International Collaboration Opportunities for the US Fusion Sciences Program

International Collaboration Task Group, US BPO

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Outline

1. Purpose of study
2. Criteria, Methods & Challenges
3. ReNeW Issues For International Collaboration
4. Assessment Opportunities for Enhanced Collaboration
5. Timescales and Findings

International Collaboration Task Group, BPO

Charge

Evaluate and prioritize the opportunities for US collaboration on EAST, KSTAR, JET, and JT60SA to prepare for US participation on ITER and to address the issues and gaps discussed in the recent report "Issues, Gaps, and Opportunities: Towards a Long-Range Strategic Plan for Magnetic Fusion Energy", DOE-SC-0102.

Members

- D. Humphreys
- *C. Kessel* *(Resigned to head Pathways Study)*
- T. Luce
- S. Milora
- S. Sabbagh
- D. Whyte
- M. Zarnstorff (Chair)

Motivation: International Collaboration more Important

- Preparation for ITER. Intrinsically an international collaboration
- Some high priority ReNeW / Greenwald-panel issues require capabilities not available in US
  - Long-pulse, superconducting coils
  - Stellarators
  - Larger scale and burning plasmas
- Invitations for US to Partner on International Facilities, with shared responsibility and financing
  - Wendelstein 7-X: whole program
  - JET: Extension past 2014 & DT program
  - BA: IFMIF & JT-60SA
  - Requests to strengthen: KSTAR, EAST, LHD

Criteria for Comparison of Opportunities

- Address and resolve critical fusion research issues
  - ReNeW and FESAC reports,
  - Cannot be resolved on present US facilities

- Maintain and develop key US strengths

- Prepare for participation in ITER and further steps towards fusion energy.

In addition: US collaboration should have impact.

Methods for Enhanced Collaboration

- To address US priorities & involve US community, US needs to contribute resources

- To achieve key challenging goals, US may need to make substantial investments and commitments
  - Take responsibility for parts of program on foreign facility
  - Dedicate staff; equipment
  - Continuous engagement
  - Partnership (as on ITER)

- To be successful, should be synergistic for both parties

  Requires US to have & maintain relevant expertise

- Requires open communication, commitment by all parties

Challenges of International Collaboration

- Different national programs have different goals & constraints
- Host sets priorities – loss of control
- Planning required to maintain or develop US scientific leadership
  - Explicit agreements with host for responsibilities
  - Use of resources to explore novel ideas
  - Coordinate with domestic activities to maintain expertise & value, bring knowledge gained into US program
- Challenging for US personnel
  - Families
  - Relocated personnel may not return

International Facilities: Technical Opportunities

	JET	AUG	EAST	KSTAR	JT-60SA	MAST	LHD	W7-X	RFX
status	mature	mature	emerging	emerging	construction	mature	mature	construction	mature
R (m)	3.1	1.65	1.85	1.8	2.97	0.85	3.7	5.5	2
B (T)	4	3.3	3	3.5	2.25	0.55	3	3	
Ip (MA)	5	1.2	1.5	2	5.5	1.2	< 0.1	0	2
R / a	3	3.3	4.1	3.6	2.5	0.3		11	4.4
	DT					Super-X			
configuration	SN	SN (DN)	DN	DN	DN	DN/SN	3D, helical	3D, quasi-isodyn.	RFP
kappa, delta	1.8, 0.4	1.8, 0.5	1.9, 0.65	2, 0.8	1.9, 0.5	2.5, 0.6			1, 0
RMP max. mode #	n=2	n=4	-	n=2	n > 1	n=6	n=5, m=1	n=5, m=1	n =24, m=2
Heating (ult.) (MW)	51	34	31	28	41	10	36	20	
coil conductor	Cu	Cu	SC	SC	SC	Cu	SC	SC	Cu
pulse length (s)	20	10	1000	300	100	1	~3600	1800	~0.2
PFC material	W / Be	W on C	C / Mo→W	C	C	C	C	C	C

- Key characteristics not available in US facilities
- Important collaboration activities and opportunities on all

ReNeW Issues: Key Characteristics of International Facilities

- Steady-state / very long pulse : SC coils
- Large scale tokamaks & stellarator - closer to burning plasmas
- DT plasmas
- Other ITER-like characteristics
  - PFC materials;
  - In-vessel control coils
- Novel divertor geometries, 2D & 3D
- Actively cooled internal components; thermally equilibrated; high temp.
- Remote maintenance

Many ReNeW Issues Only Accessible by International Facilities

- Tabulated in Section 3 of Report
- Only considered existing facilities or those under construction
- Issues in every thrust, every topical area
  Includes technology issues
- Current International Facilities do not cover all issues
  Opportunities for new or upgraded domestic facilities.
  => Need balance between domestic and collaborations

Plans and Opportunities Assessed
For each Confinement Facility

Section 4

- Facility technical capabilities & development plans

- Technical importance to US program

  Which ReNeW issues can be resolved?

- Opportunities for enhanced US collaboration

  Synergy with US program, opportunities for leadership

  Potential for impact by US participation or partnership

  Timescales

  Specific challenges?

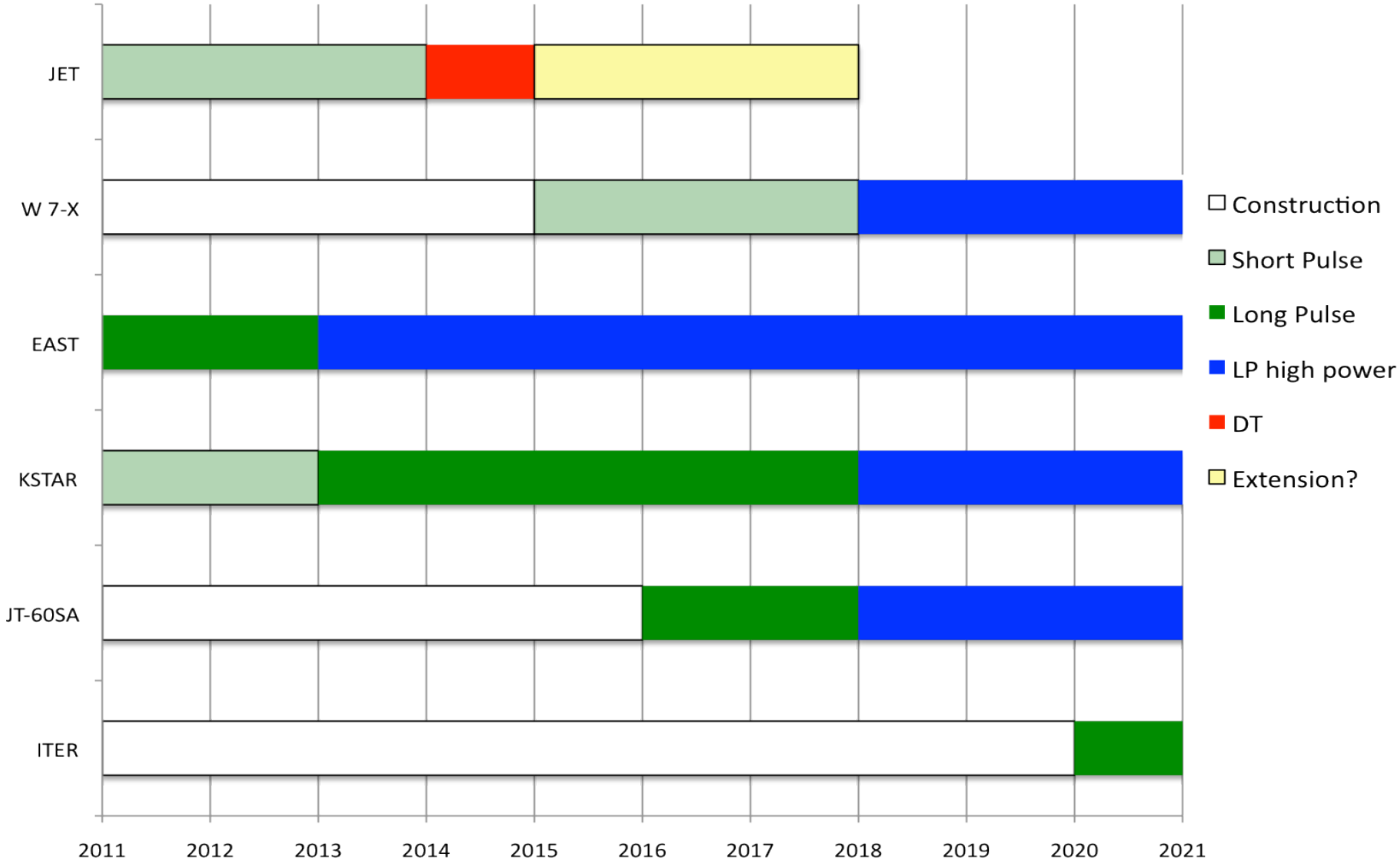
Greatest opportunities: EAST, JET, JT-60SA, KSTAR, W-7X

Ability to Impact ReNeW Issues Assessed

	EAST	JET	JT-60SA	KSTAR	W7-X
Th 1: Measurement techniques for burning plasma					
Long-pulse steady-state diagnostics					
Long-pulse machine protection					
Develop DEMO prototypical alpha diagnostics					
Remote maintenance and calibration of diagnostics					
Th 2: Control of transient events in burning plasma					
Long-pulse ITER prototype regime, without ELMs & disruptions					
Test extrapolation of ELM & disruption avoidance and mitigation to larger scale					
Long pulse instability control at high beta-N					
Th 3: Role of Alpha particles in burning plasma					
Validate understanding of effect of fast-ion instabilities in steady-state scenarios, at larger scale					
Understand interactions between fast-ion and global MHD instabilities in steady-state scenarios					
Impact of fast on losses on first wall in steady scenarios					
Test control of alpha heating profile					
Th 4: Qualify operating scenarios and physics for ITER					
ITER scenarios with DT, including alpha particles (with ITER-like PFCs)					
ITER scenarios with superconducting coils, relevant H&CD methods, long pulse					
PFC cleaning for long-pulse					
Test ITER fueling and pumping at largest scale					
Development of burn control strategies (sim.)					
Th 5: Expand limits for controlling and sustaining fusion plasmas (tokamaks)					
Maintain AT scenarios suitable for high fusion power gain for long pulse, restricting diagnostics & actuators					
Determine min. diagnostic & actuator set needed for high fusion power gain long pulse					
Develop & demonstrate long-pulse fueling & exhaust systems					

Available < 5 years	Available < 10 years	Under consideration

Facility Evolution Timescales



Of the SC tokamaks, EAST will have earliest integrated capability

Opportunities for Enhanced Collaboration With Highest Impact

- **JET**: ITER operating scenarios with DT plasmas & ITER-like walls & largest available scale. Reduce risks for ITER, e.g., validating ITER chosen methods to suppress ELMs and avoid and mitigate disruptions.

- **W 7-X**: Disruption-free high-performance confinement in a large-scale optimized stellarator, operating limits, compatibility with divertors.

- **EAST**: Long-pulse PMI with prototypical metallic walls (tungsten and/or lithium), including high ambient wall temperature.

- **EAST** and **KSTAR**, followed by **JT-60SA**: Steady-state, high-performance confinement in tokamaks, including operating limits, ability to operate disruption-free, and compatibility with divertors. EAST will have earliest capability. JT-60SA will have largest scale.

Timely Decisions Required

- **JET** invitation for US partnership: need to start immediately
- To participate in aggressive **EAST** program, need to dedicate resources quickly.
- **W-7X** invitation for US partnership: must decide level in next couple of years, before niches fill.
- Impact of **KSTAR** collaboration can be strengthened with increased funding.
- Level of **JT-60SA** participation and timing should be explored.

Activities

- Conference calls

- Input from facilities (EAST, JET, JT-60SA, KSTAR, LHD, MAST, RFX-mod, W7-X)
- Presentations at PAC meetings, conferences, workshops, coordination meetings
- JET-RMP, JET-ECH, and W7-X collab. Proposals
- Visits to facilities

- Requested & received input from
  - BPO Research Committee
  - VLT leadership
  - International Collaboration Leaders in US