Potential research programme for JET upgrade

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JET with Tungsten Wall and ECRH: preparation for re-baselined ITER

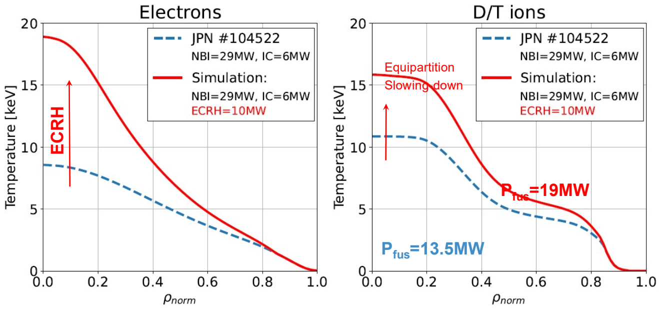
JET: **DT capable tokamak** with fully integrated **Tritium**, control systems, fusion diagnostics and Remote Handling capabilities
ITER re-baselining: 1st **Deuterium** plasmas ~2035, **Tungsten** (W) wall, **ECRH** dominant heating (cost/schedule & DEMO relevance)
Proposal: **JET extension** with **W wall** and **10 MW of ECRH** until ITER ready: design/restart, D, Ww+ECRH+Boronization in H?, **D**, **DT**
Use JET to train ITER staff on a DT machine. Maintain, develop, transfer expertise for next fusion generation, in a real device.

W wall + ECRH: answer ITER and reactor questions

- Prepare ITER operational scenarios, in **D** and **DT**
- **Re-optimize scenarios:** 6MW RF, 30 MW NBI **+10 MW ECRH**
- Confirm efficient **core W screening with central ECRH** → does it allow for better confinement (less gas, less need for ELM flushing)
- Will **core ECRH raise turbulent transport** & **reduce confinement**?
- Will P_{rad} increase or decrease overall? **ECRH** → **Stationarity?**
- Use independent **electron** & **ion** heating to disentangle **fast ion effects** on **turbulence**, anomalous **ion heating**, **α-heating** on electrons.

Hybrid plasmas, ATs, ITBs: β_N> 2.5, maximize fusion

- ILW: Moderate n_e, **low collisionality, hot ions**, central NBI, reasonable W control, low q shear, high q_{95}, moderate ELM's
- Hot electron core → Better W control: lower gas, higher $T_{i,ped}$, $T_{i,core}$, increased confinement, steadier performance
- ECRH and ECCD for **q-profile control** → access higher β regime with high p_{fast}, control MHD, investigate AEs and their effects
- **Raised critical energy** increases **fast ion populations** (NBI, RF, α's): more effects of fast ions on plasma, boost fusion reactions, **Aes**
- When does increased **fast ion** pressure **stabilise turbulence**?
- Reach T_i~T_e from an initial hot ion regime?
- Enhanced core **ion heating** with ECRH added to central NBI/ICRH



ETS H&CD workflow

Baseline plasmas: high I_p & n_e, T_i~T_e dominantly thermonuclear

ILW: high n_e, poor NBI penetration, W accumulation *vs.* flushing by ELMs

- **Re-optimizate**: with boronization, impurity seeding, **enhanced central heating**, sawtooth control, pellets, **small/no ELM regimes**
- aim for **long stationary phases**
- Confinement saturation *vs.* power peaking and central **ECRH** & **ICRH**. Does high n_e+ ECRH lead to **T_i clamping**?
- **Additional ECRH** allows studies in H-mode at higher field, current, simultaneously closer to **fusion-relevant pedestal, f_{GW}, β_θ, ν***
- Particle & energy **transport studies** (L&H mode), transient effects
- Operation with **no divertor cryo-pump** to mimic ITER's relatively **low pumping** capacity (**size** effect, Tritium budget)
- **Isotope studies H, D, T**: various **D+T** mixtures, L-mode, L-H transition (with ECRH, also in **H** at higher I_p, B_t), H-mode
- Mimic ITER's **low activation phase**

FUSION TECHNOLOGY, SAFETY AND DIAGNOSTICS [3,4]

Maintain expertise in Tritium handling integrated with tokamak

Activated Corrosion Product experiment. Sampling existing cooling loops.
Water Activation: 14MeV neutrons activate water, 2.5 MeV don't. DTE3.
Single Event Effect studies. DTE3 tests in basement, move to Torus Hall.
Short term activation study of ITER/DEMO samples. Characterise short term nuclides. Requires programmed exposure in KN2 during DT.
Simulate ITER low activation phase with varying D+T mixtures
Fusion power: ITER regulator requires frequent measurements of fusion power with 2 independent diagnostics, at least 10% accuracy
(1) 14 MeV neutron counting (2) 17 MeV DT gamma rays [5,6]

- Measure DT total fusion power with 14 MeV neutron and 17 MeV gamma ray along same LOS. Reduce uncertainties, no calibration needed

α measurement: use ^{4}He+^{10}B reactions to measure α's, ITER-relevant

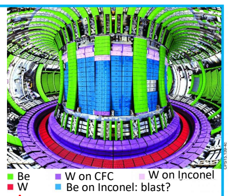
"JET is too old". NO, the tokamak is in good shape, *still intact*.

2025-26 plant inspection, refurbishment, minor upgrades, restart

- **Tritium plant** (AGHS): + storage, parallel processing, **Boron filter**
- **Cryogenics**: replace/repair elements, add He liquefiers
- **Electrical:** inspect PF coils, power supplies, generators
- **Cooling water**: old pipes, add water cooling to some PS
- **Baking plant**: replace blower
- **Glow Discharge Cleaning:** replace electrodes in vessel
- **Shield beams and doors:** integrity to be checked/improved
- **Review neutron budget & Safety Case**, redefine **neutron limit**, allow **Boronization.**
- **Enough Tritium left for new DT campaign.**

2025-27 design & **D** ops, 2028-30 upgrades, 2030-35+ **D**, **DT**, **D** (or **H**)

W Wall: replace Be with W-coated tiles [1], RH



- Recycling, retention, dust, particle balance
- Increased sputtering? W level?
- ECRH **burn-through with W limiter operation**: low n_e, stray radiation? → with I_p **> 1MA**
- Boronization, layer life-time, **Tritium retention???**
- W effect on **disruptions and mitigation**? Consider **2nd SPI**?

Gyrotrons: 10 MW, 170 GHz, X-mode 2nd harmonic, 3T [7,8] STEP, ITER and DEMO-relevant

- Existing, approved proposal, in ILA port. Test multifrequency gyrotrons ? Prototype gyrotron systems can be tested in JET in ~5 years.

Modern control systems: applications to ITER, STEP, JT-60SA, DEMO, including control of heating systems

- **Integrated** tokamak plant **control system** (ITER architecture?): wall & divertor protection, disruption and mitigation, heating, control of burning plasma, q-profile, ITB, MHD, NTM, detachment, dud detection, termination, e-runaways, etc ***with multiple actuators,*** potential applications for AI

[1] Philipps, 2010 FED, 85, Issues 7-9, 1581
[2] JET T&DT Special Issue NF Vol 63, 11 (2023)
[3] Villari ISFNT 2023, [4] X Litaudon NF 2024
[5] Rebai PRC 2024 [6] Dal Molin PRL 2024
[7] Giruzzi et al 2011 NF 51 063033,
[8] Lennholm et al 2011 FED 86 805

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