Discussion Sessions with inputs from the sessions Chairs

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- **Not a summary, not to be comprehensive**
- **But to provide our own (partial) view**
- **But to note high level actions/issues raised during the session ?**

LPO (Performance) – Part 1 C. Holcomb

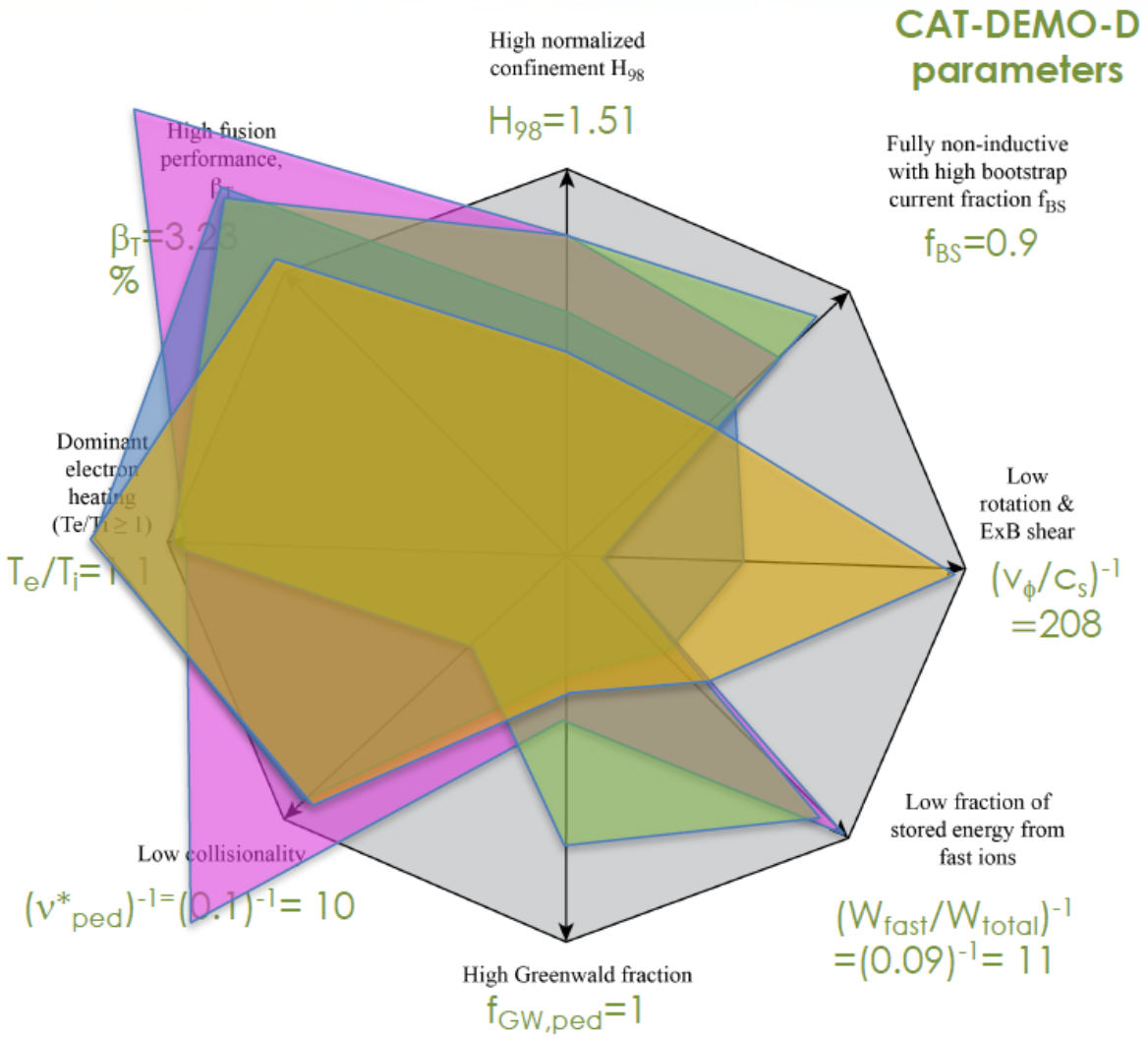
- **ITER:**
  - Uncertainty of confinement (H_{98y2}) and transport for hybrid and steady-state scenarios – how to extrapolate from existing devices to reduce uncertainty
  - Uncertainty of SOL and pedestal transport, λ_q, ELMs
- **EAST:**
  - Need for continued improvement in H&CD coupling & efficiency
  - Need to eliminate hot spots, improve heat flux & particle exhaust capabilities, & recycling control
  - Continual improvement in diagnostics & long pulse controls
- **LHD:**
  - Highlights dynamic nature of PWI on 1000+ second timescales even while core plasma is steady: changes from sink to source
  - Need for active control of recycling, detachment & radiation, flakes, etc.
  - Open questions: how well can we predict this PWI on long time scales? Will ITER be similar with W divertor?
- **W7-X**
  - Commissioning going well, plasma operation will start soon
  - First operation with massive water cooling, heating power for the plasmas will be raised carefully
  - Identified need for heating & fueling system enhancements
- **WEST**
  - Goal to test ITER Plasma facing units in long pulse, needing sustained high P_{SEP}
  - Issue: need to assess & optimize LH-current drive efficiency & impacts of SOL parameters
  - need to assess long pulse evolution of deposited layers on surfaces that could lead to ejection of W-rich flakes
  - Open questions about how WEST high fluence results translate to ITER

LPO (Performance) – Part 2 S. Coda

The full-size vs compact DEMO approaches

- AUG LPO research programme aimed at paving way to EU-DEMO steady state scenario
- Covering broad range of parameters to develop and verify models for extrapolation to DEMO and beyond
  - Core Transport (ExB ↔ FI)
  - Anomalous Flux Diffusion
  - Core/Edge MHD stability
- Successful operation in full W environment

from A. Bock (AUG)



from C. Holcomb (DIII-D)

LPO (Performance) – Part 3 J. Stober

- **A. Garofalo, ‚High beta pol on EAST & DIII-D‘**
  - ELM for access acceptable?, Barrier Physics (Width, loction?), no-ELMs and reactor collisionality
  - Helium ash / impurities, RWM stability at low rotation, compatibility with detachement
- **R. Buttery: ‚Reduced size Tokamak power plant‘**
  - Evidence for confinement increase with Bt? current drive improvements (under test at DIII-D),
  - reliable entry to regime, assumptions on pedestal pressure at high density, ELM issues at high delta,
  - Power handling, wall materials
- **T. Wakatzuki, ‚long pulse operation JT-60 SA‘**
  - Collaboration (U.S. ?), low bootstrap fraction ?
- **K. McClements, ‚STEP‘**
  - GK verification, RWM stabilisation, Divertor concepts and EBW-CD to be tested at MAST-U
  - Access to performance ramp-up and ramp-down ?
- **L. Xu, ‚MHD Mode dynamics in EAST long pulse‘**
  - How universal are the M3D findings for flux pumping with respect to observations on ther machines.
- **General**
  - Non-linear ‚flat-shear‘ high beta GK-simulation are a limitting factor due to large radial range necessary for a ‚local‘ result

LPO (Control) – Part 1 T. Morisaki

Biewer: *Establishing fusion reactor control scenarios based on information from a reduced set of nuclear-compatible diagnostics*

Minimizing diagnostics data and simplifying instrument
ITER will be a good test bench for reduced set of nuclear-compatible diagnostics

Huang: *Real-time plasma control of fully non-inductive operation in EAST 1056s long pulse discharge*

Issues found and solved in 1000 s sustainment; Magnetics, Integrator, Real-time equilibrium reconstruction, Fully non-inductive current drive

Moreau: Control and protection challenges in fully metallic tokamak WEST for long pulse operation

Raw data => modelling, sophisticated analysis code, cross diagnostics => machine protection

Even for the machine control or protecting, sophisticated analysis code and/or modelling, machine learning technique is essential

LPO (Control) – Part 2 H.-S. Bosch

Asdex Upgrade (R. Schramm)

- Model based development of AT-discharges can be a very useful tool

LHD (T. Yokoyama)

- Radiation collapse limits the plasma density
- Statistical evaluation of parameters that can be used as a predictor shows, that 5-6 are sufficient to predict a collapse.

LHD (H. Kasahara)

- Real-time feedback of plasma density works ok, but the response time is determined by the hardware
- Particle confinement is gradually decreasing during LPO in D/H-plasmas

Pellet Fueling (M. van Berkel)

- Integrated simulations of pellet-fueled discharges have been started

Plasma-Wall Interaction (PWI) – S. Brezinsek

- **Identification of PWI topics relevant for present-day long pulse devices „to operate“**
  - Wall conditioning techniques (Li-evaporation, in-situ coatings, GDC)
  - Plasma operation with attached divertor conditions
  - Low recycling divertor operation
  - Ignore Tritium and neutron damage
- **Identification of PWI topics relevant for reactor-like long pulse devices „to perform“ safely**
  - Wall conditioning techniques excluding in-situ coatings (dust and safety limit)
  - Plasma operation with semi-detached divertor conditions
  - High wall temperature operation
  - Self-sufficient T-cycle
- **Identification of PWI topics relevant for reactor-like long pulse devices „above the limit“**
  - Explore limitations to minimise risks: aging of PFCs, melting, neutron damage
  - Role of transients (ELMs, VDE) and their prevention, mitigation, or control

Have the PWI-limits in your mind when developing advanced steady-state scenarios, but don‘t use PWI yet as short-stopper to explore a regime!

Issue for heat and particle balance – K. Hanada

- **Reduction of Heat load on divertor is still difficult for tokamaks, but better for stellarators (W7-X).**
- **Low recycling: many Tokamak (strong divertor pump: LHD) plays an important role in good confinement on tokamaks and stellarators.**
- **How can we get low recycling in long pulse operation?**
  - **-** Li ? EAST
  - Be ? JET, ITER
  - B ?: LHD
  - C: we have experienced.
  - New pumping: LHD
- **Does plasma induced deposition layer work well (WEST, QUEST)?**
- **He including ashes problem (fuel dilution) will be coming up soon. Open issue to be further investigated ?**
  - **He Bubble, Fuzz**
  - **New diagnostics need to be developed (CEA).**
- **He impact (Bubble?, Fuzz) on DT recycling**
- **Future choice of materials for LPO in reactors ?**

RAMI and Nuclear Technologies – D. Van Houtte

- The need for a nuclear power plant to operate in long-pulse with a high Availability, will imply strong requirements on the fusion device systems/components that cannot be totally satisfied with current design solutions.

- Tungsten is a commonly assumed candidate for PFC. It is tested in several devices and will be used for ITER divertor. **However, innovative materials, including liquid metals, specific shape, advanced manufacturing and new concept need be explored to address many challenges (high power removing, neutron activation, fatigue, erosion, re-deposition…) depending on plasma conditions.**

- Significant advance has been achieved with RF waves, including long-pulse H-mode operation up to several minutes with several MW. **However, several challenges still need to be addressed to be able to satisfy the power plant requirements (better CD efficiency at high density, hot spots control, high availability of power supply during pulse…).** LHFW is proposed as an alternative CD method at high density for fusion reactor.

- Some progress has been done with NBI heating and current drive (EAST) in terms of bootstrap and non-inductive discharges, but ions beam still need to be improved in terms of fast ions lost and impurities release affecting long-pulse plasma operation.

- In addition to previous first line systems, a lot of other systems as PFC systems, diagnostics, power supplies, cooling systems, gas/pellet injectors,… are currently being developed or/and improved **but for most systems there is still a long way to go to satisfy the requirements of a nuclear power plant in terms of performance, availability and safety.**

Final words

- **Define figure of merits to take into account PWI issues in LPO to be applied for multi-machines tokamaks/ Stellerators comparison**
  - Recycling, retentions , divertor fluence, pumping conditions, wall temperature ?
- **Importance of real time control for LPO**
  - But extrapolability of the control schemes towards ITER and/or reactors needs to be assesssed ?
- **Significant progress on scenarios and on LPO development**
  - We need to understand the part of development that is «local »/machine dependent from the part that can be extrapolated to guide future operation for ITER , or reactor design ?
  - Importance of modelling for development and future extrapolation ?
- **Engineering and nuclear aspects were not fully covered**
- **Thanks for the high quality presentations and discussions**
- **Plan for a similar TM meeting in Nov. 2024 (most likely at IAEA) where major progress are expected on LPO**