Status and Plans for APEX Task A
Plasma/Liquid-Wall Interactions

T.D. Rognlien and M.E. Rensink

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Outline

• Highlights from FY03

• Close-out plans for FY04

• Unresolved edge-plasma issues impacting first-wall/blanket design
Progress in 3 main Task A areas in FY03

• Highly radiating edge plasma for CLIFF design
  – FED papers
    • CLIFF overview paper
    • Divertor integration

• Consequences of convective edge-plasma transport
  – FED paper
    • Convective transport with Task V (Kotschenreuther)

• Continued analysis of low-recycling edge-plasmas (with ALIST/ALPS)
Attached plasma solutions now allow high wall temperature for flibe/flinabe

Improvements in model details of vapor impurity transport to the core has lead to systematic increase in allowable $T_{\text{wall}}$

![Graph showing impurity concentration vs. average impurity gas flux from wall (m$^{-2}$ s$^{-1}$)]

**Temperature Limit Results**
- ITER slab: $T_w = 390$ C
- ARIES-RS, uniform $T_w$: $T_w = 450$ C
- ARIES-RS, nonuniform $T_w$: $T_{in}=300$ C, $T_{out}=480$ C
- ARIES-RS, nonuniform $T_w$, tilted plate, He incl.: $T_w = 515$ C

However, attached plasmas give too large a divertor heat flux
Stable fully-detached edge plasmas have been found that give allowable divertor heat flux

- Careful adjustment of the hydrogen pumping is the key
- Fluorine from flibe is dominant radiator
- Stability to core MARFE or divertor burn-through defines operating window
- Helium removal needs verification

Peak surface heat flux < 10 MW/m²
Detached plasmas utilize high edge-plasma density for radiation efficiency

- Impurity radiation scales as $P \sim n_e n_Z$
Plasma outward convection in the outer SOL may be a substantial source of wall sputtering.

- Experimental data shows large transport in the far SOL, implying ion flux = \(-D \frac{d(n_i)}{dr} + n_i V_{\text{conv}}\)

- UEDGE modeling calculates edge plasma conditions and flux to wall

- NUT neutral code (IFS - Task V) calculates radial penetration of recycled neutrals and return high-energy CX neutral flux

Sputtering from CX neutrals is a serious concern for liquids or solids.
NSTX full-coverage Li modeling: Low recycling increases midplane temperatures by factor of ~2

- Low recycling decreases edge density for fixed source
- For R=0.2, \( \bar{n} \sim L_{||} \)
- Sputtering increases for low recycling (high \( T_e \))

Increased edge temperature may reduce core turbulence
Contamination of core from lithium divertor being modeled by coupling UEDGE & WBC MC code

- Heat and particle flux to module computed by UEDGE
- Temperature rise of Li surface from heat transfer (Ulrickson)
- Sputtering of Li from U. III. composite model (Allain et al.)
- WBC calculates lithium source near the divertor plate (Brooks)
- UEDGE uses this Li source to calculate lithium density throughout the edge region
Lithium flows throughout the SOL, but core boundary concentration appears low

- Lithium concentration peaks in outer SOL and private-flux regions
- Primary forces keeping Li in divertor are $E_p$ & hydrogen drag
- Lower recycling good because
  - Lower sputtering hydrogen flux
  - Monotonic downward $E_p$; $R=0.2$ much better than $R=0.9$
  - Higher sputtering rate is bad
Task A plans for limited FY04 APEX budget focus on strong plasma radial convection

- Evaluate effectiveness of helium pumping with plasma convection (with Task V)
- Determine the impact of helium pumping and plasma convection for highly-radiating detached-divertor-plasma solutions
Initial calculations indicate low helium density in private-flux region

- Attached ARIES-RS case with same convection for hydrogen and helium

- Psi < 1 corresponds to private-flux region where He pumping port is likely

- More detached divertor plasmas may allow better He migration to the PF region
Important unresolved edge-plasma issues with direct first-wall/blanket relevance

- Plasma radial convection and subsequent neutral sputtering of the wall
- Ability to predict the scaling of plasma convection to future devices
- Nature of wall-impurity transport with convection
- Viable locations for helium pumps
- Core and edge-plasma line radiation power-flux profiles and wavelengths
We have succeeded in a first coupling a 3D turbulence code to the 2D UEDGE code

- Within the iterative coupling scheme, the BOUT turbulence is evolved for a time, $t_1 \sim 50-100 \text{ms}$

- During the same iteration step, UEDGE takes a larger time step, with $t_0 > 10 \text{ ms}$

- Resulting final state is thus a statistical steady-state

Comparison of transport and turbulence time scales

UEDGE evolved here by switching from iteration $m=3$ to $m=8$ turbulent fluxes
Surface plots show full structure of final effective diffusion coefficient & neutral density

- Diffusion coefficient has a strong ballooning character as expected for curvature driven modes

- Neutrals arise self-consistently from recycling at the divertor and outer wall

a) Final effective diff. coeff. (m = 9)

b) Final neutral density

Outer divertor

Inner divertor
Summary: Task A has made many contributions to APEX

- Modeled impurity intrusion from liquid walls, thus setting $T_{wall}$
- Evaluated heat flux profiles from particles & impurity radiation
- Analyzed properties and benefits of the low-recycling regime
- Initial study of the effect of strong plasma convection (with Task V)
Future work will focus helium pumping and plasma convection

- Helium pumping for attached plasmas
- Convection and helium pumping for detached plasmas
- Scaling of plasma convection to future devices
- Wall impurity transport with plasma convection