Advanced Design Studies: Recent Accomplishments and Plans

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Electronic copy: http://aries.ucsd.edu/najmabadi/TALKS

ARIES Web Site: http://aries.ucsd.edu/ARIES

Distribution of Advanced Design Research

- Advanced Design area covers a large number of activities:

	FY02	FY03 (Cong)
Next Step option	1,000 + 2,157	2,004
ARIES (IFE & MFE) System Studies	1,945	1,913
Socio-economic Studies	173	198
VLT Management	791	788
Initiatives/Reserves	167	197
Burning Plasma Applications	120	119

- This presentation covers only ARIES and socioeconomic research.
- Dale Meade will cover NSO activities

Socioeconomic Studies

- Socioeconomic Studies were scaled back drastically in FY02 (from 300k to 170k).

- Only two groups performed socioeconomic research in FY02:
  - ✓ PPPL (John Schmidt et al.)
  - ✓ PPNL (John Clarke et al.)

- A paper by W. Meier, F. Najmabadi, J. Schmidt, and J. Sheffield was presented at 18th Congress of World Energy Council in Argentina.

PPPL Socio-Economic Studies

- If fusion realizes its development goals it will be part of a portfolio of energy sources during the last half of this century
- The systems aspects of this portfolio will become important because the value of one energy sources depends on the other elements in the system
- A statistical analysis shows an interesting relationship between time varying sources such as wind and high availability systems such as fusion
- Energy storage will probably play an increased role in future energy systems and must be factored into our analysis
- Systems studies have yielded surprising initial results on the relationship of energy storage to systems such as fusion and sources such as wind
- These initial results will be discussed at the ISNFT meeting and further developed with the Princeton University Center for Energy and Environmental studies during next fiscal year.

ARIES Research Plans

- SEAB and FESAC have recommended power plant studies for both inertial and magnetic fusion systems. Thus, OFES decided in FY00 that ARIES Team will perform both IFE and MFE research.
- ARIES-class MFE and IFE studies together require an annual budget of about $3.8M, much larger than present funding.
  - ✓ ARIES Effort was divided between a large-scale (~ 3/4 effort) and a small-scale (~1/4 effort) studies.
- During the last two years, we have performed a major IFE study (ARIES-IFE) and smaller MFE research.
- Interaction with OFES, VLT director, and community leaders indicate the desire for a shift in emphasis:
  - ✓ A major MFE study focusing on compact stellarators;
  - ✓ Continuation of IFE research at a lower but viable level.
- But both these activities cannot be done under the present budget (discussed later). We need advise from VLT PAC and VLT director and decision by OFES on how to proceed.

ARIES Program charter was expanded in FY00 to include both IFE and MFE concepts

MFE activities in FY02 (~30% of total effort):

- **Systems-level examination of RFP** to assess impact of recent physics data on TITAN RFP (vintage 1988) embodiment.
  - ✓ RFP community provides physics input on a "voluntary" basis.
  - ✓ ARIES Team provides system and engineering support.
  - ✓ Project will be completed by the end of FY02.
- **Preparatory study on compact stellarators**
- **Update of ARIES System code**
  - ✓ Combined effort by PPPL/UCSD.
  - ✓ Project will be completed by the end of FY02.
- **Collaboration with European Power Plant Study**:
  - ✓ A new Task (task 9) has been initiated under IEA cooperative agreement on the environmental, safety, and economics aspects of fusion power.

ARIES Program charter was expanded in FY00 to include both IFE and MFE concepts

IFE activities in FY02 (~ 70% of total effort):

- **Continuation of ARIES-IFE project**
  - ✓ **Scope:** Analyze & assess integrated and self-consistent IFE chamber concepts in order to understand trade-offs and identify design windows for promising concepts.
  - ✓ Project will be completed by the end of FY02.
  - ✓ Three classes of chamber options were considered in series in each case both direct-drive (lasers) and indirect-drive (Heavy-ion) targets:
    - Dry-wall chambers: Completed (some on-going work on heavy-ion beam transport)
    - Wetted-wall chambers: Analysis to be completed by March 2002.
    - Thick-liquid wall chambers: March-October 2002.

Dry-wall chambers are credible and attractive options for both lasers and heavy ion drivers.

- Accurate target output spectrum (both laser and heavy-ion) has been produced.
- Time of flight of ions reduces heat flux on the wall significantly.
- Use of an armor separates energy/particle accommodation function from structural and efficient heat removal function:
  - ✓ Armor optimized to handle particle and heat flux.
  - ✓ First wall is optimized for efficient heat removal.
- There is considerable synergy and similarity with MFE in-vessel components.
- Design windows for many components have been identified and a set of self-consistent system parameters have been developed.
- Research in heavy-ion beam transport and focusing for chambers at relatively high pressure (10s mTorr to several Torr) shows that neutralized transport and focusing in 6-m size chambers is feasible. Research in pinch transport is on-going.

ARIES Research Plans for FY03-FY05

We would like to continue ARIES IFE research

- ARIES-IFE has been technically successful. It is an excellent example of , IFE and MFE researchers together and large synergy between MFE
- Continuation of ARIES-IFE effort has been endorsed by IFE community leaders *e.g.*, Sethian letter to Baker (1/01), IFE community leaders to McKnight (9/01), Meier to Baker (1/02).
- New research areas have started that can have major impact in the near future. Continuation of this research will lead to high return per $. ARIES can contribute significantly by examining high-risk high-payoff options.
- Focus of ARIES IFE activities will be critical issues for <u>heavy-ion</u> inertial fusion as highlighted by ARIES-IFE research.
  - ✓ Beam transport and focusing for chambers at relatively high pressure: 10s mTorr to several Torr. Resolution of stand-off issues widens possibilities for heavy-ion chambers and dramatically improves concept attractiveness.
  - ✓ Detailed studies of aerosol generation and transport to explore thin-liquid wall chamber concepts.
  - ✓ Detailed studies of selected system for thick liquid wall concepts.

ARIES Research Plans -- IFE

- Continuation of IFE research by ARIES Team requires ~600k of resources mostly used by IFE advocates/experts.

Beam transport and focusing (LBNL, SNL, MRC)	200k
Target manufacturing, injection, & tracking (GA)	100k
IFE System studies and target yield calculations (LLNL)	100k
Chamber physics and engineering (UCSD, U.W., G Tech)	200k

IFE Advocates/experts	400k
Redirection of ARIES core groups	200k

We would like to initiate a three-year study of compact stellarators as power plants

- Initiation of NCSX and QSX experiments in US; PE experiments in Japan (LHD) and Germany (W7X);
- Review committees have asked for assessment of compact stellarator option as a power plant; Similar interest has been expressed by national stellarator program.
- Such a study will advance physics and technology of compact stellarator concept and addresses concept attractiveness issues that are best addressed in the context of power plant studies.
- NCSX and QSX plasma/coil configurations are optimized for most flexibility for scientific investigations. Optimum plasma/coil configuration for a power plant may be different. Identification of such optimum configuration will help compact stellarator research program.

ARIES-Compact Stellarator Program is a Three-year Study

<u>FY03: Development of Plasma/coil Configuration Optimization Tool</u>

1. Develop physics requirements and modules (power balance, stability, α confinement, divertor, *etc.)*
2. Develop engineering requirements and constraints.
3. Explore attractive coil topologies.

<u>FY04: Exploration of Configuration Design Space</u>

1. Physics: β, aspect ratio, number of periods, rotational transform, sheer, *etc.*
2. Engineering: configurationally optimization, management of space between plasma and coils.
3. Choose one configuration for detailed design.

<u>FY05: Detailed system design and optimization</u>

ARIES-Compact Stellarator Program Plan is a ~$1.9M/year effort

- ARIES-Compact Stellarator study is of the same depth and scope as previous ARIES studies
- ARIES effort is composed of a core group (UCSD, U. W., PPPL, RPI). Advocate/expert groups are brought as needed for each project. Typically 2/3 of budget is for core group (~$1.2M) and 1/3 for advocate/expert groups (~$0.6M).
- Discussion with national stellarator program leaders indicate that ~$600k per year is needed for stellarator experts to participate in the ARIES compact stellarator study. Thus, ARIES-Compact Stellarator program is a ~$1.9M/year effort.

- Unfortunately, continuation of IFE effort at a low but viable level and initiation of compact stellarator activity requires TWO advocate/expert groups to be brought in. There is not sufficient fund at present budget level (small decrease from last year) to do this.

We need advise from VLT PAC and VLT director and decision by OFES on how to proceed.

- ARIES budget in FY99 was ~$2.3M. ARIES Team performed ONE MFE study.
- ARIES budget in FY03 is ~$1.9M. We cannot perform ONE MFE study and a small but viable IFE study.

Directions for ARIES Team Research:

1. Only Compact stellarator research for FY03-FY05. (Constant budget)
2. Compact stellarator and small but viable IFE activity for FY03-FY05 (Requires additional ~$400k per year).

Impact of Various Budget Scenarios

- **<u>Constant Budget case:</u>** Compact stellarator research for FY03-FY05

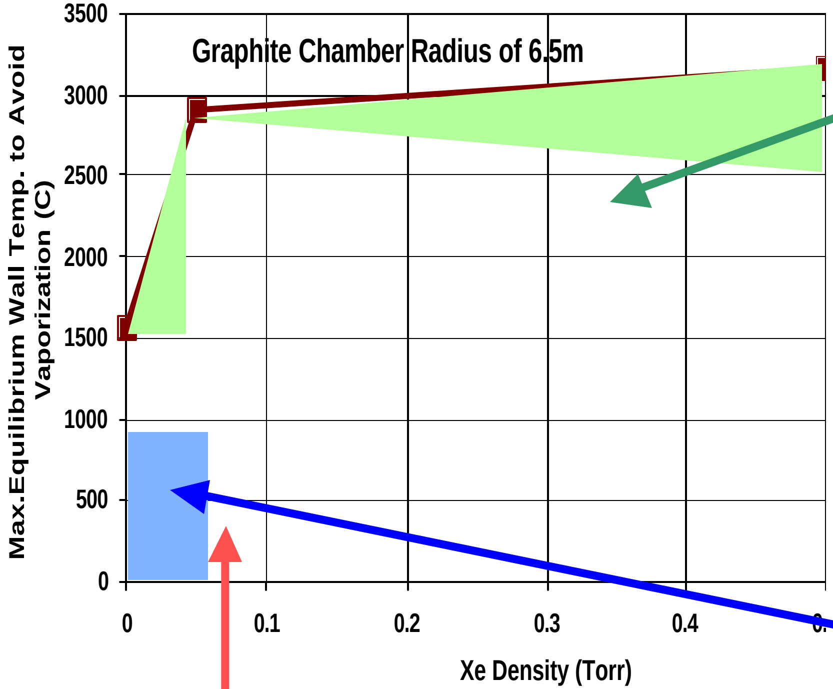
- **+10% Case:** No change in scope. Restore cuts in core groups and healthy support for expert/advocate group.

- **+20% Case:** Perform both compact stellarator research and small but viable IFE studies.

Backup Material

Highlights of results from ARIES-IFE study

Design Windows for Direct-Drive Dry-wall Chambers



Thermal design window

- ✓ Detailed target emissions
- ✓ Transport in the chamber including time-of-flight spreading
- ✓ Transient thermal analysis of chamber wall
- ✓ No gas is necessary

Target injection design window

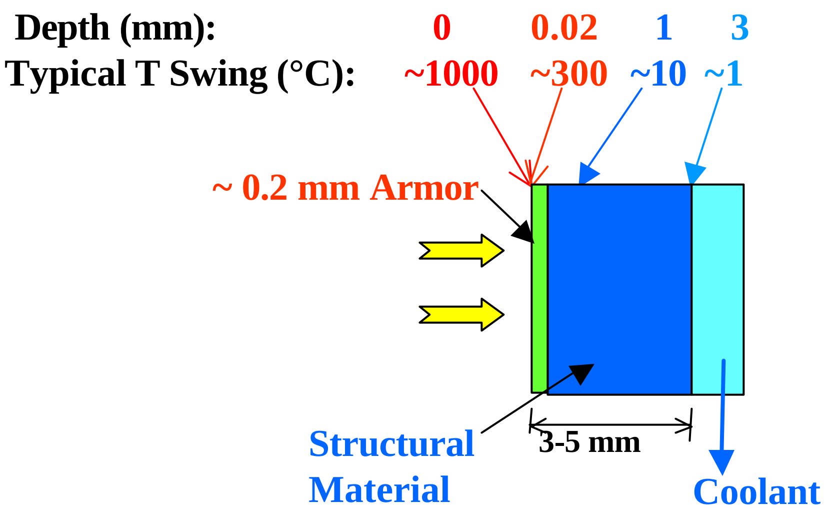
- ✓ Heating of target by radiation and friction
- ✓ Constraints:
  - Limited rise in temperature
  - Acceptable stresses in DT ice

Laser propagation design window(?)

- ✓ Experiments on NIKE

All the Action Takes Place within 0.1-0.2 mm of Surface -- Use an Armor

- Photon and ion energy deposition falls by 1-2 orders of magnitude within 0.1-0.2 mm of surface.



- Beyond the first 0.1-0.2 mm of the surface. First wall experiences a much more uniform q'' and quasi steady-state temperature (heat fluxes similar to MFE).

- **Use an Armor**
  - ✓ **Armor optimized to handle particle and heat flux.**
  - ✓ **First wall is optimized for efficient heat removal.**

- **Focus IFE effort on armor design and material issues, blanket design can be adapted from MFE blankets.**

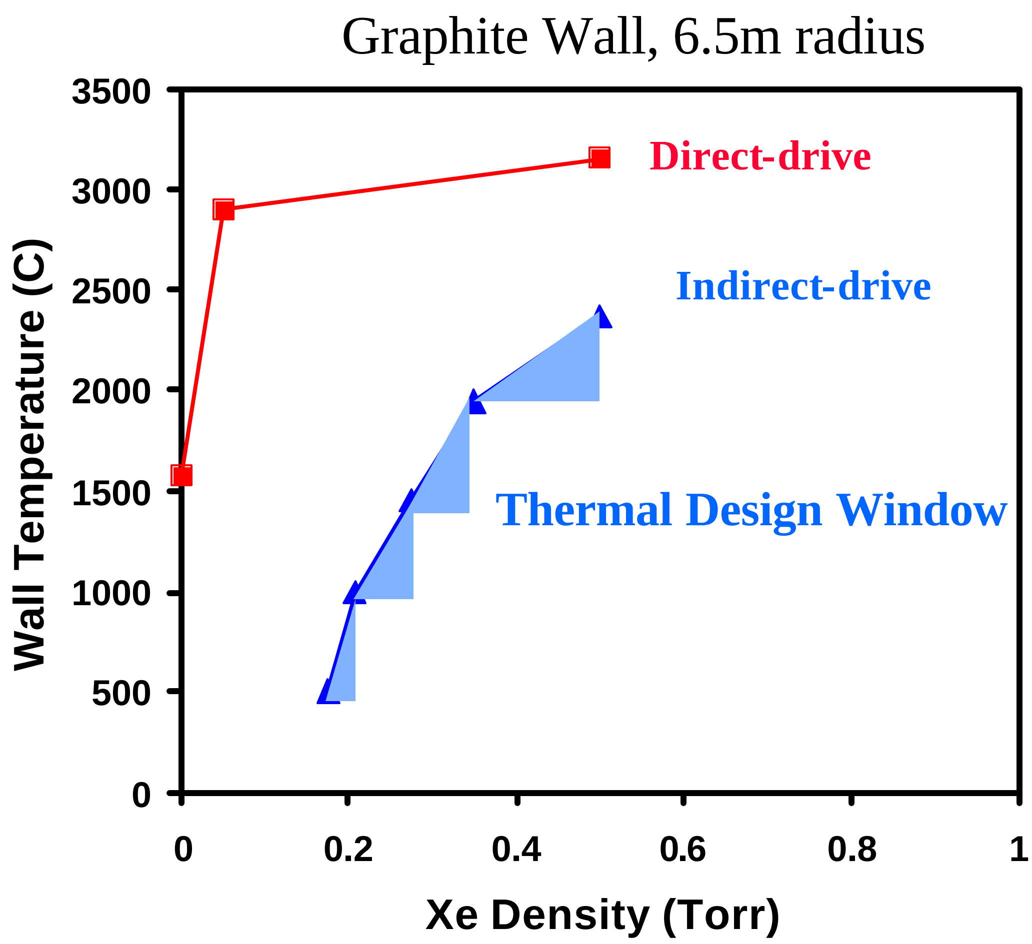
IFE Armor Conditions are similar to those for MFE PFCs (ELM, VDE, Disruption)

	ITER Type -I ELM's	ITER VDE's	ITER Disruptions	Typical IFE Operation (direct-drive NRL target)
Energy	<1 MJ/m^2	~ 50 MJ/m^2	~ 10 MJ/m^2	~ 0.1 MJ /m^2
Location	Surface near div. strike points	surface	surface	bulk (~µm's)
Time	100-1000 µs	~ 0.3 s	~ 1 ms	~ 1-3 µs
Max. Temperature	melting/ sublimation points	melting/ sublimation points	melting/ sublimation points	~ 1500-2000 °C (for dry wall)
Frequency	Few Hz	~ 1 per 100 cycles	~ 1 per 10 cycles	~ 10 Hz
Base Temperature	200-1000°C	~ 100°C	~ 100°C	~ >500 °C

- **There is a considerable synergy between MFE plasma facing components and IFE chamber armor.**

Design Window for Indirect-Drive Dry-Wall Chambers

- Gas pressures of ≥ 0.1-0.2 torr is needed (due to large power in X-ray channel). Similar results for W
- No major constraint from injection/tracking.
- Operation at high gas pressure may be needed to stop all of the debris ions and recycle the target material.
- Heavy-ion stand-off issues:
  - ✓ Pressure too high for neutralized ballistic transport (mainline of heavy-ion program).
  - ✓ ARIES program funded research in neutralized ballistic transport with plasma generator and pinch transport (self or pre-formed pinch) in FY02.



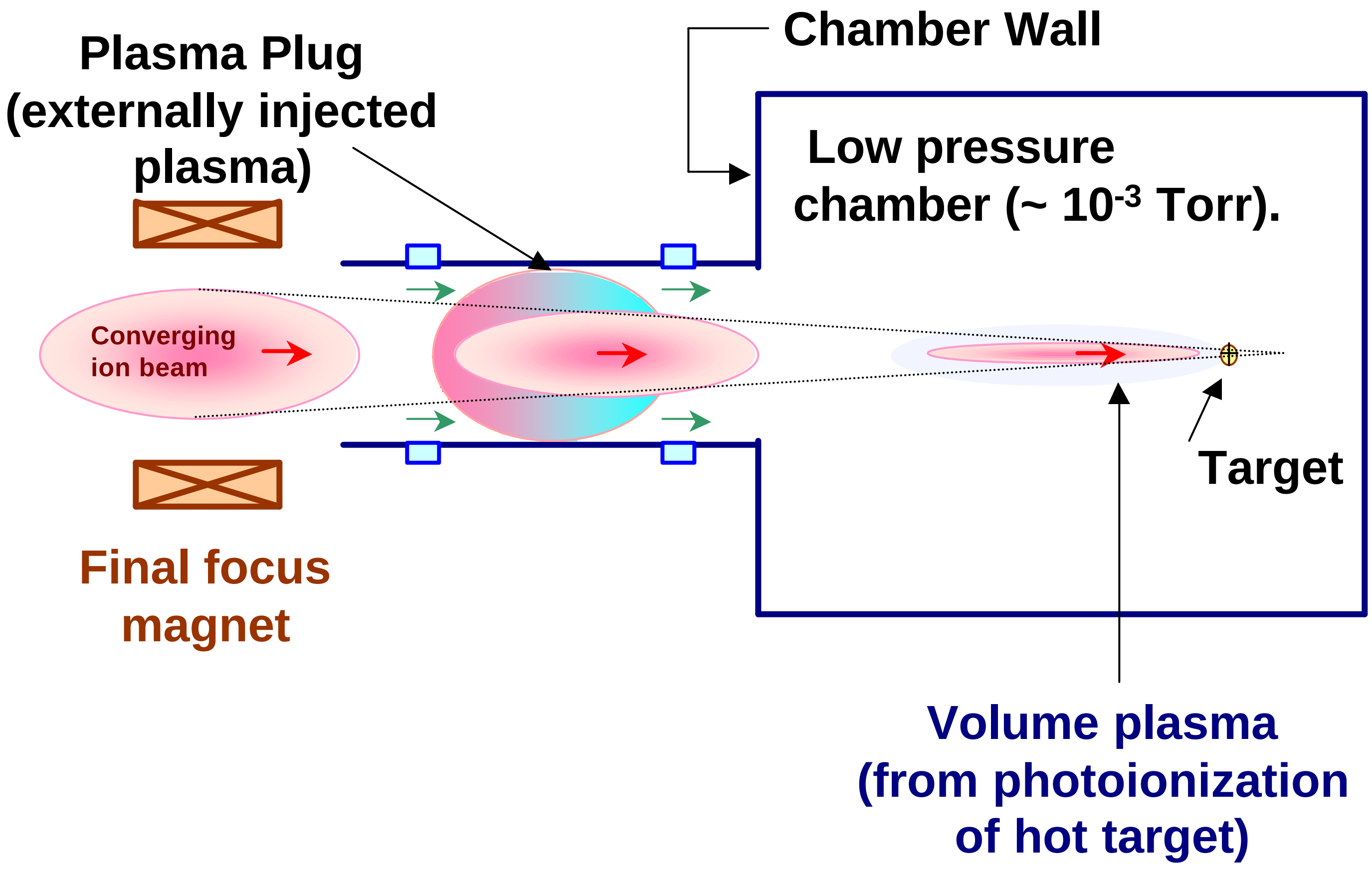
Beam Transport Option for Heavy-Ion Driver

Transport Mode / Chamber Concept	Ballistic Transport *chamber holes ~ 5 cm radius* *most studied*		Pinch Transport *chamber holes ~ 0.5 cm radius* *higher risk, higher payoff*	
	<u>Vacuum-ballistic</u> *vacuum*	<u>Neutralized-ballistic</u> *plasma generators*	<u>Preformed channel</u> ("assisted pinch") *laser + z-discharge*	<u>Self-pinched</u> *only gas*
<u>Dry-wall</u> *~6 meters to wall*	Not considered now: Requires ~500 or more beams	Not considered: insufficient neutral-ization for 6 meters	Option: uses 1-10 Torr *2 beams*	Option: uses 1-100 mTorr ~2-100 beams
<u>Wetted-wall</u> *~ 4-5 meters to wall*	HIBALL (1981) Not considered: Needs £ 0.1 mTorr leads to ï	OSIRIS-HIB (1992) Possible option: but tighter constraints on vacuum and beam emittance	Option: uses 1-10 Torr *2 beams*	PROMETHEUS-H (1992) Option: uses 1-100 mTorr ~2-100 beams
<u>Thick-liquid wall</u> *~ 3 meters to wall*	Not considered: Needs £ 0.1 mTorr leads to ñ	HYLIFE II (1992-now) <u>Main-line approach</u>: uses pre-formed plasma and 1 mTorr for 3 meters *~50-200 beams*	Option: uses 1-10 Torr *2 beams*	Option: uses 1-100 mTorr ~2-100 beams

ARIES-funded research shows that neutralized ballistic transport <u>is feasible</u> for 6-m chambers

ARIES has funded research on pinch transport

Neutralized Ballistic Transport



Slide from D. Welch (MRC) presentation at Jan. 2002 ARIES Meeting

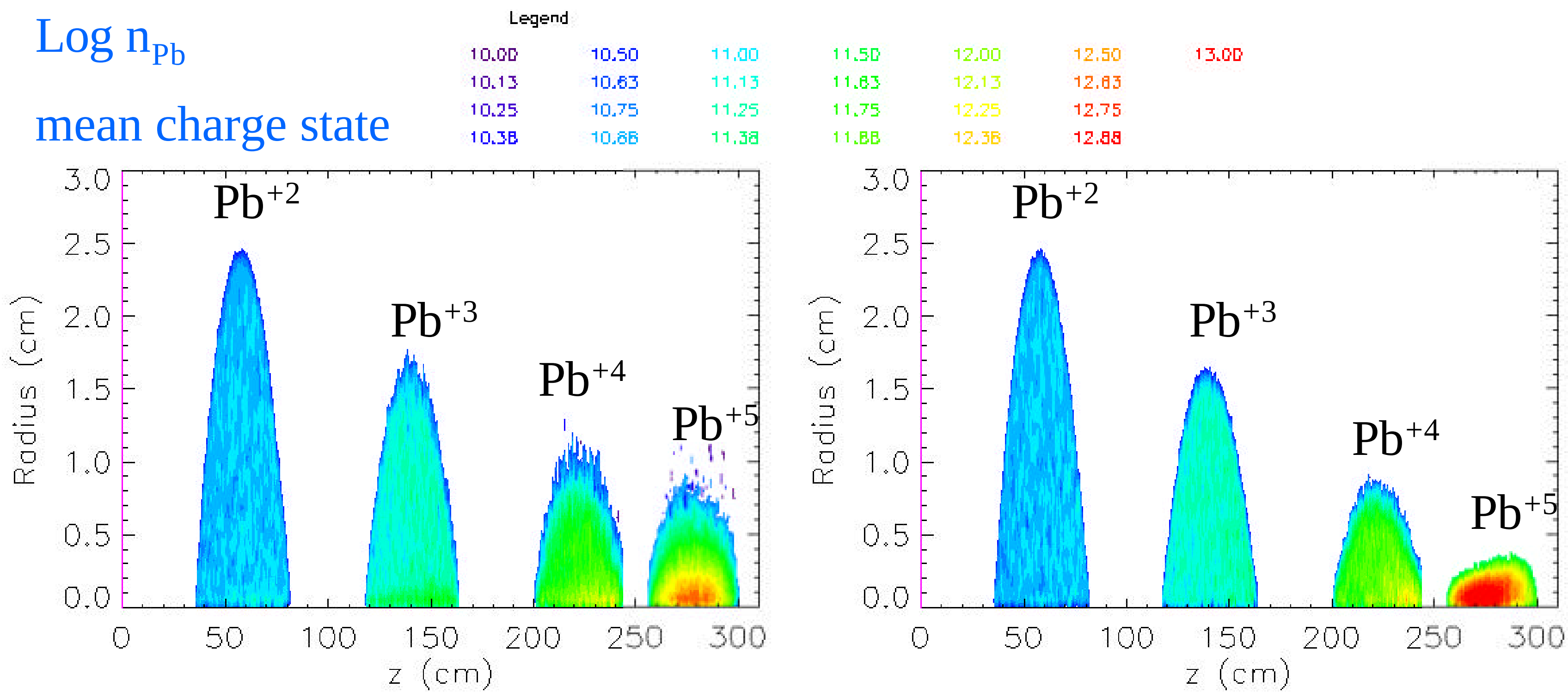
Plasma neutralization crucial to good spot

Stripped ions deflected by un-neutralized charge at beam edge*

Plasma provides > 99% neutralization, focus at 265 cm

Log n_{Pb}

mean charge state



No Plasma

Plasma

*D. A. Callahan, Fusion Eng. Design **32-33**, 441 (1996)

Slide from D. Welch (MRC) presentation at Jan. 2002 ARIES Meeting

Conclusions

- Photo ionization plasma assists main pulse transport - but not available for foot pulse
- Without local plasma at chamber, beam transport efficiency is < 50% within 2 mm for “foot” pulse
- Electron neutralization from plasma improves efficiency to 85% - plasma plug greatly improves foot pulse transport
- Lower chamber pressure should help beam transport for both foot and main pulses given plasma at chamber wall
- 6-m NBT transport with good vacuum looks feasible for dry wall chamber design
- System code: “Alpha” factor for neutralization roughly 1 in vacuum, increases with increasing pressure and propagation distance