Science and Technology of Inertial and Magnetic Fusion Energy

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UCLA Fusion Technology Program
(Prof. Mohamed Abdou)

- ITER
- VENUS
  - Solid Breeder Blankets
    - Tritium transport in lithium ceramics & Be
    - Innovative techniques for thermal control
    - Thermomechanics experiments & models: HiTeC, ICE, PBX
  - Liquid Metal Components
    - MHD models for thermal & fluid flow analysis of blankets
    - Free surface film flows (divertor, HHFC)
  - Tritium Fuel Cycle
    - Integral dynamic fuel cycle model
    - Tritium extraction from liquid metals
- TFTR Radioactivity and Shielding Exp'ts
- Reactor Design Studies
  - Prometheus
  - MFE DEMO
  - IFE Facilities and Technology R&D
- Neutronics
  - US/JAERI collaboration on integral experiments and analysis
  - UCLA leads the US effort
  - Development of computational techniques; sensitivity/uncertainty analysis
  - Radioactivity & decay heat experiments; measurement techniques for nuclear heating

Test Program
- UCLA leads US efforts
- Definition of test program, international space allocation and device utilization
- Requirements on major device parameters

Nuclear Design
- Blanket tritium & thermal design and analysis
- Divertor design and analysis
- Shielding design for penetrations

Nuclear R&D
- Insulated duct MHD – experiments & modeling
- High heat flux compliant layers
- Thermal hydraulics: gap conductance, particle beds, purge flow characteristics
UCLA Fusion Technology Program

• Recognized internationally for being at the forefront of the world’s effort on fusion technology.

• The Program is focused on:
  1) Key Scientific issues and R&D for the technological feasibility and attractiveness of fusion energy.
  2) Education and Training of future scientists/engineers.

• The Program includes:
  1) Theory, modelling
  2) Experiments
  3) Analysis
  4) Innovative design

• Key Elements:
  – Blanket (Tritium Breeding and Energy Conversion)
  – Fuel Cycle
  – Divertor (Plasma Particle and Heat Removal and Impurity Control)
  – Design Studies

• Strong Collaboration with others nationally and internationally.

• Integrated team of bright graduate students, faculty, and experienced research staff.
MEGA Loop for Liquid Metal Magnetohydrodynamics Studies

- Research on LM film flow behavior in fusion magnetic fields
- Innovative concept for liquid metal divertor
- First wall candidate for Inertial Confinement Fusion Reactor

Loop Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Metal</td>
<td>Bi-Pb-In-Sn-Cd</td>
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<tr>
<td>Melting Point</td>
<td>47 C</td>
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<tr>
<td>Maximum Flow Rate</td>
<td>1.5 l/s</td>
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<tr>
<td>Loop Volume</td>
<td>15 liters</td>
</tr>
<tr>
<td>Pump Power</td>
<td>13 kW</td>
</tr>
<tr>
<td>Maximum Field Strength</td>
<td>1.8 KG</td>
</tr>
</tbody>
</table>
U.S. DEMO He-Cooled Solid Breeder Reference Blanket

View of One Lower First-Wall/Blanket Segment

- DEMO Mid Plane
- He-Supply-Manifold (simplified)
- Poloidally-Cooled Blanket Coolant Panel
- Alternating Layers of Be and Solid Breeder
- First Wall Poloidally-Cooled
- Poloidally-Cooled-Side Wall Panel
- He-Return Manifold
UNICEX – Solid Breeder Unit Cell Thermomechanics

Purpose

- Demonstrate thermal control
- Generate empirical data
- Improve models and basic understanding

Key Features

- Prototypical materials
  Li2ZrO3 bed
  Be binary bed
- He & water coolants
- Breeder and multiplier purges
- Plate heaters at center and interfaces
Solid Breeder Thermomechanics Laboratory

- Several experiments on thermomechanical interactions among the physical elements and environmental conditions of solid breeder blankets
- A series of unique experiments that have attracted international collaboration
- Joint collaboration with industry (Rockwell, MDA)
- Provide scientific and engineering data for ITER
- UCLA Leads Efforts on ITER Test Program
  - Technical issue analysis; - Test article design; - Engineering scaling development
- Industrial Affiliates Provide Support on ITER Test Blankets
  Engineering Integration in Key Areas:
  - Remote handling; - Ancillary equipment; - Engineering interface and Test port design
The National Ignition Facility—192 Beam

Amplifier columns

Main amplifier power conditioning system

Spatial filters

Cavity mirror mount assemblies

Beam control and laser diagnostic systems

Interstage and beam transport system

Laser and beam transport structural support systems

Pockels cell assembly

Optical pulse generation system

Control room

Target chamber

Polarizer mount assembly

Master oscillator room

Transport turning mirror mounts

Final optics system
IFE First Wall Protection Modeling at UCLA

- Inertial jet flow on inverted surface

- Film flow stability and response to impulsive loading
  - isochoric heating
  - x-ray ablation impulse

- Shock propagation and effect in thin liquid film

Vertical film flow at $Re = 200$ with periodic inlet conditions and no inflow through substrate. The solid line is a time $t = 0.12$ s with subsequent lines every 0.02 s.

Vertical film flow at $t = 0.2$ s (solid) and $t = 0.20226$ s (dotted) with blast commencing at $t = 0.2$ s.
Inertial Fusion Chamber Technology Test Stand

Facility Requirements
- Overhead crane
- Highbay area (> 18 feet)
- Floor space (~ 1500 sf)
- Cooling water (~ 300GPM)
- 480 VAC power (~ 400KW)
Dynamic Fuel Cycle Modeling

- Comprehensive dynamic modelling to determine the time-dependent tritium flow rates and inventories in the entire fusion system

- The model is now being used by ITER and the other organizations to:
  - evaluate whether the D-T cycle can be closed in a real engineering system (engineering feasibility of the DT cycle)
  - minimize tritium inventories in various components of the fusion system
Fusion Neutronics R&D and Design Activities at UCLA

**Nuclear Responses**
- Tritium Production
- Nuclear Heating
- Induced Activation and Decay Heat
- Shielding/Radiation Streaming

**Elements**
- Integral Experiments
- Experimental Techniques and Measuring Methods
- Code Development
- Basic Data measurements & Evaluation
- Basic data Processing and Working Libraries

**Participation in the Nuclear Design of Several Reactor Concepts**
- ITER FW/Blanket/Shield
- IFE (Prometheus-L and Prometheus-H)
- VENUS

**Objectives of the R&D Program**
- Provide the Experimental Database Required for Approval and Licensing of the Device
- Verification of the Prediction Capabilities and Generation of Design Safety Factors
- Reduce High Cost Associated with Large Safety Factors Used to Compensate for Uncertainties

**International**
- USDOE/JAERI Collaborative Program

**National**
- ITER R&D
- TFTR
- NIF
UCLA Collaboration with Japan on the World’s Premier Fusion Neutronics Activities

Neutronics source surrounded by a mockup of a Fusion blanket

Phase-III
Experimental Arrangements

PHASE-IIIA
(Reference)

PHASE-IIIB
(Armor)

PHASE-IIIC
(Armor with Opening)

- Program includes experiments and analysis for tritium breeding, radioactivity, and nuclear heating
- Results are of critical importance to the feasibility and the attractiveness of fusion devices such as ITER
Concept of Experimental Arrangement

Phase-II

Phase-I

Phase-III

Rotating Neutron Target

Pseudo-Line Source

Fixed Target
Fig. APP.IV.1 SS316/Water Experimental Assembly
Design Safety Factor Versus Confidence Level for Tritium Production Rate

- (Confidence Level for Calculations not to Exceed Measurements)
Calculated-to-Experimental Values of Induced Radioactivity for Several Elements

Overall C/E plot for all Material & Cases

LIB90
REAC*63
REAC*175
JENDL

Element