization in the following two areas, but do not rank order the facilities:

1. *The ability of the facility to contribute to world-leading science in the next decade (2014 – 2024)*. Please include both existing and proposed facilities/upgrades and consider, for example, the extent to which the proposed or existing facility or upgrade would answer the most important scientific questions; whether there are other ways or other facilities that would be able to answer these questions; whether the facility would contribute to many or few areas of research and especially whether the facility will address needs of the broad community of users including those supported by other Federal agencies; whether construction of the facility will create new synergies within a field or among fields of research; and what level of demand exists within the (sometimes many) scientific communities that use the facility. **Please place each facility or upgrade in one of four categories: (a) absolutely central; (b) important; (c) lower priority; and (d) don't know enough yet.**

2. *The readiness of the facility for construction*. For proposed facilities and major upgrades, please consider, for example, whether the concept of the facility has been formally studied; the level of confidence that the technical challenges involved in building the facility can be met; the sufficiency of R&D performed to-date to assure technical feasibility of the facility; and the extent to which the cost to build and operate the facility is understood. **Please place each facility in one of three categories: (a) ready to initiate construction; (b) significant scientific/engineering challenges to resolve before initiating construction; and (c) mission and technical requirements not yet fully defined.**

Each SC program Associate Director will contact the Chair of his or her Federal Advisory Committee to discuss and coordinate the logistics of executing this charge. We realize that the six SC programs will require somewhat different approaches, in part based on recent and future community planning activities. In addition, if you would like to discuss the charge further, please feel free to contact Pat Dehmer (patricia.dehmer@science.doe.gov). Thank you for your help with this important task.

Appendix B:

FESAC Subcommittee on Future Facilities

Rich Callis (General Atomics)

Ray Fonck (University of Wisconsin-Madison)

Chuck Greenfield (General Atomics)

Chuck Kessel (Princeton Plasma Physics Laboratory)

Steve Knowlton (Auburn University)

Rick Kurtz (Pacific Northwest National Laboratory)

Mike Mauel (Columbia University)

Harry McLean (Lawrence Livermore National Laboratory)

Jon Menard (Princeton Plasma Physics Laboratory)

Juergen Rapp (Oak Ridge National Laboratory)

Don Rej (Los Alamos National Laboratory), Vice Chair

John Sarff (University of Wisconsin-Madison), Chair

Dennis Whyte (MIT)

Martin Greenwald (MIT), ex offico

Albert Opdenaker (DOE-FES), ex officio

Appendix C: Subcommittee Meeting Agendas

February 1, 2013 In-person Meeting #1, Gaithersberg, MD

7:45-8:15	Set up ReadyTalk, *etc*
8:15-9:00	Q&A with FES, Jim Van Dam and Gene Nardella
9:00-9:45	Conflict of Interest Procedures, Brian Plesser, DOE General Counsel
9:45-10:00	Break
10:00-10:30	Discussion of the charge: scope, assessment
10:30-11:30	Discussion of the four proposed facilities/upgrades from FES, anticipated white papers ("lay of the land"), connection to Rosner *et al* report
11:30-1:00	Discussion of process: approach, evaluation method, next steps, etc.

Mar ch 2-3, 2013 In-person Meeting #2, Gaithersberg, MD

Recusals to resolve direct COI (not present for discussion)

- Advanced MFE alternates -- Menard (Kessel absent)
- Fusion materials -- Rapp, Rej
- HEDLP – none (McLean, Rej present for general discussion; Chair to determine when they leave the room if specific white papers are discussed)
- Integrated PMI toroidal facility -- Menard, Whyte (Kessel absent)
- FNSF – none
- DIII-D /Upgrade -- Callis, Greenfield
- NSTX-U and Alcator CMod -- Menard, Whyte (Kessel absent)

Saturday, March 2

8:30-8:45	Discussion of agenda and plan for report preparation following the meeting
8:45-10:15	Advanced MFE alternates
10:15-10:30	Break

10:30-12:00	Materials for fusion
12:00-1:00	Working lunch
1:00-2:30	High energy density laboratory plasma research (HEDLP)
2:30-4:00	Integrated PMI toroidal facility (MFE)
4:00-4:15	Break
4:15-5:45	Fusion nuclear science (MFE)
6:30	Dinner together
Evening	Define & draft facility descriptions based on discussion (becomes outline for 1-2 pagers)

Sunday, March 3

8:30-9:00	Discussion of DIII-D and DIII-D Upgrade
9:00-9:30	Discussion of NSTX-U and Alcator C-Mod
9:30-10:00	Categorization of existing facilities for "world leading science"
10:00-10:15	Break
10:15-2:00	Review refined facility descriptions, finalizing "world leading science" and "readiness" categories

Appendix D: Call for Community White Papers

The FESAC Subcommittee formed to address the DOE Office of Science charge on proposed scientific user facilities invites community input in the form of short, directed white papers. The instructions for composing these white papers are given below. The final report for this charge must be delivered to DOE by March 22, 2013. This leaves little time for the Subcommittee to do its work and report to FESAC. Hence the **DUE DATE FOR WHITE PAPERS IS THURSDAY, FEB 14**.

Documents pertaining to this call for white papers:
(http://science.energy.gov/fes/fesac/reports/)
* The charge letter dated 12/20/2012 from Dr. Brinkman, Director, Office of Science, DOE
* Letter from Dr. Edmund Synakowski, Associate Director, Fusion Energy Sciences to Dr. Martin Greenwald, FESAC Chair
* 1-page descriptions of four facilities proposed by FES as described in Step 1 of Dr. Brinkman's letter

Instructions for white papers:
* DUE DATE: THURSDAY, FEB 14, 2013
* Recommended length of 4 pages or less (1 in margins, 12 pt font, single-spaced)
* Papers should include references to supporting material, but must be self-contained in providing the information requested below
* Email papers to John Sarff (jssarff@wisc.edu) and Don Rej (drej@lanl.gov)
* **Required contents for the white paper**:
  - Summary of the research that will be performed on the facility and how this research leads to world-leading science.
  - Description of the facility (new, upgrade, or coordinated program using multiple facilities). A graphic that would represent the facility in a 1-page description is recommended.
  - Description of the facility's impact beyond the FES mission, if relevant.
  - Context for the facility with respect to research gaps, needs, and opportunities as described in recent FES planning documents: ReNeW, Priorities-Gaps-Opportunities, MFE Priorities Subcommittee Report (available soon), etc.
  - Context of the facility relative to the world effort in fusion and plasma science research. Describe how the facility would extend beyond existing research capabilities, noting important differences in physical parameters.
  - Provide an estimate of the construction cost, annual operation cost, and schedule. Also include an estimate of the value of the existing facility for proposed upgrades. Describe the basis for these estimates.
  - Assess the readiness of the facility concept using the criteria and categories indicated in Dr. Brinkman's letter. Justify this assessment by referring to specific scientific and engineering requirements for the proposed facility.
    (a) Ready to initiate construction.
    (b) Significant scientific/engineering challenges need to be resolved before initiating construction.
    (c) Mission and technical requirements are not yet fully defined.

Appendix E: List of Community White Papers Received

Author(s)	Title or Subject
D. T. Anderson, F. S. B. Anderson, A. Bader, J. D. Callen, C. Deng, C. C. Hegna, S. T. A. Kumar, K. M. Likin, J. N. Talmadge	HELIcally Optimized Stellarator: HELIOS
D. Asner	The Project X Energy Station as a Candidate Fusion Materials Facility
N. D. Browning	National Facility for Imaging Nuclear Materials and Processes (INMaP)
R. Cauble	Jupiter II - Next-generation International User Facility for Laser-based High Energy Density Science
B. E. Chapman, A. F Almagri, J. K. Anderson, D. J. Den Hartog, J. A. Goetz, K. J. McCollam, M. D. Nornberg	Facility for Fusion Optimization and Validation (FFOV)
R. P. Drake, K. Krushelnick, R. Clarke, A. Galvanauskas, S. Yalisove, A. Thomas, C. Joshi, M. Koepke, F. Beg	Versatile Laser User Facility (VLUF)
J. C. Fernandez	High intensity Laser Laboratory: A Proposal for a Future DOE Office of Science Experimental User Facility
A. M. Garofalo, V. S. Chan, T. S. Taylor, C. P. C. Wong, M. Abdou, N. B. Morley, A. Ying, G. A. Navratil, B. J. Merrill, M. E. Sawan, G. R. Tynan, R. S. Willms	A Fusion Nuclear Science Facility (FNSF) for a Fast-Track Path to DEMO
D. A. Gates, A. Boozer, T. E. Evans, R. J. Goldston, A. Hassam, B. Lipschultz, D. A. Maurer, G. H. Neilson, R. Parker, K. Tritz, F. Volpe, H. Weitzner, G. A. Wurden, M. C. Zarnstorff	QUASi-Axisymmetric Research (QUASAR) Experiment
W. Gekelman, T. Carter, G. Morales, C. Niemann	The Basic Plasma Science Facility - Upgrade for the next decade and beyond
N. M. Ghoniem, R. Wirz, D. Goebel	Request for Upgrade of Plasma-Material Interaction Facilities at UCLA
S. H. Glenzer	FORWARD user facility proposal for High Energy Density science, (Fundamental Optical Research With Advanced x-Radiation Diagnostic)
R. J. Goldston, H. L. Berk, S. C. Hsu, T. P. Intrator, D. D. Ryutov, X. Tang, S. Zweben	Divertor Physics Experiment
D. L. Hillis, T. Biewer, J. Brooks, J. Canik, J. Caughman, R. H. Goulding, J. Lore, L. Owen, Y-K. M. Peng	Addressing PMI science and PFC technology for ITER, FNSF and DEMO with MPEX (Material Plasma Exposure eXperiment)
T. R. Jarboe, D. A. Sutherland, C. Akcay, R. Golingo, C. J. Hansen, A. C. Hossack, G. J. Marklin, K. Morgan, B. A. Nelson, R. Raman, B. S. Victor, S. You	Facilities needed for the development of economical fusion power
S. Kaye	NSTX Upgrade: The Ability of the Facility to Contribute to World-Leading Science
J. W. Kwan	Integrated Beam-High Energy Density Physics Facility (IB-HEDPF)
B. LaBombard, E. S. Marmar, J. Irby	High Power Density Advanced Divertor Test Facility - Alcator DX
E. A. Lazarus	A simpler approach to a fusion neutron source

Author(s)	Title or Subject
J. Li, R. G. Ballinger, J. Minervini, M. Short, H. Barnard	A Superconducting Cyclotron Accelerator Based Materials Test Center for Surface and Bulk Radiation Damage Studies
B. Lipschultz, R. Goldston, R. Maingi, J. Brooks, R. Doerner, A. Hassanein, I. Hutchinson, E. Marmar, S. Prager, C. Skinner, M. Zarnstorff, S. Zweben	High-Power Divertor-Tokamak Experiment (HDTX)
R. Maingi, J. P. Allain, J. N. Brooks, R. J. Goldston, A. Hassanein, M. A. Jaworski, M. Ono, S. C. Prager, D. N. Ruzic, C. H. Skinner, V. A. Soukhanovskii, M. C. Zarnstorff	NSTX-PMI: An Upgrade to NSTX-U for a PMI-Centered Mission
W. Manheimer	The Scientific Prototype
E. Marmar	Alcator C-Mod National Fusion Facility
B. J. Merrill, L. C. Cadwallader, M. Shimada, P. Humrickhouse, D. A. Buchenauer, R. Kolasinski, R. A. Causey	Critical Safety and Tritium Applied Research Facility Upgrade
D. D. Meyerhofer	Ultra-high Intensity Laser Initiative at the University of Rochester's Laboratory for Laser Energetics
N. B. Morley, M. A Abdou, A. Y. Ying, S. Smolentsev, S. Willms	Tritium Fuel Sustainability and Fusion Power Extraction Research
H. Neilson, D. Gates, R. Goldston, S. Prager, M. Zarnstorff, S. Milora, S. Zinkle, T. Taylor	Toward a Fusion Nuclear Science Facility
S. P. Obenschain, J. D. Sethian, A. J. Schmitt	Krypton Fluoride Laser Target Interaction Facility
M. Peng, J. Canik, C. Neumeyer, M. Ono, A. Redd, S. Sabbagh	ST-FNSF White Paper for FESAC Subcommittee on Facilities
K. Schoenberg, J. Shlachter	MTS White Paper to the Fusion Energy Sciences Advisory Committee, Subcommittee on Future Facilities
J. Slough, R. Milroy, B. Nelson, F. Ohuchi, U. Shumlak, R. Raman, G. Votroubek, D. Kirtley, C. Pihl	Fusion Neutron Test Facility
L. L. Snead, P. D. Ferguson, N. M. Ghoniem, J. Marian, G. R. Odette, M. W. Wendel, B. D. Wirth	Fusion Material Irradiation Test Station (FMITS) at SNS
M.R. Wade, D.N. Hill, R.J. Buttery	DIII-D National Fusion Facility
M. R. Wade, D. N. Hill, R. N. Buttery, A. G. Kellman	DIII-D National Fusion Facility Upgrade to Prepare for the Burning Plasma Era
W. B. Webb	Stringsynthesis Fusion
S. Woodruff	++ Spheromak Proof of Principle / Compact Fusion Neutron Source
G. A. Wurden, W. A. Reass, P. Turchi, J. H. Degnan, C. Grabowski, B. Bauer	The Prometheus Magneto-Inertial Fusion Research Facility
K. M. Young	Virtual Laboratory for Plasma Diagnostics, Instrumentation and Control for Advanced Fusion Devices
M. C. Zarnstorff, A. Cohen, D. A. Gates, H. Neilson, S. Prager	A Next Step Stellarator Experiment

Appendix F: Additional Guidance from FES

Department of Energy
Washington, DC 20585

January 24, 2013

Dr. Martin J. Greenwald
Plasma Science and Fusion Center
Massachusetts Institute of Technology
175 Albany Street
Cambridge, Massachusetts 02138

Dear Martin,

You recently received a letter (attached) from Dr. William F. Brinkman, Director, Office of Science (SC), transmitting a new Charge for the Fusion Energy Sciences Advisory Committee (FESAC) on the prioritization of proposed scientific user facilities for SC. Step 1 of the process associated with this new charge is that I provide a list of such facilities (attached) for consideration by FESAC and its selected subcommittee. Attached to this letter is that list.

As indicated in the Charge letter, the subcommittee may add to or subtract from this list. You will recall that in 2003, SC released the *Facilities for the Future of Science: A Twenty-Year Outloo*k. The FES program had the number one facility on the list, ITER. In 2007 a second report, *Four Years Later: An Interim Report on "Facilities for the Future of Science: A Twenty-Year Outlook",* was released and ITER was still number one on the list. Having such a position and maintaining it is a testament to the value of the community and this office working together in making such a strong scientific case for ITER.

Now we are asked to partake in another facility prioritization exercise. In order to put together the strongest and most compelling set of possible future fusion facilities and in consideration of the very tight time schedule, I'd like to articulate a number of considerations for the deliberations of both FESAC and its subcommittee. These conditions/constraints are identified below:

- As we all appreciate, ITER is unique not only in the world-leading science it is expected to accomplish, but in how it is being conducted under an international agreement with seven Members. As a consequence, SC leadership has determined that ITER is not to be considered in this exercise.
- I share your belief that the fusion community needs to be clear regarding what investments are required for fusion to succeed, and where the U.S. can make world-leading contributions. However, as the subcommittee explores ambitious options, I urge FESAC to give serious consideration to those facilities or upgrades that are at the more modest end of the budget continuum as well. This is reflected in part by the options from FES that I am forwarding to you with this letter. Also, note that you are encouraged to

take the $100M lower bound as approximate. You may consider facilities or upgrades that are below the $100M level, although the $20M level is probably too low.

- With the above bullet in mind, it is permissible to consider activities consisting of a series of upgrades that bundled together define a mission space that gives such a package an identity and a clear objective for world-leading capabilities. In addition, a collection of smaller facilities could be considered together if their collective science goals are coherent and they address a common scientific area, again with the outcome being a world-leading capability.

Finally, let me again emphasize the tightness of the schedule. A final letter report is due no later than March 22, 2013. I will be available to discuss this charge further as well as present our list to FEASC at the next meeting on January 31.

Let me convey my thanks and appreciation to John Sarff for agreeing to serve as the Chair for this subcommittee, and to Don Rej for agreeing to serve as Vice Chair in support of John.

If you have any questions please feel free to contact me.

All the best,

Edmund J. Synakowski
Associate Director of the Office of Science
for Fusion Energy Sciences
Office of Science