Spherical Torus Coordinating Committee (STCC) Goals, Progress, and Plans – A Discussion

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PPPL
December 20, 2007
Princeton, New Jersey

DOE established a U.S. ST Coordinating Committee (STCC) with broad representation and charter

- Membership composed of leaders of major ST R&D components
  - Three ST experiments: NSTX (**Jon Menard**), Pegasus (**Aaron Sontag**), LTX (**Dick Majeski**)
  - ST R&D on diagnostics (**Fred Levinton**) and theory-modeling-simulation (**Bill Dorland**), and by universities (**Steve Sabbagh**), national laboratories (**Don Hillis**), and GA (**Rob LaHaye**)
  - Chaired by **Martin Peng**
- Purpose: enhance U.S. ST R&D in support of US FES Program
- Functions:
  - Define & clarify roles of ST in FES Program
  - Coordinate milestones, plans, and longer term goals
  - Review and report progress relative to funded R&D
  - Represent and advocate ST Program nationally, and internationally through the IEA ST Executive Committee
- Meetings and conference calls as needed
- Charter expected to evolve

STCC plunged into an assessment of critical research on NSTX for the next 3 years

- First STCC meeting held during APS meeting to clarify charter and schedule activities.
- Asked by DOE during the following week to answer:

  "What critical research should NSTX carry out during FY08-FY10 toward the scientific basis for CTF-type of facility?"
- All members participated as best possible given short notice.
  - 11/30/07: conference call
  - 12/5/07: dinner meeting in Oak Ridge, TN
  - 12/6/07: morning meeting at ORNL
- Identified large number (>40) of possible research topics.
- Applying "Measures of Criticality" to arrive at answers.
- Effort is of high interest to the U.S. ST R&D community.

Table I. NHTX and CTF plasma conditions and requirements, the underpinning topics, and U.S. ST research proposal/opportunities by STCC members:

1) **High confinement operation regimes with low collisionality with NBI-dominated heating, driven current, fueling and torque (CTF, NHTX)**:								
	NSTX	Pegasus	LTX	Th/M/S	Univ	Lab	Diag	GA
1a) electron turbulence and transport (Dorland, Menard)	√		√	√	√		√	√
1b) momentum transport (LaHaye, Menard, Sabbagh)	√		√	√	√		√	√
1c) particle transport (Dorland)	√		√	√	√		√	
1d) ion turbulence and transport (Menard, LaHaye)	√		√	√	√		√	√
2) **Rotationally stabilized MHD near and above the no-wall limit (CTF, NHTX)**:								
	NSTX	Pegasus	LTX	Th/M/S	Univ	Lab	Diag	GA
2a) error field threshold below which RWM etc. is stabilized by NBI-driven rotational (Sabbagh, Menard)	√			√	√			√
2b) understand physics of RWM stabilization in presence of error fields above this threshold (Sabbagh)	√		√		√			√
2c) active control of RWM and RFA (Sabbagh)	√				√			√
2d) Understand sources of plasma viscosity (Sabbagh)	√				√			√
2e) disruption scaling, avoidance and mitigation (Menard)	√							√
2f) NBI-driven rotational shear stabilization of NTM in ST and compare (LaHaye, Menard)	√				√		√	√
2-A) **Advanced ST physics regime (NHTX), operation above baseline, steady-state, q-profile control, AT would be beneficial to CTF performance**								
2-A-a) Near vertical stability control limit (Menard)	√	√			√			√
2-A-b) operation near ideal wall limit (Sabbagh)	√				√			√
2-A-c) q profile control for sustained stability (Menard, Sabbagh)								√

3) **Fast ion physics and instability effects (CTF, NHTX only in DD)**:								
	NSTX	Pegasus	LTX	Th/M/S	Univ	Lab	Diag	GA
3a) *AE avalanche and MHD impact on fast ion phase space distribution (Menard)	√			√	√		√	√
3b) J-NBI predictability in sustained f-BS ~ 0.5, high confinement, beta ~ no-wall plasma (Hillis, Menard)	√						√	√
4) **Pedestal, SOL and divertor physics (CTF, NHTX)**:								
	NSTX	Pegasus	LTX	Th/M/S	Univ	Lab	Diag	GA
4a) stabilization of pedestal MHD (LaHaye, Sabbagh)	√	√	√		√		√	√
4b) H-mode threshold with radiative divertor (Hillis)	√						√	√
4c) SOL micro-turbulence and power flux thickness in high confinement plasmas (Hillis),	√			√		√		√
4d) ELM mitigation approaches (pellet pacing, mid-plane coil) (LaHaye, Sabbagh)	√			√				√
4e) plasma-facing material for reduced recycling and particle control in carbon wall (Menard, Majeski)	√					√		
4d) plasma-facing material for low recycling and particle control in metal wall (Majeski, Menard)		√	√			√		
5) **Solenoid-free initiation, ramp-up (CTF), and sustainment-assist (CTF, NHTX) accounting for poloidal field and iron core induction**:								
	NSTX	Pegasus	LTX	Th/M/S	Univ	Lab	Diag	GA
5a) CHI (Sontag)	√				√			
5b) Plasma Gun (Sontag),		√						
5c) ECH/EBW (Hillis, Menard),	√	√				√		
5d) Multiple-harmonic fast wave (Menard, Hillis, Majeski)	√	√				√		
5e) NBI ramp-up (Menard)	√							√
5f) Modeling for initiation and ramp-up (Sontag, Menard)	√	√		√		√		

6) **Operational scenario integration and robustness (CTF, NHTX)**:								
	NSTX	Pegasus	LTX	Th/M/S	Univ	Lab	Diag	GA
6a) initiation (Sontag)	√	√			√			
6b) ramp-up (Menard, Hillis)	√							
6c) sustainment (Menard, Hillis)	√					√	√	√
6d) plasma control (Sabbagh)	√				√		√	√
6e) time-dependent integrated modeling (Dorland, Menard)	√					√		√
6f) shot reliability (parameter domain of operation, large margin from limits, verified modeling, which physics to validate?) (Sabbagh)	√							√
7) **Strategic predictive capability (CTF, NHTX)**: (Dorland) (consult with Bill and redo.)								
	NSTX	Pegasus	LTX	Th/M/S	Univ	Lab	Diag	GA
7a) standard model for ion turbulence and transport,				√				√
7b) standard model for electron turbulence and transport,				√				√
7c) standard model for momentum transport,				√				√
7d) standard model for particle transport				√				√
8) **Strategic, unique diagnostics (CTF, NHTX)**: (Levinton, Hillis) (what are the diagnostic capabilities and needs to support the research topics?)								
	NSTX	Pegasus	LTX	Th/M/S	Univ	Lab	Diag	GA
8a) current profiles,	√						√	√
8b) density fluctuation profiles,	√					√	√	√
8c) electron temperature fluctuation profiles,						√	√	√
8d) ion temperature profiles,	√							√
8e) magnetic field and fluctuation profiles,							√	√
8f) rotation profiles,	√							√
8g) energetic particle phase space profiles.	√						√	√

Transparent "Measures of Criticality" are needed to clarify the likely, relative values for NHTX-CTF type of facilities

Scientific Motivation:

1) **Physics Regime:** The degree in which present experimental plasma is in a similar physics regime to the anticipated NHTX and CTF regimes. In the case of diagnostics, the degree in which the proposed diagnostic scientific understanding and capability addresses the measurements needs of major research topics. (H, M, L)
2) **Science Gap:** The degree of gap or uncertainty in our scientific (and technological) understanding needed to enable adequate projections to the design of these facility options. (H, M, L)

Design Motivation:

3) **Future Design Benefit:** The degree of benefits to the projected designs, performance, and risks of such facility options due to this degree of uncertainty. (H, M, L)

Readiness:

4) **Present Research Maturity:** The degree to which the research at the concept exploratory level can marginally (H), significantly (M), or strongly (L) enable cost and time efficient research at the proof of principle level.
5) **3-Years Progress:** The degree to which the critical research will have ample (H), moderate (M), or limited (L) capability and opportunity to reach important conclusions. [This will help identify the research opportunities for longer-term NSTX research.]

Place in World:

6) **World-Leading:** The degree to which the US ST capability supporting this recommended research supersedes (H), equals (M), or lags (L) the U.K. and Japan ST research programs.
7) **Benefit to ITER:** The degree to which the US ST capability supporting this recommended research is uniquely (H), substantially (M), or marginally (L) important to the broader toroidal fusion science (and technology) research in addressing ITER issues and needs.
8) **Benefit from ITER:** The degree to which the recommended research links scientifically to tokamak, ITER and BA research to weakly (H), substantially (M), or strongly (L) benefit the knowledge base for future ST-based FS&T facility options. [Example: If ITER support R&D actually acquires in a few years the science base for ELM mitigation, uncertainties in ELM mitigation in ST would be substantially reduced.]
9) **Unique contributions to toroidal plasma science:** The degree to which the research can make uniquely important contributions to key issues in the science of toroidal fusion plasmas.

Application of the Measures is straightforward, but also pin-points needed information not available at present

Research Topic	**1c) momentum transport (La Haye, Menard, Sabbagh)**	
Proposed Research	Run steady-state and perturbative momentum transport experiments to develop a predictive capability for the rotation profile in next-step STs	
Physics Regime	**H**	Next-Step STs, if dominated by NBI co-injection power, are expected to exhibit toroidal rotations approaching larger fractions of the Alfven velocity, a regime readily achievable on NSTX (and later on MAST when 5 MW power becomes available).
Science Gap	**H**	High plasma rotation is very important for next-step STs, but neither empirical scalings, nor more fundamental predictive capability exist for momentum transport/confinement.
Future Design Benefit	**H**	High plasma rotation for ExB suppression of ITG turbulence is likely needed to achieve neoclassical ion transport levels for the very high confinement regimes envisioned for next-step STs. High plasma rotation is also beneficial for RWM stabilization, error field shielding, and NTM stabilization. The sensitivities of design size, cost, performance, and risks to uncertainties in momentum transport under large NBI co-injection need to be assessed to estimate the acceptable range of uncertainties in near term research on this topic.
Present Research Maturity	**M**	The diagnostics and momentum modification tools (such at non-resonant magnetic braking) are already in place on NSTX, and this research is part of a 2008 Joule milestone
3-Year Progress	**M**	Good progress can be made in separating diffusive momentum transport versus pinch effects toward developing an improved empirical scaling for momentum transport, but a full predictive capability for momentum transport is likely not possible in 3 year time-frame, but may be achievable in 5 years.
World-Leading	**H/ M**	The ability to inject high NBI torque levels, high spatial resolution toroidal and poloidal CHERS diagnostics, and the magnetic braking capability of NSTX make NSTX very well suited for this research. MAST contributes at a lower NBI power at present, and can contribute equally when 5-MW NBI becomes available in 2008-2009.
Benefit to ITER	**M**	Improved understanding of momentum transport could help predictions of what rotation levels will be achieved on ITER.
Benefit from ITER	**L**	ITER is expected to reach toroidal rotation velocities normalized to Alfven velocity that are of the order of several percents, due to small torque normalized by the ITER toroidal moment of inertia.
Unique contributions to toroidal science	**H**	NSTX studies of the diffusion of momentum could provide deeper insight into which modes and the associated turbulence mechanisms (such as Coriolis effects) are responsible for momentum transport.
Comments	LONGER TIME FRAME: Envisioned, but now cancelled upgrades in a 3 – 5 year time frame (2nd NBI, non-axisymmetric control coil capability and/or upgraded power supplies) will significantly enhance the probability of success of this research.	

The ST community is given opportunities to present reasons for strong ST R&D in the FES Program

- Now: Develop a strongest case to maintain NSTX research during FY08-FY10, to inform DOE's pending decisions regarding the future of NCSX and PPPL.
- Next: Move forward with work to define and clarify the roles of ST in FES Program
  - What should be the 20-year vision of the ST Program, as part of the U.S. FES Program?
  - What should be the 10-year goals, and 5-year goals to realize this vision?
  - What should be the 3-year goals and plans to reach these mid-term goals?
- The STCC plans to work closely with, and account for the interests of, the ST R&D stakeholders in carrying out its duties

Back-up

FESAC Greenwald Panel: Relationship of Initiatives to Gaps

How Initiatives Could Address Gaps

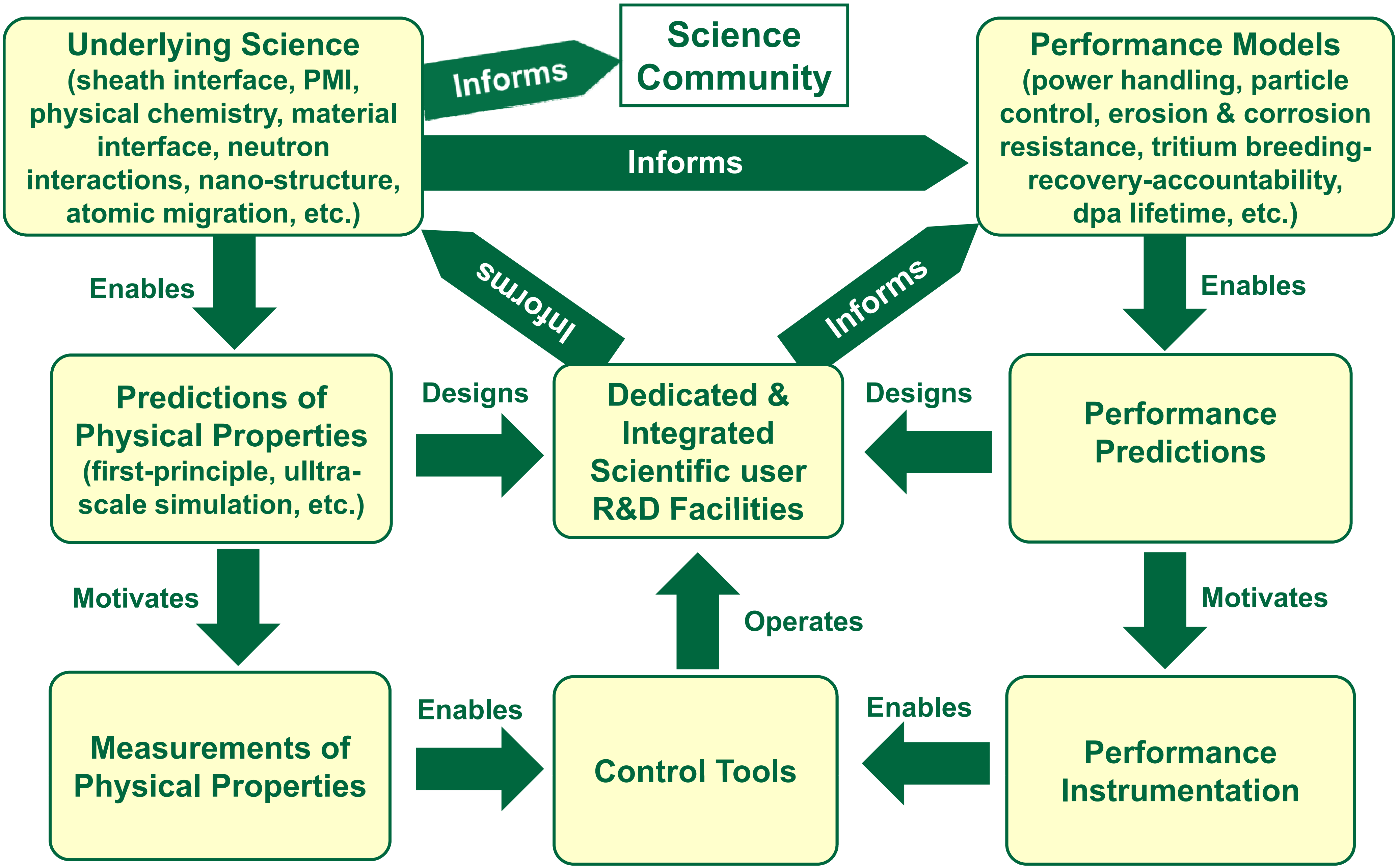
Legend

Major Contribution	3
Significant Contribution	2
Minor Contribution	1
No Important Contribution	

	G-1 Plasma Predictive capability	G-2 Integrated plasma demonstration	G-3 Nuclear-capable Diagnostics	G-4 Control near limits with minimal power	G-5 Avoidance of Large-scale Off-normal events in tokamaks	G-6 Developments for concepts free of off-normal plasma events	G-7 Reactor capable RF launching structures	G-8 High-Performance Magnets	G-9 Plasma Wall Interactions	G-10 Plasma Facing Components	G-11 Fuel cycle	G-12 Heat removal	G-13 Low activation materials	G-14 Safety	G-15 Maintainability
I-1. Predictive plasma modeling and validation initiative	3	2		2	2	3	1		2						
I-2. ITER – AT extensions	3	3	3	3	3		2		2	2	1	1		1	1
I-3. Integrated advanced physics demonstration (DT)	3	3	3	3	3	1	3	2	3	3	1	1	1	1	1
I-4. Integrated PWI/PFC experiment (DD)	2	1		1	2		2	1	3	3	1	1		1	1
I-5. Disruption-free experiments	2	1		2	1	3		1	1	1					
I-6. Engineering and materials science modeling and experimental validation initiative							1	3	1	3	2	3	3	2	1
I-7. Materials qualification facility							1			3	2	1	3	3	
I-8. Component development and testing			1				2	1		3	3	3	2	2	2
I-9. Component qualification facility	1	1	2	1	2		3	2	2	3	3	3	3	3	3

Fusion Engineering Science and Technology R&D

Demo knowledge base requires interactive R&D among stakeholders of underlying science and enabling capabilities



Nuclear Component Testing (NCT) aims to complement ITER mission and fill many DEMO R&D gaps

- **Mission of the Nuclear Component Testing (NCT) activity:**

  Create a lowered-risk, reduced-cost approach to a fusion environment beyond the ITER level, and utilize it to test, discover, innovate, and develop the remaining needed physical and engineering sciences knowledge base for Demo.

- **Recommended# simultaneous component testing capabilities substantially exceed those planned for ITER**

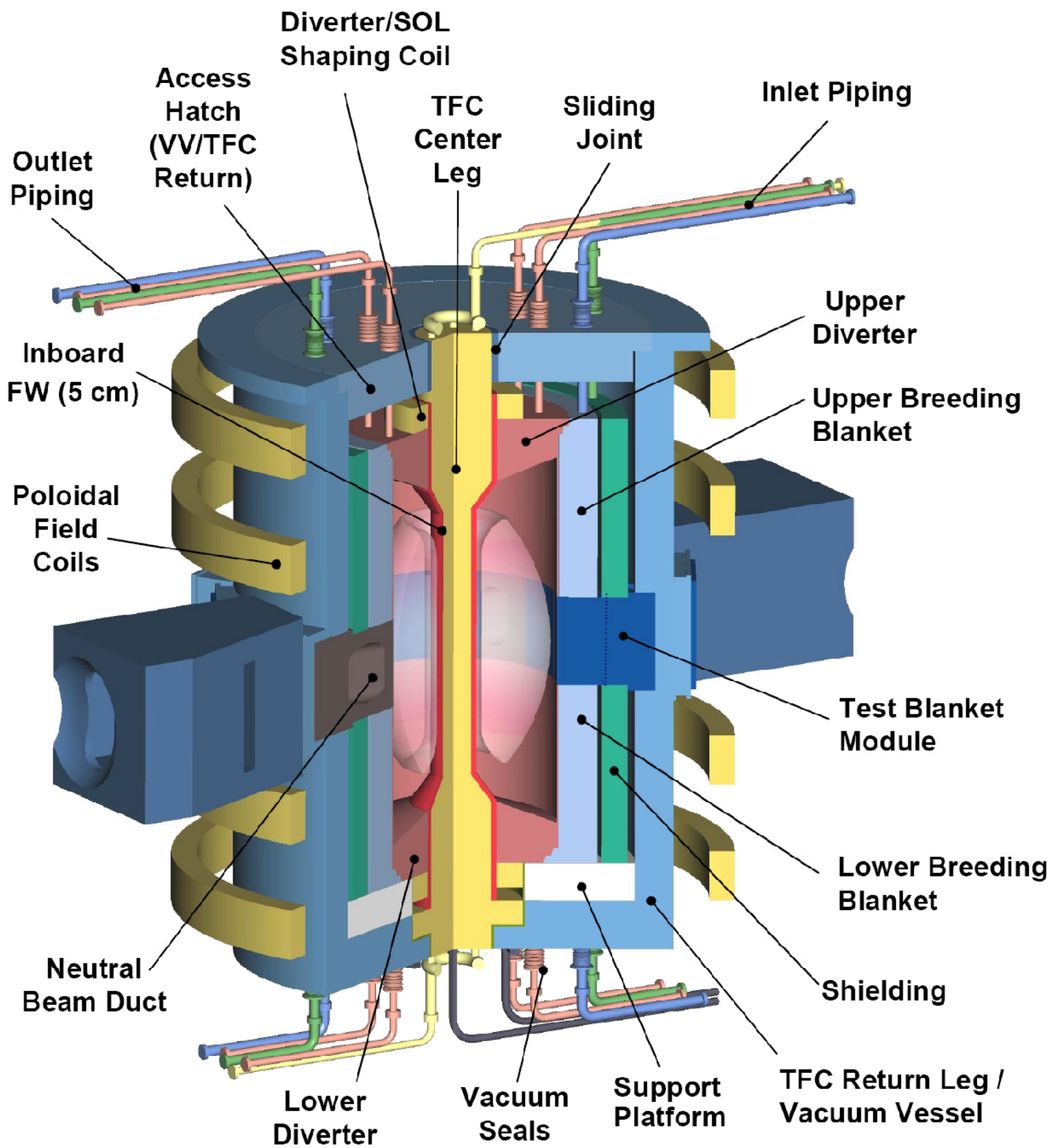
Performance metrics	ITER	Capabilities#	Demo Goals
Fusion Power (MW)	500	75-150	~2500
Burning plasma energy gain Q	5-10	2.5-3.5	~20
Plasma control: H&CD (MW), fueling	~80	31-43	~125
Burning plasma operation mode	S*-H*	HIHM*	A*
Divertor heat flux (MW/m^2)	~10	≤10**	~10##
Total area of (test) blankets (m^2)	~6	≥10 (test modules)	~670
Continuous operation	~hour	~day→2 weeks	~months
14-MeV neutron flux on module (MW/m^2)	~0.8	1.0-2.0	~3
Total neutron fluence goal ($MW\text{-}yr/m^2$)	~0.3	6	~6-15
Duty factor goal	~1%	30%	50%-70%
Tritium self-sufficiency goal (%)	~0	~100	≥100

Abdou et al., Fusion Technology **29** (1996) 1; other references.

* Operation modes: S = Standard, H = Hybrid, A = Advanced; HIHM = Hot-Ion H-Mode

** SOL geometric flux expansion considerations only; ## Pacher et al, IAEA FEC 2006, FT/P5-42

ST configuration offers attractive designs for fusion engineering science & technology R&D

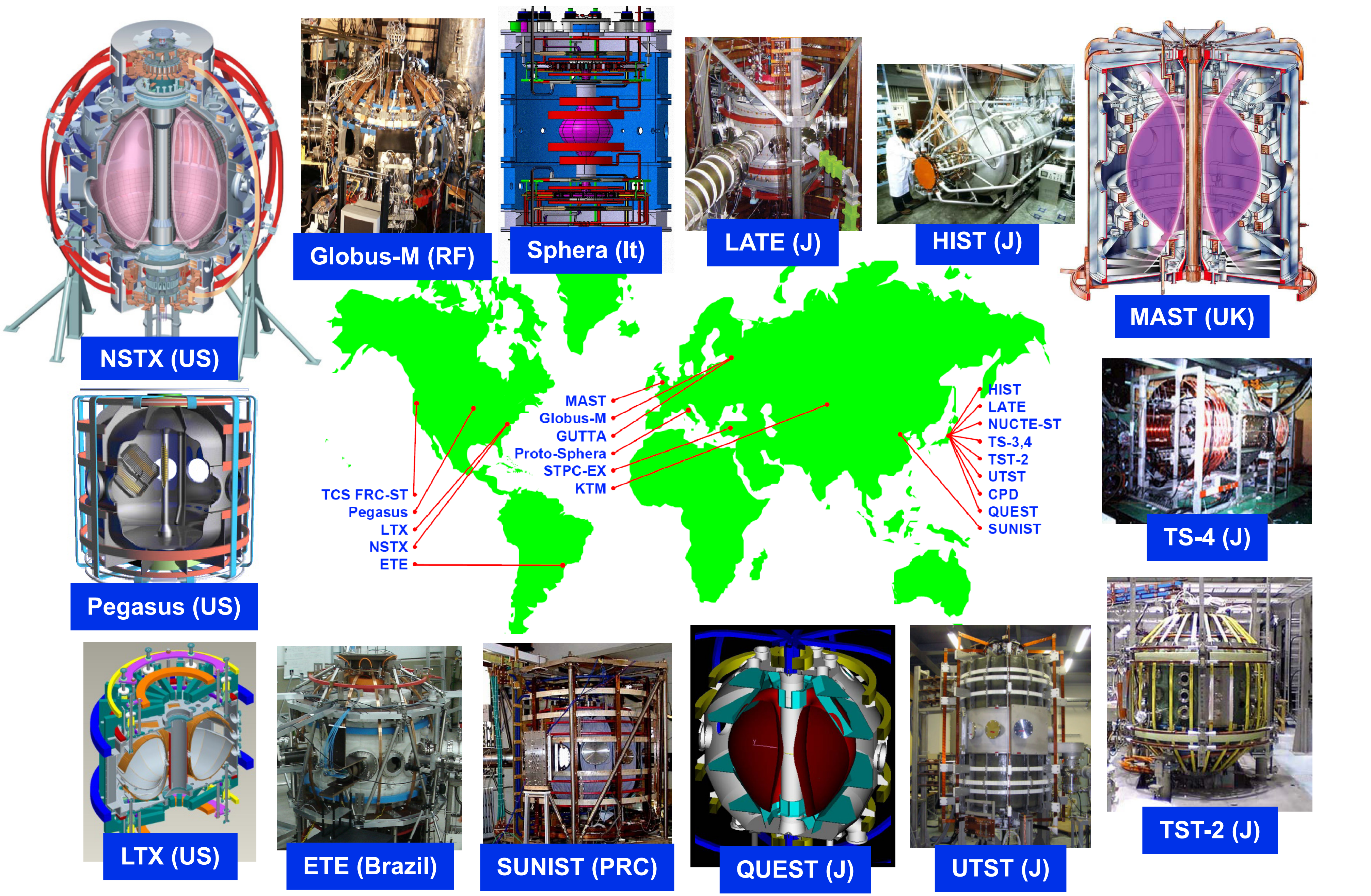


W_L [MW/m^2]	0.1	1.0	2.0
R_0 [m]		1.20	
A		1.50	
kappa		3.07	
q_{cyl}	4.6	3.7	3.0
B_T [T]	1.13	2.18	
Ip [MA]	3.4	8.2	10.1
Beta_N	3.8		5.9
Beta_T	0.14	0.18	0.28
n_e [10^{20}/m^3]	0.43	1.05	1.28
f_{BS}	0.58	0.49	0.50
T_{avgi} [keV]	5.4	10.3	13.3
T_{avge} [keV]	3.1	6.8	8.1
Q	0.50	2.5	3.5
P_{aux-CD} [MW]	15	31	43
E_{NB} [keV]	100	239	294
P_{Fusion} [MW]	7.5	75	150
T M height [m]		1.64	
T M area [m^2]		14	
Blanket A [m^2]		66	
$F_{neutron-capture}$		0.76	

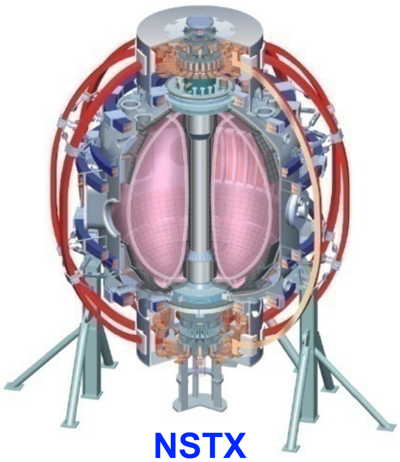
IEA ST Implementing Agreement provides timely tools to enhance worldwide ST research cooperation

- **Objective**
  - **Strengthen cooperation among ST research programs and facilities to**
  - **Enhance effectiveness and productivity of fusion science and technology research**
  - **Extend the scientific and technology database of toroidal confinement concepts to the ST regime**
  - **Establish a scientific and technological basis for the successful development of fusion power using ST**
- **Contracting Parties (Executive Committee Members)**
  - **EURATOM (Gianella, Lloyd)**
  - **National Institutes of Natural Sciences (NINS) (Motojima, Takase)**
  - **USDOE (Eckstrand, Peng)**

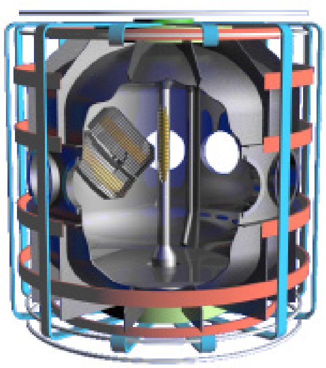
World ST Program is growing in capabilities and goals



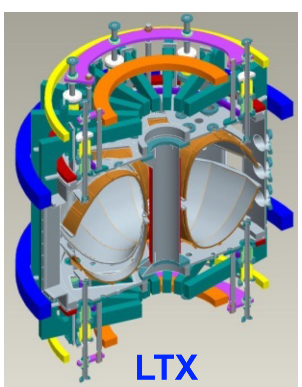
Combining Proof-of-Principle & Concept Exploration offers timely opportunities to obtain the needed data



NSTX



PEGASUS



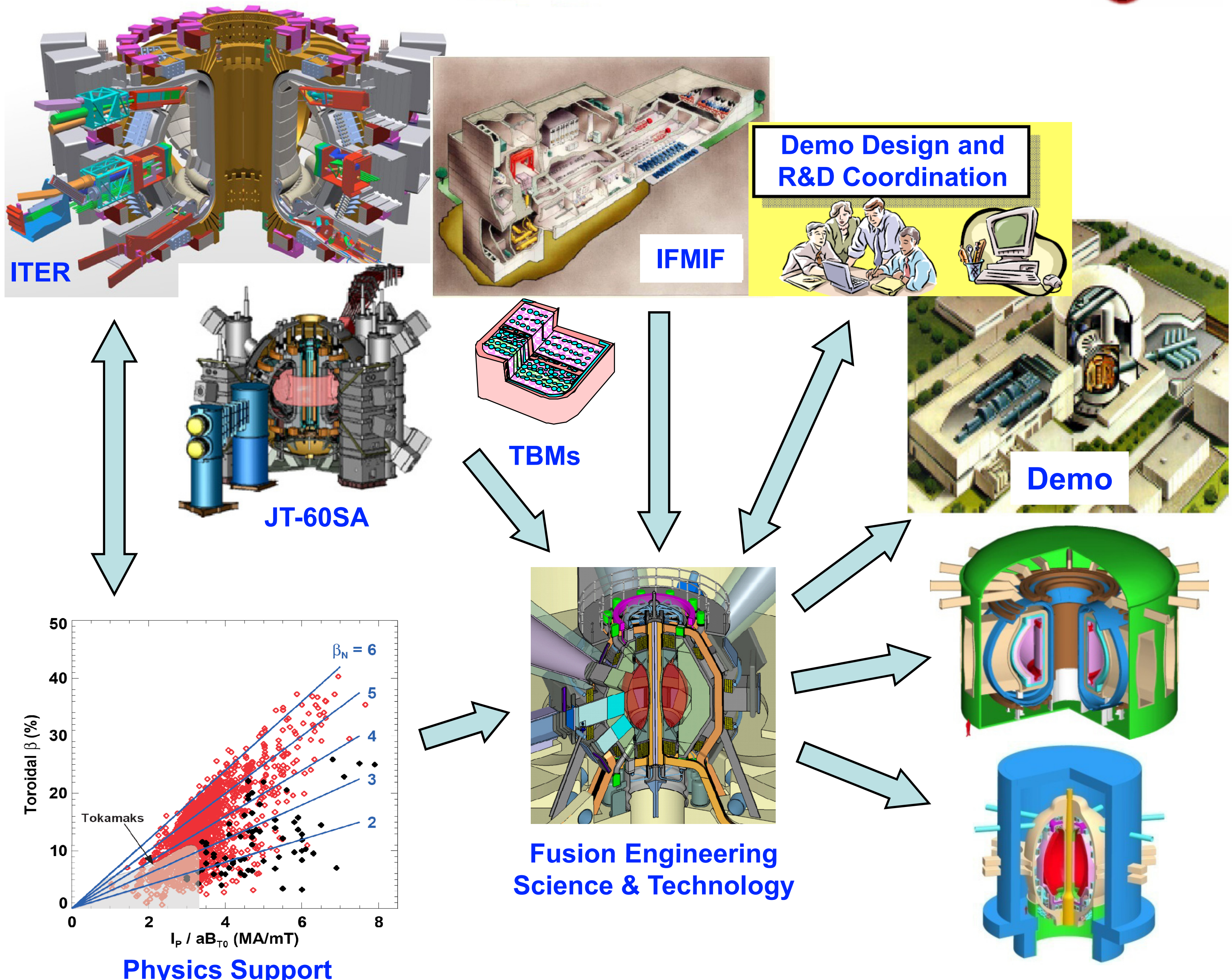
- NSTX: establishes ST physics basis
  - Commonalities in Tokamak physics (ITPA); new insights
  - ST issues: start-up, over-dense plasma waves, divertor, etc.
- Pegasus & LTX: explore key scientific feasibilities
  - Plasma gun start-up; very low A physics
  - Plasma & lithium wall; very low recycling physics

	NSTX (PoP)	Pegasus (CE)	LTX (CE)
R_0 (m)	0.85 – 0.95	0.2 – 0.45	0.4
A	1.3 – 1.6	1.12 – 1.3	1.5
I_p (MA)	1.5	0.3	0.4
R_0B_T (m-T)	0.51	0.1	0.13
I_N (MA/m-T)	7.2	20	3
P_{NBI} (MW)	7	TBD	0.2
P_{RF} (MW)	6	1	TBD
τ_{pulse} (s)	1.5	0.05	0.25

World ST R&D is an integral part of fusion program that supports, supplements, and benefits from ITER & BA activities

World ST Exps

CPD
ETE
Globus-M
GUTTA
HIST
KTM
LATE
LTX
MAST
NSTX
NUCTE-ST
Pegasus
QUEST
Sphera
STPC-EX
SUNIST
TCS FRC-ST
TS-3
TS-4
TST-2
UTST



Suggested IEA ST work in the Era of ITER & BA

- Two broad areas of research collaboration (Annexes: 2008-2011)
  I. Coordinate collaboration on research and upgrades in support of ST development
  II. Coordinate development of component test facilities with Broader Approach in support of Demo
- Organize annual international workshops (ISTW07 – Kyushu 10/07; ISTW08 - Frascati) and research collaboration forums
- Promote & represent ST fusion R&D in worldwide
  - Invite of Brazil, PRC, RF, etc. to join Agreement
  - Enhance coordination of activities within Contracting Party
  - Publish special ST issue in refereed journal (~2008)
  - Create and maintain world ST website and links

The ST community is prepared to work actively with ITER and BA to meet the Grand Challenge of fusion energy

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