QPS Experimental Program
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QPS PAC

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Topics

- **Mission and Experimental Program.**
- **Diagnostic plans.**
- **Capability of present design to address issues:**
  - **configuration flexibility;**
  - **needed heating power.**
- **Heating Plans/Assessments.**
- **Tasks before CDR.**

MISSION

- **Explore the physics consequences of quasi-poloidal symmetry.**
- **Extend stellarator physics to low aspect ratio:**
  - **equilibrium robustness with strong toroidal coupling;**
  - **transport control;**
    - » **bootstrap,**
    - » **confinement,**
    - » **poloidal flows,**
  - **stability;**
    - » **ballooning,**
    - » **neoclassical tearing modes.**

Specific Issues

PROGRAM AREA	PHYSICS ELEMENTS
VACUUM MAGNETIC GEOMETRY, FLEXIBILITY	startup/low beta geometry: dominant |B| components, ergodic regions, islands, aspect ratio, ellipticity, triangularity, helical axis, etc.
MHD EQUILIBRIUM, ROBUSTNESS OF FLUX SURFACES	finite-beta geometry: flux surfaces, magnetic axis shift, interior ergodic regions and magnetic islands
BOOTSTRAP CURRENT	variation (reduction) with coil currents, effect on magnetic islands, ergodization of flux surfaces, and tearing modes
POWER BALANCE	power deposition, power losses
TRANSPORT	electron density profile, electron temperature profile, ion temperature profile, electric field
MHD INSTABILITY	frequency spectrum, mode structure, correlations
PLASMA EDGE, DIVERTOR GEOMETRY	limiting aspect ratio, edge magnetic structure and islands, diverted flux bundle

Notional QPS Operations Plan

FY2006		FY2007	FY2008	FY2009	FY2010
	Ph 0	Ph 1	Ph 2	Ph3	Ph 4
constructior	commis-sioning	mapping	configuration characterization	Heating & Confinement	MHD equilibrium & stability
ECH Power	0.2 MW		0.5 MW	1 MW	1 MW
ICRF Power				0.1 MW	2 MW
1st gyrotron		2nd gyrotron	3rd & 4th gyrotron	test antenna	two ICH antennas
diagnostics					
start set in project	long	e-beam	Soft X-ray arrays	charge-exchange	filterscopes	edge interferometer
CCD camera	lead	screen	Spectroscopy	Thomson scattering	divertor probes	high freq. magnetic loops
H-alpha	diag.	or rods	Rogowski coils	reflectometer	IR camera	fast X-ray array
diamagnetic loop	prep		Magnetic loops		divertor bias	additional diagnostics??
interferometer			Bolometers		fluctuation diagagnostics	
divertor					
passive, low power			Test Div. plates	medium power plates, baffles	upgrade?

blue = in project black = funded from operations red = TBD

Commissioning

Heating/Divertor	Diagnostics	Measurements
ECH ~ 200 kW passive, low power	CCD camera H-alpha diamagnetic loop interferometer	test coil sets, power supplies, controls, vacuum quality, “pink glow” plasma”

Field Line Mapping

Heating/Divertor	Diagnostics	Measurements/Analyses
--	e-beam, fluorescent screen or rods	examine surface quality for various configurations, vary e-beam energy field to look at drift orbits

Configuration Characterization

Heating/Divertor	Diagnostics	Measurements/Analysis
ECH ~ 500 kW test plates	soft x-ray arrays, spectroscopy, diamagnetic loops, magnetic loops, bolometers	characterize stored energy, temperatures, and density for different configurations, evaluate divertor performance, find reference configurations, compare with analyses

Heating and Confinement

Heating/Divertor	Diagnostics	Measurements/Analyses
ECH ~ 1 MW ICH ~ 0.1 Mw medium power plates, baffles	charge exchange, Thompson scattering, diamagnetic loops, magnetic loops, bolometers	measure profiles at significant power and estimate power balance, compare with models, examine neoclassical vs anomalous confinement, measure currents (coils + reconstruction), look for impact on confinement, and bootstrap component, look for flows, test ICH, EBW

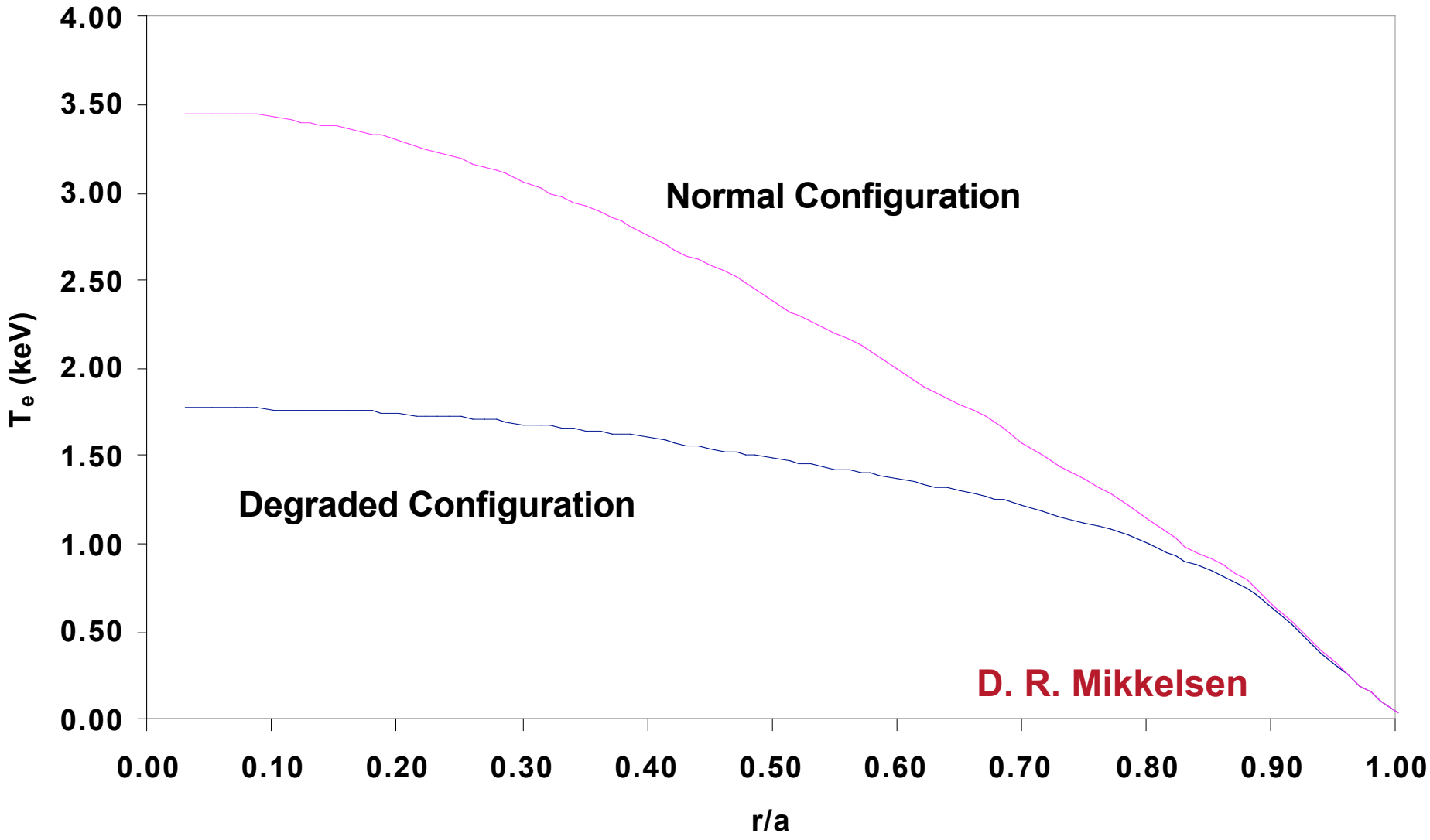
MHD Equilibrium and Stability

Heating/Divertor	Diagnostics	Measurements/Analyses
ECH/EBW ~ 1 MW ICH ~ 2.0 MW divertor bias plate upgrade?	Filtercopes, divertor probes, IR camera, additional fluctuation measurements?	push stability, equilibrium boundaries; characterize fluctuation response, island/erogodic region development. and equilibrium robustness,

Physics of Neoclassical Transport Can be Tested by Varying the Configuration

- Effects of configuration changes are assessed by holding anomalous transport levels constant while varying the configuration.
- Low density, hot electron plasmas show greatest changes between normal and degraded configurations.
- Power of ~1 MW with B = 0.5 T are used for present calculations.

The Change in Neoclassical Transport is Clearly Visible in the Electron Temperature Profiles

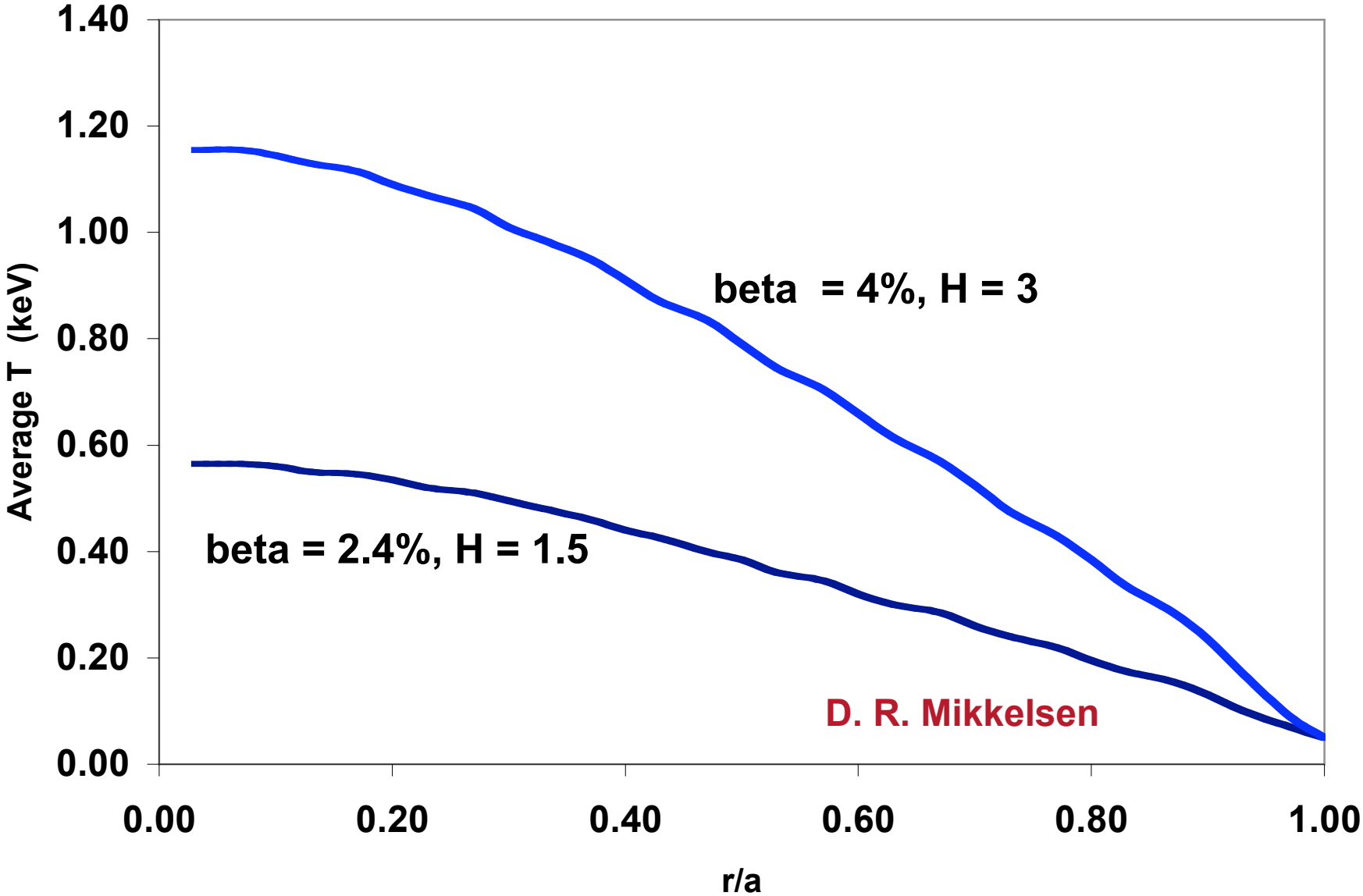


ECH Heating Options

- 53.2 GHz, 2nd harmonic, low field, X-mode launch
  - normal ECH density limit ~ 1.7×10^{13} cm^{-3}
- 28 GHz fundamental
  - low field O-mode launch
  - density limit 0.9×10^{13} cm^{-3}
  - high field launch density limit 1.8×10^{13} cm^{-3}
- 28 GHz, 2nd harmonic, low field, X-mode launch
  - normal ECH density limit ~ 0.8×10^{13} cm^{-3}

Options will be evaluated during project design

~2 MW Is Sufficient for 2% Beta with $n_{avg} \sim 10^{20}$ m^{-3}



Additional Heating Will Be Provided by Low Frequency Systems

- **1.5 Mw at 40-80 MHz;**
  - **HHFW;**
  - **good results on NSTX.**
- **2.0 Mw at 6-20 MHz:**
  - **high field "beach" heating;**
  - **minority (electrons or ions) heating.**

The design allows a range of antenna locations: options will be preserved in design/construction and choices made during experimental program.

EBW Heating Has Been Demonstrated on W7-AS

- **Allows heating of overdense plasmas:**
- **Two gyrotron frequencies will allow overlap in density range.**
- **Edge density gradient control essential:**
  - **islands, control coils used on W7-AS;**
  - **limiters planned for NSTX.**

NSTX program will provide valuable data.

Ballooning Stability Limits Can Tested by Varying Current and Pressure Profiles

<J•B>	Reference	Flatter	More Peaked
Reference	stable	weakly unstable	weakly unstable
Ohmic	strongly unstable	strongly unstable	strongly unstable
Low-edge **bootstrap**	stable	moderately unstable	weakly unstable

I = 60 kA, b = 2.0 %, stability is optimum for I of optimized configuration.

Present Estimates Indicate that Eddy Currents Are Manageable

- **Poloidal currents flow in the structure:**
  - **present estimates for τ are in the 20 ms range;**
  - **significantly longer times could reduce pulse length;**
- **Toroidal currents flow in the vacuum vessel and support structure:**
  - **present estimates for τ are in the 10 ms range;**
  - **significantly longer times could reduce current ramp rates and make plasma control more difficult.**
- **Estimates critical to design will be refined using 3-D eddy current analyses and circuit models.**

Design Provides Flexibility for Diagnostic Geometry

- **Details of placement can be developed as needed during construction as part of pre-ops effort:**
  - **V3FIT collaboration is essential.**

Summary

- **The QPS design provides the needed performance, flexibility, and diagnostic and heating access to fulfill the mission.**
- **A staged plan of heating and diagnostics provides:**
  - **basic device commissioning;**
  - **flux surface characterization;**
  - **configuration exploration;**
  - **electron heating and transport studies;**
  - **high power heating and equilibrium studies.**
- **Essential analyses can be completed to support the CDR.**