DEVELOPING THE BASIS FOR TARGET INJECTION AND TRACKING IN INERTIAL FUSION ENERGY POWER PLANTS

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IAEA Technical Committee Meeting
June 7-9, 2000
Madrid, Spain
TOPICS

• Technology Development Strategy
• Current Target Designs
• Target Injection and Tracking Requirements
• Critical Issues for Target Injection
• Approach to Resolution of Issues
• Analyses
• Experimental
• Conclusions
TARGET INJECTION IS A CRUCIAL COMPONENT OF THE IFE COMMUNITY’S PHASED DEVELOPMENT STRATEGY

- Do Development Necessary To Support a Decision for Next Machine at Each Step

RADIATION PREHEAT TARGET FOR IFE (NRL)

INDIRECT DRIVE TARGET FOR IFE (LLNL)
INJECTION AND TRACKING REQUIREMENTS CAN BE SEVERE

- Cryogenic Targets with Carefully Layered Symmetric DT ICE
- Place ~500,000 Per Day (5-10 Hz) into a High Temperature Chamber (500°-1500°C)
- Reliable, High Precision Placement (±5 mm)
- Indirect/Direct Drive Requires Tracking and Beam Steering to ±200µm/20µm
- Sombrero Is Reference Direct Drive Chamber Concept
  - Challenging for target injection
  - Large, ~1500°C chamber with xenon gas-fill to protect dry wall (0.5 torr at std T)
  - Leads to high velocities and significant accelerations
- Indirect Drive Targets Have Protective Hohlraum
A STRATEGY FOR DEMONSTRATING SUCCESSFUL TARGET INJECTION AND TRACKING HAS BEEN DEFINED

- We Must Address these Critical Issues:
  - Ability of targets to survive thermal environment in chamber
  - Accuracy and repeatability of target injection
  - Ability of targets to withstand acceleration during injection
  - Ability to accurately track targets
HEATING OF INDIRECT DRIVE TARGETS DURING INJECTION IS VERY SMALL

- **ANSYS Finite Element Model Used:**
  - LLNL Close-Coupled Distributed Radiator Target
  - Estimated Properties for Low-Density Hohlraum Materials Based on Thin Layers

- **Heating Profile for Injection Process:**
  - Acceleration phase for 32ms with 300 K surface temperature applied at rear
  - Coasting phase for 30ms at a velocity of 100 m/s
  - In-Reactor phase for 30ms. Radiation heat load applied at surface assuming 930 K emitter (OSIRIS) and 90% reflection

- **Results Show Negligible DT Heating During Injection**

Ref: Nuclear Fusion Vol. 39 No. 11, 1999
HEATING DURING INJECTION IS A CRITICAL ISSUE FOR DIRECT DRIVE TARGETS

- **Two Sources of Heat Flux in a Sombrero-Like Chamber - Thermal Radiation & Convection (Gas Heating)**
- **Thermal Radiation**
  - Wall emission treated as diffuse blackbody radiation
  - First wall average temperature = 1485°C (1760K)
  - Total thermal radiation heat flux is ~54 W/cm²
- **What are the Effects of a Surface Heat Flux on Direct Drive Target?**
  - Estimated with ANSYS finite element model
  - Yield strength and elastic modulus extrapolated from D₂ data
  - “At Risk” region represents reaching the yield stress
  - “Failure” is assumed if the DT temperature exceeds the triple point
- **Conclusion:** The Surface Heat Flux Must be Less Than ~ 1 w/cm² to Prevent Damage to the DT Layer
THERMAL RADIATION HEAT LOAD CAN BE REDUCED WITH A HIGHLY REFLECTIVE OUTER SURFACE

- Consistent with the Concept of the High-Z (Gold) Film on the NRL Radiation Preheat Target
- Measurements of Gold/Kapton Multi-Layer Film
  - Total reflectivity of Gold/Kapton is Low
- Literature Data Show Gold Reflectivity Up To 98% Can Be Obtained With Gold Film Thicknesses Greater Than 2000 Å
CONVECTIVE HEATING LOAD IN A SOMBRERO CHAMBER IS ALSO A MAJOR HEATING SOURCE

- The Convective Heat Flux Increases with Velocity
  - Using Whitaker continuum equation with slip flow corrections

- More Importantly and More Damaging, The Asymmetric Nature of the Heating Increases at Higher Velocities (ANSYS Flotran)

- Corrected Whitaker Results Agree Well with Flotran at Xe Pressure of 0.5 Torr

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<tr>
<th>Velocity (m/s)</th>
<th>Flotran (W/cm²)</th>
<th>Whitaker (W/cm²)</th>
<th>Sombrero (W/cm²)</th>
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PARAMETRIC ESTIMATES OF THE DT HEATUP UNDER VARYING REACTOR TEMPERATURE AND CHAMBER PRESSURE CONDITIONS HAVE BEEN PERFORMED

- **Bottom Line = DT Heatup is Far Outside the Survival Range for the Reference Chamber Conditions**
- **Options:**
  - Reduce the fill gas pressure
  - Reduce the chamber temperature
  - Provide other wall protection methods
  - Provide additional target protection (e.g., change the target design)
- **A Number of Potential Target Protection Methods Have Been Proposed**
  - Sacrificial frozen gas on the surface of the target
  - Co-injection of a “wake shield” to clear the area in the front of the target
  - Using a sacrificial sabot that protects the target until reaching the target chamber center
  - Fast-formed liquid target – an open-pore foam target filled with DT that is cooled until injection, then utilizes the chamber heating to generate an all-liquid DT fuel with a smooth inner surface
CURRENTLY DEVELOPING A DIRECT SIMULATION MODEL TO IMPROVE OUR PREDICTIVE CAPABILITY FOR CONVECTIVE HEATING

- Simulate Individual Interactions Between Gas Molecules and Between the Surface of the Target and Gas Molecules
- Preliminary Results Agree Reasonably Well with Corrected Whitaker Equation

Temperature distribution of gas Target at 18K
0.05 Torr of Xenon at 1760K
Injection at 800 m/s
AN INTEGRATED TESTING PROGRAM IS AN ESSENTIAL PART OF THE DEVELOPMENT STRATEGY

- Accurate Modeling of the DT Response Requires Material Property Data (Survival Under Acceleration)
  - DT strength and modulus at relevant temperatures measured at LANL
  - DT properties as a function of time (He-3)
- Thermal Response of the Target With DT Can Be Determined in A Stationary Cryostat at LANL
  - Evaluate evolving target designs, and reflective coatings
- Team Formed with LANL to Maximize Leverage of Resources


Cryogenic Pressure Loader (CPL) at Los Alamos

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- Eventually, all of the analyses and modeling should lead to a demonstration of successful injection of prototypical targets under representative conditions
THE DESIGN OF A REP-RATED TARGET INJECTION AND TRACKING SYSTEM IS UNDERWAY

- The Intent is to Provide Not Only a Facility to Demonstrate Injection Technology, But Also to Aid in the Development of Survivable Targets
- Technical Approach:
  - Phase I: Demonstrate injection and tracking accuracy first at room temperature
  - Phase II: Upgrade to cryogenic operations and high temperature chamber
CONCLUSIONS

• Critical issues have been identified and agreed upon by the IFE community

• Development plan prepared to address the critical issues

• Ultimate goal is to demonstrate injection into hot chamber

• Preliminary results and analyses for Indirect Drive target injection and tracking accuracy are encouraging

• Preliminary analyses for Direct Drive target injection shows changes in reference concept are needed

• An integrated systems study is starting next month directed by UCSD; dry wall chamber issues will be addressed first