Plasma Chamber and APEX Budget Plans
for FY 2000 (and FY 2001)

Spokesperson: Mohamed Abdou

OFES/VLT Budget Planning Meeting
Germantown, April 6, 1999

FY 2000 Proposed Plans and Budgets

Technology Area: Plasma Chamber Spokesperson: M. Abdou

Part I: VLT Director's Proposed Budget: $2200K

Task Description	Funding by Task	Institutions
• Neutronics - IEA FNT Neutronics Task Group - Nuclear Data and Analysis - Neutronics Code and Data Support	• 90	 UCLA (30) TSI (30) ORNL/ RSICC (30)
• International collaboration on thermomechanical properties for beryllium and pebble bed ceramics	• 300	UCLA (with EU, J)
• APEX - Various Tasks (see APEX Table)	• 1750	UCLA, ANL, ORNL, UW, LLNL, PPPL, GA, SNL, INEEL, LANL, plus competitive solicitation
• Support for ALPS - MHD Liquid Flow Modelling and Analysis	• 60	UCLA

International Collaboration on Thermomechanical Properties for Beryllium and Pebble Bed Ceramics

Relevant Information

- Part of IEA Collaboration
    - Japan provided Li_2O
    - EU provided Li_4SiO_4

- The only remaining connection to the world blanket program (Japan + EU Program: > $20M)

- Tasks involve the completion of existing 3 Ph.D. theses based on small-scale laboratory experiments and modelling to obtain fundamental property data

Tasks

1. Ceramic Pebble Bed Interface Conductance and Effective Thermal Conductivity Measurements
2. 3-D Discrete Numerical Simulation of Packed Bed Material Interactions and Thermomechanical Properties
3. Interface Heat Conductance between Non-Conforming Beryllium and Steel Surfaces Subjected to Non-Uniform Thermal Deformations

APEX

Strategy: Follow PAC's Recommendations

"The Advanced Technology Program ("APEX") focused on liquid walls is an INNOVATIVE activity with well-articulated and EXCITING goals. It is UNIQUE in the World Program. We applaud the programmatic vision. This research constitutes about 80% of the advanced technologies program. We believe this emphasis is appropriate at the present time."

From PAC Letter to VLT Director; January 17, 1999

Key Strategy Points for APEX Plan for FY 2000

1. Budget Limitations: Focus effort on most promising concepts, defer some detailed tasks
   - Put two concepts on hold: (EM-Restrained LM, APPLE)
   - Closely couple the two concepts with High-Temp. Refractory Alloys (EVOLVE and He-cooled)

2. Follow PAC recommendation in funding allocation:
   - 80% Liquid - 20% Other Concepts

3. Competitive solicitation for Proof of Principle Experiments

4. Emphasize modelling and initial small-scale laboratory experiments

5. Focus on highest priority issues:

   Liquid Walls
   1. Plasma-Liquid Surface Interface (under ALPS)
   2. Fluid Flow Hydrodynamics Configurations
   3. Temperature Control (Free Surface and Bulk Temperatures)
   4. Plasma-Liquid Interface (e.g. Field Penetration): PPPL Leads

   High-Temperature Refractory Alloys
   1. Materials Issues
   2. Two Phase Flow for EVOLVE
   3. Failure Modes and Rates

FY 2000 Proposed Plans and Budgets

Technology Area: **APEX** Spokesperson: M. Abdou

Part I: VLT Director's Proposed Budget: $1750K

• APEX (Direct Support)	• 1750	UCLA, ANL, ORNL, UW, PPPL, LLNL, GA, SNL, INEEL, LANL
1. Plasma-Liquid Surface Interactions 2. Concept Exploration and Analysis 3. Modelling and Numerical Simulation 4. Small-Scale Laboratory Experiments 5. International Collaboration 6. Competitive Solicitation	Under ALPS 1225 225 150 150	 Covered under other tasks
• APEX (Indirect Support) A. Safety and Environmental Analysis B. He Cooling, High Temp. Refractory, others C. Materials D. Tritium	 (150) (200) (50) (20)	 INEEL SNL ORNL LANL

FY 2000 Proposed Plans and Budgets

Technology Area: **APEX** Spokesperson: M. Abdou

Part I: VLT Director's Proposed Budget: $1750K

Task Description	Funding by Task	Institutions and Funding
LM-MHD free surface modelling with spatially and temporally variable magnetic field	125	UCLA (100), PPPL (25)
Turbulent heat transfer modelling for flibe free surface including MHD effects	100	UCLA
Plasma-Interface -Field penetrations, disruptions, etc -Plasma-Liquid Interaction	 100 -----	 PPPL (75), ANL (25) Covered under ALPS
Data base for liquids, tritium chemistry and control, power conversion	100 + (20)	ANL (100) + LANL (20)
Hydrodynamics configuration analysis and development for FRC, ST, and Toroidal systems including void penetrations	200	UCLA (150), LLNL (50)
Free-surface heat transfer analysis and thermal hydraulics for Li, Sn-Li, and flibe in various flow configurations and confinement concepts	100	UCLA
Mechanical design and maintenance scheme for liquid concepts in various confinement systems	120	ORNL (110), UW (10)
Material evaluations and analysis (including High-Temperature Refractory alloys)	80 + (50)	ORNL (50 +50), UCLA (30)
Neutronics and activation analysis	140	UW (70), UCLA (70)

FY 2000 Proposed Plans and Budgets (cont'd)

Task Description	**Funding by Task**	**Institutions and Funding**
Liquid Wall (thin and thick) concepts design analysis and integration	150	UCLA (100), LLNL (50)
LM Free Surface Experiments in toroidal geometry (extension of MEGA loop) and flibe simulant flow and HT on concave surfaces	150 + (50)	UCLA (100), PPPL (50), SNL (50)
High-Temperature Refractory Alloy Concepts (EVOLVE and He-Cooled) -MHD Analysis of Two-Phase Flow -Failure Modes and Rates -Materials, Neutronics, Activation, Safety -Mechanical Design -Design and Analysis	 40 + (30) 30 + (100) ------- 30 105 + (70)	 ANL (40) + SNL (30) GA (30), SNL (50), INEEL (50) Included under other tasks ORNL ANL (45), GA (40), UW (20), SNL (70)
Other Key Issues	30	TBD
Safety and Environmental Analysis for APEX (all concepts) -Li, Sn-Li, flibe Comparative Analysis -Volume vs Hazard Study and Strategy -Failure Modes and Rates for Refractory Concepts -Safety and Environmental Issues and Analysis	(150)	INEEL
Competitive Award Solicitation	150	TBD

FY 2000 Proposed Plans and Budgets

Technology Area: Plasma Chamber Spokesperson: M. Abdou

Part II: Incremental Tasks

Task Description	Funding by Task	Institutions
• Ceramic Pebble Bed Construct UNICEX: Unit Cell Experimental Evaluations of Thermal and Mechanical Interactions among Structure/Coolant/Ceramic Breeder/Beryllium Materials	200	UCLA (100), ORNL (50), ANL (30), INEEL (20)
• APEX		
1. Enhance the effort on liquid wall concept exploration, design, analysis, and modelling	400	ORNL, ANL, UCLA, UW, PPPL, UT, UCSD, LLNL
2. Add turbulence diagnostics and enhance effort for turbulent heat transfer experiments	150	UCLA, PPPL
3. Support for CDX-U scoping experiments with liquid metal limiter and divertor and Support Modelling	200	PPPL, UCLA
4. Serious Modelling and Analysis of Plasma-Liquid Inertions (Field Penetrations, Effect of Variations in Magnetic Field, Plasma Disruptions, etc.)	200	PPPL, GA, SNL, ANL
5. Experimental data on flibe and Sn-Li	200	ANL, ORNL
6. Construct a joint MFE/IFE Thermofluid Facility for Hydrodynamics and Heat Transfer for Thick Liquid Wall Concepts (Total Cost: $1 M over 2-year)	500	UCLA, PPPL, LLNL, GA, ANL, SNL

Competitive Peer-Reviewed Awards Planned for APEX for FY 2000

- $150K is allocated in the APEX Budget for FY2000 for competitive Peer-Reviewed Award(s)

- The Topic is Proof-of-Principle (PoP) Experiments

- The specific focus is under discussion

  The prevailing view is to focus on Preconceptual Design for PoP Experiment(s) on Liquid Walls

  i.e. identify the testing requirements and the best approach to satisfy these requirements

Plan for FY 2001

1. Neutronics

- Maintain services effort to the community
- Work with the Nuclear Data Community to measure and evaluate high priority data needs
- Funding: $150K
- Organizations: ORNL, TSI, UCLA

2. International Collaboration on Thermomechanics for Beryllium and Pebble Bed Ceramics

- Complete FY 2000 Tasks
- Continue IEA Collaborative Tasks
- Construct UNICEX: Unit Cell Experimental Evaluations of thermal and mechanical interactions among structure/coolant/lithium ceramic/beryllium materials
- Funding: $500K
- Organizations: UCLA, ORNL, ANL, PNL, INEEL

3. APEX

- Transition to and focus on Proof of Principle stage for most promising concepts
- Funding: $3M
- Organizations: UCLA, ANL, ORNL, UW, PPPL, SNL, INEEL, LLNL, GA, LANL

Plan for FY 2001 for APEX

Objective:

To make the transition from the Exploration Phase to the Proof-of-Principle Phase for the most promising innovative concept(s)

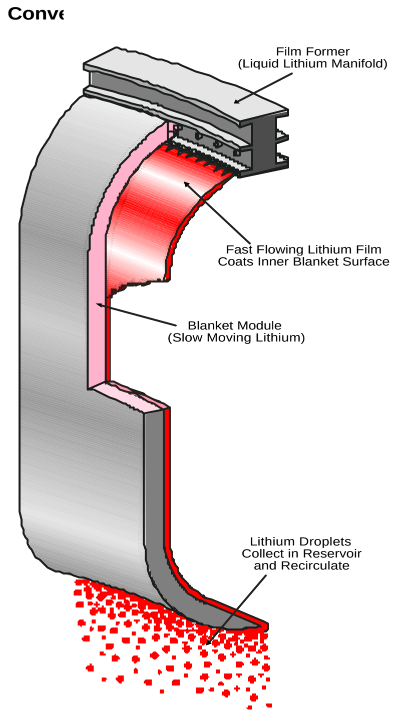
Focus of Proof-of-Principle Phase:

1. Modelling and Predictive Capability
2. Laboratory Experiments for Fundamental Data
3. Conceptual Design and Analysis
4. One or Two Proof-of-Principle Experiments

APEX

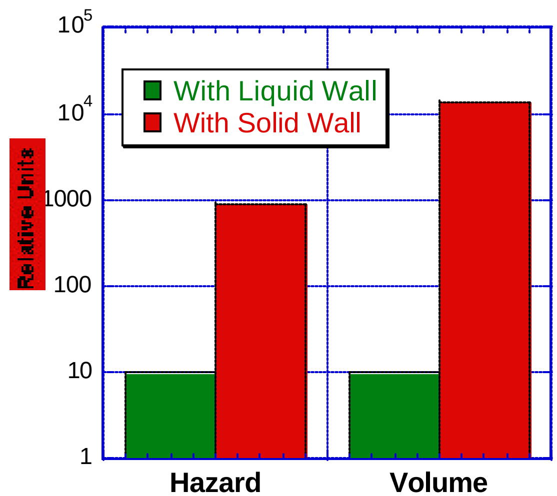
Exploring revolutionary concepts that substantially improve the vision for an attractive fusion energy system

- **High Power Density**
- **High Thermal Efficiency**



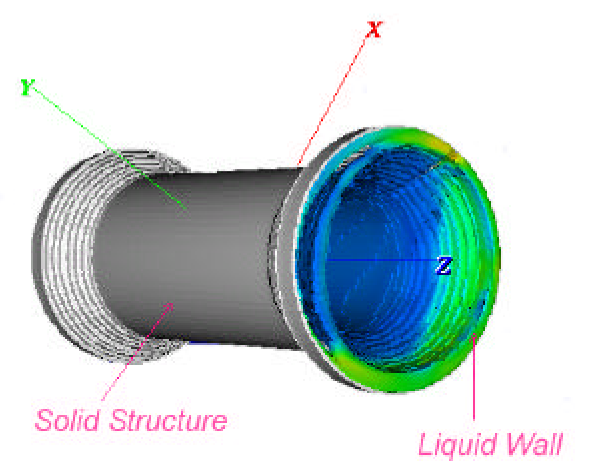
Liquid walls can handle Neutron Wall Loads up to 30 MW/m^2 with high surface heat load

- **Inherent Low Activation**
- **Solve Waste Problem**



Liquid walls reduce both radio-active hazard and waste volume by shielding structures and increasing lifetime

- **High Reliability**
- **Fast Maintenance**



Liquid walls eliminate vulnerable structures (e.g. FWs) that fail often and require frequent maintenance

APEX Modelling and Simulation Tasks

❑ LM-MHD Free Surface Modeling with Spatially and Temporally Variable Magnetic Fields

The effort is aimed at extending the LANL 3-D Telluride computer code to handle MHD effects. Development of MHD related computational algorithms are already underway at UCLA.

Objectives

- **Characterize the effects of 1/R toroidal field dependence, polodial field variation, and various idealized plasma instabilities on liquid metal wall hydrodynamic characteristics.**
- **Determine the equilibrium configuration and heat transfer of liquid wall concepts using liquid metals and assess the need for insulator coatings.**

❑ Free Surface Turbulent Heat Transfer for Flibe including MHD Effects

Effort is initiated in FY99.

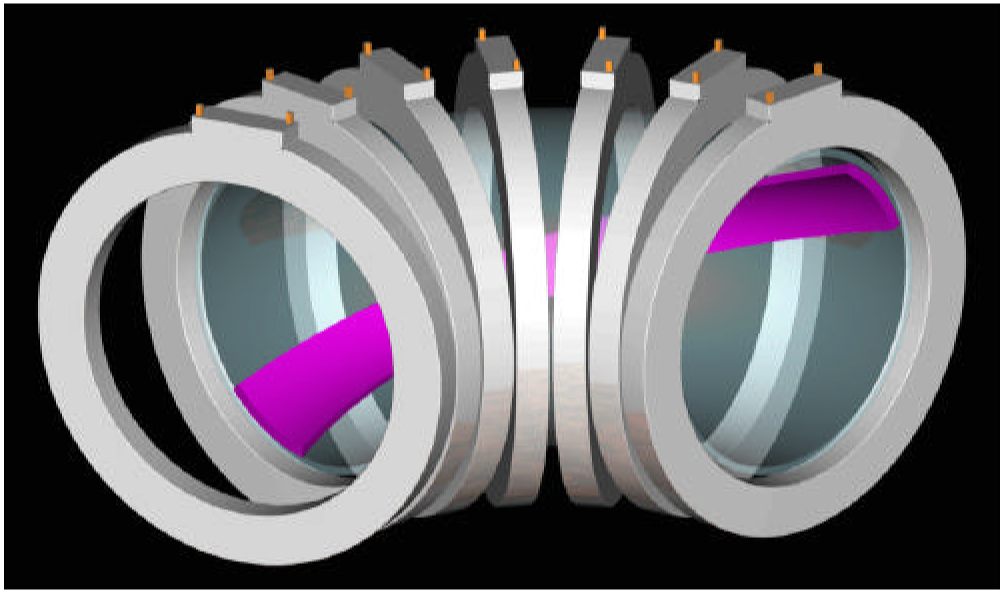
Modelling thermo-fluid physics and heat transfer for turbulent Flibe surfaces in a vacuum, including turbulence generation and interaction with free surface and magnetic fields

❑ Field Penetration and Plasma Control Analysis *(PPPL takes the lead using an existing code)*

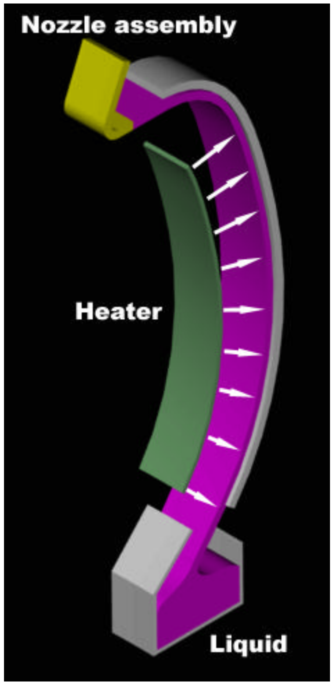
APEX Small-Scale Laboratory Experiments

Small-scale laboratory experiments for thermofluid physics and MHD free surface to explore phenomena and obtain key property data for liquid walls

- **Liquid metal (LM) free surface flow in steady and non-constant magnetic field experiments in toroidal geometry**
- **Flibe simulant turbulent flow and heat transfer experiments**
- **Sn-Li vapor pressure, vapor composition, and thermal conductivity experiments (under incremental funding)**



Partial toroidal magnetic field test system coupled to the existing MeGA loop facility

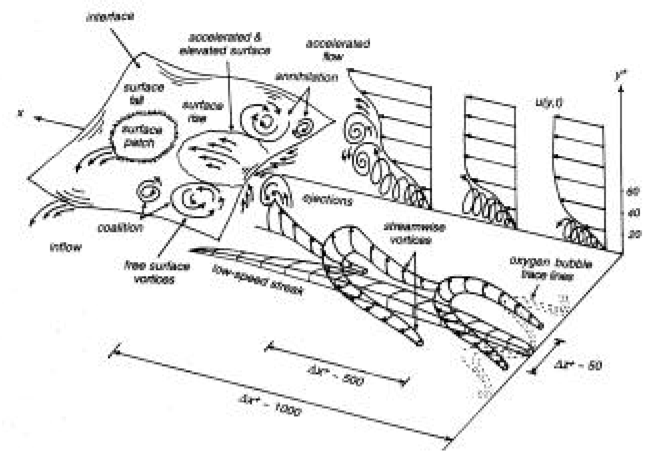


Schematic view of a free surface flow heat transfer experimental test stand

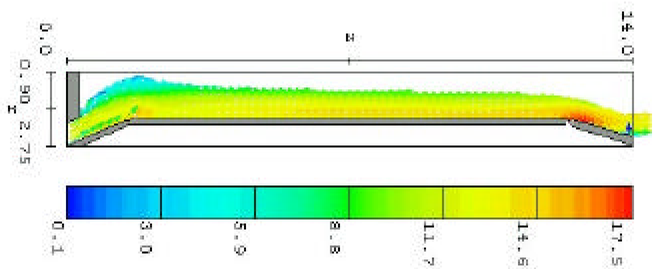
APEX Liquid Wall Research is Pushing the Frontiers of the Applied Sciences

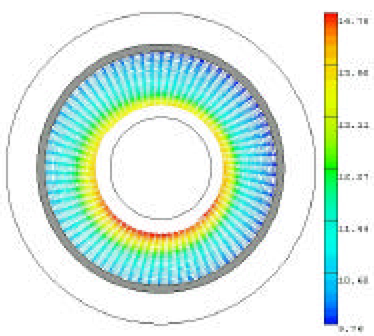
e.g. Understanding and modeling role of turbulent convection in free-surface flibe heat transfer

e.g. Predicting evolution of LM-MHD free surface waves, and induced 2D-MHD turbulence structures



Turbulence structures generated at the liquid-solid interface govern heat transfer and impurity flux at liquid-plasma interface





Calculated velocity and surface depth for inner vortex flow

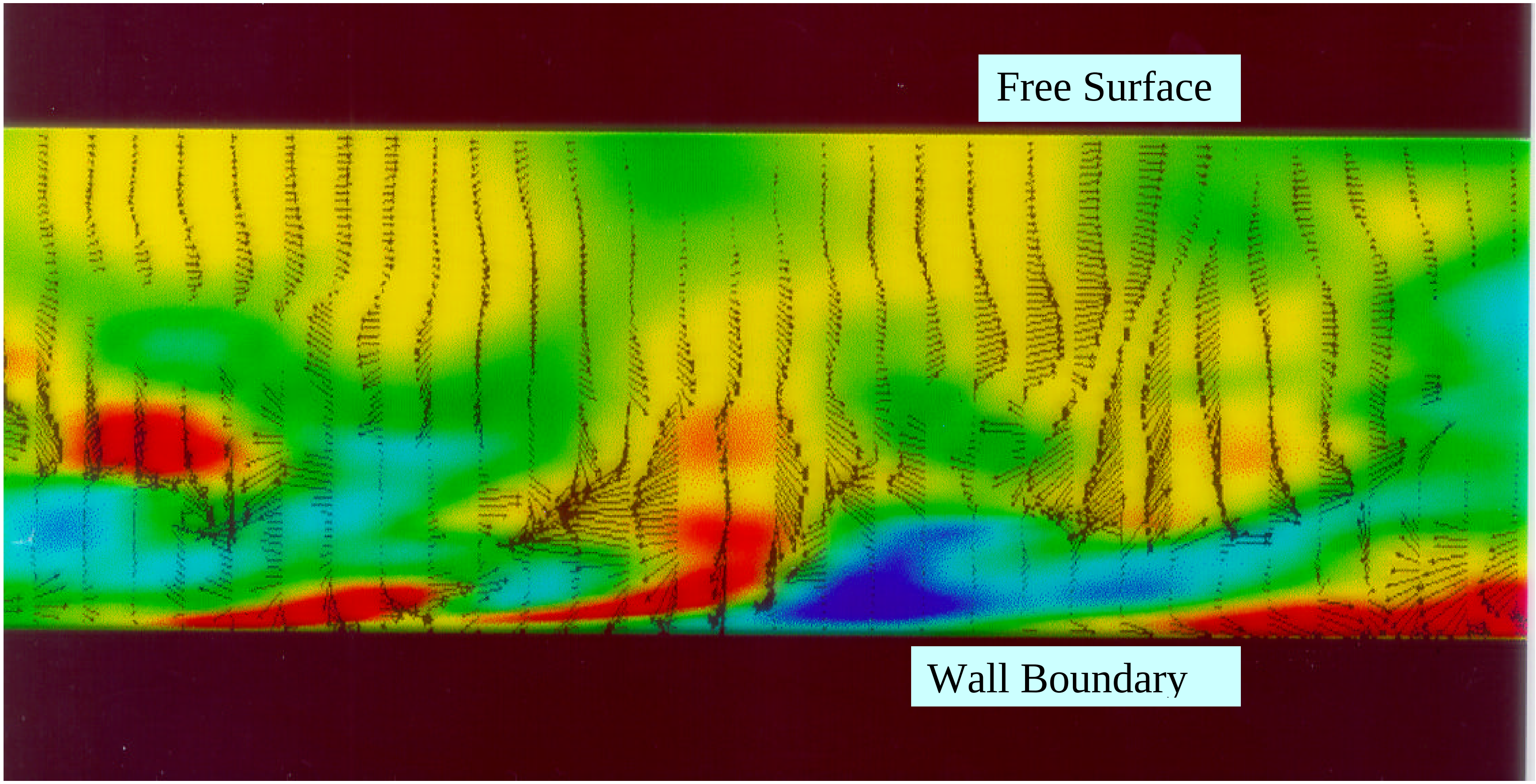
e.g. Terraflop/Tbyte simulation of complex geometry, large-scale, liquid flows with free surfaces

e.g. Interaction of spatially and temporally varying magnetic fields on 3D LM-MHD flows.

APEX Modeling of Free-Surface Flow is A Challenging Engineering Science Problem and is Attracting Outstanding International Experts

(UCLA/Toyama/Tokai University Collaboration- Professors Satake and Kunugi)

Reynolds number ~ 5000



Contributions to Engineering Science

Model Development for Free-Surface Liquid Hydrodynamics, MHD and Turbulent Heat Transfer Contributes to:

- ❑ **Advancing state-of-the-art computational algorithms to handle high Reynolds number turbulent flows, micro-scale turbulent eddies, and the free surface flow boundary tracking**

- ❑ **Understanding heat and mass transport phenomena at liquid/vacuum interface through detailed modeling of fluid flow structures**

Spin-off Opportunities

This is an extremely challenging interdisciplinary scientific problem, with relevance to fields such as **Oceanography** and **Metallurgy**, as well as other **high heat flux applications such as Rocket Engine Design**

e.g. Metallurgy for Mold Casting and Stirring

The fluid motion during solidification of metallic casts has a large effect on the microstructure of the cast components.

Ceramic Breeder Pebble Bed Modeling Contributions to Engineering Science

3-D Discrete Numerical Simulation Code Development Addresses Fundamental Processes of Microstructure Evolution on Overall Packed Bed Performance

- **Advanced computational techniques as well as a sophisticated understanding of material interactions and thermomechanics are required for unique fusion environmental conditions:**
  - High Temperature (differential thermal expansion, thermal creep)
  - Irradiation Swelling
- Incorporate computational results into innovative design/fabrication techniques

Spin-off Opportunities

The biggest problem encountered in plasma spray technology is how to design a powder feeding apparatus that can provide a uniform feeding rate

A Slight Modification of this Modeling Capability Can Be Used to Explore an Innovative Design of a Powder Feeding Apparatus for the Plasma Spraying Industries.