American Nuclear Society
Fusion Energy Division
June 2018 Newsletter

Letter from the FED Chair, Arnold Lumsdaine, Oak Ridge National Laboratory, Oak Ridge, TN.

The most significant event that the Fusion Energy Division sponsors is our biennial topical meeting on the Technology of Fusion Energy (TOFE), which is less than six months away now. The 2018 TOFE will be embedded with the ANS Winter meeting in Orlando, Florida from November 11-15. The technical program is still in development, but there are some remarkable special sessions that are planned, including:

- Privately funded fusion ventures
- Licensing and safety for advanced fission and fusion reactors
- High temperature superconductors (Transformative Capabilities)
- Advanced Materials and Manufacturing (Transformative Capabilities)
- Tritium fuel cycle control (Transformative Capabilities)
- Liquid metal plasma facing components (Transformative Capabilities).

We also plan to have a special student paper session, and a ceremony to give the FED Outstanding Achievement and Technical Accomplishment awards. The plenary program will include distinguished speakers from fusion technology programs around the world. But the most important ingredient in a successful TOFE is the participation of the members of FED. Put it on your calendars and encourage your colleagues to attend.

We welcome three new members to the FED Executive Committee:

- Jan Berry (retired, US ITER)
- Takumi Hayashi (National Institutes for Quantum and Radiological Science and Technology, Japan)
- Gregg Morgan (Savannah River National Laboratory).

We are also grateful for the members who are rotating off the Executive Committee: Ahmad Ibrahim and Takeo Muroga. Chase Taylor, who has served two years in a replacement role, will continue to serve one more year (thus completing a full three-year term) in replacement of Lauren Garrison as Lauren has been elected the Division Secretary/Treasurer.

This brings us to the biannual elections of new officers. As just mentioned, Lauren Garrison (Oak Ridge National Lab), who has served on the Executive Committee and managed the TOFE student paper competition since 2016, has been elected Secretary Treasurer. Paul Wilson (University of Wisconsin-Madison) has been elected Vice Chair. Under normal circumstances, the Vice Chair assumes the chair after a two-year term. Unfortunately, we have some unusual circumstances this year. Keith Rule, who has served as an excellent Vice Chair since 2016, has retired from Princeton Plasma Physics Lab, and is not able to move into the Chair as schedule in June 2018. In order to ensure a smooth transition for the Division, the Executive Committee voted, and I agreed, to have me serve one more year as the Chair, with Dr. Wilson then assuming the chair in June 2019. I am confident that we have some excellent people in place to bring the Division into the future.

One way that we are encouraging the next generation towards the goal of bringing fusion energy to fruition is by our sponsorship of an undergraduate scholarship. The Schultz undergraduate scholarship has been awarded to Ashley Goluoglu of the University of Florida. Hearty congratulations, Ashley.

One last piece of news. Our illustrious newsletter editor, Prof. Laila El-Guebaly (University of Wisconsin-Madison), has decided to put up the keyboard and retire from that role. She has been the driving force behind the newsletter for decades, in addition to the myriad technical contributions that she has made to ANS FED and to the international fusion technology community. She has done this so long and so well that it is difficult to imagine what FED and the TOFE meetings would look like without her ideas and energy working behind the scenes. All of us should be grateful for her efforts, and I want to take the small (and certainly inadequate) platform that I have here to express our gratitude. Thank you, Laila!

I hope to see many of you at TOFE in November.

New ANS "Fusion" Fellow 2018. Susana Reyes, Lawrence Berkeley National Laboratory, Berkeley, CA.

The ANS Grade of Fellow in an honorific membership grade conferred only on ANS members for outstanding accomplishment in any one of the areas of nuclear science and engineering. It is the Society's highest membership grade, to which a select group of your professional associates have been elected. Selection comes as a result of nomination by peers, careful review by the Honors and Awards Committee, and election by the Society's Board of Directors. The list of current fellows, nomination steps, guidelines, and nomination forms can be found at: http://www.ans.org/honors/va-fellow/

It is a pleasure to report that we have a new ANS "Fusion" Fellow added to the honors rank: Prof. **James P. Blanchard** (University of Wisconsin-Madison). Prof. Blanchard's election to the rank of Fellow recognizes his contributions to the advancement of nuclear science and technology through the years.

Congratulations for such a great honor!

List of Officers and Executive Committee Members, Susana Reyes, Lawrence Berkeley National Laboratory, Berkeley, CA.

The FED election was held in the spring of 2018. Paul Wilson (Univ. Wisconsin-Madison) will be incoming vice-Chair/Chair-elect and Lauren Garrison (ORNL) will serve as Secretary-Treasurer. Jeanette (Jan) Berry (currently retired, formerly US-ITER), Greg Morgan (SRNL), and Takumi Hayashi (QST, Japan) were elected to the Executive Committee. Congratulations to all!

We thank the outgoing Executive Committee members, Ahmad Ibrahim (ORNL) and Takeo Muroga (NIFS), for their excellent service to the Division.

FED Officers:

Arnold Lumsdaine (ORNL) Chair (16-19)
Paul Wilson (Univ. of Wisconsin-Madison) Vice-Chair/Chair-elect (18-19)
Lauren Garrison (ORNL) Secretary/Treasurer (18-20)

Executive Committee:

Nicole Allen (PPPL) (16-19)
Jeanette (Jan) Berry (currently retired, formerly US-ITER) (18-21)
David Donovan (Univ. Tennessee-Knoxville) (17-20)
Takumi Hayashi (QST, Japan) (18-21)
Greg Morgan (SRNL) (18-21)
Arkady Serikov (KIT, Germany) (17-20)
Gregory C. Staack (SRNL) (17-20)
Chase Taylor (INL) (16-19)
Leigh Winfrey (Penn State University) (16-19)

Past Chair:

Susana Reyes (LBNL) (17-19)

FED Standing Committee Chairs:

Nominating: Susana Reyes (LBNL) – Chair
Honors and Awards: Susana Reyes (LBNL) – Chair
Program Committee: Paul Wilson (Univ. of Wisconsin-Madison) – Chair

FED Representatives on National Committees:

ANS Publications: Leigh Winfrey (Penn State University)
ANS Public Policy: Susana Reyes (LBNL)
ANS Program Committee: Paul Wilson (Univ. of Wisconsin-Madison)

Editors:

Newsletter: Robert Duckworth (ORNL)
Fusion Science and Technology Journal: Leigh Winfrey (Penn State University).

FED Treasurer's Report, Kelsey Tresemer, Sandia National Laboratories, Livermore, CA.

The Fusion Energy Division continues to experience steady growth, both financially and in regards to membership. For the fourth year in a row, member numbers have grown, totaling 1041 FED members as of December 2017. This steady increase also marks the FED crossing a new milestone: we now comprise 10.1% of all ANS Division membership. Congratulations!

Financial statements are strong at $24,885.18 as of 3/31/18, though we are slightly behind in membership dues, so if you haven't renewed this year, please do so at your earliest convenience.

We are happy to report that, in light of the successful launch of the Schultz Scholarship which had been the savings goal for the FED for several years, plus two very successful conferences which created strong revenue (2016 Tritium and 2016 TOFE), last year the Executive Committee voted in favor of increasing overall student support from $1700 to $2400 which goes to fund students' travel to conferences and other technical awards. The Committee also voted in favor of increases to the award amounts for our biennial Outstanding Achievement and Technical Accomplishment awards which are now $2500 and $1500, respectively. These awards are given at the TOFE meetings every two years and we hope the new awardees enjoy these changes.

Though these increases do place a greater burden on our budget, our low overall expenses, plus our recent growth and excellent meeting revenue allow us to enjoy supporting future fusion scientists and honoring the tireless efforts of our peers.

Lastly, please join me in welcoming Lauren Garrison as the incumbent FED Executive Committee Secretary and Treasurer! It has been my pleasure to serve the Executive Committee these last six year and I look forward to watching its continued success.

2018 ANS-FED Awards – Reminder for Nominations Deadline, Susana Reyes, Lawrence Berkeley National Laboratory, Berkeley, CA.

The Honors and Awards Committee of Fusion Energy Division of American Nuclear Society [ANS-FED] is seeking nominations for two ANS-FED Awards:

- Outstanding Achievement Award: This award is for recognition of a continued history of exemplary individual achievement requiring professional excellence and leadership of a high caliber in the fusion science, and engineering area.
- Technical Accomplishment Award: This award is for recognition of a specific exemplary individual technical accomplishment requiring professional excellence and leadership of a high caliber in the fusion science and engineering area.

Detailed descriptions of the awards (purpose, criteria, and procedure) and past recipients can be found at http://fed.ans.org/awards

Note that the nominees will only be considered for the particular award for which they are nominated. The nomination deadline has been extended to **July 1, 2018**. The awards will be presented at the 23rd ANS Topical Meeting on the Technology of Fusion Energy (23rd TOFE), which will be embedded in the ANS annual meeting in Orlando, FL, November 11-15, 2018.

Nomination package must include:

1. The nomination letter including a description of the exemplary achievements and the recommended citation to appear on the award plaque.
2. Additional letters supporting the nomination (a minimum of three and a maximum of five, including the nominator letter).
3. Nominee's CV and publication list.

Incomplete submissions will not be considered. Please send complete nomination packages electronically to:

Susana Reyes
ANS-FED Honors & Awards Chair
sreyes@lbl.gov

Nominators of 2016 nominees are encouraged to update their nomination packages and re-submit electronically.

An Outstanding Student paper award will also be given at the 23rd TOFE meeting through a separate process. Details of the Outstanding Student paper award will be forthcoming in conjunction with the meeting announcement.

News from *Fusion Science and Technology* Journal, Leigh Winfrey, FS&T Editor, Penn State University, State College, PA.

Statistical Summary

The following is a summary of paper statistics and editorial activities for *Fusion Science and Technology* (FS&T).

During the period January 1, 2017, to December 31, 2017, FS&T received a total of 130 manuscripts. During the period of January 1, 2018 to May 15, 2018, FS&T received 37 manuscripts.

Of the 130 manuscripts received in 2017, 63 were from North America, 14 from Europe (including Russia), 46 from Asia, and 7 from Others, with the following breakdown: 93 were accepted, 31 were withdrawn/rejected, and 6 are under review/revision. Of the 37 manuscripts received in 2018, 12 were from North America, 6 from Europe (including Russia), 18 from Asia, and 1 from Others, with the following breakdown: 5 were accepted, 6 were withdrawn/rejected, and 26 are under review/revision.

The following dedicated issues were published during the period 1/1/17 to 5/15/18:

- APS Special Issue on Plasma Material Interactions – FS&T (Jan 2017)
- Selected papers from Tritium 2016 – FS&T (Apr. & May 2017)
- Selected papers from TOFE2016 – FS&T (Sep. & Oct. 2017)
- Selected papers from the 22nd Target Fabrication Meeting (Mar. & Apr. 2018).

The following issues are scheduled/planned for late 2018, 2019, and beyond

- Selected papers from the 2nd IAEA Technical Meeting on Fusion Data Processing (July & Aug. 2018)
- Special issue on Fusion Neutronics (Early 2019)
- Selected papers from TOFE2018 – FS&T (Mid 2019)
- Special issue on New Concepts in Fusion and Enabling Technologies (Early/Mid 2019).

New for 2018

I am honored to have been chosen to take over as editor of FS&T from Dr. Nermin Uckan, who served the journal with passion and dedication for 17 years. Her leadership has made FS&T the journal that it is today. As I begin my tenure, I am excited for the opportunity to secure and expand that legacy and take forward the journal's mission of sharing research in fusion plasma physics, plasma engineering, and fusion nuclear. My goal as editor of FS&T is not only for the journal to remain the leading source of information on fusion technology, science, and its development, but to stimulate discussion and to highlight research on how we move fusion research forward to the next stage of basic science research and device engineering.

Call for Papers

Fusion Science and Technology is the journal of the ANS Fusion Energy Division—it belongs to us and needs us to thrive. I highly encourage all engineers, technologists, academics, and scientists working in fusion research to submit to **your** journal. With several improvements in recent years—including a new publishing partner, rising impact factor, speedy online publication, and the availability of open access publication—FS&T is a vibrant platform for fusion research. I welcome your contributions to our prestigious journal. See these websites for calls for new special issues, author information, and submission instructions:

http://www.ans.org/pubs/journals/fst/
https://www.tandfonline.com/toc/ufst20/current
http://www.ans.org/pubs/journals/fst/authors/
http://www.editorialmanager.com/fst/default.aspx.

Fusion Award Recipients, Laila El-Guebaly, Fusion Technology Institute, University of Wisconsin-Madison, Madison, WI.

Fusion awards have been established to formally recognize outstanding contributions to fusion development made by members of the fusion community. The following awards (listed in alphabetical order) were available to the newsletter editor at the time of publishing this newsletter. We encourage all members of the fusion community to submit information on future honorees to the editor to be included in future issues. The ANS-FED officers and executive committee members congratulate the honored recipients of the 2017-2018 fusion awards on this well-deserved recognition and our kudos to all of them.

ANS Arthur Holly Compton Award

The American Nuclear Society has awarded the 2018 Arthur Holly Compton Award to Prof. **Paul Wilson** (University of Wisconsin-Madison) in recognition of his outstanding contributions to education. The citation reads: For his unparalleled contributions to nuclear engineering computing education through innovating locally, volunteering nationally, and advising a next generation of computational nuclear engineering educators.

IEEE Fusion Technology Award

Larry Baylor (Oak Ridge National Laboratory) has received the 2018 Fusion Technology Award from the IEEE's Nuclear and Plasma Science Society (NPSS). The NPSS Standing Committee recognized **Baylor** for his "research and leadership in the field of plasma fueling strategies for magnetically confined plasmas," and specifically honored his work designing the fueling, pumping and disruption mitigation system for the US ITER Project.

Nuclear Fusion Award

The winner of the 2017 award is **F. Ryter** (IPP, Germany) for the paper Experimental evidence for the key role of the ion heat channel in the physics of the L-H transition.

ONGOING FUSION RESEARCH

Worldwide Timelines for Fusion Energy, Laila El-Guebaly, Fusion Technology Institute, University of Wisconsin-Madison, Madison, WI.

The development of practical fusion power systems takes decades to bring fusion from the current conceptual design phase to market penetration. Since the beginning of fusion development in the 1950s, nations with strong fusion programs have been developing long-term plans and schedules with the end goal of operating fusion power plants in 50 years. So far, this has been a sliding scale vision and it is still uncertain when exactly fusion will contribute to the commercial energy mix, perhaps in a few decades if the social and political climate creates a demand for fusion energy maintained with strong governmental support, realistic funding, and international collaboration between the U.S., Europe, Japan, Korea, China, and India.

How the proposed U.S. roadmaps fit into the larger international picture? This brief report outlines the projected worldwide roadmaps to fusion energy for the U.S., Europe, Japan, Korea, China, and Russia. Even though numerous worldwide roadmaps and plans have been developed in recent decades [1-9], the schedule for placing a fusion power plant on the grid is still evolving and many countries revised their previous roadmaps primarily because of the delay in ITER.

There is a wide agreement between the international fusion communities that a demonstration (DEMO) plant is the last step necessary to reduce the technical and programmatic risk associated with the first commercial power plant. Beyond ITER, multiple small-scale facilities and significant fusion technologies remain to be developed to bridge the large gap between existing fusion experiments and DEMO operation. In the U.S., design teams proposed the two-machine pathway, shown in Fig. 1, where the first machine would be a Fusion Nuclear Science Facility (FNSF) (based on tokamak (US-I pathway) [10], spherical tokamak (US-II pathway) [11], or stellarator [12]) followed by a DEMO which is envisioned to be identical in content (i.e., same confinement concept, materials and technologies), but varying in performance level (such as fusion power and availability). In this approach, more advanced physics and technical stepping-stones remain to be developed and validated before building a DEMO that should mimic advanced U.S. power plants designed by the ARIES and PPPL teams. Just recently, a group of researchers suggested proceeding *now* toward DEMO using present physics and technology to achieve fusion energy in the next several decades (US-III pathway), hoping the U.S. energy market will accelerate the development of fusion in the near future with a substantial increase in funding and governmental support.

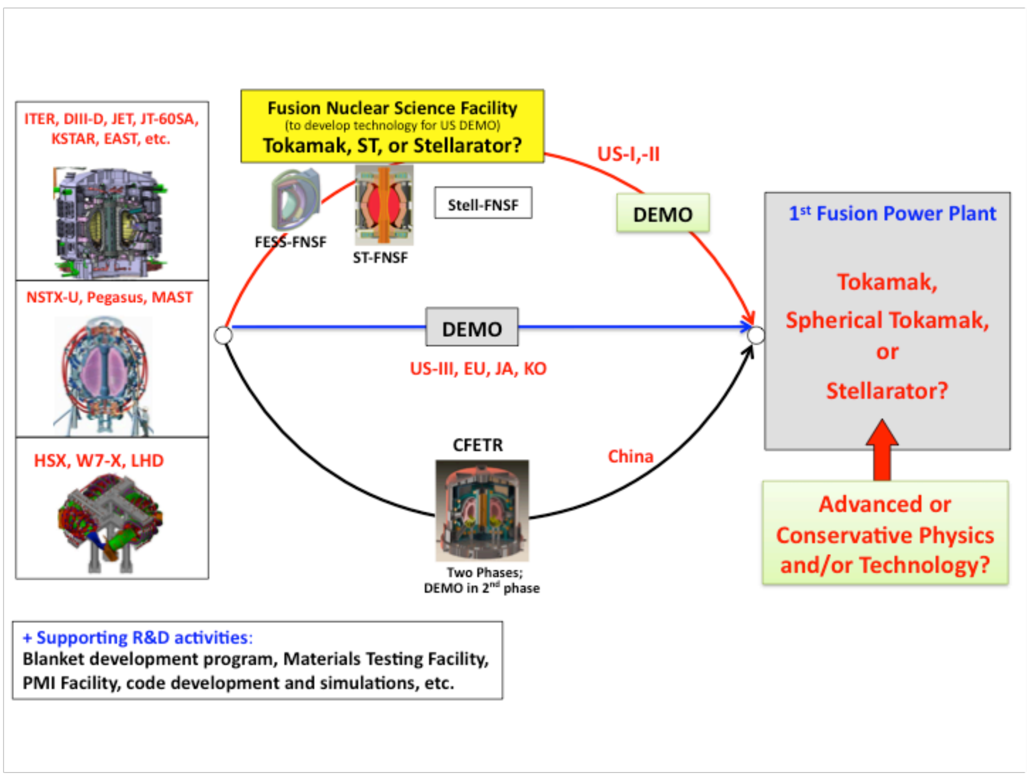

Figure 1. Worldwide pathways from experimental facilities to first fusion power plants.

Figure 2 displays the current projection of the timelines for DEMO and first commercial power plant that might be built in the U.S. and other countries whose fusion programs are explicitly energy-oriented. Note that these timelines adopt different approaches, depending on the level of risk (two-step approach or single DEMO machine), the degree of assumed technology readiness, the extent of physics and technology extrapolation beyond ITER (near-term or more advanced physics and technology for DEMO/power plants), and the desired economic competitiveness of power plants [13]. As Figure 2 illustrates, most countries projected operating DEMOs in 30-40 years, targeting power production from DEMO in the 2045-2055 timeframe:

- See the article below by F. Federici for the European roadmap. The EU DEMO is in a pre-conceptual design phase. Major decisions will be made during the 2020s, followed by detailed DEMO design, hoping the 2035-2045 ITER D-T phase will confirm these decisions. The EU DEMO could operate around 2050.
- See the article below by K. Tobita for the Japanese DEMO. Because of delays in ITER, it seems risky for Japan to define the fusion schedule beyond 2035. Nevertheless, Japan is currently defining the timetable for the essential R&D activities needed before building the DEMO. The fusion energy will be ready in Japan for commercialization in the middle of this century.
- Korea suggests a scenario for a multi-phase operation [5], where Phase-I starting in 2042 would have an FNSF-type mission and the following Phase-II would rebuild the facility to be a true DEMO by replacing all in-vessel components [14] to produce a net electric power of 600 MW in the early 2050s. The first-of-a-kind power plant will start operating in 2060.
- The China Fusion Engineering Test Reactor (CFETR) is the next device in the roadmap for the realization of fusion energy in China [9]. The machine will operate in two phases: Phase-I with steady-state operation of CFETR with modest 200 MW of fusion power; Phase-II aims at DEMO validation with a fusion power over 1 GW. The CFETR components of Phase-I will be upgraded and rebuilt to a larger size device for the DEMO of Phase-II.
- Per M. Popov (Kurchatov Institute), Russia is currently preparing the long-range National Program for the Plasma and Controlled Thermonuclear Fusion Research. The formation of the National Program will be accomplished in the future.

The pressing questions are: What are the necessary steps to move the roadmap to a higher level of confidence on the performance toward the end goal of a fusion power plant? Are the ambitious plans consistent with the current status and rate of progress in fusion R&D? Is there convincing evidence of governmental commitment and spending at the levels necessary to dramatically accelerate progress in closing the large gaps in materials, technology, and magnetic confinement science?

Aside from the schedule and prominent strategic approach, all countries should invest upfront in R&D programs that could lead to more attractive DEMO/power plant, possibly through higher magnetic field (from high-temperature superconducting magnets), some advances in divertors and plasma confinement, higher temperature blankets and ODS structural alloys, and advanced manufacturing techniques (such as additive manufacturing and nano-fabrication) [15], otherwise the end-product will be too large and expensive.

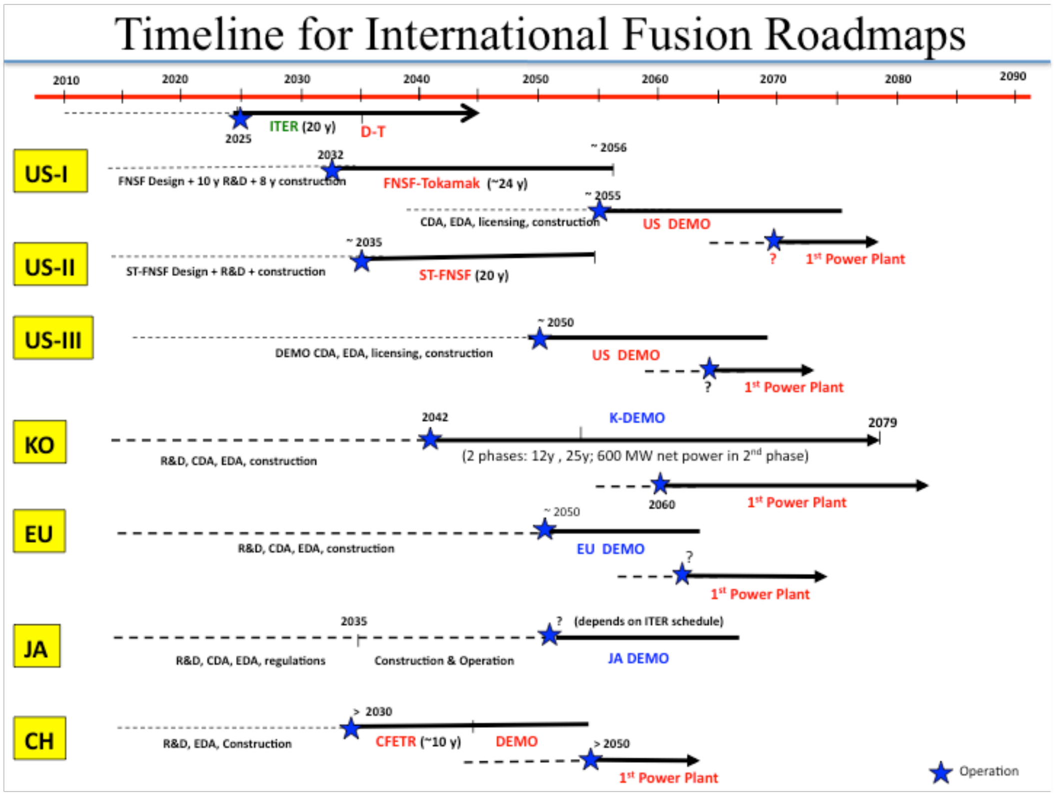

Figure 2. Projection of DEMO and first power plant operation.

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Progress and Updates on DEMO Design Activities in Europe, Gianfranco Federici, EUROfusion Consortium, Garching, Germany.

Introduction

As part of the Roadmap to Fusion Electricity, Europe is conducting in the EUROfusion Consortium, a pre-conceptual design study of a DEMOnstration (DEMO) Fusion Power Plant to come in operation around the middle of this century, aiming to demonstrate (i) the production of few hundred MWs of net electricity and (ii) the feasibility of operation with a closed-tritium fuel cycle [1,2]. ITER is a key facility in the EU strategy and the EU DEMO design and R&D are expected to benefit largely from the experience gained in the design, construction and operation of ITER. Nevertheless, there are outstanding physics, materials and engineering challenges, with potentially large gaps beyond ITER that need to be timely overcome. This paper briefly describes the progress and updates on DEMO design activities in Europe. More details can be found elsewhere (e.g., see [3] and reference therein).
The organizational arrangement under which the DEMO design work is carried out in EUROfusion is rather unconventional and different from what is done in other projects. The plant engineering and design/physics integration are coordinated centrally, whereas the design and R&D of individual systems is executed in geographically-distributed work packages (WPs) that are projects in their own. The necessary horizontal integration between various WPs is insured by the project leaders and the central team. Because of the limitation of space, we invite the interested readers to consult the following references

for the specific WPs: breeding blanket - WPBB [4]; balance of plant – WPBOP [5]; diagnostics and control – WPDC [6]; divertor - WPDIV [7]; heating and current drive – WPHCD [8]; magnets – WPMAG [9]; materials – WPMAT [10]; remote maintenance – WPRM [10]; tritium fuelling and vacuum – WPTFV [12]; safety and environment – WPSAE [13]; early neutron source – WPENS [14].

Programmatic and Timeline Considerations

At present, the DEMO design has not been formally selected and detailed operational requirements are not yet available. However, the DEMO plant high-level requirements have been defined following interaction with an external stakeholder group composed of experts from industry, utilities, grids, safety, licensing, etc. The design should be capable of producing electricity (up to ~500 MWe), operating with a closed fuel-cycle and to be a facilitating machine between ITER and a commercial Fusion Power Plant (FPP). The approach advocated by the EU fusion roadmap, is to consider in the early design phase a plant concept that would allow fast deployment of fusion energy. It is argued that by delaying the design of DEMO in anticipation of the ultimate advances in plasma physics and technology, one would postpone the realization of fusion indefinitely [1]. Thus, emphasis has been placed from the very beginning on the study of key design integration issues (KDIIs) that affect that whole DEMO nuclear plant architecture, arising from remote maintenance, power conversion aspects, safety, nuclear licensing, and technology feasibility. Postponing integration, assuming that it restricts innovation and inhibits an attractive DEMO plant, risks designers being oblivious to integration issues and developing design solutions that cannot be integrated in practice. Such work is essential to develop an understanding of the importance and relative difficulties of various design integration and technological problems to be solved in a DEMO Plant and provides the clear context for further design improvements and future R&D. Contacts were also made with Gen IV fission and ITER to learn from their experience. Some of the key outcomes are that (i) fusion is a nuclear technology and as such, will be assessed with full nuclear scrutiny by a nuclear regulator; (ii) there is a need for a traceable design process with a rigorous Systems Engineering approach; (iii) the technical solutions should be based on maintaining proven design features to minimize technological risks and have sufficient design margins; and (iv) safety, reliability, maintainability should be key design drivers [15].

The assumption underpinning the EU Roadmap is that ITER will broadly perform as expected and this allows a degree of concurrency between ITER exploitation and the development of a low-extrapolation baseline DEMO design. The current DEMO development plan consists of the following three phases: *(i)* a Pre-Concept Design Phase to explore a number of DEMO plant concepts and develop system requirements up to 2020 *(ii)* a Concept Design Phase to mature and validate the baseline concept up to 2027; and *(iii)* an Engineering Design Phase beginning roughly around 2030 to develop the detailed design and prepare for the launch of major procurement activities around 2040's, after ITER nuclear operation has confirmed the robustness of the underlying assumptions. Figure 1 provides an overview of the analysis of dependencies identified between the revised DEMO and ITER schedules. From this figure it can be understood that DEMO design validation from ITER should not be seen as a single discrete event, but rather ongoing and progressive flow of information into the program – allowing continuous validation of specific aspects of the DEMO design, and if necessary, updates to the baseline.

Design Choices Under Considerations

Currently, work continues to be focused on the design of a pulsed baseline DEMO plant concept (see Fig. 1) that integrates all the major DEMO sub-systems to understand integration risks and resolve design interface issues (see Table 1) [3]. Considerations are also given to a design based on the later-stage ITER Scenario (i.e., Q = 5, I_p=9 MA) [16] and able to operate in a short pulse mode (e.g., 1 hr) for nominal extrapolated performance (H98=1.0) and capable of moving to steady-state operation while maintaining the same fusion power and net electrical production in the case of a better confinement being feasible (see Fig. 1 (iii). However, this option requires a much higher confidence in physics extrapolation and highly reliable and efficient current-drive and control systems, which need to be deployed by day-1 and still need to be developed. The definition and analysis of the physics scenarios for the concept design and identification of the physics basis development needs are described elsewhere [17].

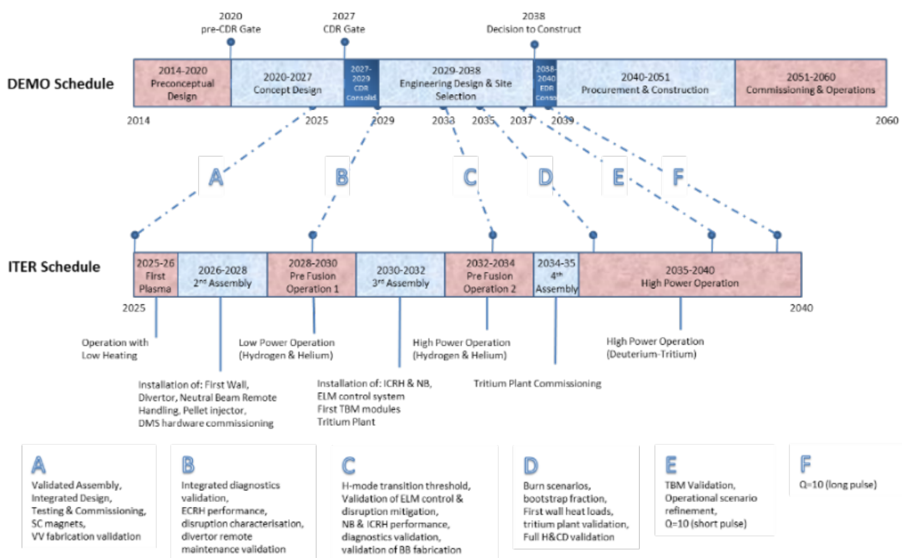


Figure 1 - Overview of phasing and key technical inputs from ITER DEMO Schedule.

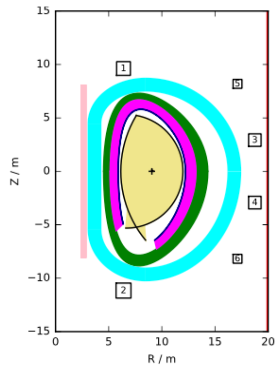
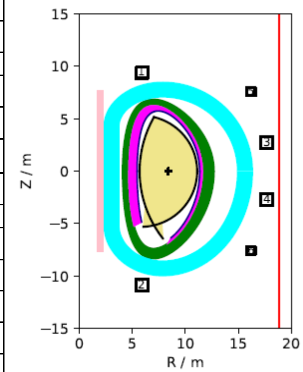
The additional design features incorporated in the present design are listed in Table 2. Example of KDIIs that are being investigated in the pre-concept design phase are shown in Table 3. They have been selected because they have a strong impact on plant and tokamak design, safety, maintainability and licensing and a number of design variants are being considered as potential foreseeable solutions. Gate Reviews are planned in 2020 to effectively assess Design Maturity/ System Design Readiness help evaluate and down-select among multiple design options.

Trade-off Studies and Sensitivity Analyses

Studies are in progress to substantiate the design especially for aspect that strongly affect machine performance and plant architecture (see for example [3] and references therein). These include, for example:

- Sensitivity studies to determine impact of uncertainties of key physics assumptions that affect plasma performance [18]. It should be noted that there are still large uncertainties in some of the physics assumptions, even for relatively well-established plasma operating conditions, and this is an important factor for the selection of the technical features of the device.
- Trade-off studies to understand the impact on varying some design parameters on plasma performance, integration, remote maintenance, etc. Most notably this has been done for the aspect ratio, the reduction of the thickness of the outboard breeding blanket, the number of TF coils, the impact of a double null divertor on the TBR, etc.
- Initial safety accident analyses focusing on loss of coolant/loss of flow events that revealed the need for a large duct size leading to a pressure suppression system to keep the vacuum vessel pressure within its design limit for the more extreme events. A provisional study of the potentially largest contributors to occupational radiation exposure is also in progress, with the aim of influencing design choices to minimize potential doses. All these topics, together with others, are chosen to address a full range of safety issues, and to ensure that safety is fully taken into consideration in the conceptual DEMO design.
- Preliminary assessments of radioactive waste, focused on the influence of design options on the quantity and classification of waste [19]. R&D has been launched on techniques for detritiation of solid waste, and on the feasibility of recycling, together with industrial partners.
- Extensive neutronic analysis to confirm the ability of the adopted design solutions to achieve adequate TBR, shielding and activation levels.
- Preliminary studies to integrate auxiliary systems such as H&CD (EC, NBI, IC), fueling and diagnostics systems. Aspects being analyzed include: the opening in the breeding blankets and the impact on the breeding blanket segment design, remote maintainability, neutronics impact on the systems themselves and on other systems (e.g. shielding of the TF coils), safety.
- Assessment of the plasma vertical stability and impact of thermal transients on the first wall.
- A first DEMO plant layout study has been performed in collaboration with AREVA GmbH to define the DEMO tokamak building layout for the two options of using either water or helium to remove the heat from the breeding blanket (see Fig. 2 (ii) and [20]). This preliminary layout serves to identify system integration issues, and to develop a technically feasible, operable, and a maintainable and safe plant design. It enables the identification of areas in which there are significant technical uncertainties, and to provide a clear basis for safety and cost analysis and further improvements.

Table 1. DEMO design options under study

DEMO1		**Parameters**	**Flexi-DEMO**		
			$lop_{(ind)}$ (a)	$hop_{(ss)}$ (b)	
	9, 2.9	R_0, a (m, m)	8.4, 2.71	8.4, 2.71	
	3.1	A	3.1	3.1	
	5.9	B_T(T)	5.8	5.8	
	18, 3.6	I_p (MA), q	16.63, 4	14.17, 4.7	
	1.6, 0.33	k_{95} / δ_{95}	1.69, 0.33	1.69, 0.33	
	12.6	$\langle T_e \rangle$ (keV)	12.1	15.1	
	0.73	$\langle n_{e,vol} \rangle$ ($10^{20}m^{-3}$)	0.88	0.75	
	2.2	Z_{eff}	2.23	2.86	
	1.1	H	1.13	1.48	
	2	t_{bum} (hrs)	1	St. State	
	39	f_{bs} (%)	47	66	
	<10	P^*_{CD} (MW)	>100	>100	
	161	P_{div} (MW)	165	194	
	120	P_{LH} (MW)	123	109	
	2014/500	P_{fus} / $P_{e,net}$ (MW)	2000/395	2000/399	
	1.0	Av_{NWL}(MW/m^2)	1.15	1.15	

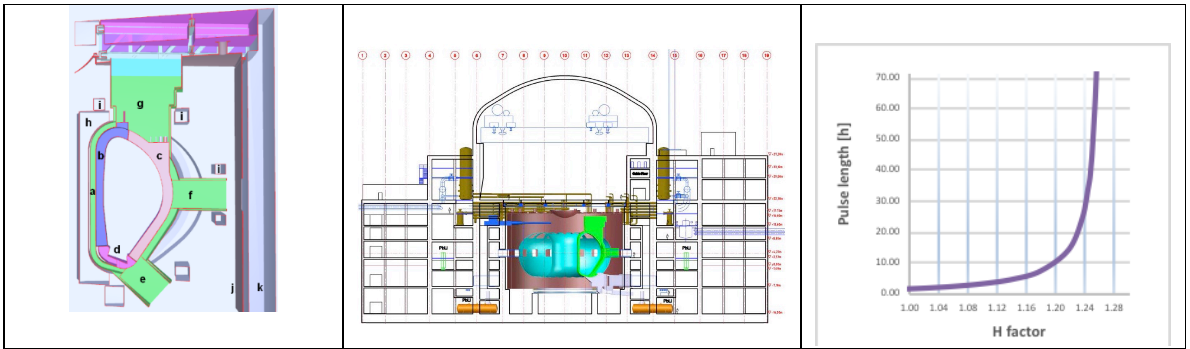
(a) Low operating point (lop), H = 1 and 1 hr discharge
(b) High operating point (hop), H = 1.25 and steady state operation
* refers only to the plasma current drive, and not to the MHD instability control.

Table 2. Preliminary design features

– Single-null water cooled divertor; PFC armour: W
– LTSC magnets Nb3Sn (grading)
– B_{max} conductor ~12 T
– EUROFER as blanket structure and AISI 316 for VV
– Maintenance: Blanket vertical RH / divertor cassettes
– Lifetime: starter blanket: 20 dpa (200 appm He); 2^{nd} blanket 50 dpa; divertor: 5 dpa (Cu)

Table 3. Example of key design integration issues where a decision is expected early in the conceptual-design phase

- Wall protection limiters to withstand plasma transients
- Integrated design of breeding blanket and ancillary systems and impact on plant design
- Engineering and Integration design risks arising from advanced magnetic divertor configurations
- Breeding blanket vertical segment-based architecture
- Power Conversion System Options, i.e. direct or indirect
- Integrated design of tokamak building concepts incl. ex-vessel maintenance
- Pumping concepts based on tritium direct recirculation
- Development of a reliable plasma-operating scenario including supporting systems (e.g., Heating and Current Drive (HCD) and plasma diagnostics/control systems.



(i)	(ii)	(iii)

Fig. 2: (i) Tokamak elevation build: a) vacuum-vessel; breeding blanket (inboard); c) breeding blanket (outboard); d) divertor; e) lower port; f (equatorial port; g) upper port; h) toroidal field coils; i) poloidal field coils; j) cryostat; k) bioshield; (ii) DEMO tokamak building complex; and (iii) Pulse length as a function of the H factor for the alternative scenario Flexi-DEMO.

Summary

Although, there are still differences of opinions around the world on how to bridge the gaps between ITER and a fusion power plant, there are outstanding issues common to any next major facility after ITER, whether a component test facility, a Pilot Plant, a DEMO, or else. These include the need to develop foreseeable sound technical solutions for the problems of power exhaust, T-breeding, cooling and extraction of heat from breeding blanket, remote maintenance for the in-vessel components, robust magnet designs, qualified structural and PFC materials, nuclear safety, etc. The European strategy foresees a DEMO Power Plant to follow ITER to be built in order to operate around the middle of this century. A staged-design approach is proposed, based on (i) developing and evaluating system designs in the context of the wider integrated plant design; (ii) targeted technology R&D and system design studies that are driven by the requirements of the DEMO plant concept and respond to critical design feasibility and integration risks; (iii) evaluation of multiple design options and parallel investigations for systems and/or technologies with high technical risk or novelty (e.g., the choice of breeding blanket technology and coolant, power exhaust solution and configuration, power conversion systems, etc.). It should be noted that this approach represents an important change in the EU fusion laboratory culture and that involvement of industry and exploitation of international collaborations on a number of critical areas is desirable. In particular, incorporating lessons learned from the ITER design and construction, building of relationships with industry and embedding industry experience in the design are needed to ensure early attention is given to industrial feasibility, costs, nuclear safety and licensing aspects.

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Current Status and Issues of the Conceptual Design of Japanese DEMO, Kenji Tobita, QST, Rokkasho, Aomori, Japan.

With the progress of ITER construction, Japanese fusion community came to recognize the necessity of a definite pathway to the demonstration (DEMO) of fusion power based on a common view of the community on the targets, timeline, and the division of roles for DEMO development. The DEMO development before construction is divided into three phases as follows [1]:

- Pre-Conceptual Design Phase (2015-2019)
- Conceptual Design Phase (2020 - 2024)
- Engineering Design Phase (2025 - 2035).

In order to implement DEMO design as a national project, the "Joint Special Design Team for Fusion DEMO (the Special Design Team)" was organized in 2015 and started DEMO design activities with the participation of QST, NIFS, industry, and academia working at the Rokkasho site of QST as the base of the team [2]. This is an important milestone in that the nationwide framework, working as one for DEMO development, was finally established.

Target of DEMO

Requirements for Japanese DEMO are to demonstrate (1) steady and stable electric power generation in a power plant scale, (2) reasonable availability using a remote maintenance scheme anticipated in a commercial plant, and (3) overall tritium breeding to fulfill self-sufficiency of fuel. For this purpose, Japan has been working on the conceptual design of a steady state DEMO based on water-cooled solid breeder [3, 4]. From lessons learned from previous DEMO reactor studies, such as SSTR, A-SSTR, A-SSTR2, SlimCS and Demo-CREST, the current DEMO design has conservative design parameters with the emphasis on divertor heat removal and sufficient poloidal flux supply with a central solenoid (CS) and is being designed at a major radius of 8.5 m for volt-second supply for operational flexibility especially in commissioning phase, and low fusion power (P_{fus}) of 1.5 GW for divertor heat sink design. Table 1 lists the main design parameters and the conceptual view of Japanese DEMO is depicted in Figure 1.

The near-term target is to present a big picture of DEMO by 2025, including 1) DEMO pre-conceptual design, 2) technical specs of components and facilities, 3) safety guidelines, 4) waste management scenario, 5) operational scenario, 6) mineral resources securing strategy, 7) construction cost by estimate, and 8) definition of a development plan for Engineering Design Phase (2025 - 2035).

DEMO Design Activities

Design challenges for DEMO are mainly related with high power handling for electricity generation, self-sufficient tritium production, and periodic replacement of in-vessel components damaged by neutron irradiation. All these challenges are not required for ITER, but indispensable for DEMO.

Table 1- DEMO Design parameters [5]

Major radius, R_p (m)	8.5
Aspect ratio, A	3.5
Plasma elongation, κ_{95}	1.65
Safety factor, q_{95}	4.1
Plasma current, I_p (MA)	12.3
Magnetic field on axis, B_T (T)	5.94
Fusion output, P_{fus} (GW)	1.46
Electron density, n_e (10^{20} m^{-3})	0.66
Confinement enhancement, HH_{98y2}	1.31
Normalized beta, β_N	3.4
Neutron wall load (MW/m^2)	1.0

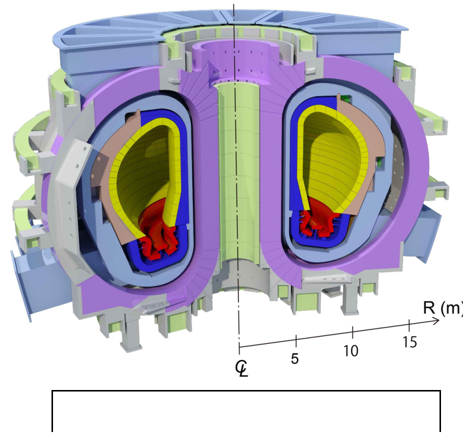

Figure 1. Conceptual view of DEMO.

Admittedly, the divertor heat removal is a critical design issue to determine the fusion output. In order to define the divertor removal strategy, Japan has been addressing comprehensive approaches based on divertor numerical simulation, heat sink design, remote maintenance and magnetic configurations, including super-x and snowflake. As a result of these design studies, the baseline divertor design assumes a single null configuration with plasma detachment and water-cooled divertor heat sink with W monoblock armor like ITER [6], albeit different materials and water condition assumed.

Breeding blanket (BB) concept is based on water-cooled solid breeder with mixed pebbles of Beryllide ($Be_{12}V$) and Lithium-Titanate (Li_2TiO_3). At present, the BB design is focused on developing a fundamental concept to satisfy the tritium self-sufficiency, considering intertwined interactions and design trade-offs with tokamak architecture, remote maintenance, plasma physics design, safety, fuel cycle, etc. In parallel with the BB design, BB-relevant materials including structural (reduced activation ferritic martensitic steel, F82H) and breeding materials have been developed partly in the framework of the Broader Approach and the US-Japan Fusion Cooperation Program. In particular, heavy neutron irradiation of F82H in HFIR plays a key role to compile an irradiated material database necessary to establish design standards and codes for DEMO.

Remote maintenance of in-vessel components is of extreme difficulty in that all in-vessel components need to be replaced with remote handling equipment in high γ-ray irradiation environment within a short period attaining an acceptable plant availability. The replacement of the in-vessel components requires remote cutting-and-rewelding and inspection of cooling pipes connected to BB modules and divertor cassettes. Satisfying all the requirements above is a great technology leap from ITER. Considering the anticipated development period for remote maintenance technology, a large-scale research and development activities must be launched shortly after the completion of the DEMO conceptual design scheduled in 2025. It must be noted that waste management strategy needs to be defined in the early stage of Conceptual Design Phase. This is because a large amount of radioactive waste is generated in every periodic replacement of in-vessel components and that one must prepare for how to deal with the waste from the beginning of DEMO operation. Within several years after removal, these removed components will be highly activated and tritiated, and also have residual heat. As a consequence, the DEMO design needs to cover the design of hot cell, waste storage and processing area for disposal based on a waste management strategy [4].

The DEMO is designed to use water cooling in pressurized water condition (290-325ºC, 15.5 MPa) to reduce the investment for development of cooling water system and power generation system on the premise that technologies and experience on these systems of light water reactors are applicable to fusion DEMO. The applicability of the existing technologies for water cooling and power generation is investigated with the cooperation of heavy industrial companies. The companies also contribute to design plant systems with an efficient use of the experience of light water reactors. Figure 2 illustrates a preliminary plant layout of DEMO although some facilities remain to be drawn. Note that the hot cell and waste-related facilities occupy a substantial area of the site because of a large amount of radioactive waste generation after every replacement.

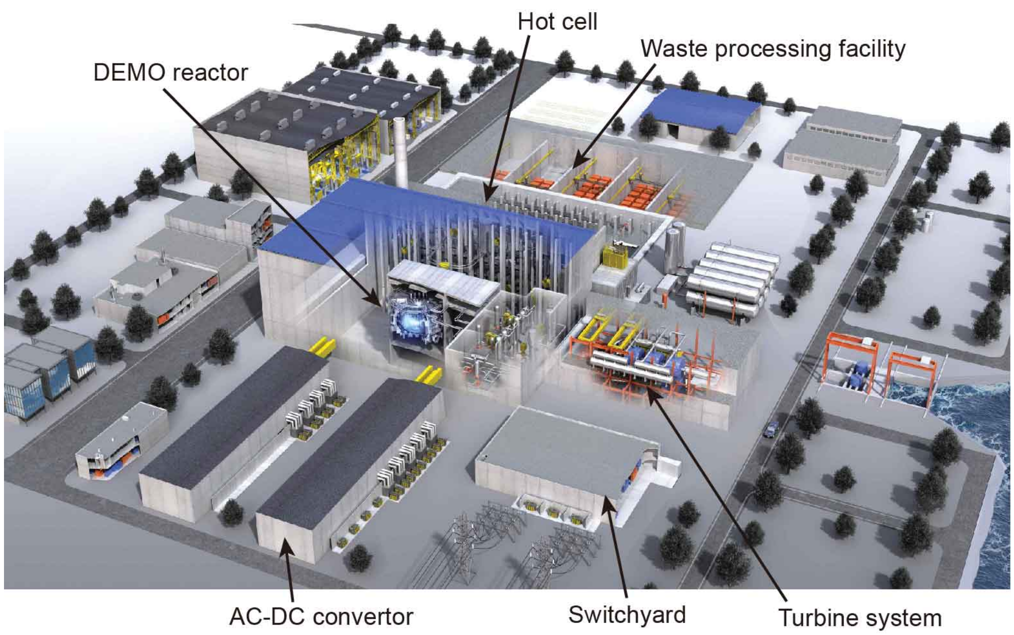

Figure 2. DEMO plant layout.

Near-term Outlook on DEMO

The Special Design Team is supposed to implement DEMO design activities along the Action Plan [7, 8] that was authorized by the Science and Technology Committee on Fusion Energy (STCFE) of MEXT and that defines the timeline of the development of technologies relevant to DEMO rather for experts in the fusion community. In 2018, the Roadmap toward DEMO will be compiled extracting the essence of the Action Plan to be comprehensive to the public and potential stakeholders.

In the middle of Pre-Conceptual and Conceptual Design Phases, i.e. around 2020, the DEMO design will be reviewed by the STCFE in light of the Action Plan. The outline of the DEMO plant concept will be integrated by 2020 in preparation for the interim review.

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CALENDAR OF UPCOMING CONFERENCES ON FUSION TECHNOLOGY*

2018:

First IAEA Workshop on Fusion Enterprises
June 13-15, 2018, Santa Fe, NW, USA
https://nucleus.iaea.org/sites/fusionportal/Pages/Fusion%20Portal.aspx

ANS Annual meeting
June 17-21, 2018, Philadelphia, PA, USA
http://www.ans.org/

23rd International Conference on Plasma-Surface Interactions in Controlled Fusion Devices (PSI 2018)
June 17-22, 2018, Princeton, NJ, USA
https://psi2018.princeton.edu

30th Symposium on Fusion Technology (SOFT)
September 16-21, 2018, Giardini Naxos, Italy
http://www.soft2018.eu

16th International Conference on Plasma Surface Engineering (PSE 2018)
September 17-21, 2018, Garmisch-Partenkirchen, Germany
https://www.pse-conferences.net/pse2018.html

6th International Conference on Nuclear and Renewable Energy Sources (NURER)
September 30-October 3, Jeju Island, Korea
http://nurer2018.org

27th IAEA Fusion Energy Conference (FEC)
October 22-27, 2018, Ahmedabad, India
Fusion-Physics@iaea.org

60th American Physical Society - Division of Plasma Physics (APS-DPP) meeting
November 5-9, 2018, Portland, OR, USA
http://www.apsdpp.org/meetings/upcoming_meetings.php

ANS 23rd Topical Meeting on the Technology of Fusion Energy (TOFE)
November 11 -15, 2018, Orlando, FL, USA
winfrey@mse.ufl.edu

ANS Winter meeting
November 11 -15, 2018, Orlando, FL, USA
http://www.ans.org/

3rd International Conference on Fusion Neutron Sources and Subcritical Fission Systems (FUNFI 3)
November 19-21, 2018, Hefei, Anhui, China
funfi@fds.org.cn

Fusion Power Associates 39th Annual Meeting and Symposium
Fusion Energy: Strategies and Expectations through the 2020s
December 4-5 in Washington, DC, USA
http://fusionpower.org

2019:

12th International Conference on Tritium Science and Technology (TRITIUM 2019)
April 22-26, 2019, Busan, S. Korea

17th International Conference on Plasma-Facing Materials and Components for Fusion Applications (PFMC-17)
May 20-24, 2019, Eindhoven, The Netherlands

ANS Annual meeting

June 9-13, 2019, Minneapolis, MN, USA

http://www.ans.org/

28th IEEE Symposium on Fusion Engineering (SOFE 2019)

June 10-13, 2019, Atlanta, GA, USA

14th International Symposium on Fusion Nuclear Technology (ISFNT)

September 22-27, 2019, Budapest, Hungary

http://isfnt-14.org/

11th Inertial Fusion Sciences and Applications (IFSA-2019)

19th International Conference on Emerging Nuclear Energy System (ICENES 2019)

October 6-9, 2019, Bali, Indonesia

http://portal.fmipa.itb.ac.id/icenes2019

61st American Physical Society - Division of Plasma Physics (APS-DPP) meeting

October 21-25, 2019, Ft. Lauderdale, FL, USA

http://www.apsdpp.org/meetings/upcoming_meetings.php

19th International Conference on Fusion Reactor Materials (ICFRM)

Oct. 27 – Nov. 1, 2019, La Jolla, CA, USA

https://icfrm-19.com

ANS Winter Meeting

November 17-21, 2019, Washington, DC, USA

http://www.ans.org/

* Calendar of other meetings (of interest to researchers in atomic, molecular and plasma-material interaction processes and data relevant to plasma physics and fusion energy research) are posted at: https://www-amdis.iaea.org/w/index.php/Calendar_of_Meetings.