Advanced Technology Briefing to VLT/PAC

Mohamed Abdou

VLT, San Diego **December 10, 1998**

Advanced Technology – Scope

Advanced technology is concerned with the longer-term technologies for high power density fusion systems that will have the greatest impact on the economic, safety and environmental attractiveness of fusion as an energy source

- Studies have shown that the most critical components are those enclosing the plasma, from the edge of the plasma to the edge of the magnet *(i.e.* "in-vessel" systems including the FW/blanket/divertor/shield /VV)

- These components must fulfill three essential functions in any fusion system.
  1. Provide the **vacuum, heat and particle removal**, and other conditions necessary for stable plasma operation
  2. Generate a **self-sufficient supply of plasma fuel**
  3. Deliver a **USEFUL PRODUCT** (e.g. power, synthetic fuel) through safe, efficient, reliable, and economical utilization of fusion plasmas

Current Activities

- APEX

Related Activities

- ALPS (Under Enabling Technology)
- Insulator Coatings (Under Materials)
- Solid Breeder Thermomechanics and Material Interactions (Under Materials)

Goal and Objectives of Advanced Technology

The goal of ***advanced technology research*** *is to extend the engineering science knowledge base, provide innovative concepts, and resolve key feasibility issues for the practical, economical and safe utilization of fusion energy.*

Objectives

Innovative Concepts:

i) **Identify and explore novel, possibly revolutionary, concepts** for the in-vessel components that can substantially improve the vision for an attractive product.

Improvements can result from:

- **increased power density capability** and **power conversion efficiency**
- **reduction of failure rates**
- **faster maintenance** and **simpler technological and material requirements**

ii) **Perform R&D of theory, modeling, and experiments to establish the knowledge base** necessary to evaluate the most promising innovative concepts.

Evolutionary Concepts: **Understand and extend the technological** limits of traditional concepts primarily through international collaboration.

The Goals of Advanced Technology Derive from Objectives and Priorities of the Fusion Community and DOE

- Advanced Technology and APEX goals are directly responsive to one of the six five-year Fusion Energy Sciences Program objectives established in the roadmapping activity at the **Leesburg Community Workshop** help in 1996

  "Accomplish marked progress in the scientific understanding of technologies and materials required to withstand high plasma heat flux and neutron wall load"

- The following letter directed to Dr. Anne Davies in January, 1998 by **Distinguished Members of the Fusion Community** articulated well the need for research on High Power Density and provided momentum and focus to Advanced Technology and the APEX study

  Poignant excerpts:

  "...toroidal confinement devices require high wall loads if they are going to have comparable mass power densities and thus be able to compete with conventional power sources."

  "...it is timely for the technology side of OFES to consider a new focus to develop first wall / blanket schemes which can demonstrate high heat and neutron fluxes."

  "This technology challenge is every bit as much of a world class problem as producing a thermonuclear plasma."

  "It is also very much in keeping with the new emphasis on science and innovation in the program."

  "...it would directly address the problem that our critics outside of fusion view as being fusion's Achilles' Heel"

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Date: January 16, 1998
Refer to: T-15-447

Dr. N. Anne Davies
Office of Fusion Energy Sciences
U. S. Department of Energy
Washington, D.C.

Dear Dr. Davies:

Like most enterprises, the ultimate success of Fusic . Energy will largely depend on how well we know our customers and how well we meet their needs. Both who our customers are and their needs have changed dramatically over the last twenty years. In the early to mid 1970s, utilities were ordering large numbers of gigawatt sized power plants. They had experienced exponential growth in demand for 50 years[1] and consequently felt that the risks involved with large capital outlays and long lead times were well justified. Any billion dollar miscalculations in capacity requirements could be passed on to the consumer through rate hikes.

The utility industry of today is very different from the one of twenty years ago. Utilities are increasingly viewing themselves as electricity distributers and retailers rather than electricity producers. This is witnessed by the fact that EPRI is increasingly being tasked to look at distribution issues rather than new means of electricity production.[2] Present additions to generating capacity are largely 200-300 MW gas turbine plants being built by independent producers. These producers are not capital rich monopolies and cannot pass overcapacity charges on to the consumers. This fact, coupled with the uncertainty of demand growth[1] since the late 70s and exacerbated by the long lead times required for large units has led to smaller, less capital intensive electrical generation units. Indeed, the last GW sized unit ordered in the United States was ordered in 1977. It is likely that the upcoming deregulation will continue and accelerate this trend.

It is our belief that the requirements of this new emerging customer can eventually be met by fusion energy provided that we make the appropriate technical choices now. Most of the alternate concepts, innovative concepts and advanced tokamaks are high beta devices which should allow them to be built in smaller unit sizes than conventional fusion machines. Many of them also offer the promise of increased simplicity. However, there is one major difficulty present in all of the toroidal confinement devices. All of them confine plasma by allowing it to slowly diffuse across the magnetic field. As a result, they require an unfavorable surface to volume ratio compared to conventional power sources such as nuclear fission.[3,4,5] Consequently, toroidal confinement devices require high wall loads if they are going to have comparable mass power densities and thus be able to compete with conventional power sources. High mass power density is even more crucial for small unit sizes since one cannot take advantage of the economies of scale in order to compensate for the high cost of the fusion power core by making it small compared to the cost of the balance of plant.

A number of possible solutions to this problem were presented at the most recent IAEA workshop on Innovative Concepts. Papers were presented on liquid walls[6,7,8] and gas blanket concepts.[9] Also, previous studies have suggested that solid walls may be able to handle large heat fluxes if the thermal load is largely in radiation.[10] High wall-load technologies of this type would also benefit conventional tokamaks and ICF as well as the alternate and innovative concepts by allowing them to go to higher mass-power densities than present designs.

5

Given this changing environment, we believe that it is timely for the technology side of OFES to consider a new focus to develop first wall/blanket schemes which can demonstrate high heat and neutron fluxes. Since the EDA phase of ITER is coming to a close, this sort of project would be an excellent way to keep innovative engineers involved in the program. This technology challenge is every bit as much of a world class problem as producing a thermonuclear plasma. It is also very much in keeping with the new emphasis on science and innovation in the program. Furthermore, it would directly address the problem that our critics outside of fusion view as being fusion's Achille's heel.[3,4,5]

references

1. J. F. Ahearne, *American Scientist* 81, 24 (1993).
2. T. Schneider, presented at "Physics of Spherical Inertial Fusion Workshop", Santa Fe, NM Jan 12-14 1995.
3. W. E. Parkins, *Physics Today* 50, 15 March (1997).
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5. C. Starr, *Physics Today* 50, 101 March (1997).
6. R. Wooley, *IAEA Workshop on Innovative Approaches to Fusion Energy*, Pleasanton, Ca, October 20-23, (1997).
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10. The TITAN Reversed-Field Pinch Fusion Reactor Study, UCLA-PP%-1200 (1990).

Sincerely,

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Implementation of Community Views and Program Restructuring Plan

- DOE's Office of Fusion Energy Sciences has adopted the following as one of the six **five-year objectives** for the program:

  "Marked progress in the scientific understanding necessary for evaluating technologies and materials required under conditions of high plasma heat flux and neutron wall load"

- The **Advanced Technology program and APEX were initiated to accomplish this objective** through a community-wide, interdisciplinary team effort complemented by competitive peer review processes to strive for the highest level of innovation and progress

- The **old blanket program** that focussed on traditional concepts of limited potential **was mostly eliminated** (reduced from an annual budget of ~$6M to ~$1M)
  - Shutdown ALEX MHD facility (~$1M)
  - Terminated Ceramic Breeder Material Irradiation Testing (~$1M)
  - Terminated US-Japan collaborative program on Neutronics Integral Experiments (~$0.8M)

- The **Strategic Pathway** for Advanced Technology in VLT was written to reflect these **new goals and objectives**

Fundamentals of Economics Show That:

1. **Attractive Vision Requires JOINT Physics and Technology Efforts**
2. **Advanced Technology (Power Extraction Technology) is Critical**

Need High Power Density
- High-Performance Plasma
- Power Extraction Technology

Need Low Failure Rate

$$COE = \frac{C \cdot i + \text{replacement cost} + O\,\&\,M}{P_{fusion} \cdot \text{Availability} \cdot M \cdot \eta_{th}}$$

Energy Multiplication

Need High Temp. Energy Extraction

$$\frac{(1/\text{failure rate})}{1/\text{failure rate} + \text{replacement time}}$$

- **Need Low Failure Rate:**
  - Innovative Power Extraction Technology
- **Need Short Maintenance Time:**
  - Simple Configuration Confinement
  - Easier to Maintain In-Vessel Technology

Power Density and Heat Flux in Fission Reactors Compared To Fusion With Traditional Evolutionary Concepts

	PWR	BWR	HTGR	LMFBR	Fusion at $3 MW/m^2$
Equivalent Core Diameter (m)	3.6	4.6	8.4	2.1	30
Core Length (m)	3.8	3.8	6.3	0.9	15
Average Core Power Density (MW/m^3)	**96**	**56**	**9**	**240**	**1.2**
Peak-to-Average Heat Flux at Coolant	2.8	2.6	12.8	1.43	50

Need Revolutionary Concepts with High Power Density Capability

i.e. **concepts capable of handling both high plasma heat flux and neutron wall load**

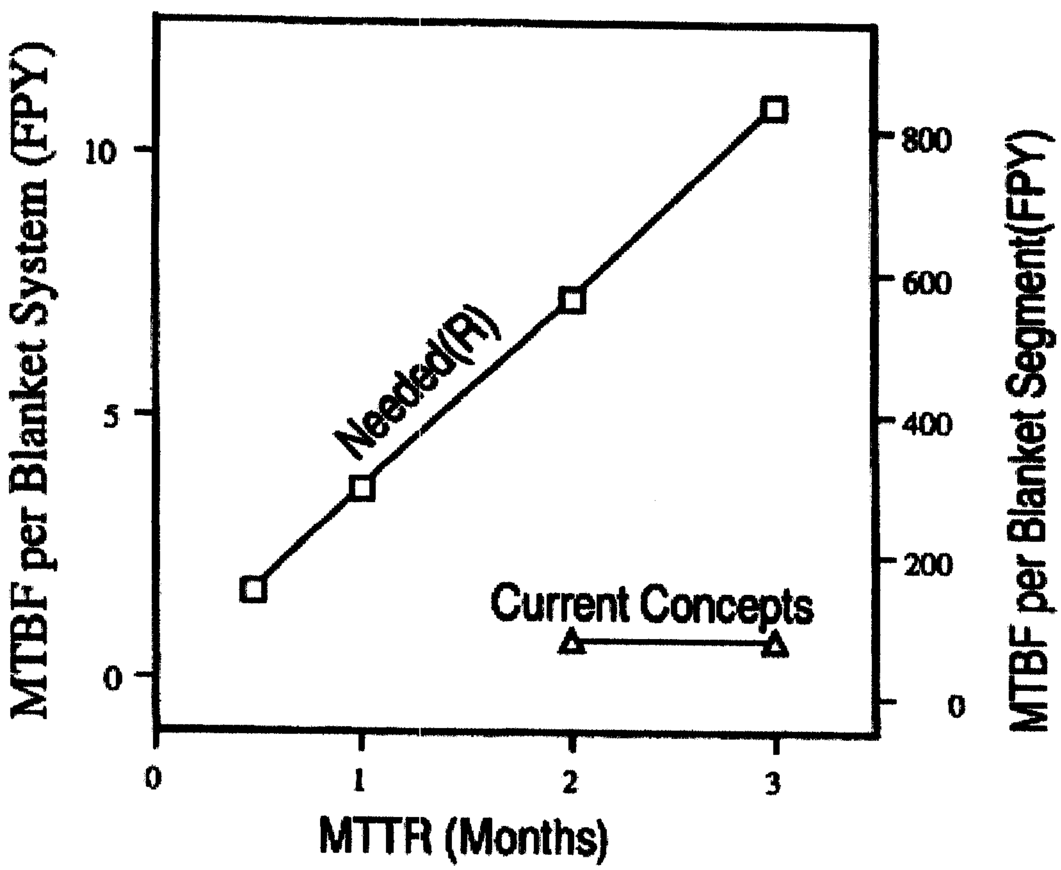
Peak Neutron Wall Load Limits for "Dry" First Wall

Material	Max. Temp (°C)	Wall-Coolant Interface Temp (°C)	Peak Neutron Wall Load Limit (MW/m^2)		
			Limited by Max. Temp	Limited by Stress Criterion	Max. Wall Load
Ferritic Steel	550	500	1.5	3.6	1.5
Ferritic Steel	550	450	2.9	4	2.9
V-Cr-Ti	700	600	3.2	5.4	3.2
V-Cr-Ti	700	550	4.7	5.4	4.7
SiC-SiC	1000	700	3.5	2.5	2.5
ODS	700	600	3	2.6	2.6
Nb-1Zr	1100	600	24.5	6.6	6.6
Tungsten	1500	600	>30	8.8	8.8
TZM	1200	600	>25	13	13
T 111	1300	600	22.3	11.6	11.6

Note: Average Neutron Wall Load is about a factor of 1.4 LOWER than the Peak Values shown in the Table.

Current FW / Blanket Design Concepts are NOT Capable of Meeting the Challenging Reliability and Maintenance Requirements

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$



Technical Evaluation Shows That Traditional (Evolutionary) Concepts Have Limited Potential

- Traditional Evolutionary Concepts:
  - Solid first wall, solid divertor plate, with pressurized coolants
  - Solid breeder or self cooled liquid metal blankets

A) Limited Performance/Economic Potential

1) Low Power Density: Neutron Wall Load ≤ 3 MW/m^2

   Factor of 200 Lower than LMFBR and 80 Lower than LWR

2) Low Conversion Efficiency: Exit Coolant Temperature < 400-500°C

3) Short Mean Time Between Failure: MTBF < 0.5 year

4) Long Mean Time to Recover: MTTR > 0.25 year
   - Traditional Concepts: MTBF ~ 2 MTTR
   - What is Needed: MTBF > 43 MTTR

B) High Cost, Long Time for R&D

- Nuclear Environment is dominant
- Need a DT Fusion Facility

APEX

initiated in 1998, full start in 1999

Objective

Identify and explore novel, possibly revolutionary, concepts for the in-vessel components that can substantially improve the vision for an attractive fusion energy system

Primary Criteria

1. High Power Density Capability (main driver)

   Neutron Wall Load > 10 MW/m^2
   Surface Heat Flux > 2 MW/m^2

2. High Power Conversion Efficiency (> 40% net)

3. Low Failure Rates

   MTBF > 43 MTTR

4. Faster Maintenance

5. Simpler Technological and Material Constraints

APEX APPROACH

1) Foster an Environment conducive to innovation
   - Encourage innovative ideas
   - Opportunities for talented young scientists/engineers

2) Understand and Advance the underlying Engineering Sciences

3) Utilize a multidisciplinary, multi-institution integrated TEAM to foster collaboration, pool talents, and expand expert and specialty input. Organizations: UCLA, ANL, ORNL, SNL, LLNL, PPPL, GA, LANL, UW, UCSD, INEL

4) Provide for Open Competitive Solicitation in 1999

5) Close Coupling to the Plasma Community
   - Plasma Interface Group
   - Joint Physics-Technology Workshops

6) Direct Participation of material scientists and System Design Groups

7) Direct Coupling to IFE Chamber Technology Community

8) Encourage International Collaboration
   - Current participation from Germany and Japan

Concepts/Ideas Currently Being Explored in APEX

- Reference Confinement
  Advanced Tokamak, Spherical Torus, Field Reversed Configuration
  (Others will be added based on Community Input)

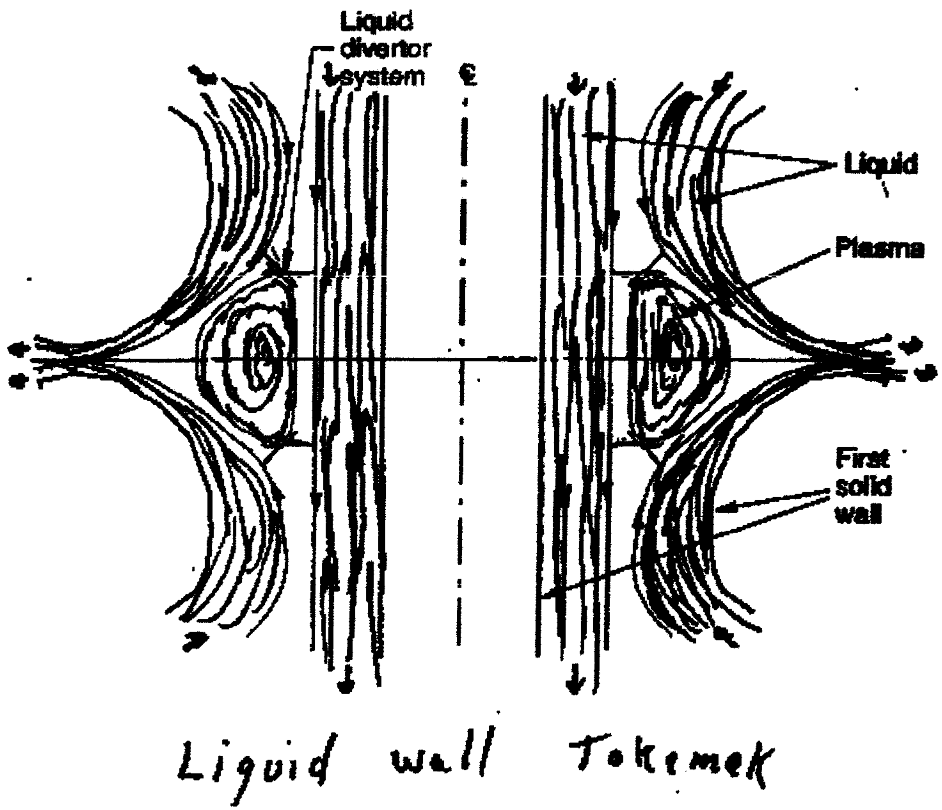
- Liquid Walls (no solid first wall)
  1. Convective Liquid First Wall
  2. Thick Liquid Blanket
     a) Gravity and Momentum Driven Only
     b) Swirling Flow
  3. Electromagnetically Restrained Thick Lithium Blanket

- Free Falling Li_2O Particulates (No solid First Wall)

- Breeder/Coolants: Lithium, Flibe, SnLi

  - High-Temperature Refractory Alloys with He Cooling or two-phase evaporative cooling

The idea of thick liquid wall is being explored because of its tremendous potential



Advantages

- High wall loading, high plasma heat flux capability making high power density systems attainable
- High fluence capability eliminating many of the material thermal stress and radiation damage problems
- Reduces activation
- Simplified maintenance and lower failure rate, increasing plant system availability

Challenging Issues

1. Plasma-liquid interface?
2. How do we form and maintain the liquid?
3. Temperature Control?

Several Innovative schemes have been proposed in APEX to ensure compatibility of free-surface liquids with plasma operation

These include

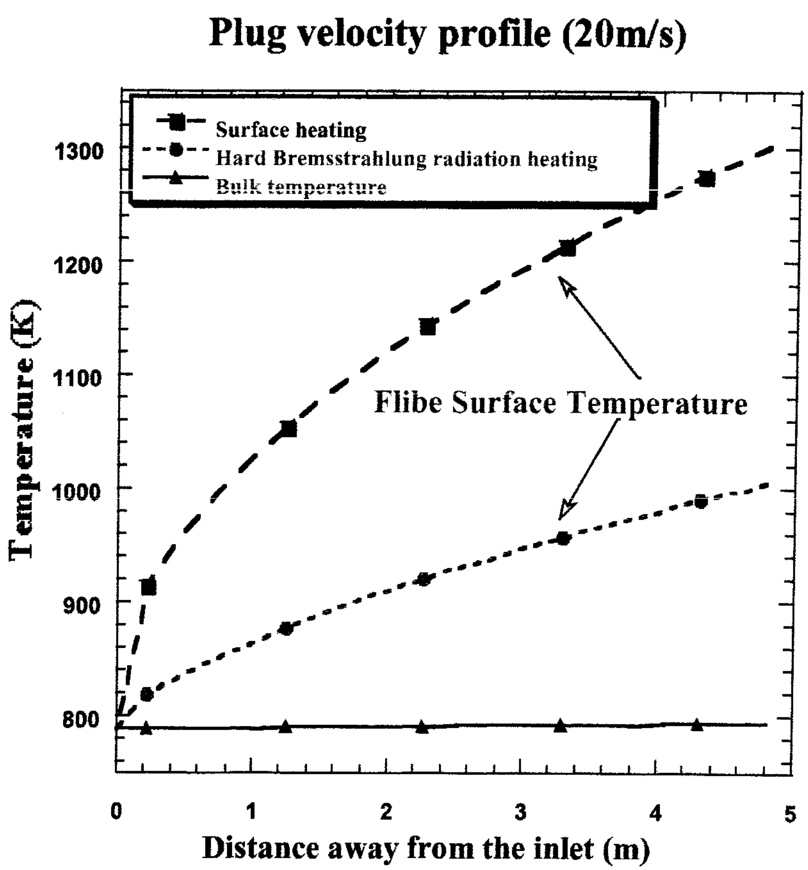
Design innovation:

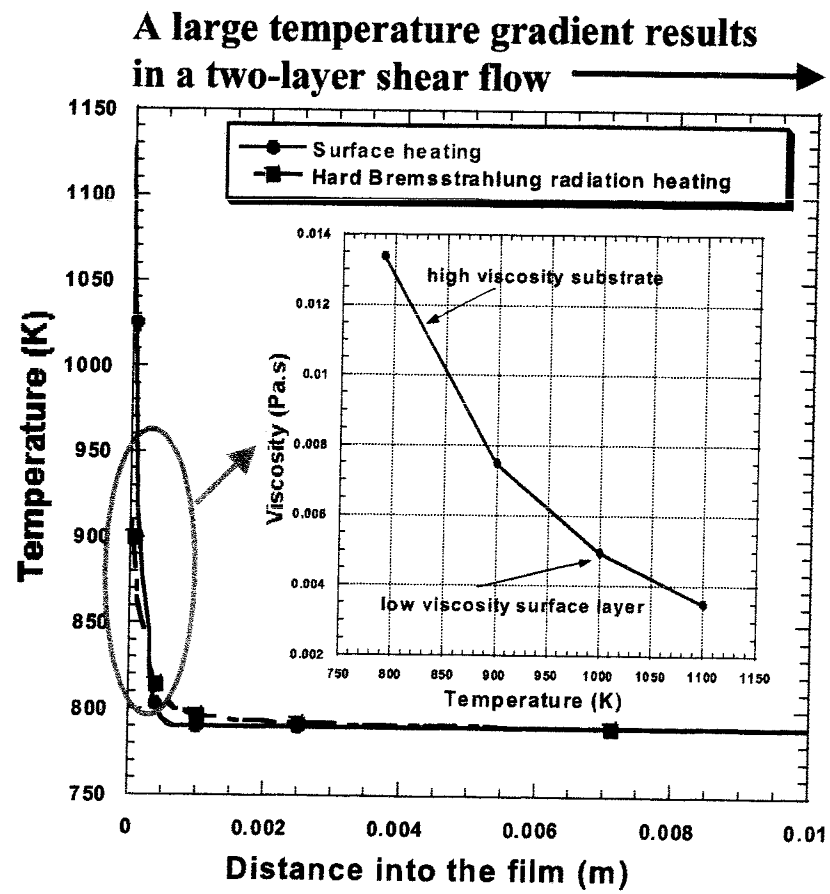
1. Fast flowing liquid jet, separate from slow moving liquid blanket, to keep surface temperature of the liquid (and hence evaporation rate) low,
2. New Schemes to promote controlled surface mixing and wave formation to eliminate surface thermal boundary layer

Material innovation: discovery of a new lithium-containing material (SnLi) that has low vapor pressure at elevated temperatures

Accounting for hard Bremsstrahlung radiation penetration: the surface heat load can be deposited deeper in the liquid; this significantly reduces the liquid jet surface temperature

High jet velocities, hard x-ray spectra and turbulent heat transfer enhancement considerably reduce Flibe free-surface temperature

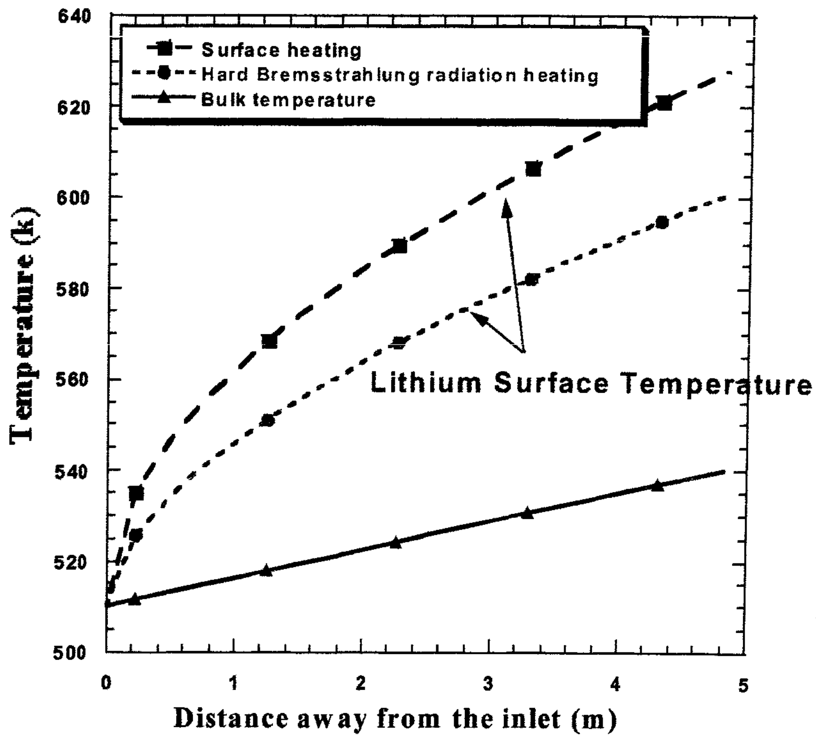


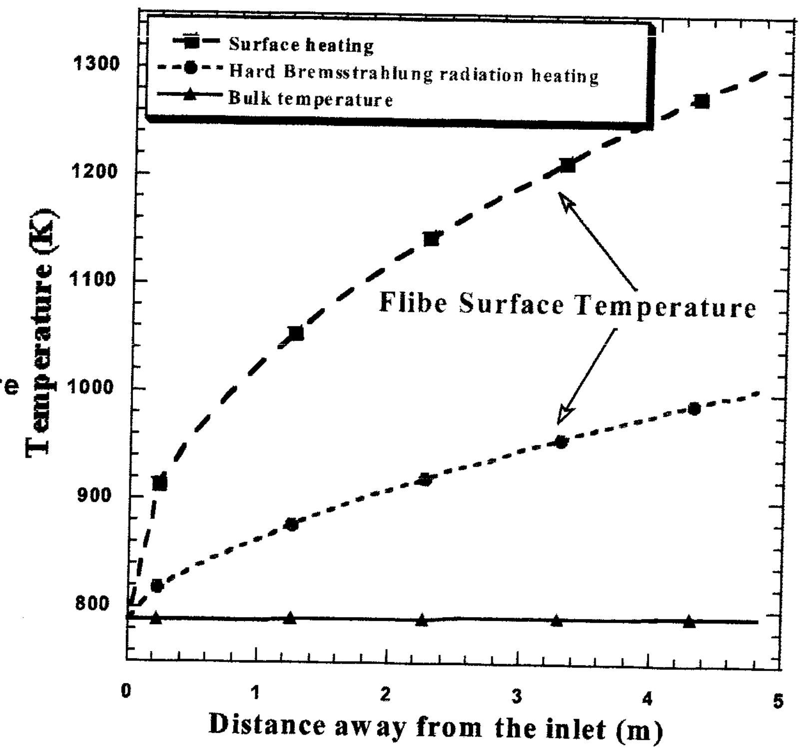


Impact of incident photon energy spectrum on liquid wall surface temperature profile

Lithium jet appears to have reasonable surface temperature due to its high thermal conductivity and long x-ray mean free path

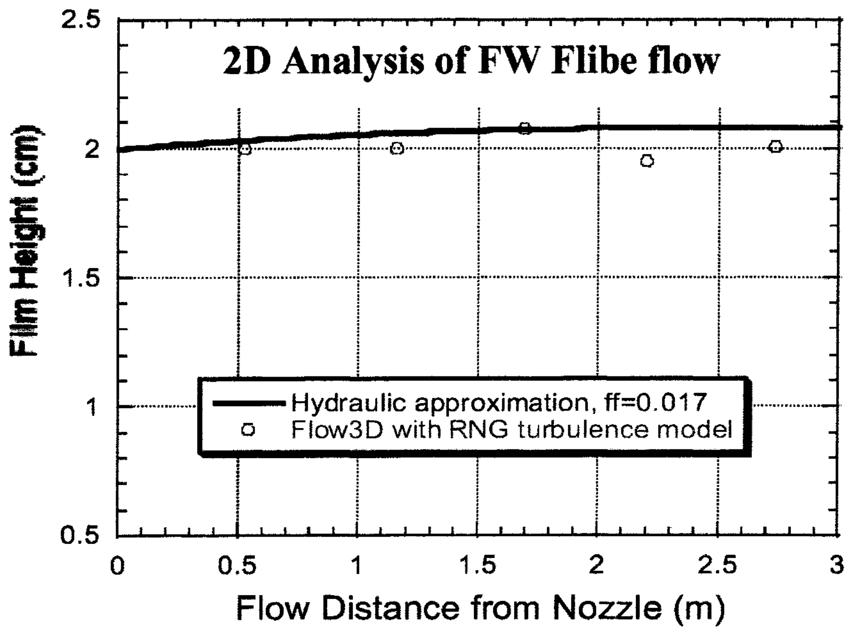
Plug velocity profile at 20 m/s, q" = 2 MW/m2
Inlet temperature: Li = 510 K; Flibe = 778 K



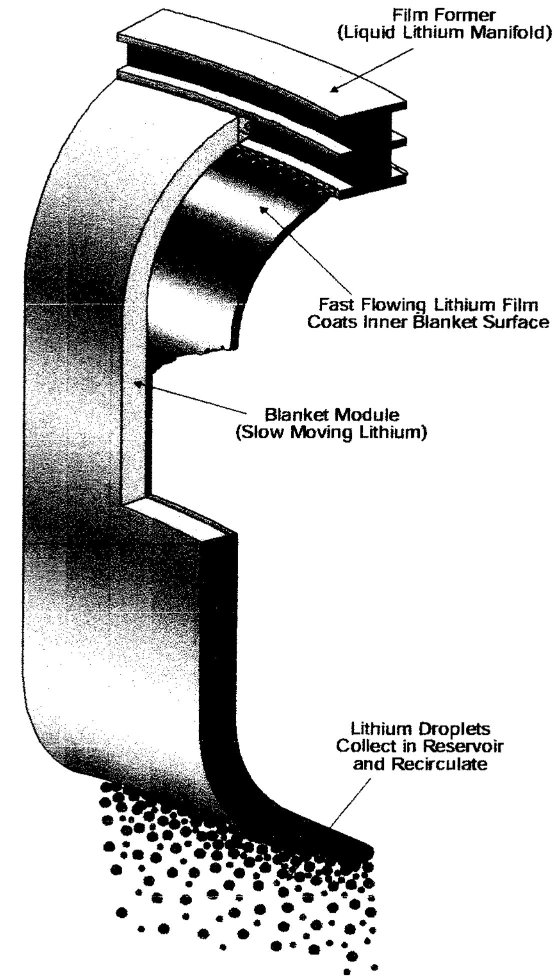


Convective Liquid Flow Firstwall (CLIFF) Concepts

- Underlying structure protected by a fast moving layer of liquid, typically 1 to 2 cm thick at 10 to 20 m/s.
- Conventional or more innovative liquid breeder blanket located directly behind the CLIFF-wall
- 2D hydrodynamic calculations confirm near equilibrium flow for Flibe at 2 cm depth and 10 m/s velocity (below)

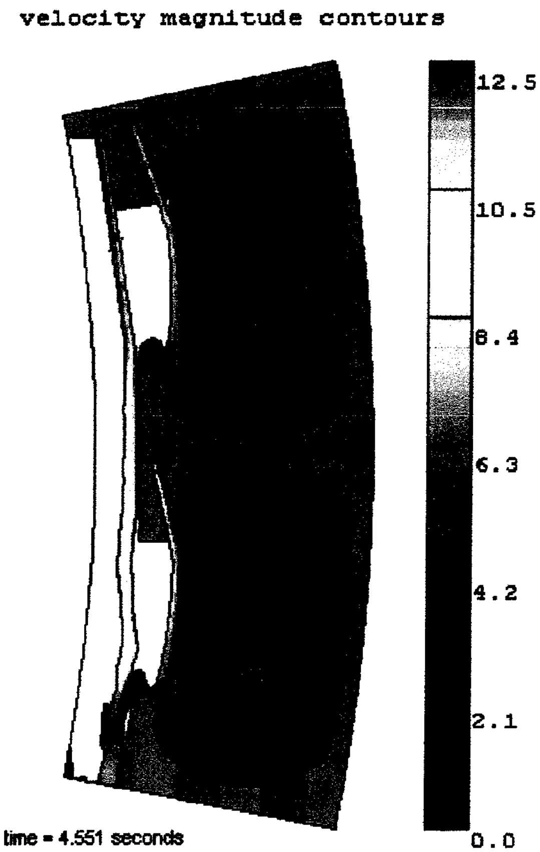


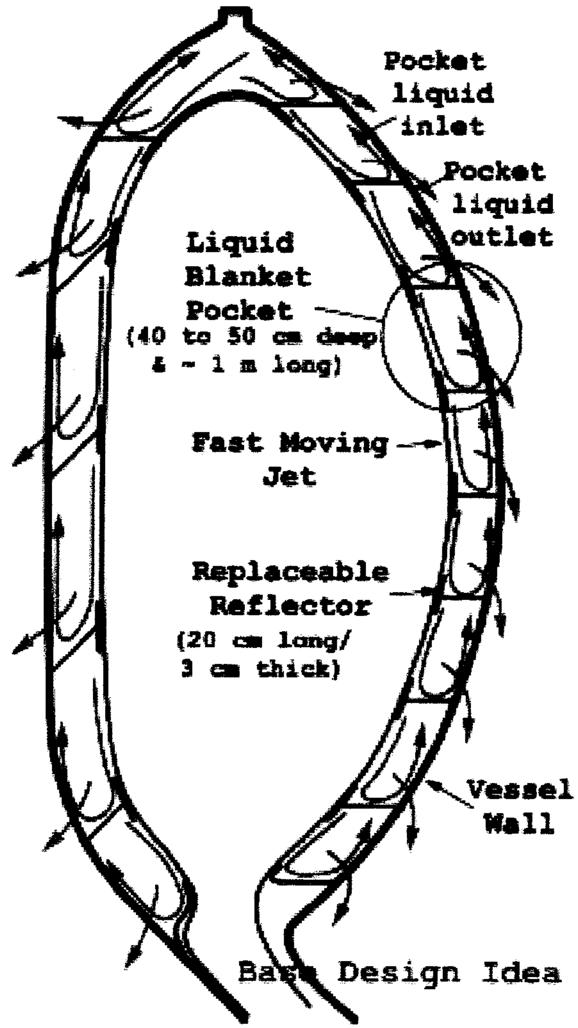
Convective Liquid layer Design



Gravity-Momentum Driven Thick Liquid Wall Concept

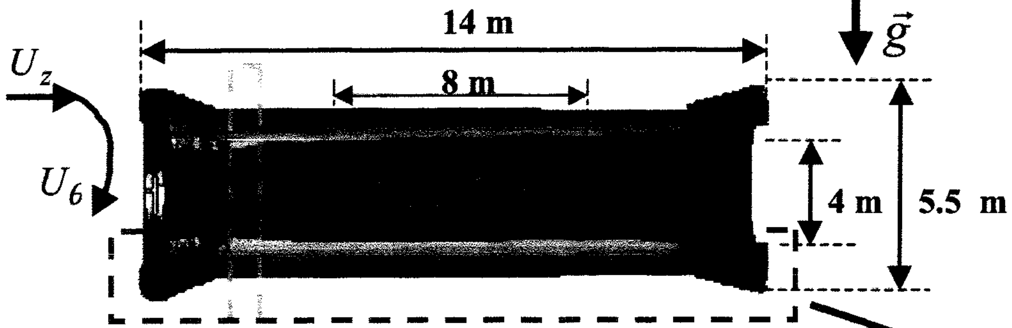
- **Utilize mechanically isolated recirculating pockets of liquid Flibe**
- **Fast liquid layer covers pocket and mechanical "reflector" surface**
- **Reflectors are easily replaceable**





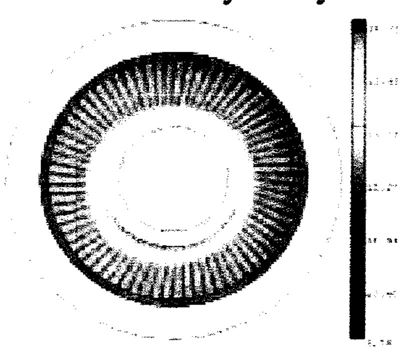
Thick-Swirling Liquid Blanket is Particularly Attractive in High Power Density FRC Configuration

- **Utilizing a swirling liquid blanket motion in FRC confinement configuration:**
  - **allows the FRC vacuum chamber to be horizontally located, which minimizes the required pumping power for high thermal efficiency.**
  - **maintains a uniform blanket thickness in the chamber with no minimum/maximum velocity requirement in the horizontal direction.**

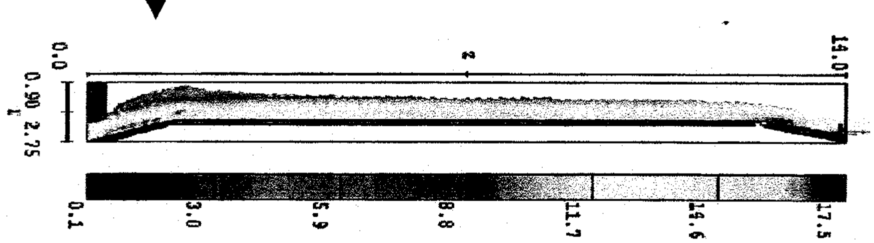


Preliminary FRC base design parameters for hydrodynamic feasibility assessments.

3-D time dependent Navier-Stokes Equations were solved using Flibe for incompressible flows using the **V**olume **o**f **F**luid (**VOF**) algorithm for free surface flows (with a constant axial and rotational velocity boundary condition at 2.75 m radius of converging inlet).



Velocity distribution in the plane (r-theta) perpendicular to the flow direction.

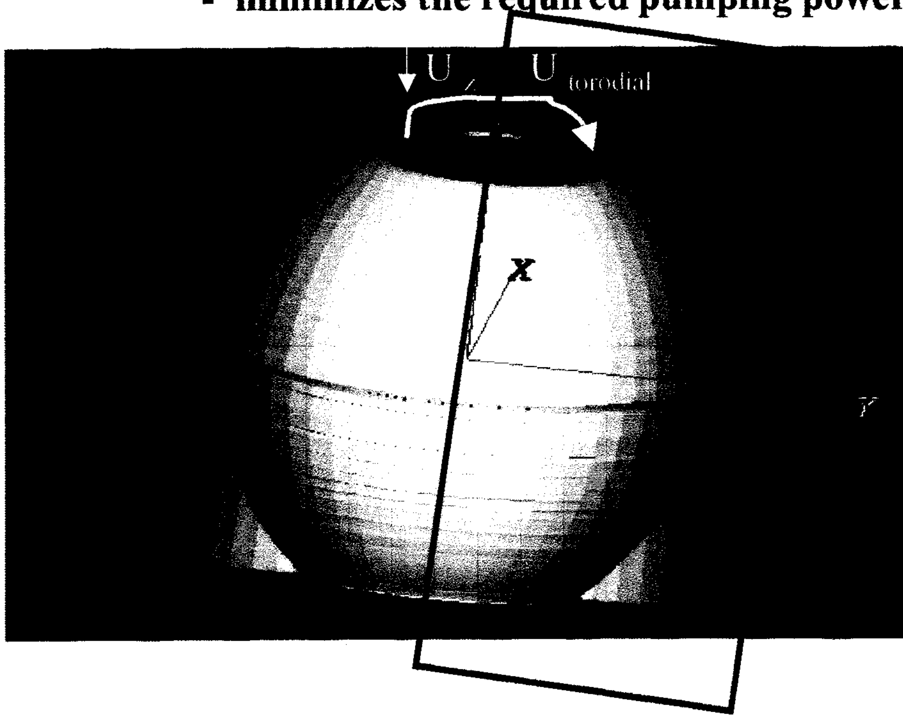


Velocity distribution in the plane (r-z) parallel to the flow direction.

Thick-Swirling Liquid Blanket in ST Configuration

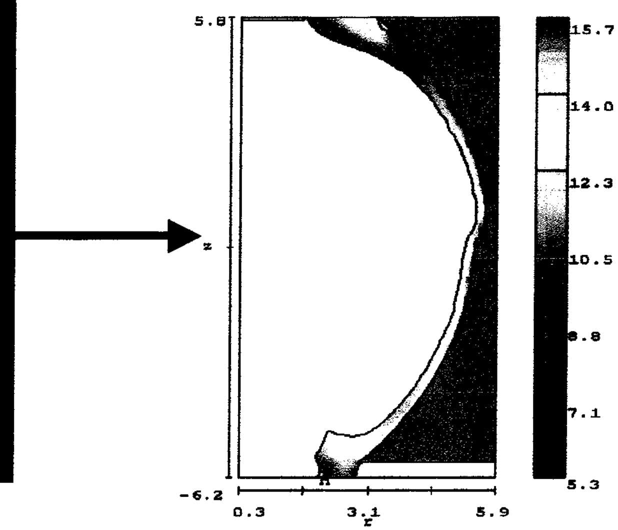
Utilizing a swirling liquid blanket motion in ST confinement configuration:

- **keeps the fluid attached to the vacuum chamber due to centripetal acceleration as a result of its toroidal motion.**
- **maintains a uniform blanket thickness in the chamber by modifying the vacuum chamber topology.**
- **keeps the flow velocity at a desired magnitude.**
- **minimizes the required pumping power for high thermal efficiency.**



3-D model of ARIES-ST geometry.

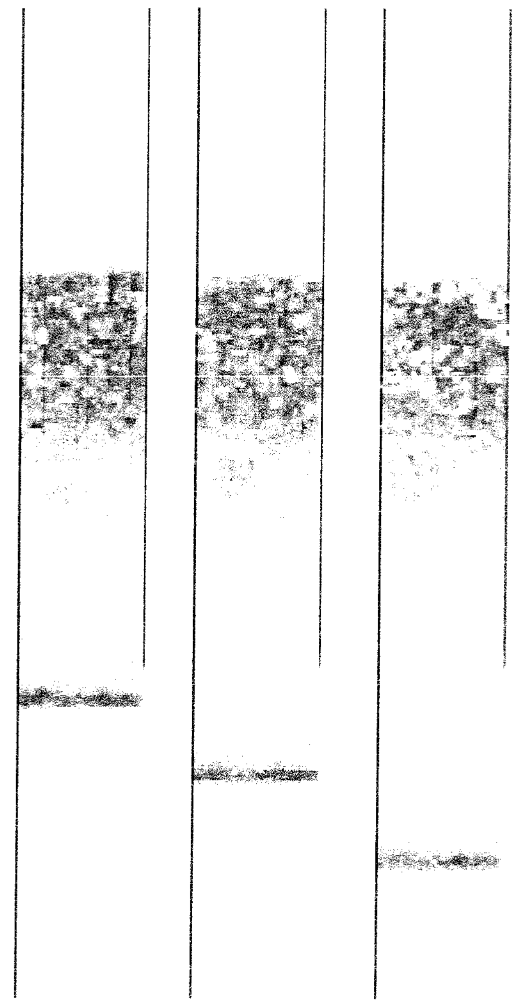
3-D hydrodynamic simulation of ST geometry when the blanket flow has constant toroidal and vertical velocity boundary condition.

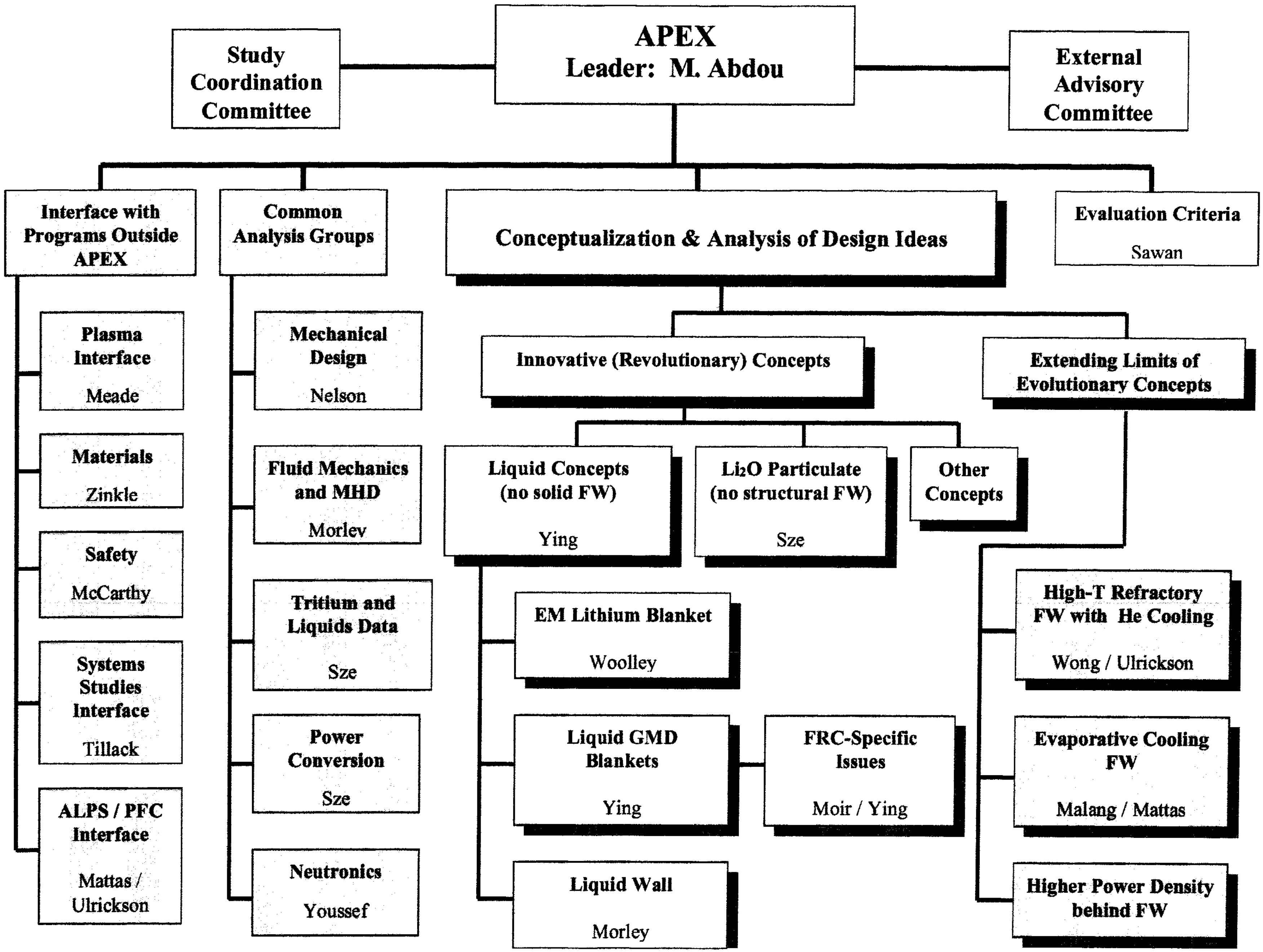


Velocity magnitude on r-z plane. The blanket thickness is constant along the poloidal direction. (Flibe is used as an operating fluid. Dimensions are in m and velocity is in m/s)

APPLE – Lithium Particulate Flow FW and Blanket

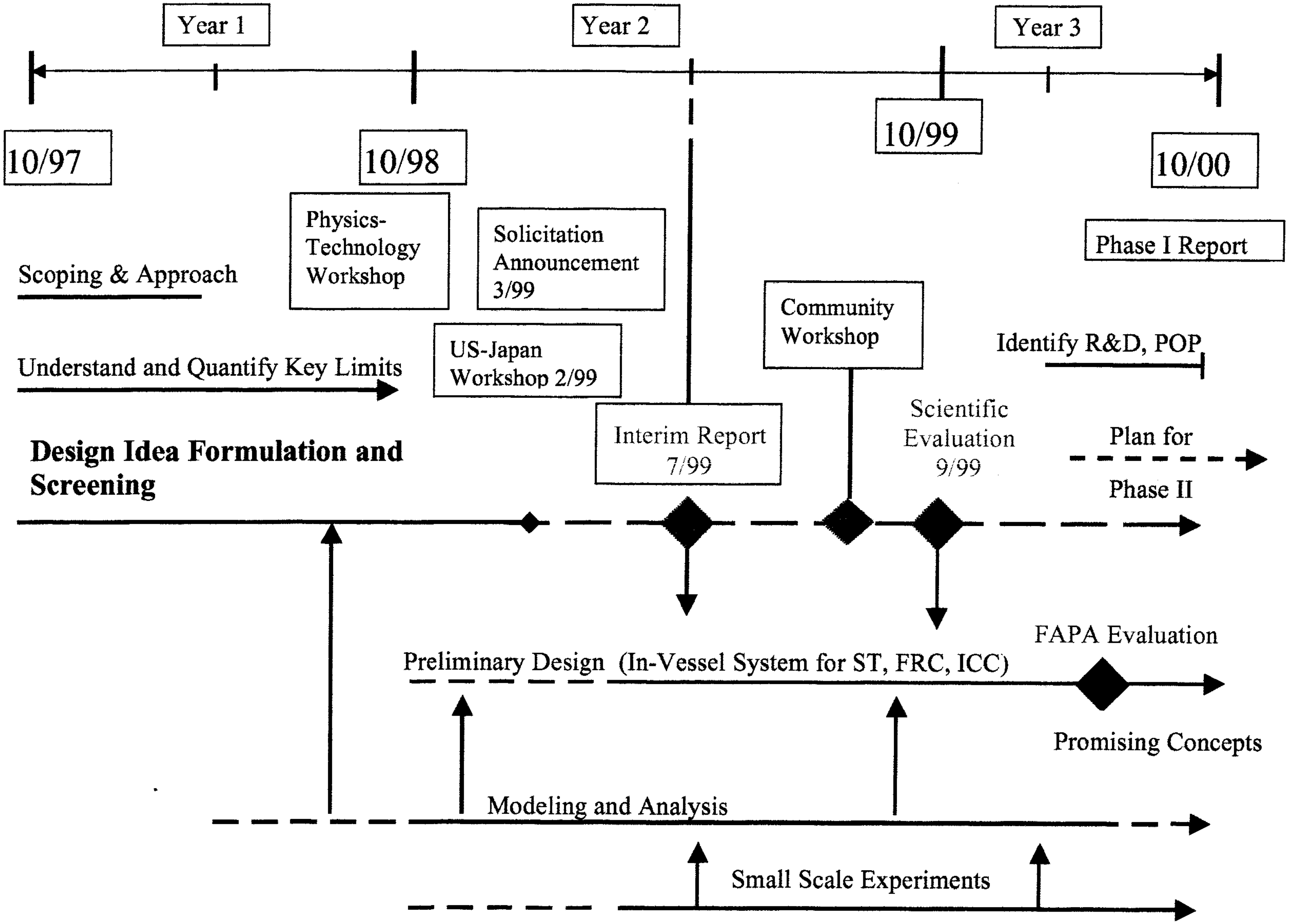
- Falling Li_2O particulate screen shields FW and divertor structures
- Dense flowing Li_2O particulate bed forms breeding blanket
- SiC baffles used to guide particulate flow
- Preliminary 2D calculations of a falling particulate flow from a feed hopper (shown right) indicate FW particulate screen has little tendency to eject particles into plasma
- Further analysis underway to determine
    1. photon screening of FW structure
    2. flow around penetrations
    3. particulate dynamics near collectors
- Design refinements needed to eliminate all plasma facing structure





APEX
Leader: M. Abdou
Study Coordination Committee
External Advisory Committee
Interface with Programs Outside APEX
Common Analysis Groups
Conceptualization & Analysis of Design Ideas
Evaluation Criteria
Sawan
Plasma Interface
Meade
Materials
Zinkle
Safety
McCarthy
Systems Studies Interface
Tillack
ALPS / PFC Interface
Mattas / Ulrickson
Mechanical Design
Nelson
Fluid Mechanics and MHD
Morley
Tritium and Liquids Data
Sze
Power Conversion
Sze
Neutronics
Youssef
Innovative (Revolutionary) Concepts
Extending Limits of Evolutionary Concepts
Liquid Concepts (no solid FW)
Ying
Li_2O Particulate (no structural FW)
Sze
Other Concepts
EM Lithium Blanket
Woolley
Liquid GMD Blankets
Ying
FRC-Specific Issues
Moir / Ying
Liquid Wall
Morley
High-T Refractory FW with He Cooling
Wong / Ulrickson
Evaporative Cooling FW
Malang / Mattas
Higher Power Density behind FW

APEX Schedule and Milestones for Phase I



Budget and Plan for Open Competition

- FY99 APEX Budget: $2155K
  - Allocation to Organizations based on task-performer-effort matrix developed through several iterations in project meetings
  - This was followed by peer review proposals (for Universities)
- Plans of Competitive Awards (Open Competition) for APEX-Related Research are being finalized
  - See Attached Figure/Time Schedule
  - See also Baker's Presentation

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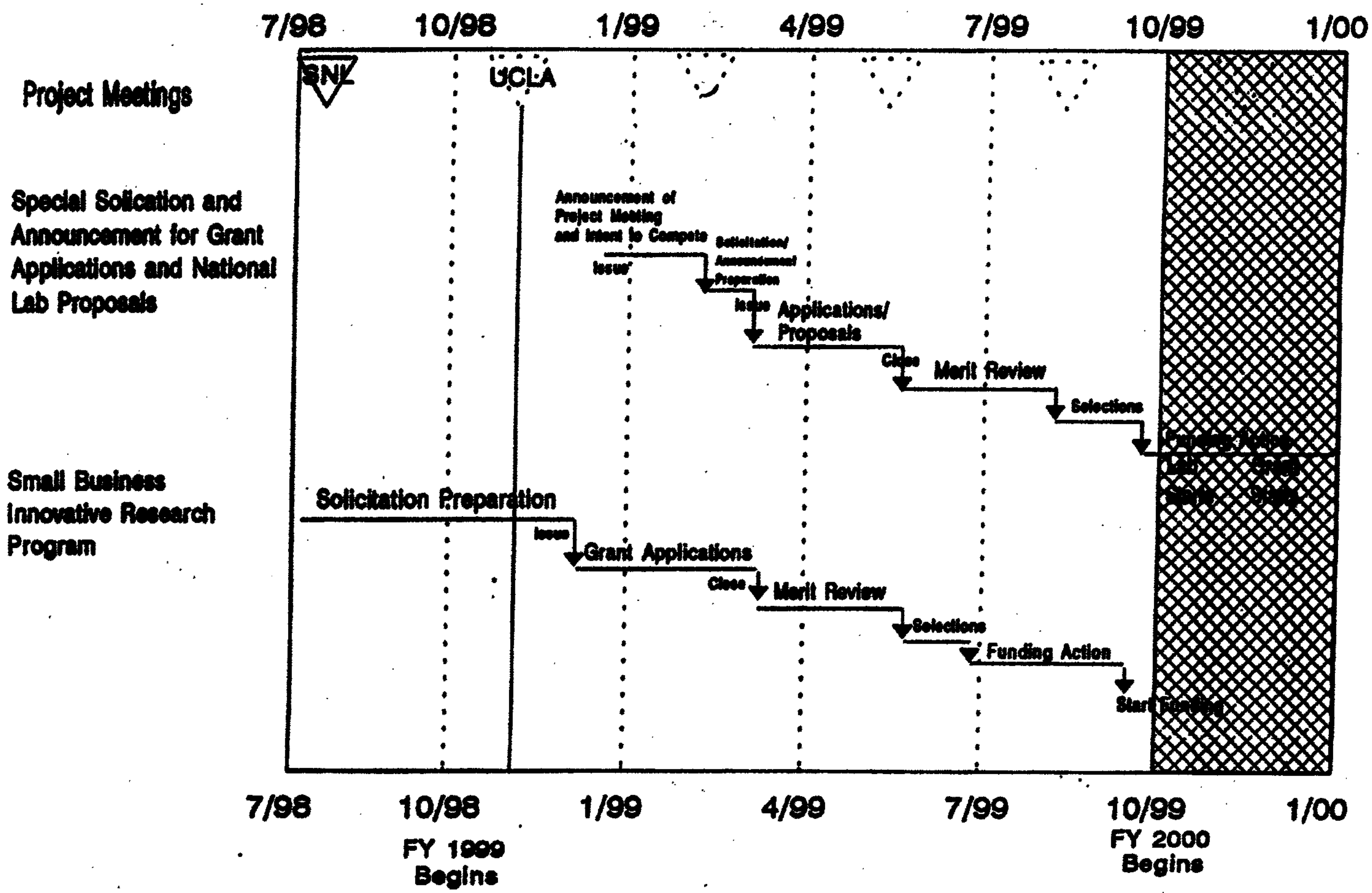
Planning of Competitive Awards for APEX-Related Research



Plasma-Interface Effort and Budget

- APEX and ALPS have built a bridge to the Plasma Physics Community through the "Plasma Interface Group"

- Plasma-edge modeling to define requirements on liquid walls is a critical area

- Funding ($180K in FY99) has been provided (out of the ALPS budget) to support plasma edge modeling (at LLNL, GA, ANL, PPPL) needed for APEX and ALPS.

- We hope that the Science Division can augment this funding to support plasma modeling and analysis for APEX and ALPS. The idea of User-Developer need to be strengthened

    - Enabling Technology "developers" support physics experiment "users"

    - Great if plasma physics "developers" support technology "users"

Deliverables for 2005

Innovative Concepts:

- Identification of the most promising innovative concept(s)
- Proof-of-Principle for most promising innovative concepts based on analysis, modeling, and laboratory experiments.

  This includes:
  - Determination of **power density limits**
  - Determination of **feasible configuration**, *e.g.* verification of hydrodynamics and heat transfer of liquid wall concepts, verification of particulate flow, *etc.*
  - **Impact on plasma performance**, *e.g.* effect of evaporation from liquid wall concepts, sputtering from particulate concepts, response to plasma disruptions, *etc.*
  - **Impact on reactor systems**: Tritium, Vacuum, Maintenance, *etc.*
- R&D plan for Proof-of-Performance for the most promising Advanced Technology concept(s)
- Critical safety related R&D (*e.g.* chemical reactivity, oxidation driven volatilization, and tritium mobilization studies)

Evolutionary Concepts: Proof-of-Principle tests of the technological limits of evolutionary concepts from R&D collaboration with EU, Japan and RF

APEX Tasks for FY 99-00

Enhanced research efforts to **identify, analyze, and evaluate high-performance advanced technology concepts** within APEX, with emphasis on high power density heat removal capability, high efficiency, low failure rate, faster maintenance and simpler material / technological constraints

- Concepts include:
  CLiFF – Convective Liquid Flow Firstwall/Divertor
  GMD – Gravity and Momentum Driven FW/Blanket with Structure Pockets
  SWIRL – Swirling thick liquid blanket for Tokamak and FRC
  EMR – Electromagnetically Restrained FW/Blanket
  APPLE – Li_2O Particulate FW/Blanket
  EVOLVE – Evaporation Cooled, Iso-Thermal Refractory Metal FW/Blanket
- General Modeling and Analysis Categories (mostly for free surface concepts)
  Hydrodynamic and **MHD** analyses
  Heat Transfer analysis
  Plasma edge calculations
  Particulate dynamics
  Thermal-hydraulics and **design**
- Initiate small scale laboratory experiments
- Interim report due 7/99, Phase I Report due 10/00

FY99-00 Tasks: Hydrodynamic and MHD Analyses of All APEX Liquid Wall Concepts

- **Calculation of flow configurations for liquid wall concepts** using existing models for 3D Unsteady Navier-Stokes Equations, including both equilibrium flow and wavelength growth rate of surface instabilities. First step in demonstrating feasibility of proposed concepts with Flibe
- Development of modeling capabilities for **analysis of simplified MHD flows with free surfaces** to analyze the equilibrium of liquid wall concepts using liquid metals, assess the need for insulator coatings
- Preliminary analysis of **effects of transient plasma conditions, complicated magnetic fields**, and inverted cylindrical geometries on free surface flows for tokamaks and FRCs utilizing simplified analytic and numerical calculations.
- Extension of above MHD work to **more general MHD / free surface computational tool**. Possibly by modification of existing Navier Stokes / free surface solvers like Flow3D or Telluride.
- Design of necessary **Hydrodynamic and MHD experiments** to validate numerical predictions and demonstrate feasibility of proposed flows.

FY99-00 Tasks: Heat Transfer Analysis for All APEX Concepts

- Determination of **maximum and average free surface temperatures** for all liquid wall concepts. Requires model development for:
  - heat transfer at wavy, turbulent free surface flows with high Prandtl number (in conjunction with hydrodynamic
  - heat transfer at possibly wavy, laminarized LM surfaces with low Prandtl number and surface boundary layers
  - effect of finite penetration of Bremsstahlung photons

- **Heat transfer from plasma to falling Li_2O particulate, from particulate to heat exchanger, and from radiating SiC baffles** for APPLE particulate concept,

- **Heat transfer through solid refractory metal components** under high power density conditions for both EVOLVE and evolutionary concepts. Thermal stress, creep and fatigue lifetimes must be evaluated at elevated operating temperatures.

- Development of required **heat transfer experiments** to validate predictive capabilities, possibly in conjunction with hydrodynamic and MHD experimental needs.

FY99-00 Tasks: Plasma Edge Efforts for All Liquid Wall Concepts (and Overlap with ALPS)

Evaluate effects of liquid surfaces on plasma

- Liquid wall shape and conductivity on plasma control and stability
- Erosion/Redeposition and Sheath analysis of surface materials
- 2-D fluid code analysis of the scrape-off layer with UEDGE coupled with 1D analysis of kinetic effects.
- Systems code study of the benefits of Li, *e.g.* low recycle 300 eV edge temperature regime, reduced current drive power.
- Coupling of core impurity transport with SOL analysis.
- Atomic data coordination. Assess existing data particularly for Flibe.
- Conduct DiMES test using Li. (GA, SNL)

Conduct PMI experiments and analyses of liquid surface behavior

- H, D, T, He, Self Sputtering
- Study surface segregation in multi-element materials
- Study hydrogen retention in candidate materials
- Study plasma effects of vaporization
- Model particle-surface interaction phenomena

FY99-00 Tasks: Thermal-hydraulics and Design for All APEX Concepts

- Utilize above heat transfer analysis **to construct thermal hydraulics models of all concepts**, to quantify high power density handling capabilities

- **Neutronics analyses of all concepts** to establish heating profiles and tritium breeding characteristics, and activation

- **Identification of feasible materials** and property database for high power density environment

- Incorporate data into **preliminary conceptual design** for evaluation by the APEX group and independent outside advisors
  - Accommodation of necessary penetrations
  - Power conversion cycle
  - Impact on other reactor systems, *e.g.* Tritium, Vacuum, Plasma Heating, Magnets

- **Comprehensive safety evaluations** based on preliminary design

Synergism between MFE and IFE

- In both IFE and MFE, the Chamber Technology has the same basic functions (heat extraction, tritium breeding, shielding, providing vacuum, reaction product management, etc.) and Many Common Issues
- Much of the R&D (modelling, experiments) can be done jointly or interactively
- Close interaction between IFE Chamber Technology and MFE Advanced Technology Communities has been VERY beneficial to both areas

Example: Liquid Walls

- Proposed for FRC in 1970 and for IFE in 1971
- Adopted in IFE designs with substantial advances in the 1980's, provided good start for APEX
- The APEX substantial modeling and new innovative solutions are now feeding back to IFE (3-D Fluid Mechanics analysis in APEX is being extended to cover IFE)
- Examples of several common issues that will benefit from joint (or closely coupled) R&D:
    - hydrodynamics in complex geometries
    - modeling and solutions for penetrations
    - solutions for conflicting requirements on temperature, high mass flow rates, and pumping power
    - vaporized material condensing on sensitive surfaces, e.g. final optics in IFE, RF antennas in MFE