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

Presented by Dan Goodin

Dan Goodin, Chuck Gibson, Ron Petzoldt, Nathan Siegel,
Larry Thompson, Art Nobile, Gottfried Besenbruch, Ken Schultz

General Atomics
Los Alamos National Laboratory
University of California, Berkeley
San Diego State University

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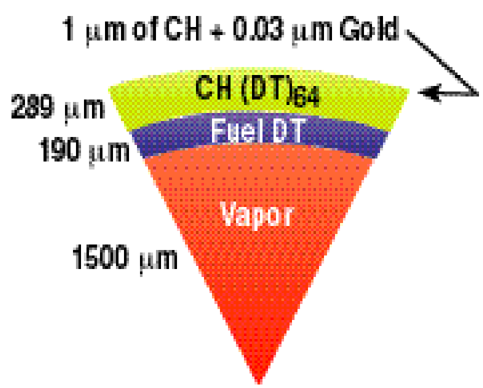
GENERAL ATOMICS

TOPICS

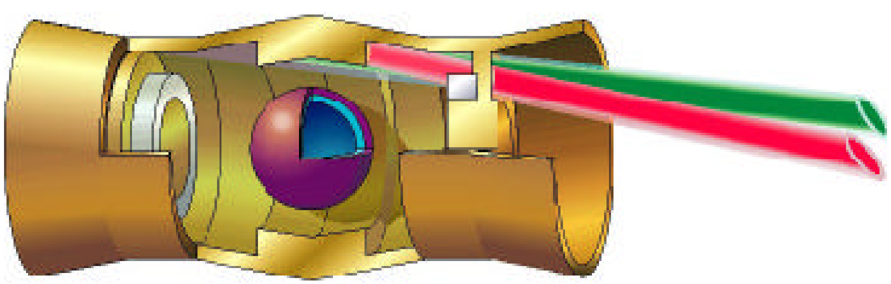
- Technology Development Strategy
- Current Target Designs
- Target Injection and Tracking Requirements
- Critical Issues for Target Injection
- Approach to Resolution of Issues
- Analyses
- Experimental
- Conclusions

TARGET INJECTION IS A CRUCIAL COMPONENT OF THE IFE COMMUNITY'S PHASED DEVELOPMENT STRATEGY

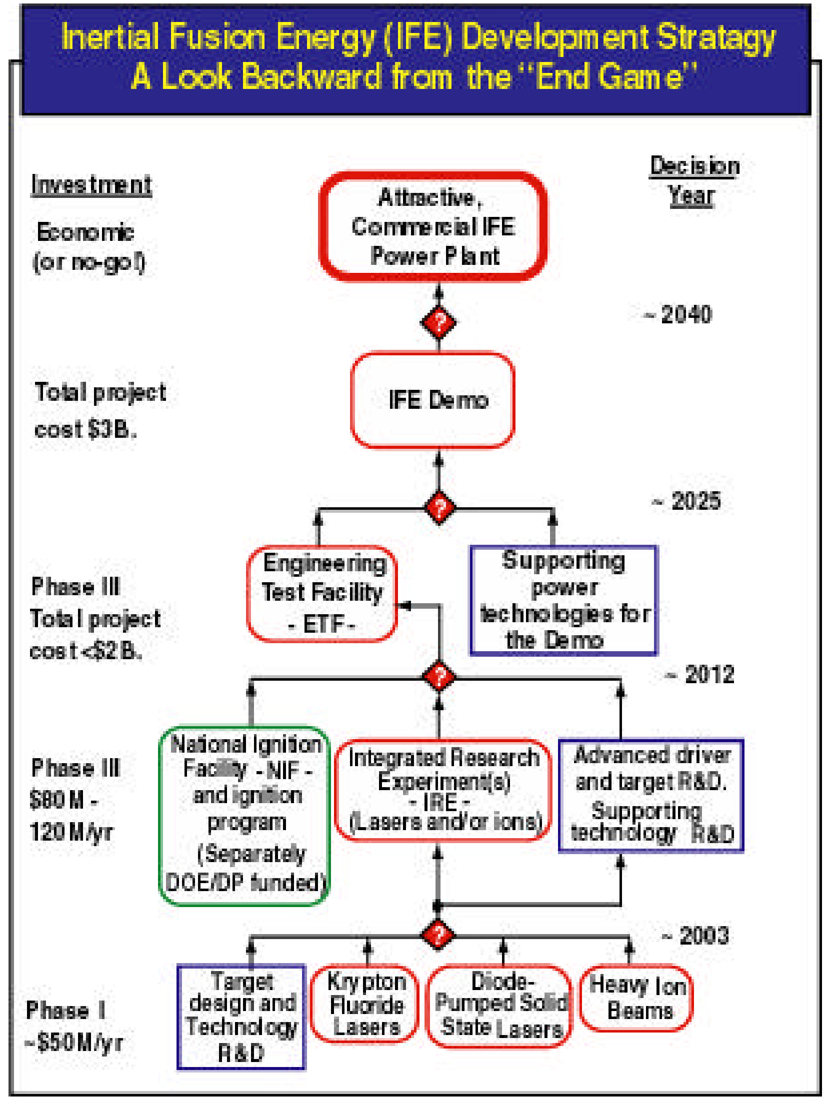
- **Do Development Necessary To Support a Decision for Next Machine at Each Step**



RADIATION PREHEAT TARGET FOR IFE (NRL)



INDIRECT DRIVE TARGET FOR IFE (LLNL)



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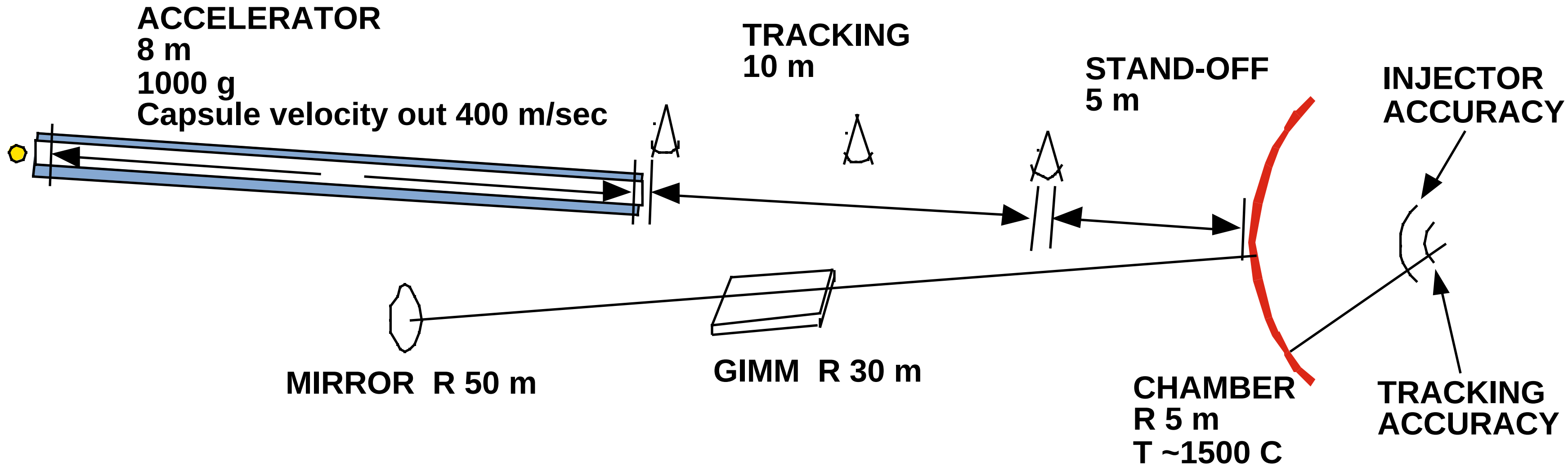
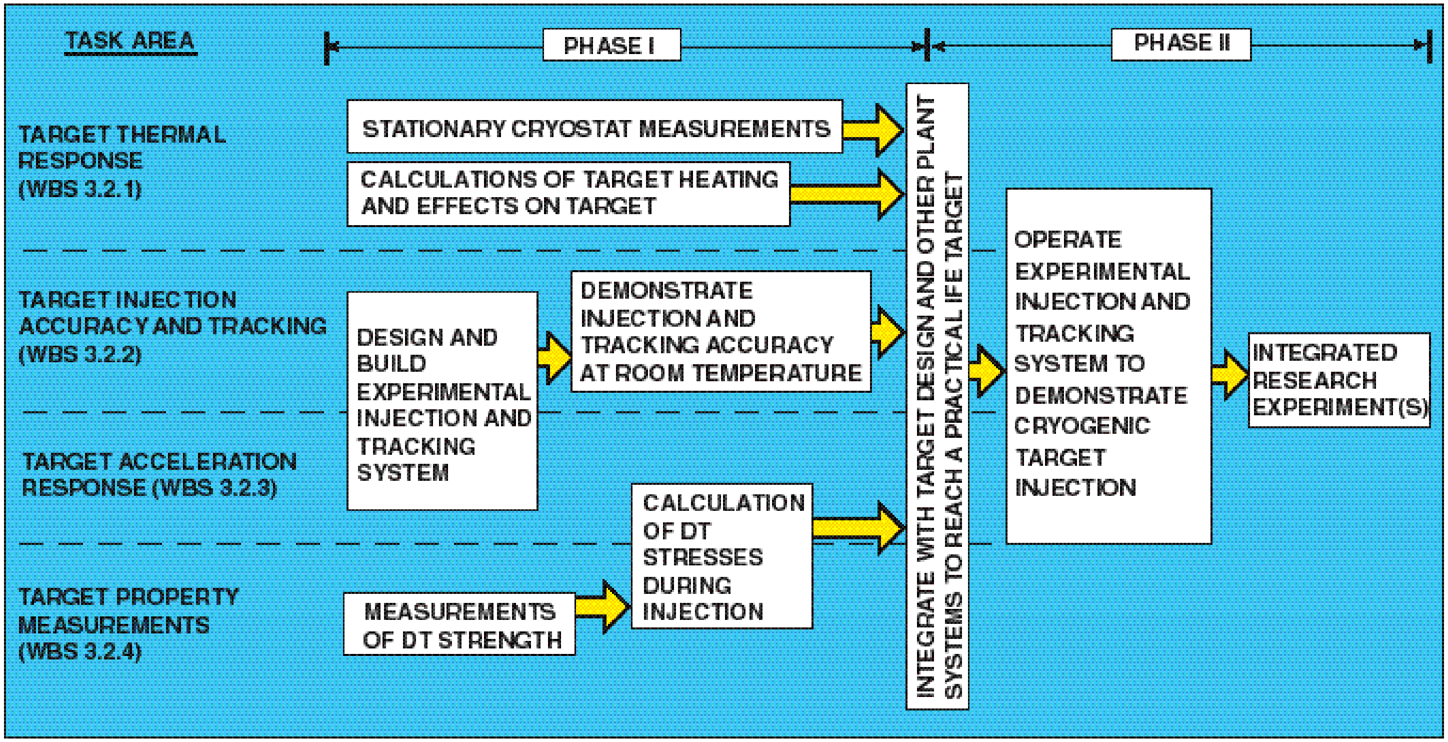
INJECTION AND TRACKING REQUIREMENTS CAN BE SEVERE



- **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



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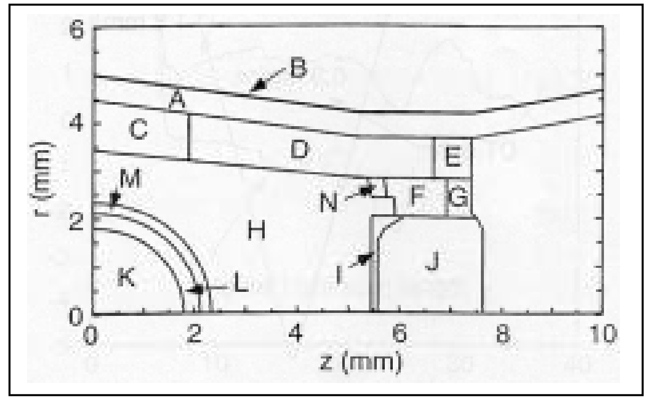
HEATING OF INDIRECT DRIVE TARGETS DURING INJECTION IS VERY SMALL

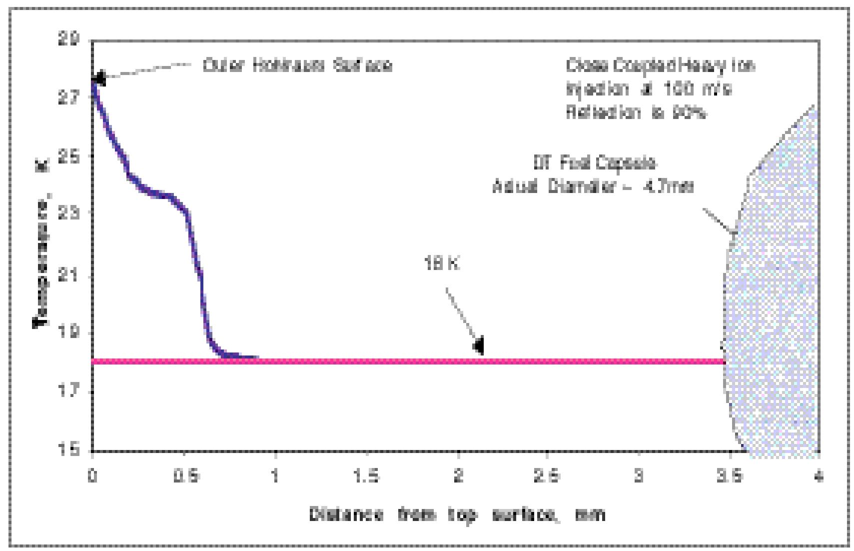
- **ANSYS Finite Element Model Used:**
  - LLNL Close-Coupled Distributed Radiator Target
  - Estimated Properties for Low-Density Hohlraum Materials Based on Thin Layers

- **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



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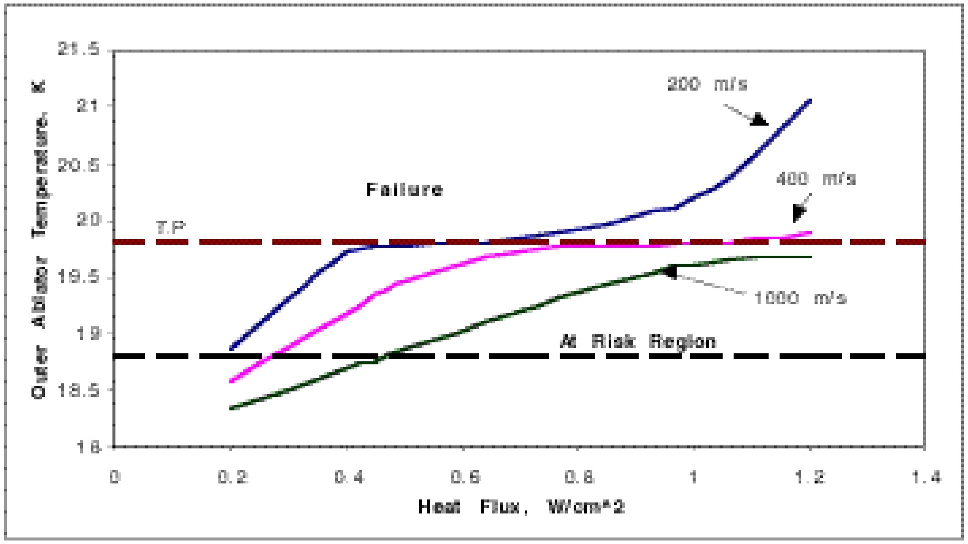
HEATING DURING INJECTION IS A CRITICAL ISSUE FOR DIRECT DRIVE TARGETS

- **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/cm^2
- **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 D_2 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/cm^2 to Prevent Damage to the DT Layer**



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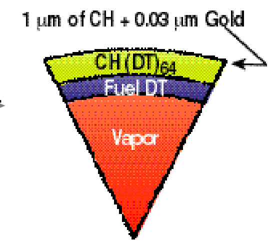
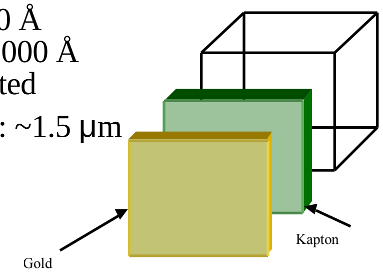
THERMAL RADIATION HEAT LOAD CAN BE REDUCED WITH A HIGHLY REFLECTIVE OUTER SURFACE

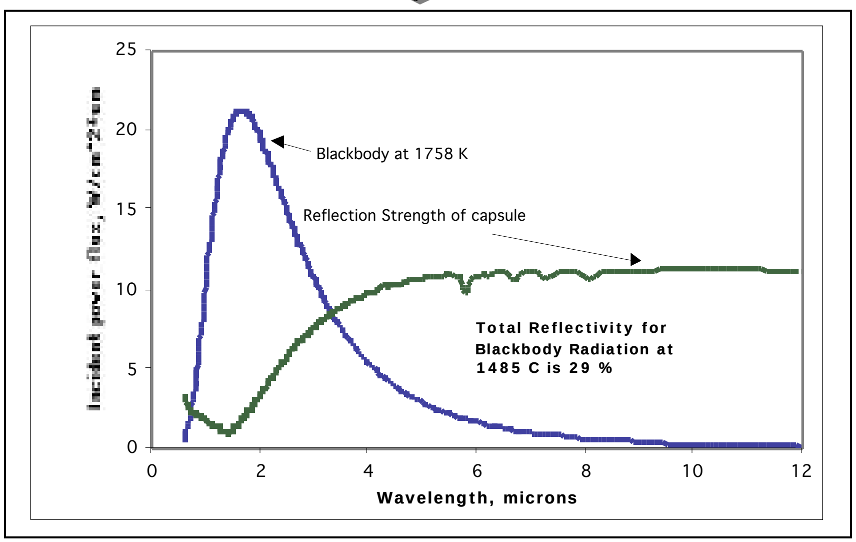
- **Consistent with the Concept of the High-Z (Gold) Film on the NRL Radiation Preheat Target**



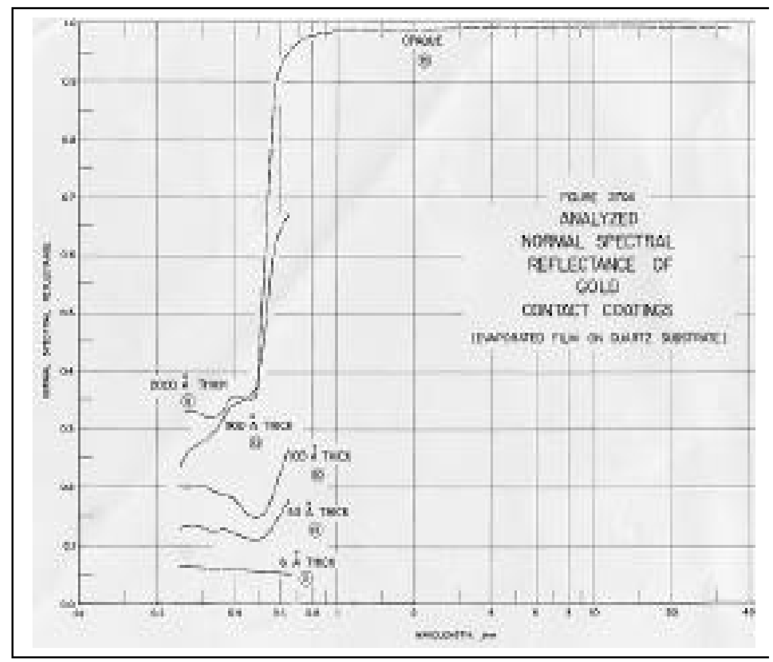
- **Measurements of Gold/Kapton Multi-Layer Film**
  - **Total reflectivity of Gold/Kapton is Low**

Gold Layer: 600 Å
Kapton Layer: 1000 Å
10 Times Repeated
Total Thickness: ~1.5 µm



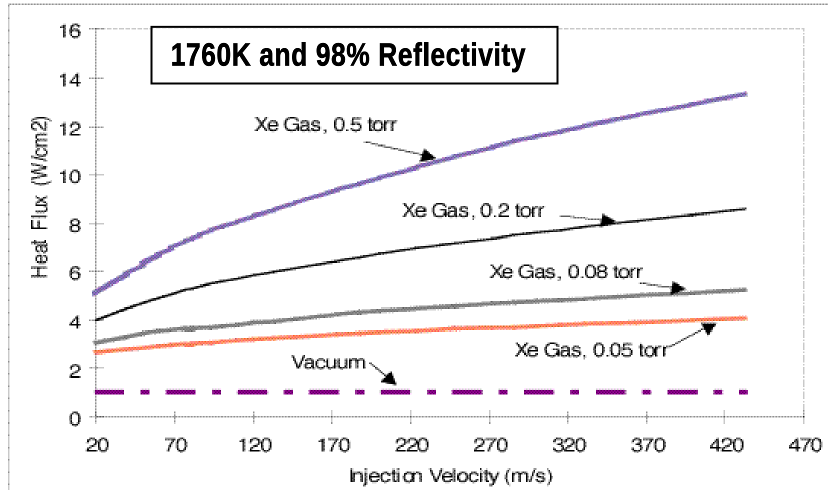


- **Literature Data Show Gold Reflectivity Up To 98% Can Be Obtained With Gold Film Thicknesses Greater Than 2000 Å**

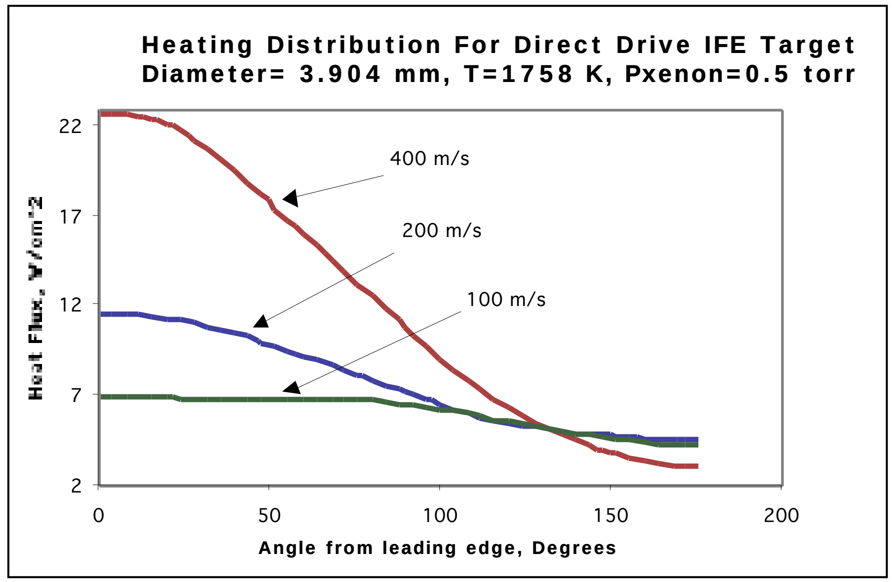


CONVECTIVE HEATING LOAD IN A SOMBRERO CHAMBER IS ALSO A MAJOR HEATING SOURCE

- **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**

Velocity (m/s)	Flotran (W/cm^2)	Whitaker (W/cm^2)	Sombrero (W/cm^2)
200	7.6	9.3	3.2
400	12.8	12.8	5.0

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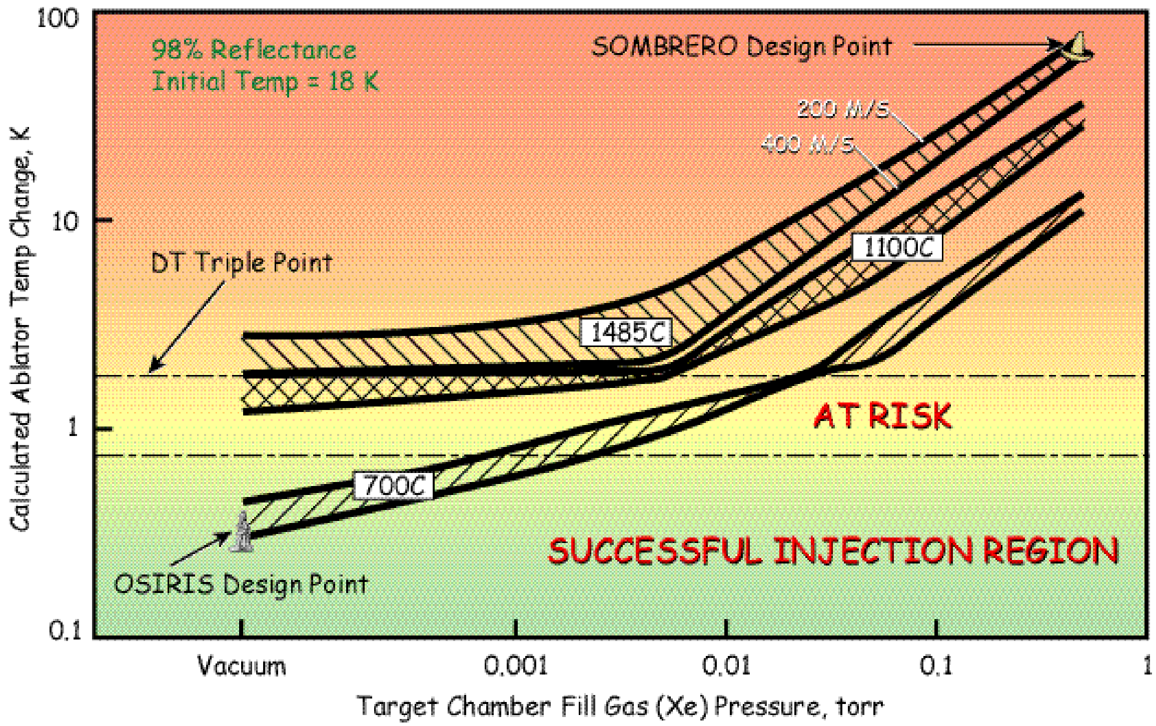
PARAMETRIC ESTIMATES OF THE DT HEATUP UNDER VARYING REACTOR TEMPERATURE AND CHAMBER PRESSURE CONDITIONS HAVE BEEN PERFORMED

- **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

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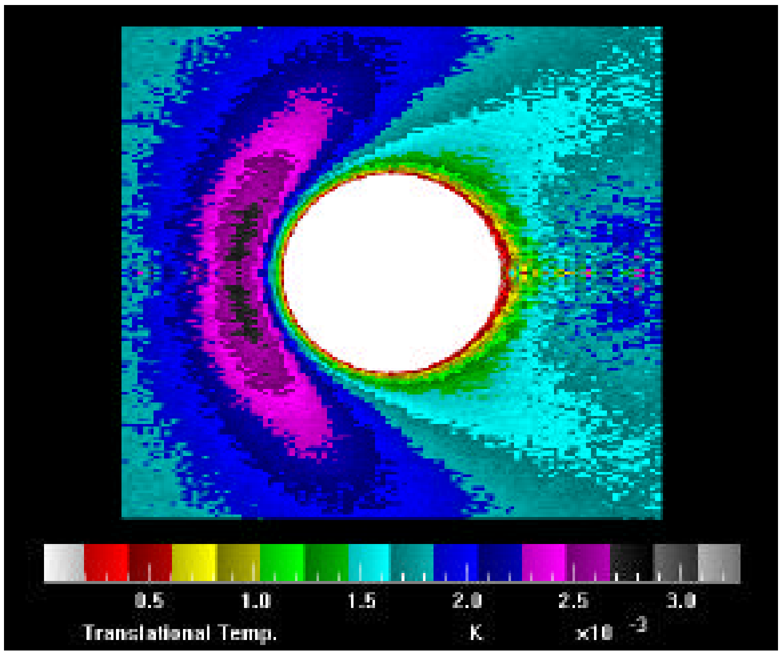
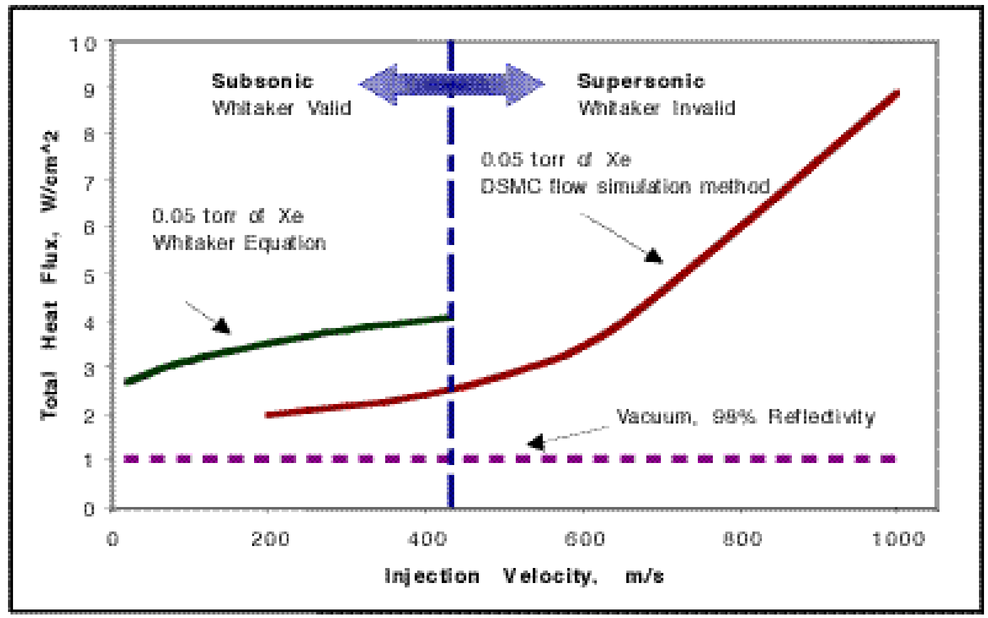
CURRENTLY DEVELOPING A DIRECT SIMULATION MODEL TO IMPROVE OUR PREDICTIVE CAPABILITY FOR CONVECTIVE HEATING

- **Simulate Individual Interactions Between Gas Molecules and Between the Surface of the Target and Gas Molecules**
- **Based on the Method of G.A. Bird (***Molecular Gas Dynamics and the Direct Simulation of Gas Flows, Oxford Univ. Press, 1994) .*
- **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



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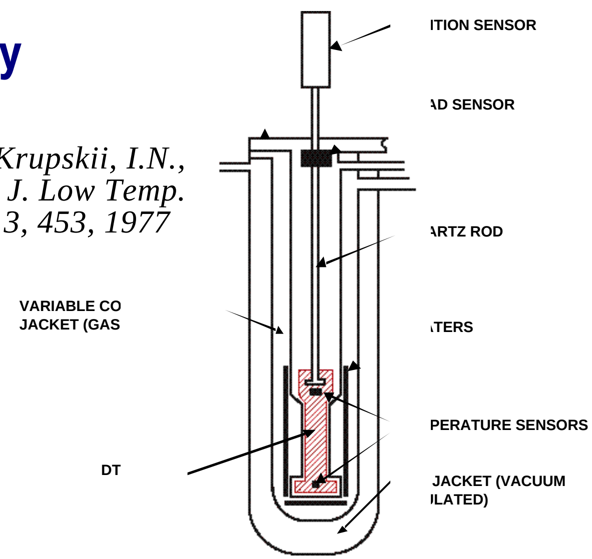
AN INTEGRATED TESTING PROGRAM IS AN ESSENTIAL PART OF THE DEVELOPMENT STRATEGY

- **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)

Ref: Krupskii, I.N., Soviet J. Low Temp. Phy. 3, 453, 1977



- **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**

	FY00		FY01		FY02	
	LANL	GA	LANL	GA	LANL	GA
3.0 Target Technology R&D						
3.1 Target Fabrication						
3.1.1 Assess Target Designs	X		X		X	
3.1.2 Investigate Target Matls & Man Tech	X		X		X	
3.1.3 Dev Manuf Process for Fab/Fill/Layer	X	X	X	X	X	X
3.2 Target Injection R&D						
3.2.1 Target Thermal Response	X		X		X	
3.2.2 Target Injection Accuracy & Tracking		X		X		X
3.2.3 Target Acceleration Response		X		X		X
3.2.4 Target Property Measurements			X		X	

Cryogenic Pressure Loader (CPL) at Los Alamos

- **Eventually, all of the analyses and modeling should lead to a demonstration of successful injection of prototypical targets under representative conditions**

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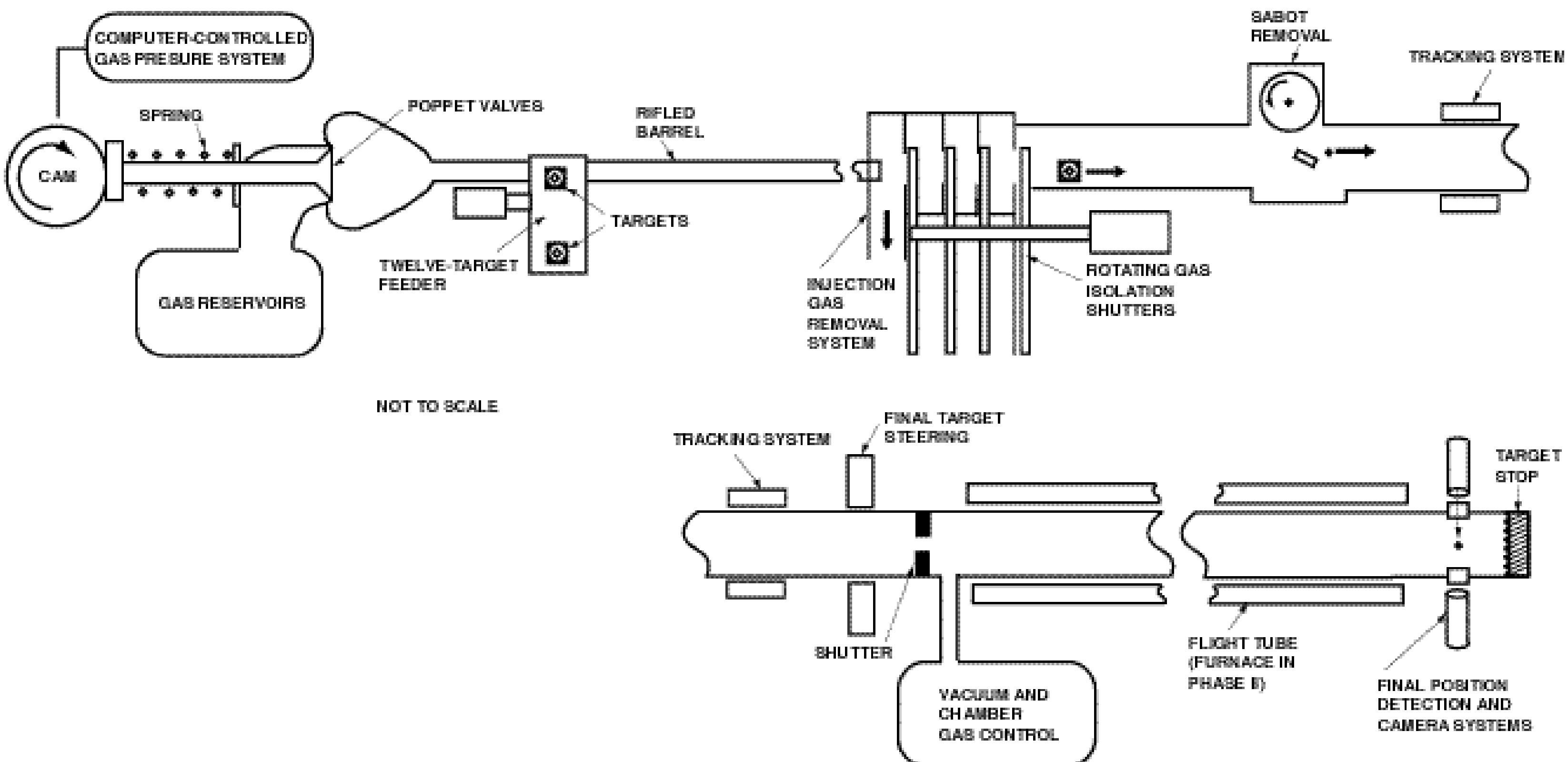
THE DESIGN OF A REP-RATED TARGET INJECTION AND TRACKING SYSTEM IS UNDERWAY

- **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**



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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