EFDA EUROPEAN FUSION DEVELOPMENT AGREEMENT
JET

JET DT Plans to end 2006

EFDA- JET Task Force DT

presented by

D Stork

(Leader, Task Force DT)

Euratom/UKAEA Fusion Association,

Culham Science Centre, Abingdon, Oxon OX14 3DB, UK

D Stork for Task Force DT : BPS2 Workshop (San Diego) May 2001

UKAEA

Health warning!

- The JET-EP programme and the JET DT programme described herein are the proposals of the JET-EP team and the EFDA-JET Task Force DT.
- Although they have been favourably received, and have passed all Peer Reviews and Committee Hearings to date -- they do not represent an agreed programme which is fully-funded (funding is being given for work-in-progress).
- The coordinators for the Task Force DT areas are:
  - Jef Ongena(ERM) and Jim Strachan (PPPL) --ELMy H-mode
  - Clive Challis(UKAEA) and Rudolf Neu(IPP) -- OS/ITB plasmas
  - Duarte Borba(EFDA-CSU Culham) and Duccio Testa (MIT) -- α- physics
  - Elena Righi (EFDA-CSU Garching) and Philippe Lamalle (ERM/EFDA-CSU Culham) -- Heating Physics
  - Paul Coad(UKAEA), Rainer Laesser(FzK) and Ralf-Dieter Penzhorn (FzK) --Tritium technology

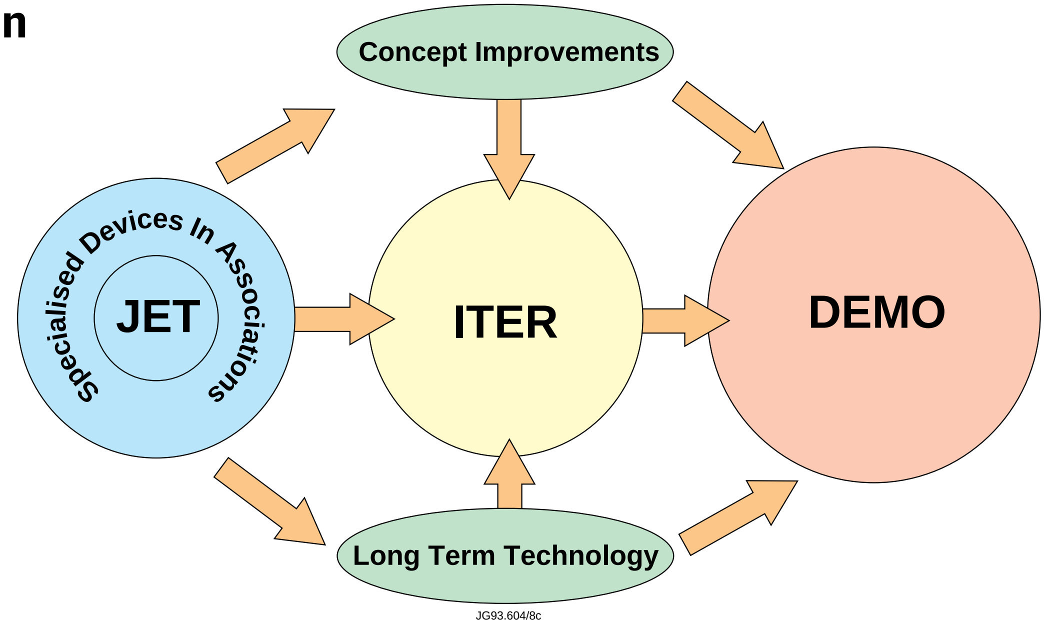
Overview

- Europe's route to a reactor – via a Burning Plasma experiment
- DT issues and the plasmas to address them:
  - Breakdown of issues as $n_T/(n_T+n_D)$, Q and P_α increase
  - Burning plasma – definition and use
- Motivation for JET DT experiments
  - JET's unique DT capability;
  - Reminder of JET DTE1 results –unfinished business
- Strategy for JET DT under EFDA
- Trace Tritium experiment
- JET-EP upgrade
- JET proposed 'DTE2' campaign

Europe's route to a reactor

- Route still runs from the present generation machines (JET under EFDA + Association machines)- via ITER-FEAT to a DEMOnstration reactor.
- ITER-FEAT remains our Burning plasma experiment.

European Fusion Strategy



DT issues and plasmas to address them (I)

- The range of DT plasma issues which can be addressed by a given machine increases as these parameters increase:
  - $n_T/(n_T+n_D)$ tritium concentration
  - $\tau_{scenario}/\tau_E$; $\tau_{scenario}/\tau_{s\alpha}$ pulse length available from load assembly
  - P_α , β_α α – heating power
    - *function of size (energy and fast particle confinement, current) and Additional Heating power*
  - Q fusion gain
    - *function of size (confinement and current) and scenario (+ a* 'threshold' *Additional Heating power)*
- A Burning plasma experiment clearly has an adequate range in all these parameters, but what can be learned from *'sub'* Burning Plasmas?

DT issues and plasmas to address them (II)

DT issue

- Particle transport – isotope effects
- Integrated scenario demonstration
  (Part 1)
  - fuel/mixture control
  - edge and recycling effects
- Energy transport
  - isotopic effects on MHD
  - isotopic effects on χ (incl effects on transport barriers)
- DT additional heating schemes

Plasma range

- Trace –T $n_T/(n_T+n_D) \sim 1–5\ 10^{-2}$
- Low Q; low $P_{\alpha,}$; $\tau_{scenario}/\tau_E > 3–5$
  - $10^{-2} < n_T/(n_T+n_D) < 0.5–1.0$
  - $n_T/(n_T+n_D) \sim 0.5$
- Low P_α upwards ; $n_T/(n_T+n_D) \sim 0.5$
  $\tau_{scenario}/\tau_E > 3–5$
  - $Q \geq 0.2$
  - $Q \geq 0.5$
- Low P_α upwards; $n_T/(n_T+n_D) \sim 0.5$
  $\tau_{scenario}/\tau_E > 3–5$; $\tau_{scenario}/\tau_{S\alpha} > 3–5$
  $Q \geq 0.2$

DT issues and plasmas to address them (III)

DT issue	Plasma range
α – particle effects	‘Significant’ P_α , β_α ; ‘long pulse’ ➢ $\beta_\alpha \geq 2–3\ 10^{-3}$ ➢ $P_\alpha \geq P_{add,e}$ integrated over scenario duration (Q > ~ 0.5 for core effects; >~1 for global effects: depends on P_{add} scheme) ➢ $\tau_{scenario} \geq 3–5\ (\tau_E + \tau_{s\alpha})$
Integrated scenario demonstration (part 2): ➢ α – particle effects	$Q \geq 10$; $\beta_\alpha > \sim 5\ 10^{-3}$; $\tau_{scenario} \sim 10\ (\tau_E + \tau_{s\alpha})$ or more also $\tau_{scenario} \sim 5\ \tau_{He}^* \sim 35–40\ \tau_E$.

The Burning plasma experiment is characterised by its ability to address the ***Integrated scenario demonstration including full α – particle effects and helium ash control.***

By its nature it can, of course, address all the issues involving lower fusion performance.

Motivation for JET DT Experiments: JET's unique DT capability

- JET has a unique capability to study DT tokamak plasmas and processes coupled with a *Divertor configuration* and an operational *Tritium recycling and purification plant.*
- A wide range of ITER-related DT specific physics can be addressed:
  - 'ELMy H-mode' (ITER reference) validation at high density ($n_e \approx n_{Greenwald}$)
    - *concept improvement evaluation (impurity seeding, high triangularity, density peaking)*
  - 'Advanced Tokamak' regime investigation
    - *α-particle confinement with high central q*
    - *isotope effects (threshold, confinement, core-edge interaction)*
  - core α-heating physics and MHD characterisation
  - DT compatible RF heating scheme qualification
- 'Live' tritium technology testing
- Validation and demonstration of high gain plasmas ($0.5<Q<1$)

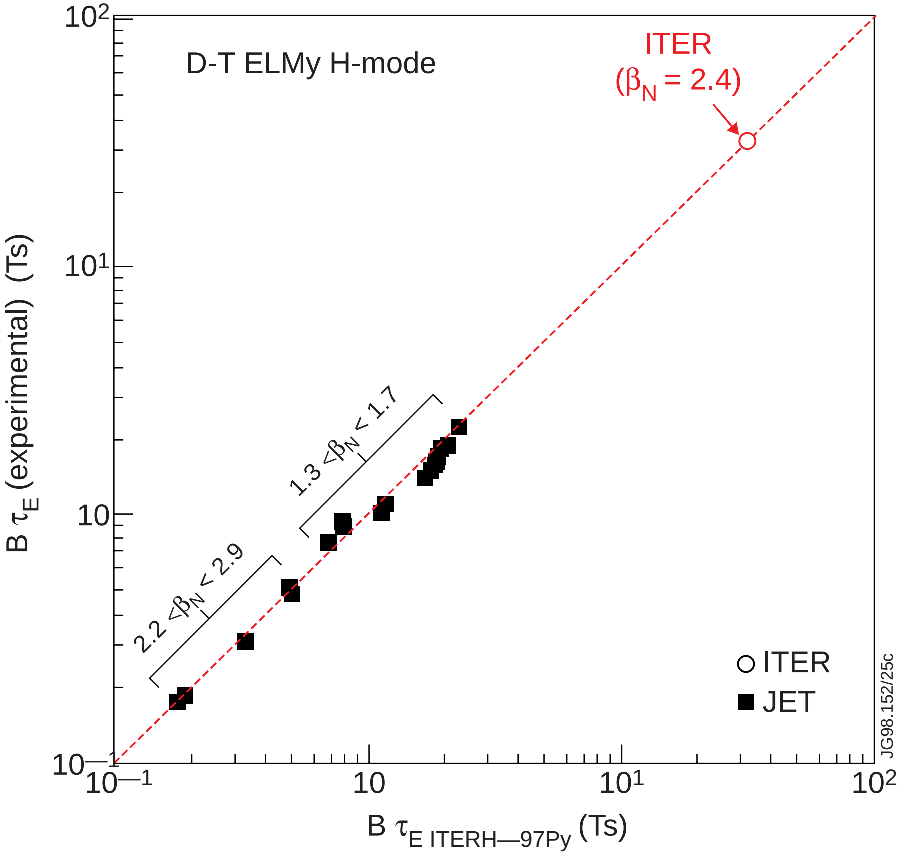
Motivation for JET DT Experiments:

DTE1 experiment results

- A series of DT experiments (with $10^{-2} < n_T/(n_T+n_D) < 0.95$ were performed in 1997 ('DTE1')
- Campaign results featured:
  - successful ELMy H-mode $\rho*$ scaling of DT plasmas to ITER;
  - heat and particle transport in ELMy H-mode DT plasmas similar to DD plasmas (no strong mass dependence $\tau_{E,\,core} \sim M^{-0.17\pm0.1}$);
  - H-mode threshold lower in DT than in DD ($P_{L-H} \sim M^{-1}$);
  - electron heating by α –particles observed in DT plasmas;
  - no instabilities seen to be caused by α – particles ($\beta_\alpha \sim 10^{-3}$ max);
  - record fusion power (16.1 MW) established in ELM-free H-mode (Q~0.65) and fusion energy (22 MJ) in ELMy H-mode (Q~0.22 for 10 τ_E)
  - $2\omega_{CT}$ and high concⁿ (D)T RF heating schemes established, albeit with poor confinement and/or problems;
  - high tritium retention found in carbon surfaces near the divertor – would indicate Safety and 'tritium economy' problems if scaled to a reactor.

DTE1 results : ‘wind tunnel scaling’ to ITER

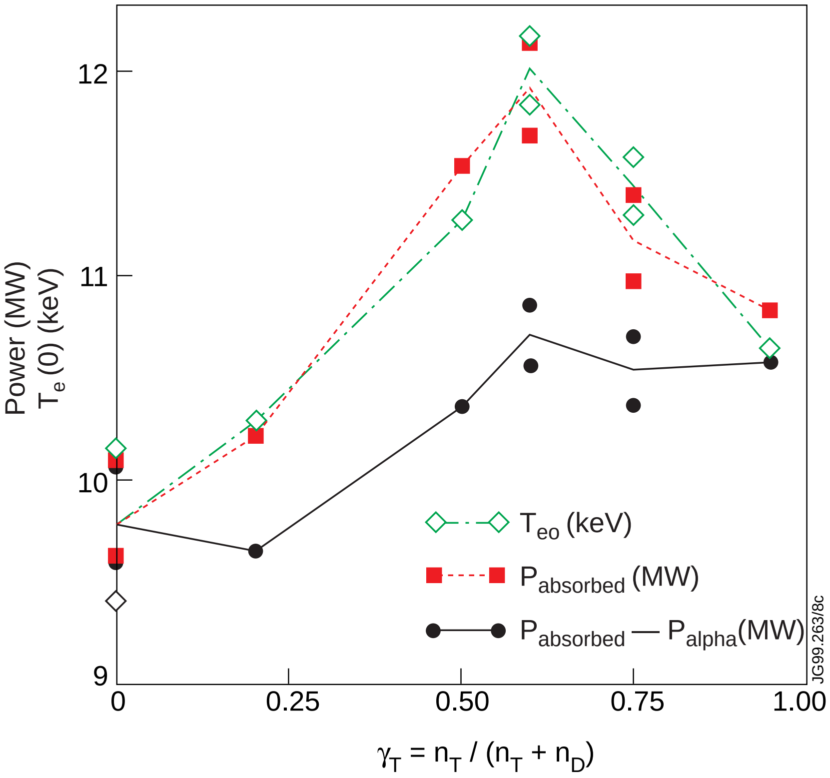
- **JET D–T ‘wind tunnel’ experiments (with ITER q, β_N and $\nu*$) provide most complete data set for extrapolation to ITER (ITER–EDA shown)**
- **Global confinement is close to Gyro–Bohm scaling (short wavelength turbulence)**



J Jacquinot et al, Nuc Fus 39(2)(1999), 235

DTE1 results : electron heating by α – particles

- At fixed input power, the ratio of T:D (including the T^0 NBI : D^0 NBI) was varied in ELM–free H–mode plasmas (Q~0.65)
- $R_\alpha \propto n_T N_D$ thus as $\gamma_T = n_T / (n_T + n_D)$ varies, expect to see $P_{\alpha e}$ reach maximum at ~ γ_T ~ 0.5
- Note that the ELM–free phase lasted only 1–2 $\tau_{s\alpha}$ thus the experiment does not test steady state



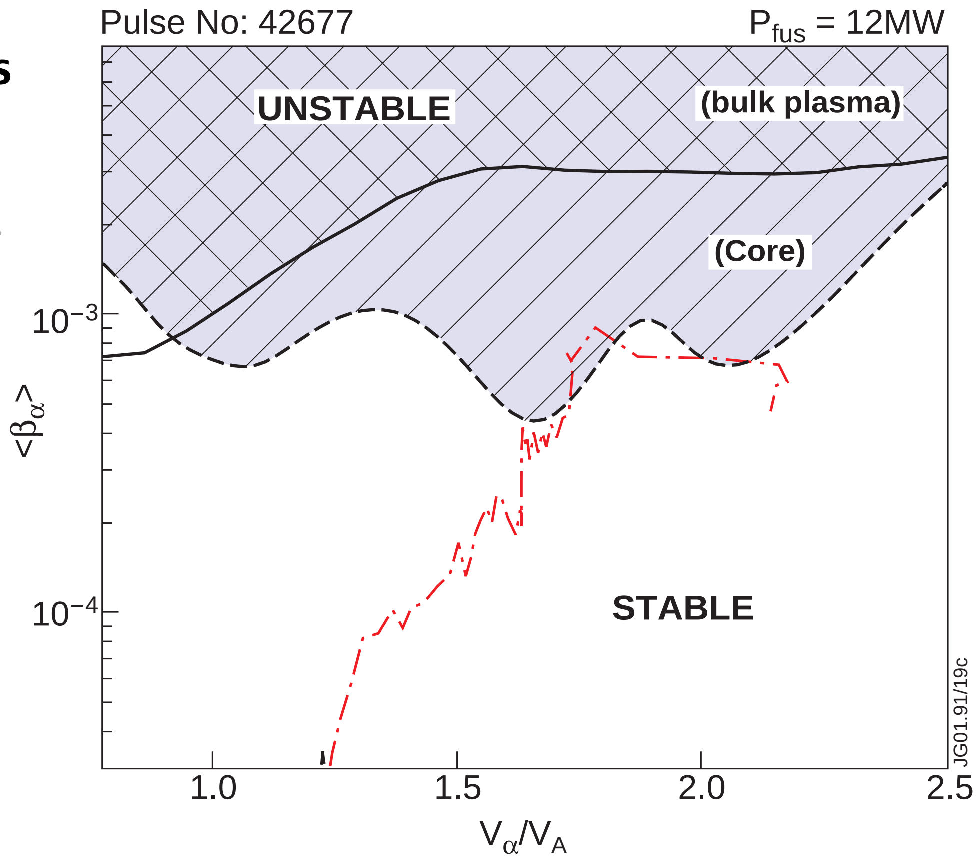
P R Thomas et al, PRL 25(1998),5548

DTE1 results : α – particle instabilities absent

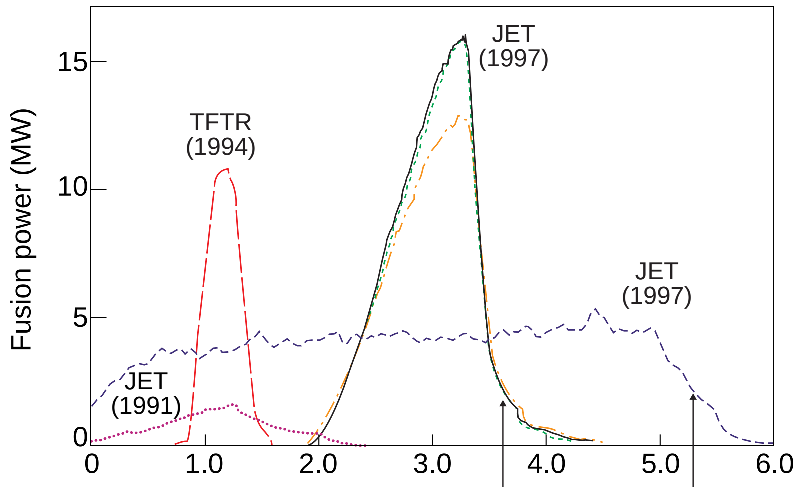
- **ELM-free H-mode DT discharges in DTE1 were close to the lower stable boundaries for core TAE modes, but no instabilities were seen**

  (Q~0.65; P_α ~ 2.4 MW)

S Sharapov

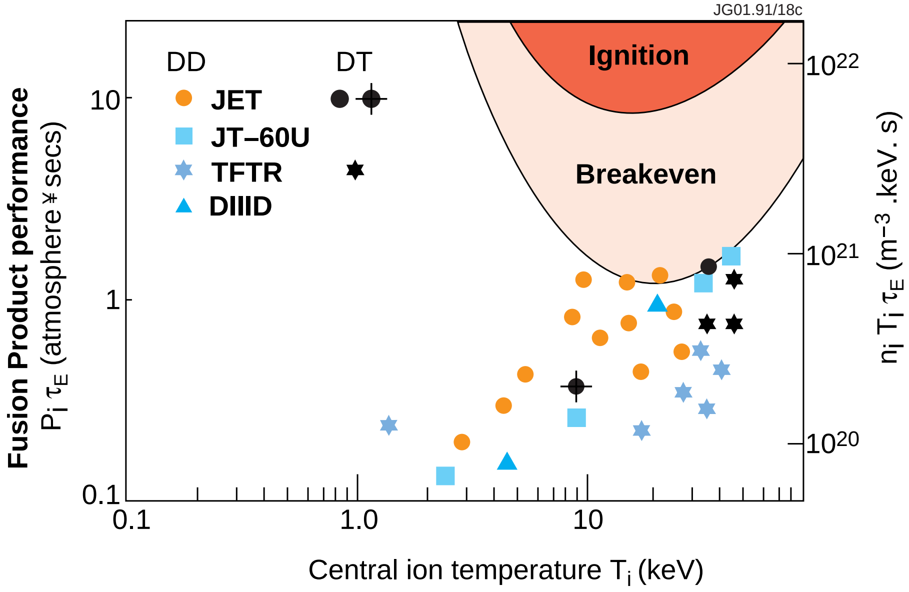


DTE1 results : transient and 'steady-state' fusion power



Transient (<1τ_E)
Terminated by MHD
Q = P_{fus}/P_{in} = 0.6 — 0.7 (●)

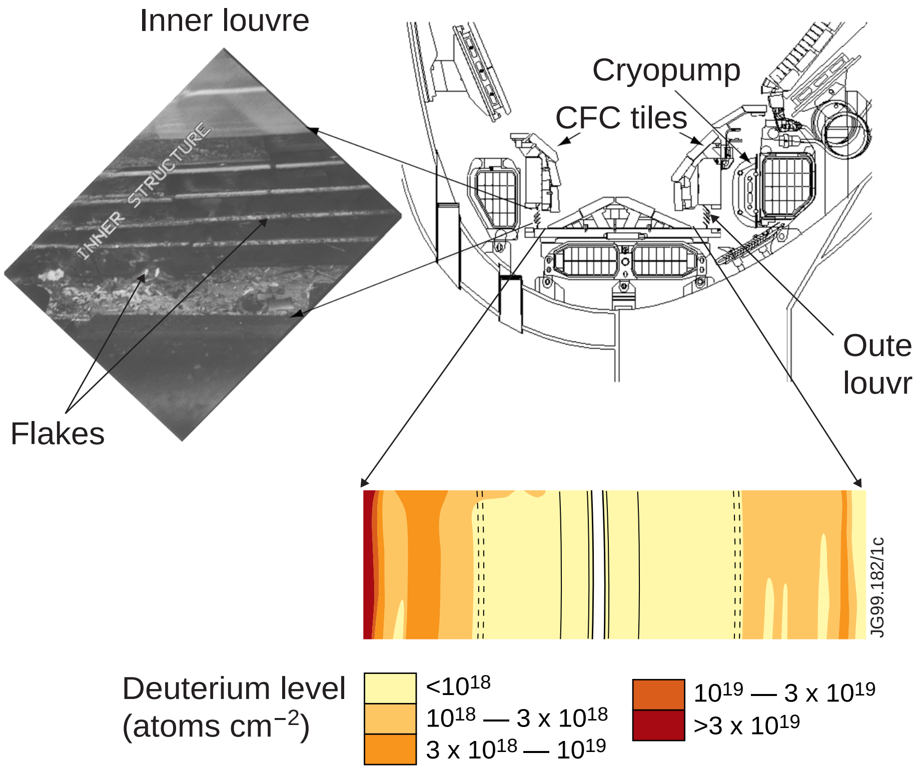
Steady (<10τ_E)
Terminated by design
Q = 0.2 (-●-) (reactor type shot)



JET: M Keilhacker et al, Nucl Fus 39(2)(1999), 209
J Jacquinot et al, Nucl Fus 39(2)(1999), 235
TFTR: K McGuire et al, Fusion Energy 1996 (Vol 1), 19
(IAEA-CN-64/01-2)

DTE1 results : Tritium retention in Torus

JET MKIIa Divertor



- **6 g out of 35 g tritium retained**
  Most retained in carbon flakes at inner Divertor louvres
- **Strong SOL flow drives impurities to inner target**
- **Inner divertor plate is colder, thus deposition dominates**
- **Flakes may result from C_2H_x release from hydrogen-rich amorphous films**

J P Coad at al.

Motivation for JET DT Experiments:

Issues unresolved in DTE1

- In spite of DTE1's success, there are several issues addressable in a sub-burning plasma which were not satisfactorily resolved or where new advances have opened up, or may open up, new experimental opportunities.
- ELMy H-mode -- work near $n_e \sim n_{GW}$ -- $T_e \sim T_i$ regimes -- deep fuelling profiles -- scaling to ITER?
- Optimised shear/ Advanced Tokamak -- never satisfactorily demonstrated in DT (scenario problems, fuel control) -- develop to steady state -- higher P_{add} available;
- Particle transport -- not systematically investigated;
- α – particle physics -- higher P_α would be available in SS OS/AT plasma;
- RF DT scenarios , systematic work with polychrome heating and more use of (^{3}He)DT.

Strategy for JET DT physics under EFDA

- **2002: Begin scenario development at high I_p, B_T and high power(including increased NBI power) for high-density ELMy H-mode and steady-state Optimised Shear mode;**
  develop 'afterglow' TAE mode scenarios.
- **2003: Systematic Trace tritium experiments on particle transport and (if possible) T-doped D pellet experiments to tag ablatant transport; HH and DD experiments to provide part of isotope scaling (eventually to include DT) database on MHD and ITB phenomena.**
- **2004: JET-EP upgrade**
- **2005: Develop higher power RF scenarios for $T_e \sim T_i$ in ELMy H-mode and OS/ITB plasmas; final scenario development at high power**
- **2006: apply ECRH to stabilise NTMs in ELMy H-mode;**
  (mid) final DTE2 experiment

Trace-tritium experiments

- **Previous JET data on trace-tritium was performed all in one day. Although the data suggested Gyro-Bohm particle transport scaling in the plasma core, the data was plagued by collinearity and signal:noise problems, also no work on particle transport by ELMs was done.**
- **To improve this, and simultaneously to exercise and retain the Facility's expertise to handle a DT campaign, Task Force DT have proposed a Trace Tritium experiment (mg of T_2 into JET) to study:**
  - **particle transport scaling in ELMy H-modes ($\rho*$, $\nu*$, β) for fuel-ions, impurities and injected He 'ash';**
  - **fuel-ion transport in OS/ITB plasmas, important for mixture control questions, relevant to a full DT programme;**
  - **effect of ELMs on fuel-ion transport;**
  - **pellet injection with '1% T-in-D' pellets and ablatant transport, especially for high field side injection**
- ***Studies would generate ~ $5.5\ 10^{18}$ 14 MeV neutrons ~ 0.3% of the neutrons allowed under the JIA***

JET-EP (Enhanced Performance) upgrade

- This upgrade to the JET facilities would:
  - Provide more flexible and higher power heating systems;
  - allow ITER-like configurations at higher plasma current (4+ MA);
  - extend the useful life of the device to 2006
- Research programme in support of ITER aimed to:
  - investigate tokamak physics in the reference ELMy H-mode and ITB scenarios;
  - act as a technology test-bed for ITER subsystems

JET-EP (Enhanced Performance) upgrade

JET capabilities after the EP upgrade

Usual JET ingredients:

- Large size coupled with Divertor configuration
- NBI 18 MW now ⇒ 25 MW in 2002
- ICRH 7 MW (range 3-11 MW)
- LH 4 MW +
- Be and full Tritium capability

plus

- ICRH 7-8 MW ITER-like antenna
- ECRH 5 MW upgradeable to 10 MW
- new Divertor Mark II HP
- new Diagnostics
- Pellet Enhancements (and possibly NBI) scale to be decided

JET-EP (Enhanced Performance) upgrade

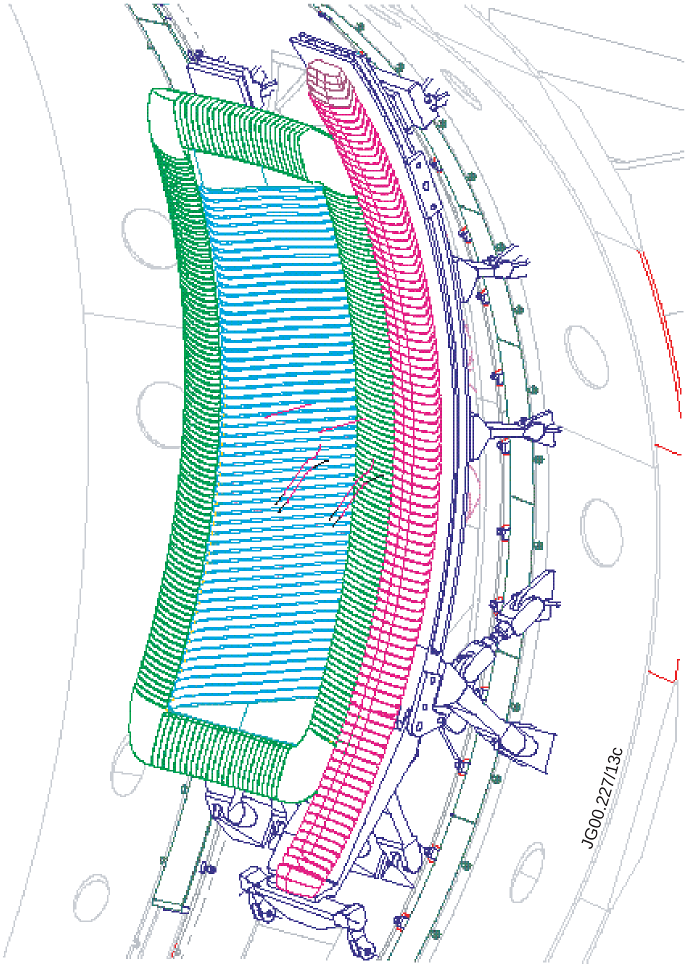
New ITER-like ICRF antenna

ITER relevant features

- **High power density**
  target ~ 8 MW. m^{-2} @ 4 Ω .m^{-1}
  (R_c=1.3Ω)
- **ELM resilience**
- **High power in 30-55 MHz range**
- **Be Faraday screen**

Resonant Double Loop design as in

Tore-Supra -- to be tested with large ELMs in JET-EP

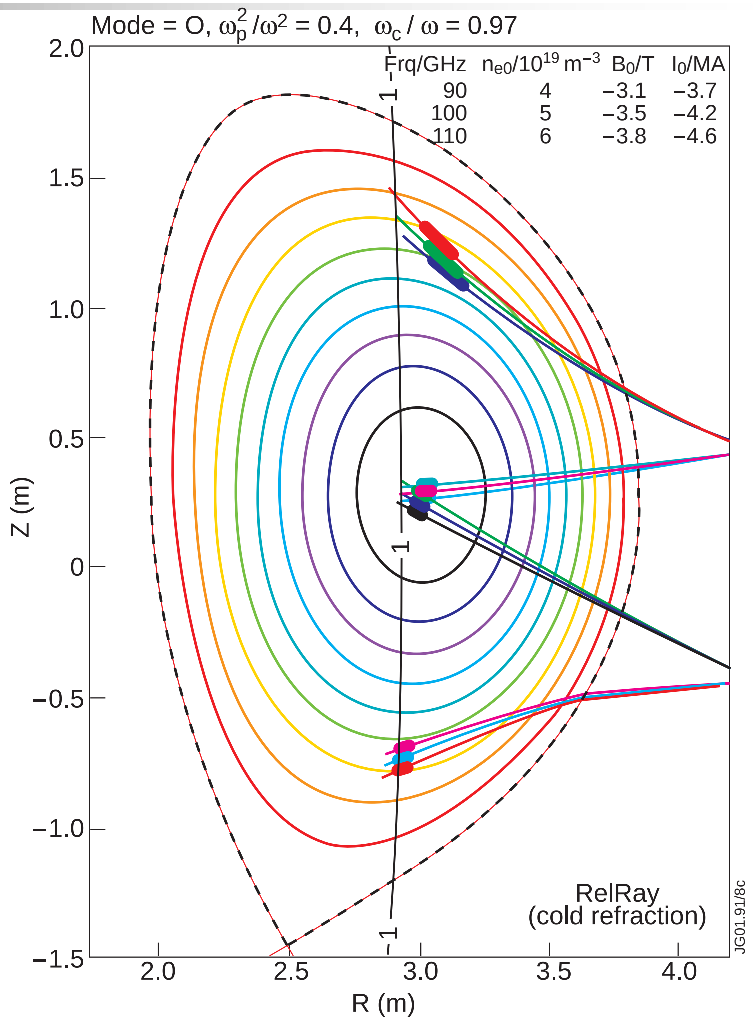


JET-EP (Enhanced Performance) upgrade

ECRH system

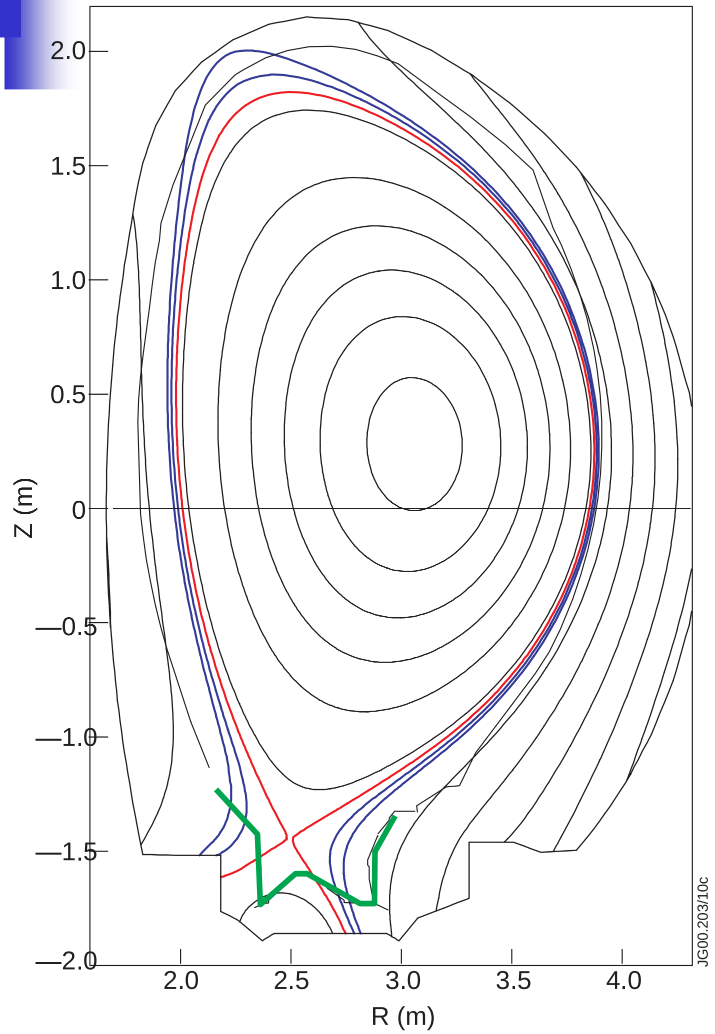
Technical set up

- **6 gyrotrons ~113.3 GHz; 1 MW each ; 10s**
- **gyrotrons with depressed collector**
- **double-containment diamond window at Torus**
- **closed or evacuated waveguides? Tbd**
- **plug-in launcher, 8 beams per port**
- **2 beams on each final mirror**
- **beam radius at absorption location: 60-80 mm**
- **last mirror steerable**
  $-45° < \phi_{tor} < +45°$
  $-30° < \theta_{pol} < +30°$

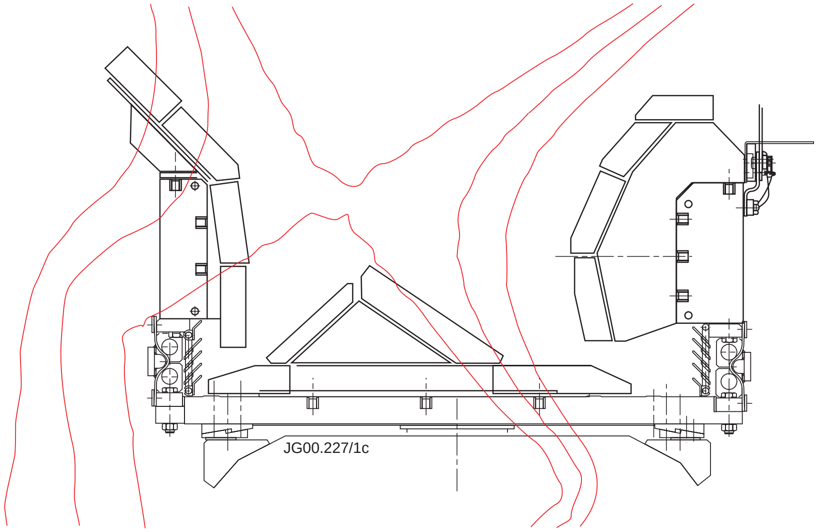


JET–EP (Enhanced Performance) upgrade

Mark II–HP divertor (50 MW, 10s)



- •Re-use Mark II support frame
- •Complete Remote handling installation
- •Radiatively-cooled CFC tiles
- •Sweeping at high power (up to 20s at 25 MW conducted power
- •ITER triangularity **δ = 0.45**



JET 'DTE2' Physics Programme
Major Programme Areas

- The JET Implementing Agreement (JIA) allows a total of 2 10^{21} 14 MeV neutrons within the lifetime of JET (considerations of radioactive waste disposal – which falls on the UKAEA as Operator). DTE1 used ~ 2.5 10^{20} neutrons.
- We therefore have (in principle) ~ 17.5 10^{20} neutrons to 'spend' under the JIA for a major JET DT programme (DTE2)
- Task Force DT proposal to the JET-EP Phase Ad-Hoc Group is to exploit JET-EP heating & current drive system capabilities with five major programme areas
  - 'ELMy H-mode' integrated ITER reference regime DT programme
  - 'Optimised Shear'/'Advanced Tokamak' integrated scenario DT programme
  - α–particle physics and related MHD studies
  - Heating physics assessments
    - *DT programme of ICRF heating schemes*
  - Tritium technology issues
    - *tritium retention studies*
    - *tritium cycle and processing studies*

JET 'DTE2' Physics Programme

Programme Area I: 'ELMy H-mode' Regime

- **'ELMy H-mode' programme**
  - **Validate integrated plasma regime in DT**
    - ***high current***
    - ***Greenwald density***
    - ***'acceptable' edge conditions***
  - **Assess reference scenario concept improvements**
    - ***high triangularity – low*** $Z_{effective}$
    - ***impurity seeding – RI-mode***
    - ***'natural' density peaking***
    - ***pellet fuelling***
  - **Study isotope scaling of NTMs**
    - ***stabilisation/de-stabilisation***
  - **Extend** ρ^* **scaling of ELMy H-mode behaviour in DT to ITER –** ***2nd priority***
  - **Probe local transport using modulated ECRH –** ***low priority***

JET ‘DTE2’ Physics Programme

Programme Area II: ‘OS/AT’ Scenarios

- ‘Optimised Shear’/‘Advanced Tokamak’ (OS/AT) programme
  - Investigate isotope effects in OS/AT plasmas
    - *accessibility conditions*
    - *confinement and performance*
  - Establish ‘steady-state’ DT high performance regime at high density for comparison with ELMy H-mode
    - *aim for* $\tau_{pulse} \approx 5\tau_{\alpha\ slowing\text{-}down}$
    - *aim for higher Q in similar conditions or similar Q at reduced current*
  - Study electron heating regime in DT
    - *ITER-like heating, fuelling and torque*
  - Assess α-particle confinement and heating in OS/AT plasmas
    - *low interior poloidal field*
  - Maximise fusion yield and/or Q – *low priority as sole objective*

JET 'DTE2' Physics Programme

Programme Area III: α–physics and MHD

- α–particle physics and related MHD programme
  - Extend α–particle heating experiments
    - *scan DT fuel ratio and plasma content as in DTE1*
    - *higher power*
    - *study ion heating in the presence of energetic α–particles*
  - Investigate α–particle driven Alfven Eigenmodes
    - *after glow experiments (as used on TFTR)*
    - *high β'_α (compared with previous experiments)*
    - *high n modes*
  - Study α–particle relationship with sawteeth, fishbones, other MHD
    - *stabilisation/de-stabilisation of MHD modes by α–particles*
    - *re-distribution of α–particles by MHD modes*
  - Isotope scaling of TAE physics
  - Parasitic absorption of LH power by α–particles – *2nd priority*

JET ‘DTE2’ Physics Programme
Programme Area IV: Heating Physics

- Heating physics programme (inc. proposed RF capabilities in JET-EP)
  - Further assess $2\omega_{CT}$ RF heating in DT plasmas – main ITER scenario
    - *fast particle losses due to sawteeth – optimise phasing*
    - *power modulation to measure direct electron heating*
    - *polychrome heating to minimise fast ion tail temperature*
  - Investigate physics of high minority concentration (D)T RF heating physics
    - *competing processes – mode conversion, ^{9}Be absorption*
    - *parasitic absorption on energetic α-particle population?*
  - Establish ELMy H-mode with high power (^{3}He)DT – main ITER scenario
    - *low concentration required (2-3%)*
    - *polychrome heating, high density*
  - Further study low minority concentration (H)DT heating – *2nd priority*
    - *potential low B ITER scenario*

JET ‘DTE2’ Physics Programme

Programme Area V: Tritium Technology

- Tritium technology programme (in parallel with other programmes)
  - Many issues can be addressed provided gram quantities of tritium are introduced into the torus
  - Tritium retention programme
    - *tritium inventory and clean-up measurements*
    - *tritium retention in introduced samples*
    - *studies of flakes, other materials?*
  - Tritium cycle and processing programme
    - *PERMCAT de-tritiation unit*
    - *nickel catalyst beds*
    - *exhaust analysis (tritiated hydrocarbons, etc)*
  - Tritium breeder blanket module experiments – *yet to be assessed*
  - In DTE1, the site inventory was 20g T_2 . 35 g was supplied to the Torus and 64 g to the NBI due to the recycling capabilities of the plant,
    For DTE2 we have , in principle, a site limit of 90 g.

JET 'DTE2' Physics Programme

Summary of Hardware/Diagnostic Developments Required

- Lost α–particle detectors
- NPA system with multiple lines of sight
- New AE antennas for high-n modes
- Improved helium concentration measurement capability
- High quality core electron T_e measurement capability, incl. at high density
- Tritium pellet injector
- Tritium technology (many activities by Operator)
  - Whole tiles or layers for wall material qualification (e.g. beryllium, tungsten)
  - Microbalance for deposition measurements
  - Clean-up hardware
  - Completion of commissioning of nickel catalyst bed for tritium cycle studies
  - PERMCAT installation and commissioning
  - Exhaust gas analysis devices
  - Installation of existing breeder blanket device

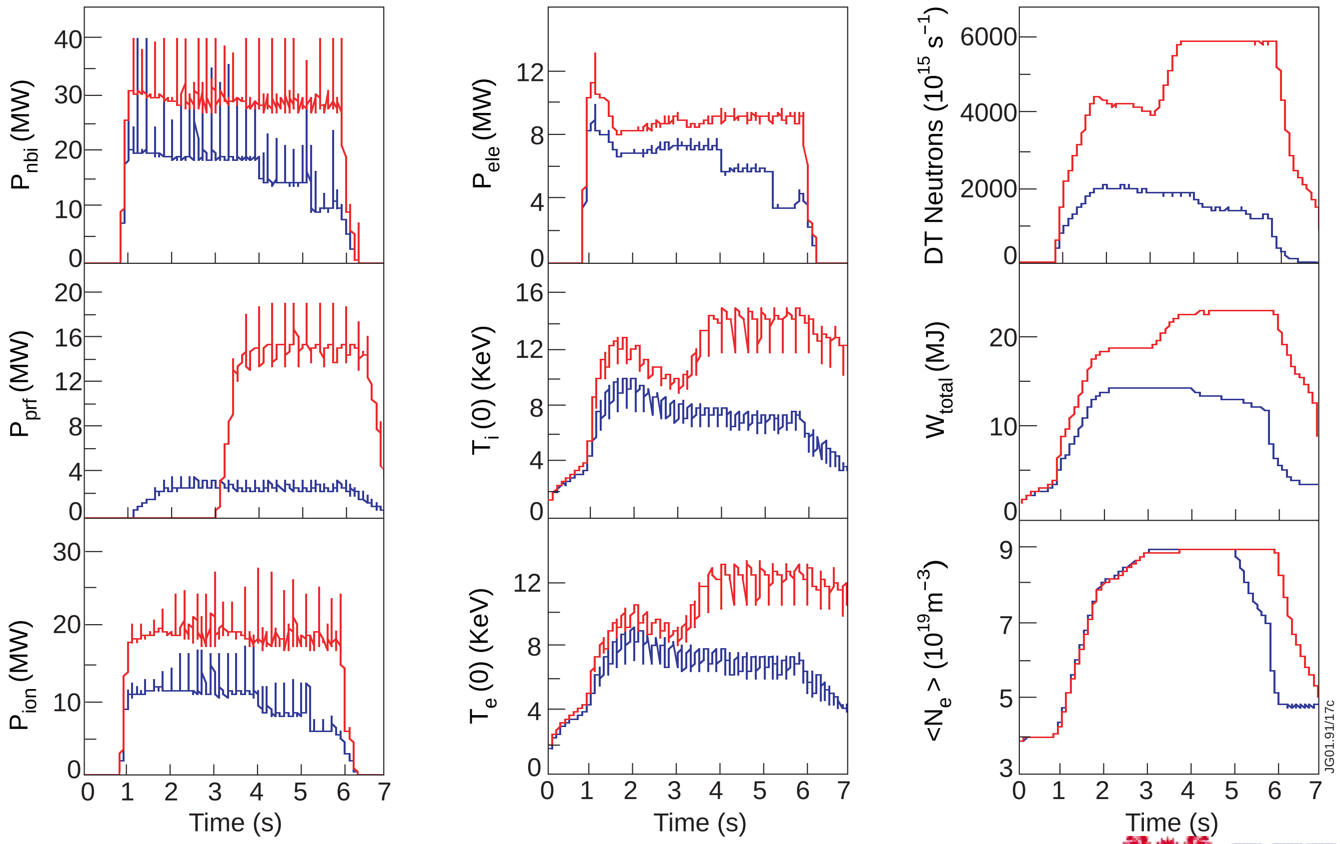
EUROPEAN FUSION DEVELOPMENT AGREEMENT

JET ‘DTE2’ Physics Programme

High performance ELMy H–modes predicted

PRETOR code simulation -- H P L de Esch (CEA, Cadarache) Q~0.35

4.5 MA / 3.4T, Elmy H-mode.
JET-EP [19.5 MW 150 KeV T^o; 13 MW 80 KeV D^o, 15 MW idealised RF (50% to ions)]
DT Pulse No: 42983



JET DTE2 *Gedanken* DT Programme
DTE1 Experience

- **For planning purposes, and to convince the UK regulatory authorities, we must have a realistic estimate of numbers of pulses (length of programme), neutron budget and likely tritium inventory.**
- **Good preparation with deuterium plasmas vital to establish reliable scenarios before DT campaigns to minimise wasted neutron production**
- **To calculate neutron production we take:**
  - **Estimates of performance from scaling or from success-oriented targets;**
  - **'Overhead' ⇒ no. 'set-up' pulses and failures per 'good' pulse based on DTE1 experience.**

DTE1 programme	'set-up' & failure : 'good' puls
ELMy H-mode	2 : 3
OS regime	3-4 : 1
Hot-ion H-mode	1 : 1
α-heating experiments (Hot-ion H-mode – inc. repeats	3 : 2

JET DTE2 *Gedanken* DT Programme *Estimated Neutron Budget (I)*

- ‘Real-time’ control valuable to minimise neutron overhead thus can prematurely stop heating plasmas that deviate from required performance trajectory
- Examples of performance assumption for accountancy purposes ($Q \equiv P_{fus}/P_{in}$)
  - ELMY H-mode – $Q \approx 0.2$ in DTE1 at 4.5MA/3.4T, $Z_{eff} \approx 2.5-3.0$
    assume : P_{in}=47MW; Z_{eff}=1.65; t_{pulse}=5s ; scaled from PRETOR
    ⇒ $Q \approx 0.63$; $P_{fus} \approx 30$MW; neutrons≈5 10^{19} per pulse (≈3% of total budget)
    (note beneficial effect of improvement of plasma purity).
  - ELMy H-mode (^{3}He)DT minority or (D)T high concentration minority heating
    $Q \approx 0.22$ in DTE1 high minority (D)T scheme at 3.8MA/3.8T
    assume : P_{RF}=15MW; $Q \approx 0.25$; t_{pulse}=5-10s
    ⇒ $P_{fus} \approx 4$MW; neutrons≈0.7-1.3 10^{19} per pulse
  - Low I_P/B_T cases and other heating scenarios assumed to achieve lower yield
- Estimate ‘realistic’ budget (based on historic failure rate) and ‘minimum’ budget (based on perfection).
- Set ‘Management Limit’ between the two to encourage good preparation and ‘Expansion programmes’ to capitalise on success of minimising yield.

JET DTE2 *Gedanken* DT Programme
Estimated Neutron Budget (II)

Programme Area	Sub-programme	'Realistic' Neutron Yield	'Minimum' Neutron Yield
ELMy H-mode *12 good pulses*	Greenwald Limit scans Greenwald Limit in other regimes NTM isotope scaling at 1.8T/1.8MA	$2.70\ 10^{20}$ $1.38\ 10^{20}$ $1.31\ 10^{20}$	$2.18\ 10^{20}$ $1.08\ 10^{20}$ $1.00\ 10^{20}$
OS/AT Regime *10 good pulses*	High yield steady-state demo Isotope scaling Dominant electron heating	$3.80\ 10^{20}$ $1.20\ 10^{20}$ $0.60\ 10^{20}$	$2.40\ 10^{20}$ $0.75\ 10^{20}$ $0.38\ 10^{20}$
α-physics & MHD *8+ good pulses*	α-particle heating α-particle driven AE modes Other physics	$2.60\ 10^{20}$ $1.70\ 10^{20}$ $0.40\ 10^{20}$	$1.50\ 10^{20}$ $1.10\ 10^{20}$ $0.40\ 10^{20}$
Heating Physics *8+30 good pulses*	2ωCT, (T)H, (T)D and (H)DT High concentration (D)T heating (3He)DT high power ELMy H-mode	$0.03\ 10^{20}$ $0.40\ 10^{20}$ $0.37\ 10^{20}$	$0.03\ 10^{20}$ $0.27\ 10^{20}$ $0.27\ 10^{20}$
Clean-up		$0.50\ 10^{20}$	$0.50\ 10^{20}$
Total	1st priority expts. 60-70 good pulses	$16.99\ 10^{20}$	$11.86\ 10^{20}$
Expansion Work	ρ^* scan	$1.34\ 10^{20}$	$0.88\ 10^{20}$

Conclusions (I)

- **Previous JET and TFTR DT experiments very successful both in physics and technology terms**
- **Many questions still unanswered**
  - **Advances in scenario development since last DT experiments**
  - **Issues raised by analysis of previous investigations**
  - **Increased power/capability available**
- **A Sub-Burning Plasma Experiment can address all DT issues except those associated with an Integrated scenario demostration of α -particle and He ash control – although for Q<1 specific α -particle effects can only be addressed tangentially. JET has a unique capability as a Sub-burning plasma experiment to address a wide range of DT issues**

Conclusions (II)

- A programme has been proposed to cover a wide range of experiments focused on ITER specific issues
  - Within JET-EP time frame (2006)
  - Within JIA neutron limitations (a Management Limit of $1.4\ 10^{20}$ neutrons is proposed)
  - Within the tritium site inventory (50 g of tritium is estimated)
- The proposal received the favourable endorsement of the JET-EP Ad-Hoc Group in their report (end-March 2001).
- The strategy is to maintain DT capability through early trace tritium experiments and is flexible for ‘end-of-life’ date