Office of Science

Office of Fusion Energy Sciences

Excellent Science Attractive Energy

Report of Nuclear Component Testing Discussion Group & National Spherical Torus Program

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Fusion Power associates Annual Meeting and Symposium

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Oak Ridge, Tennessee

A voluntary Nuclear Component Testing Discussion Group was formed to prepare input to FESAC Panel

Leaders' Group

Subgroup 2
Enabling Burning Plasma

Subgroup 1
Fusion Nuclear Technology

Members	Contributions	Organization
Abdou, Mohamed	Fusion nuclear technology, VNS	UCLA
Gates, Dave	NSTX plasma experimentation	PPPL
Hegna, Chris	Fusion plasma theory	U Wisc
Hill, Dave	Fusion plasma experimentation	LLNL@GA
Najmabadi, Farrokh	Fusion power plant conceptual designs	UCSD
Navratil, Gerald	Advanced Tokamak, PACs	Columbia U
Parker, Ron	Tokamak, tokamak-CTF, ITER-EDA, **SG2 leader**	MIT
Peng, Martin	ST, **NCT DG Coordinator**	ORNL
Baylor, Larry	Plasma enabling systems	ORNL
Forest, Cary	Plasma science	U Wisc
Hillis, Don	Experimental collaboration	ORNL
Jarboe, Tom	Innovative confinement concepts, startup	U Wash
Kotschenreuther, Mike	Turbulence theory, innovative divertors	UT-Austin
Mauel, Mike	Levitated Dipole Experiments, PACs	Columbia U
Sabbagh, Steve	MHD	Columbia U
Sovenic, Carl	Numerical fusion simulation	U Wisc
Tynan, George	Plasma science, MFE and IFE	UCSD
Whyte, Dennis	Boundary physics, BPO	MIT
Burgess, Tom	Remote handling	ORNL
Cadwallader, Lee	Fusion safety and environmental protection	INL
El-Guebaly, Laila	Neutronics, safety & environment, **SG1 co-leader**	U Wisc
Galambos, John	Systems & costing analysis	ORNL
Holder, Jeffrey	Tritium	SRNL
McManamy, Tom	Nuclear core design	ORNL
Morley, Neil	Fusion Nuclear Techcnology	UCLA
Sawan, Mohamed	Fusion nuclear technology	U Wisc
Skinner, Charles	Plasma material interaction	PPPL
Snead, Lance	Material science	ORNL
Ying, Alice	Fusion nuclear technology, **SG1 leader**	UCLA

DOE contact: Eckstrand, Steve, OFES

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

Demo issues with large gaps in knowledge base beyond ITER

Enabling Burning Plasma

SBP-1: Abnormal events avoidance / mitigation

SBP-2: Startup & steady-state operation

SBP-3: Advanced operating regime

SBP-4: Burning plasma fusion gain

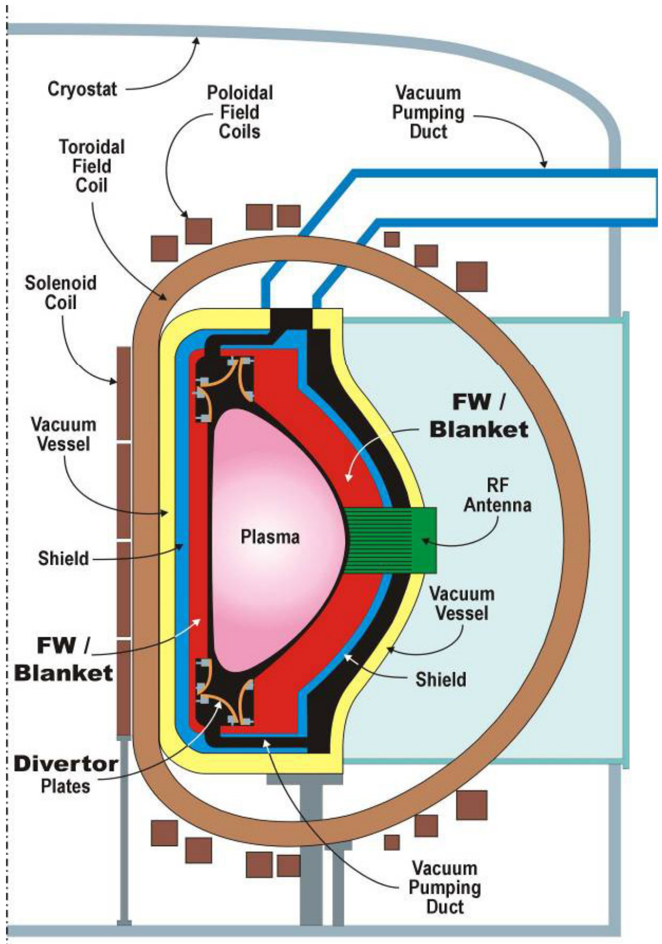
SBP-5: Divertor plasma performance

SBP-6: Burning plasma predictive capability

SBP-7: NB/RF/pellet systems performance

SBP-8: Plasma diagnostics & control

SBP-9: Power plant plasma performance



Tokamak Reactor

Required Fusion Nuclear Technology

FNT-1: S/C & N/C magnets

FNT-2: Tritium self-sufficiency

FNT-3: Tritium retention, accountability, safety, etc.

FNT-4: Materials characterization

FNT-5: Plasma facing surface performance & maintainability

FNT-6: FW/blanket/divertor materials defect control

FNT-7: FW/blanket/divertor availability and lifetime

FNT-8: Full remote handling

FNT-9: Public safety & environmental protection

FNT-10: Electricity generation at high availability

FNT-11: Regulatory permit for Demo plant operation

Nuclear Component Testing R&D gap-filling and need assessment – Questions addressed for the chosen Demo R&D topics

1. *What is the envisioned Demo goal on this topic?*
2. *What are the physical and engineering sciences knowledge base expected to be established by a successful ITER and IFMIF?*
3. *What are the expected contributions from other planned experiments and technology test facilities?*
4. *What is the gap in R&D on this topic to bridge to Demo design and construction?*
5. *In what key ways can a NCT facility contribute to filling this gap?*
6. *What other approaches can also contribute to filling this gap partially or fully?*
7. *In what ways is a NCT facility unique, or not unique, in filling this gap?*
8. *What near-term (5-10 year) R&D are needed to enable design, construction, and operation of the needed NCT facility?*

Nuclear Component Testing (NCT) Discussion Group inputs to FESAC Panel, 8/7/07, PPPL

Presentations:

- Need and opportunities for NCT gap-filling capabilities
- Why is the FW/blanket/divertor components reliability and lifetime a Demo R&D gap?
- Why is full remote handling a Demo R&D gap?
- Tungsten plasma facing surface performance

Written "2-pagers":

- Need and opportunities for NCT
- FW/Blanket/Divertor Reliability and Lifetime
- Full Remote Handling
- Plasma Facing Surface Performance and Maintainability
- Tritium Self-Sufficiency
- Tritium Retention, Accountability and Safety
- FW/Blanket/Divertor Materials Defect Control
- Public Safety and Environmental Protection
- Regulatory Permit for Demo Plant Operation

FESAC Greenwald Panel: Relationship of Initiatives to Gaps

How Initiatives Could Address Gaps

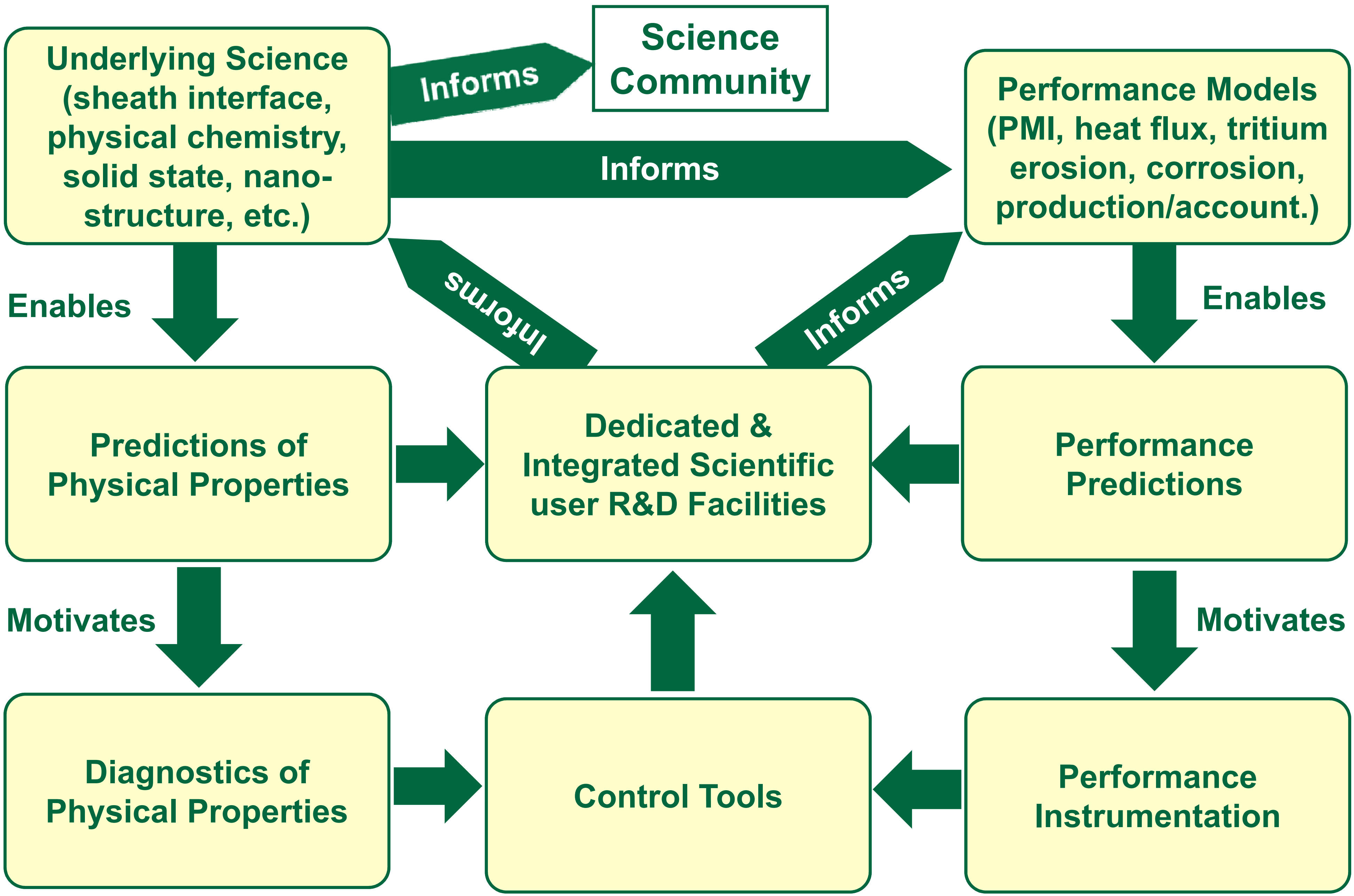
Legend

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

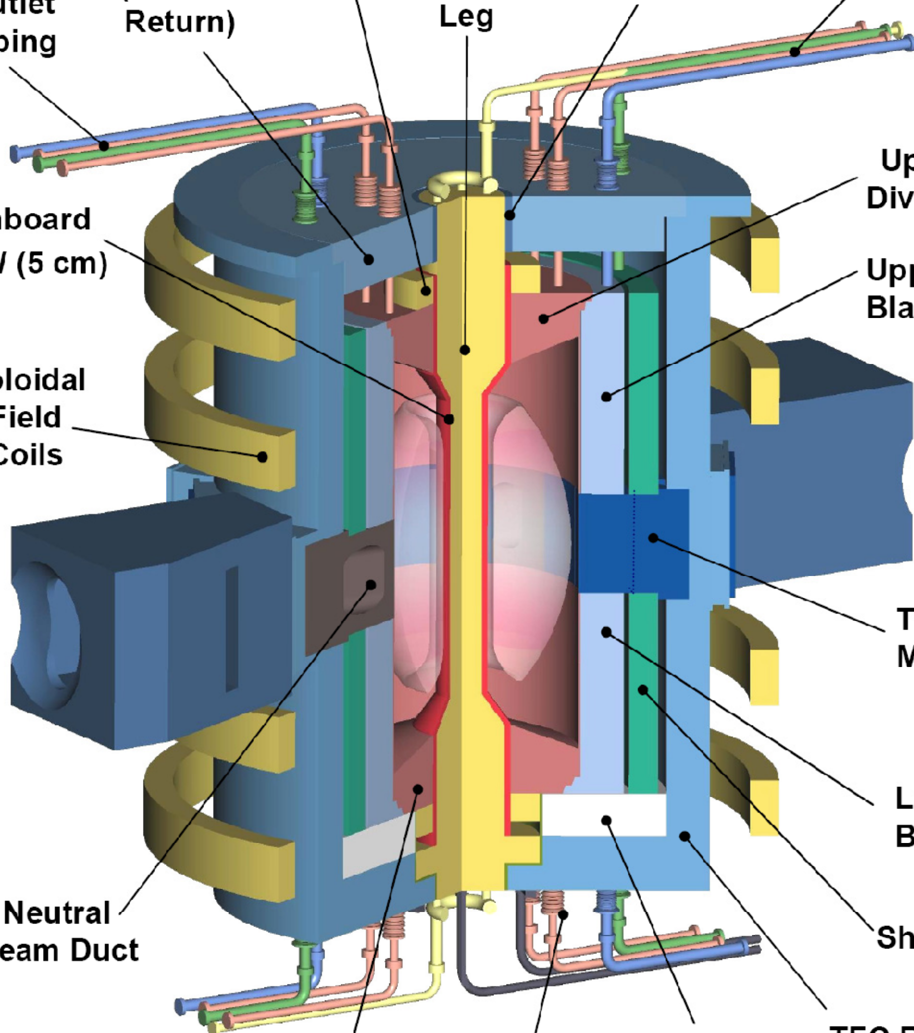
	G-1 Plasma Predictive capability	G-2 Integrated plasma demonstration	G-3 Nuclear-capable Diagnostics	G-4 Control near limits with minimal power	G-5 Avoidance of Large-scale Off-normal events in tokamaks	G-6 Developments for concepts free of off-normal plasma events	G-7 Reactor capable RF launching structures	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

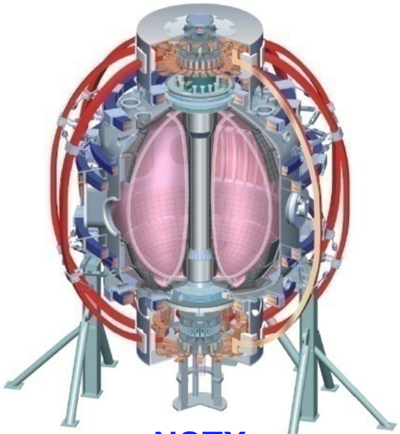


ST configuration offers attractive designs for fusion engineering science & technology R&D

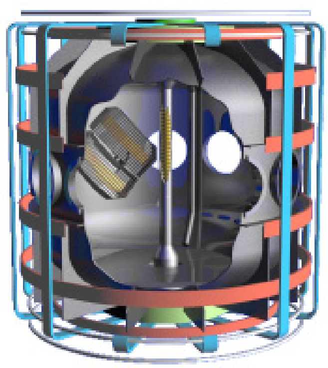


W_L [MW/m²]	**0.1**	**1.0**	**2.0**
R_0 [m]		**1.20**	
A		**1.50**	
kappa		**3.07**	
q_{cyl}	4.6	**3.7**	3.0
B_T [T]	1.13	**2.18**	
Ip [MA]	3.4	**8.2**	10.1
Beta_N	**3.8**		5.9
Beta_T	0.14	**0.18**	0.28
n_e [10^{20}/m³]	0.43	**1.05**	1.28
f_{BS}	0.58	**0.49**	0.50
T_{avgi} [keV]	5.4	**10.3**	13.3
T_{avge} [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 [m²]		**14**	
Blanket A [m²]		**66**	
$F_{neutron-capture}$		**0.76**	

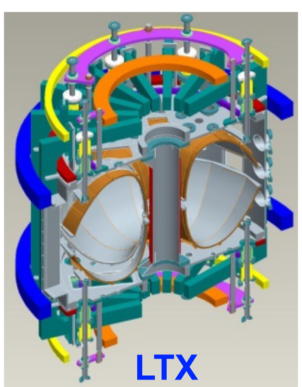
Combining Proof-of-Principle & Concept Exploration offers timely opportunities to obtain the needed data



NSTX



PEGASUS



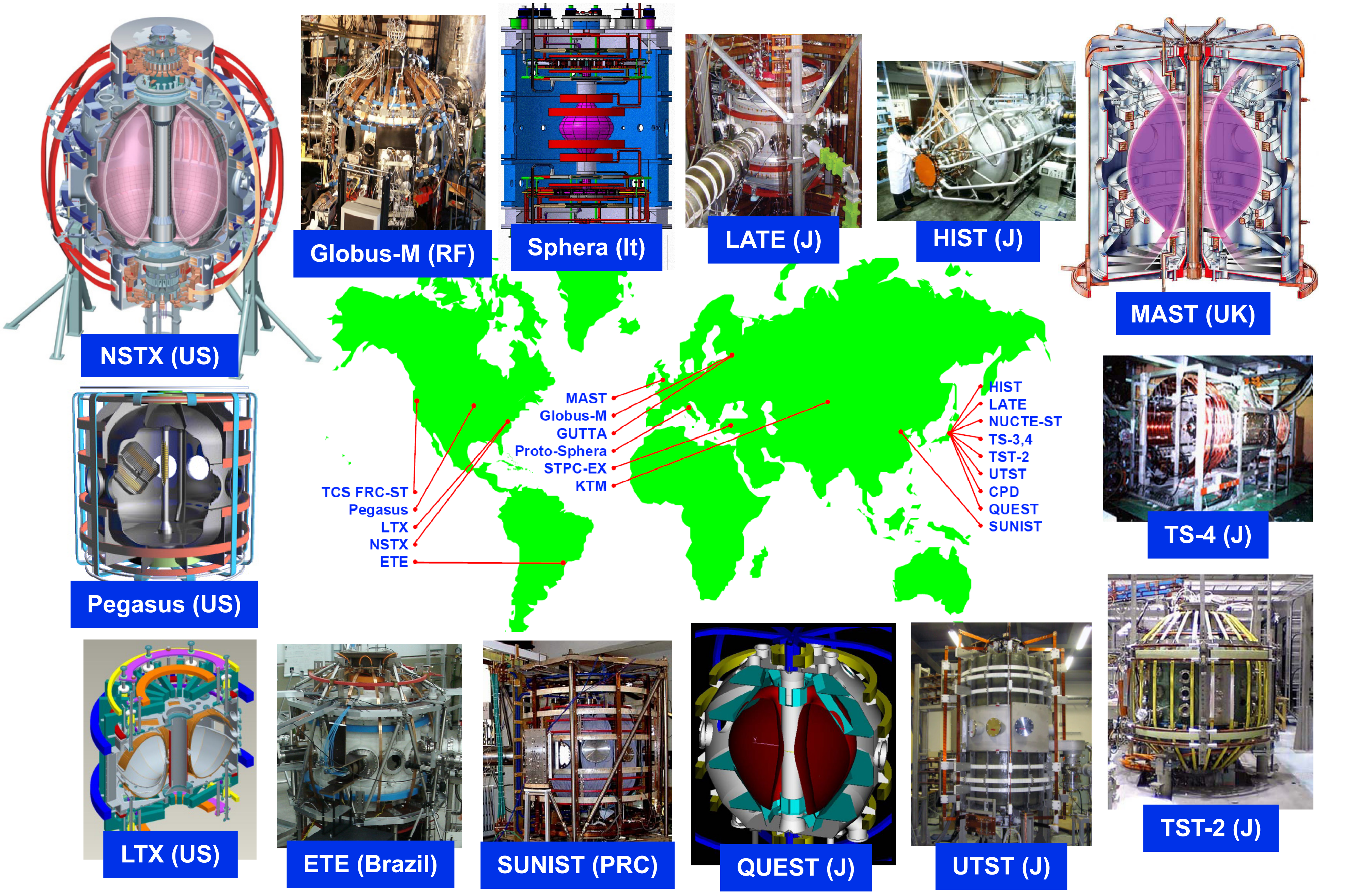
- NSTX: establishes ST physics basis
  - Commonalities in Tokamak physics (ITPA); new insights
  - ST issues: start-up, over-dense plasma waves, divertor, etc.
- Pegasus & LTX: explore key scientific feasibilities
  - Plasma gun start-up; very low A physics
  - Plasma & lithium wall; very low recycling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

U.S. ST Coordinating Committee (STCC) has begun its work to enhance ST R&D and collaborations

- Support the evolving role of ST in the U.S. fusion 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
- Membership selected to represent major 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**

World ST Program is growing in capabilities and goals



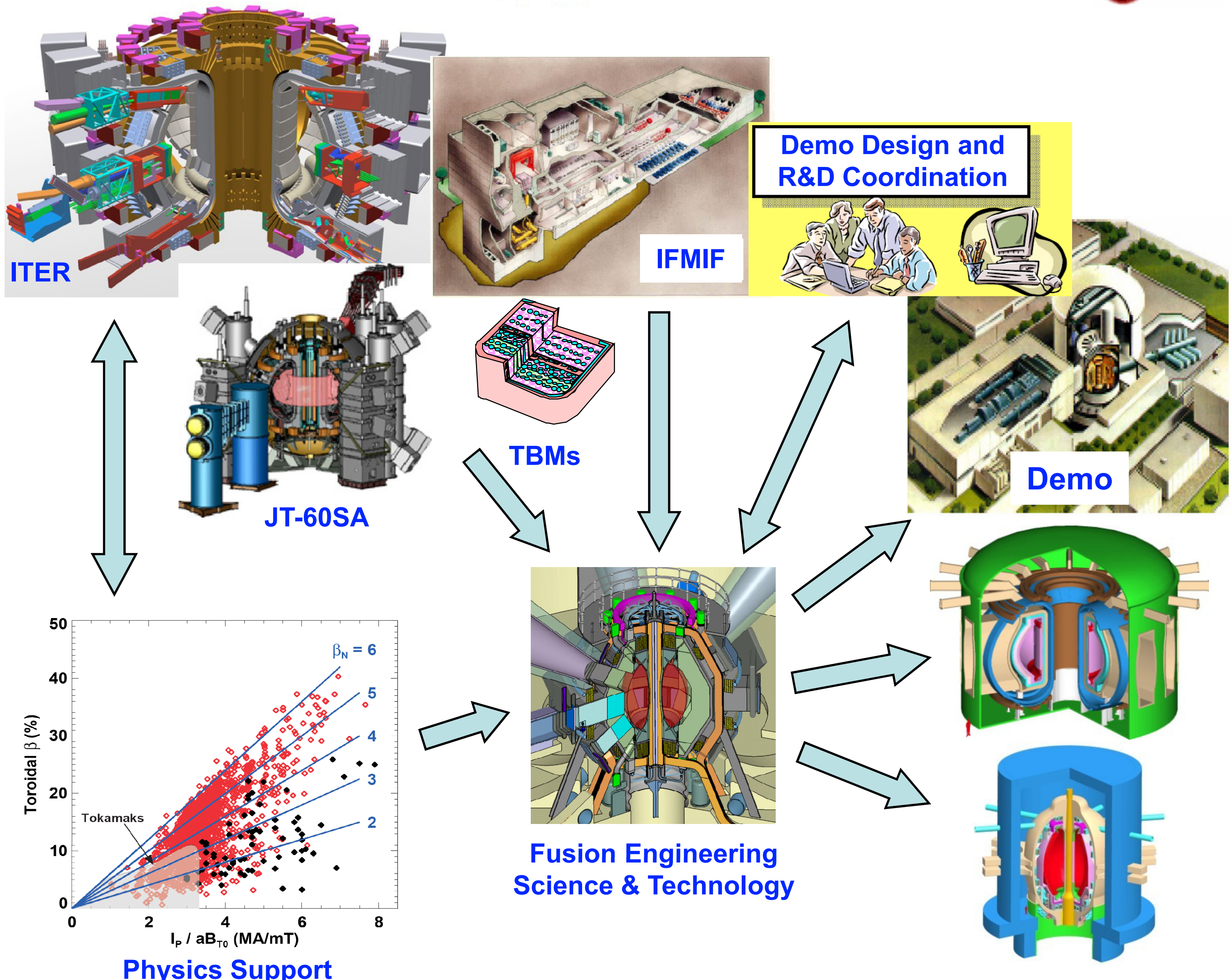
IEA ST Implementing Agreement provides timely tools to enhance worldwide ST research cooperation

- **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 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

<u>World ST Exps</u>

CPD
ETE
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