Target Injection Survival Plan:

Concepts, Methods and Experiment Design/Equipment Commissioning

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Definition of the problem addressed, reasons to approach it, and modalities of investigation

- **Goal:**

  Quantify the *response of a target* to the thermal environment of the fusion reaction chamber (hot gases, radiation heat loads).

  Acquire and apply experimental data into a *thermal model* to describe *heat flow* through the target.

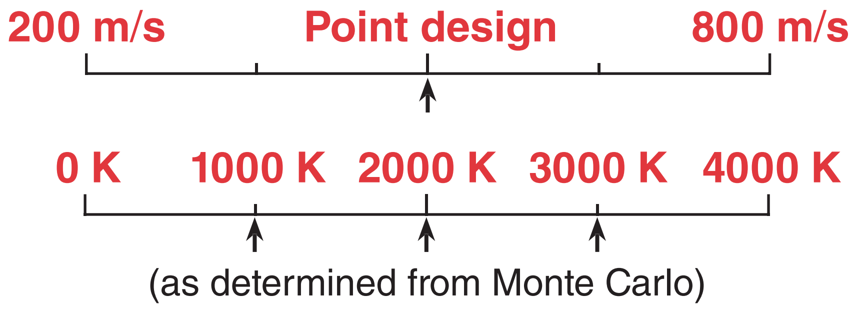
- **Experimental method:**

  Produce the environmental conditions and processes undergone by the target in the fusion chamber and measure *sticking and accommodation coefficients* of Xe (v, T, ρ) on an 18 K D_2 target.

- *Monte Carlo calculations* will guide experimental design.

Environmental conditions relevant for target injection

- Range of conditions that can be studied relative to target injection:
  - D_2 target at ~14 to 18.7 K
  - Target injection velocity
  - High temperature



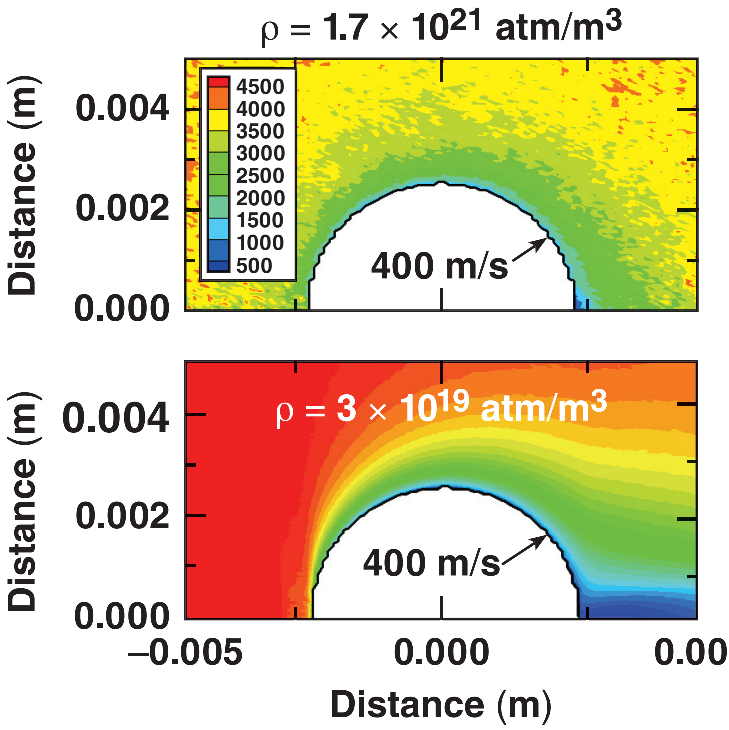
(as determined from Monte Carlo)

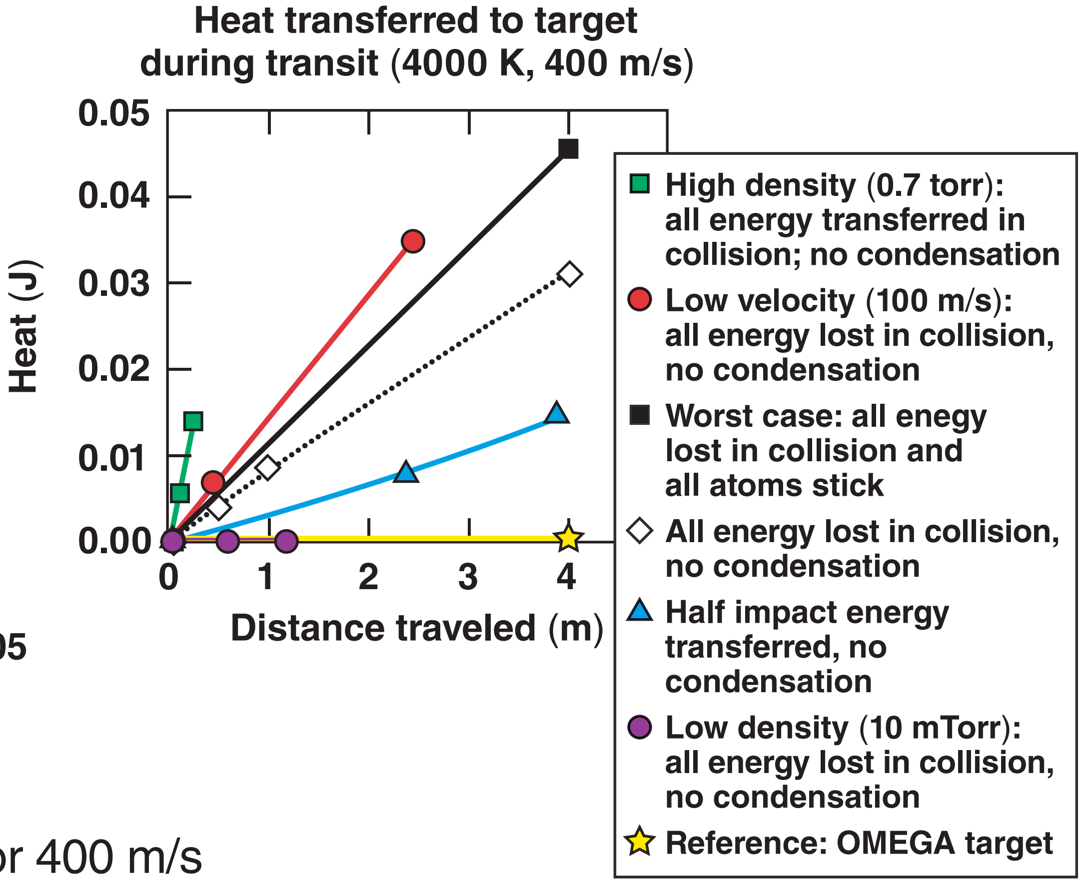
  - Vacuum (UHV)
  - Maximum incident energy flux at target
    - 330,000 W/m^2 for 10^{23} atom/m^3 (p = 3.1 torr at 300 K)
    - 25,000 W/m^2 for 10^{22} atom/m^3 (p = 0.31 torr at 300 K)

Experiment Concept and Design

Simulated conditions inside the fusion chamber

Response of a target to the heat flux (from previous Monte Carlo calculations)





- Xe gas at 4000 K
- 6-mm target injected at 100 or 400 m/s
- 6-m radius chamber

Heat load is a strong function of accommodation and sticking coefficients

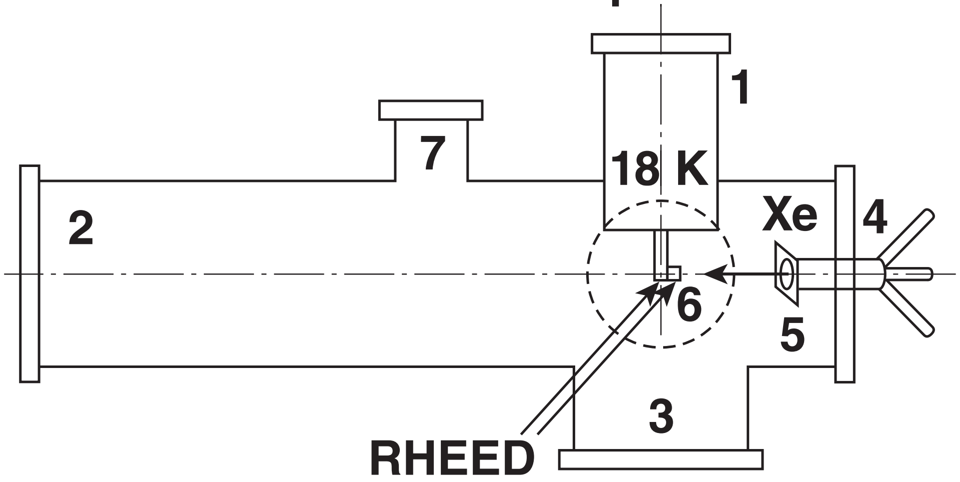
Equipment

- **Surrogate D_2 target** (**2 mm diam**)
  - to be attached to a “cold finger” in thermal contact with the second stage of a cryostat
- **40 W cryostat at 20 K**
  - low vibration device
- **Thermal gas cracker** + **supersonic nozzle** + **thermal radiation shield**
  - provide Xe atoms flux (velocity 400 m/s)
  - Xe atom beam heated at 3000 K by electron bombardment, in a tungsten capillary
  - protect the target against thermal radiation
- **Compound molecular pump**
  - volume flow rate—2400 L/s

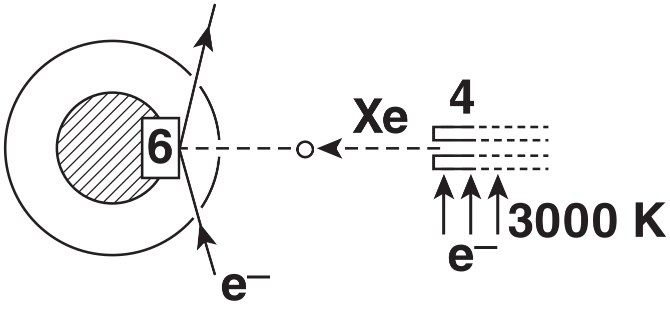
Experiment Concept and Design

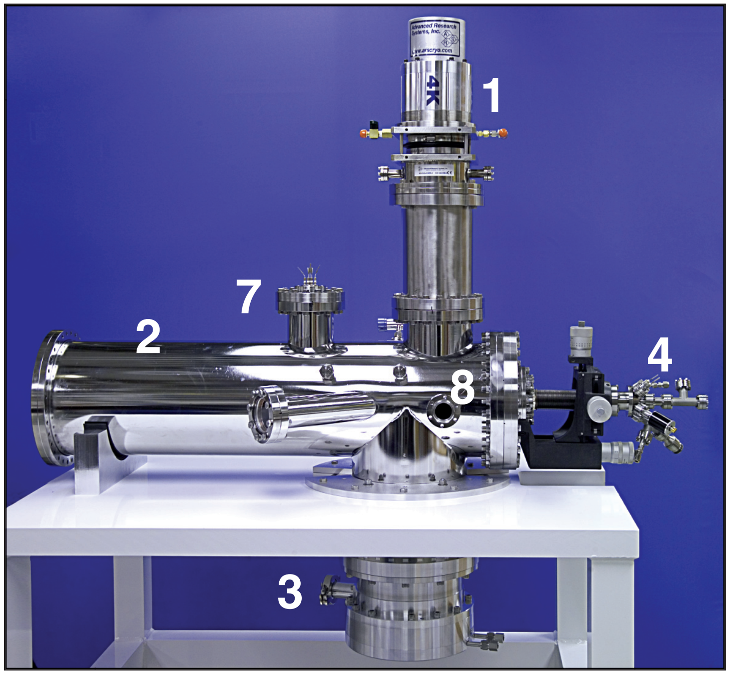
General description of the experimental setup

Schematic with components



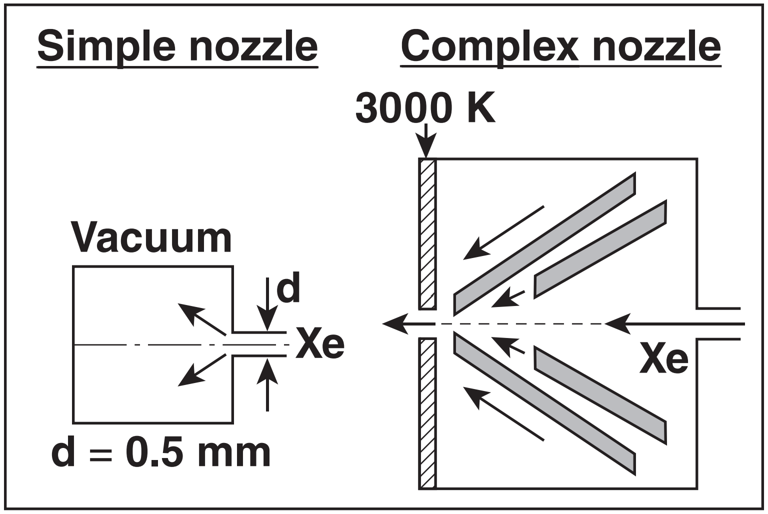
Detail for target—schematic Top view





(1) Cryostat
(2) Vacuum chamber with liquid N_2 tank
(3) Molecular pump
(4) Thermal gas cracker
(5) Thermal radiation shield
(6) Target
(7) Instrumentation
(8) RHEED gun

Nozzle design—to provide the required gas velocity and temperature
Radiation shield design—attached to the thermal gas cracker—minimize radiation load to the target assembly



Simple nozzle

Vacuum

d

Xe

d = 0.5 mm

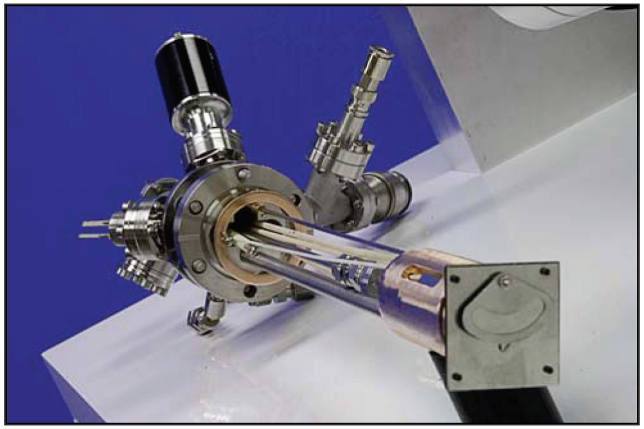
Complex nozzle

3000 K

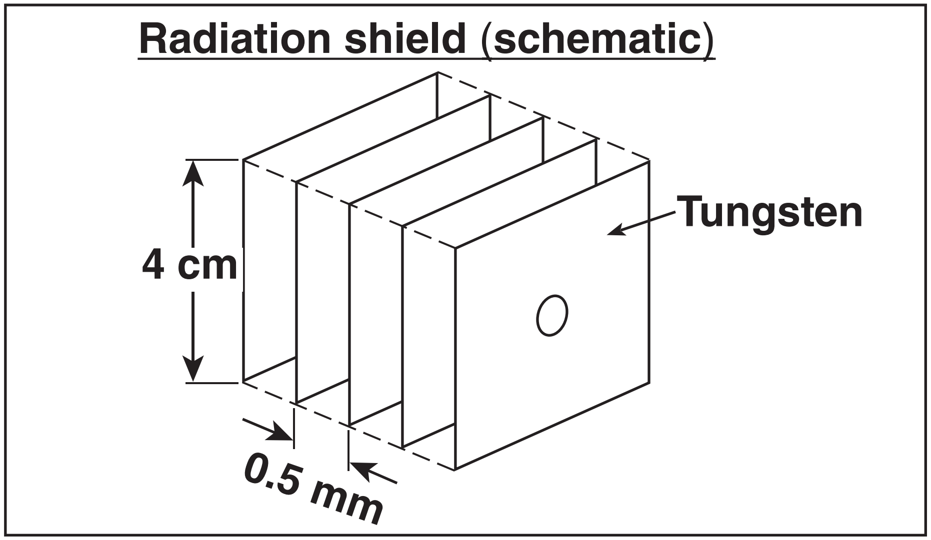
Xe

Comparison (from Monte Carlo)

	Simple nozzle	Complex nozzle
Temperature at target	600 K	1000 K
Velocity	2200 m/s	1500 m/s



Gas cracker with radiation shield



Radiation shield (schematic)

Tungsten

4 cm

0.5 mm

Experimental optimization of:

1. gas flow
2. shield configuration

What do we want to measure and how?

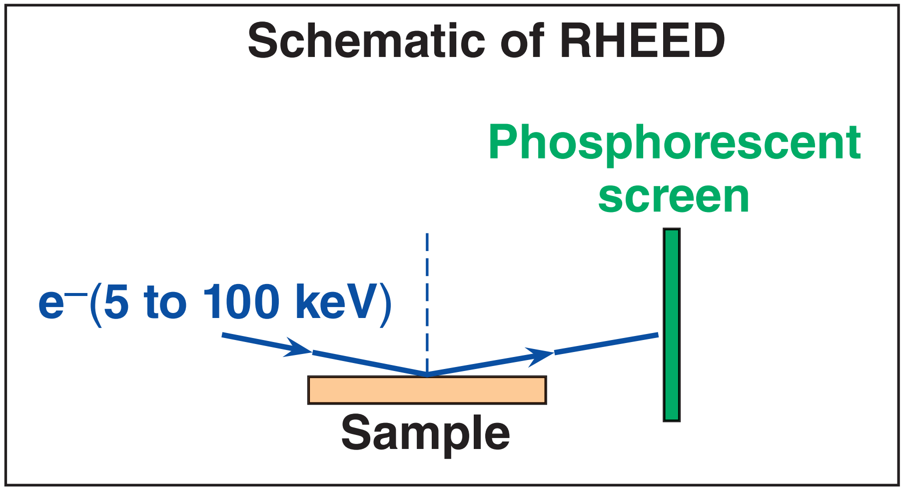
- **Measure *Xe condensation on target surface* (sticking coefficient for different dm/dt, v, T)**
  - Sticking coefficient = the absorbed atomic flux/incident flux supplied by source

  Method employed: reflection high energy electron diffraction (RHEED)
  - **Measure the rate of Xe film growth → the heat of condensation and size of the cold bow wave in front of the target**

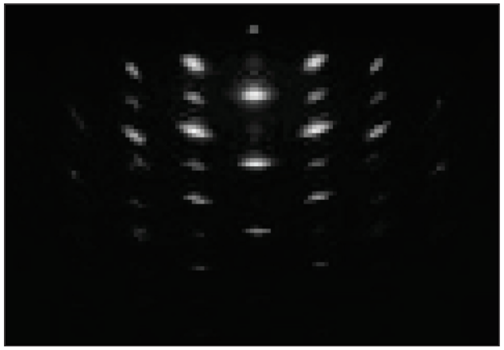
- **Measure the *total heat flux* (accommodation coefficient)**
  - Accommodation coefficient = the fraction of heat transferred between the surface and the molecule ($E_{reflected}/E_{incident}$)

  Method employed: 3ω method—thermal conduction/volumetric phase ratio

RHEED method:
Reflection High Energy Electron Diffraction

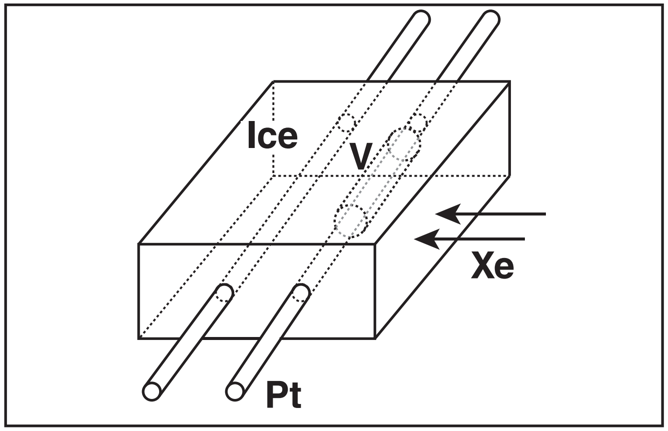


RHEED pattern

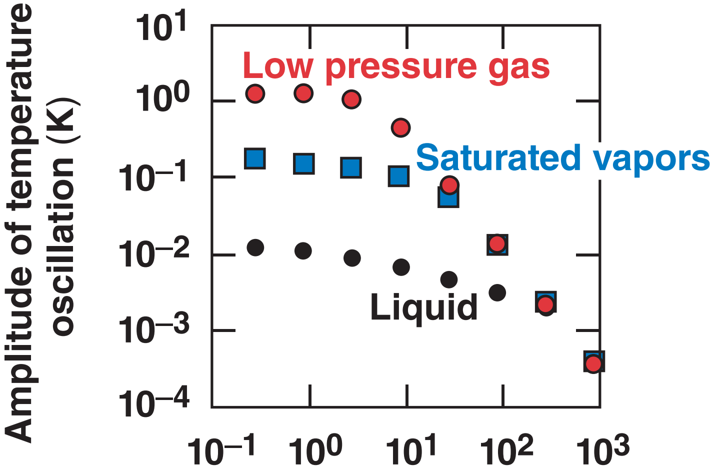


- A high-energy beam from an electron gun (~20 keV) is directed at the target surface at a very small angle.
- A phosphor screen shows a diffraction pattern (corresponding to a particular roughness of the surface).
  - Flat/smooth surface → sharp RHEED pattern
  - Rough surface → diffuse RHEED pattern
- Monitor the atomic layer-by-atomic layer growth of Xe film—possible due to oscillations in the intensity of the diffracted beam. The advantage of setup geometry: good access to the sample

3ω method: thermal conductivity estimation at cryogenic temperatures Voltage in the sensor depends upon the thermal conductivity of the surrounding fluid—which depends upon the extent of melting



Deuterium at 19 K Power = 19.3 μW



Frequency of applied current (Hz)

("Solid curve" in progress)

- **2 Pt wires (15-μm diam) = a sensor which detects the fraction of ice/liquid contacting it.**
- **Heat flux is calculated by measuring the rate the ice melts for a known Xe mass flux to the surface**
- **An ac current $I_0 \sin\omega t$ applied to the Pt wires → 2ω temperature and resistance oscillations → 3ω voltage fluctuation ($V_{3\omega}$)**
- **$V_{3\omega}$ can be measured → $\Delta T = \text{const}\,(V_{3\omega}/V_{1\omega})$ (phase-sensitive detection)***
- **Thermal conductivity estimation by comparing $\Delta T_{\text{measured}} = F(\text{frequency})$ with heat transport calculations → k_{eff}**

  $k_{\text{vol}} = k_{\text{liq}} M_{\text{liq}} + k_{\text{ice}} M_{\text{ice}}$ → ice/liquid fraction → heat flux

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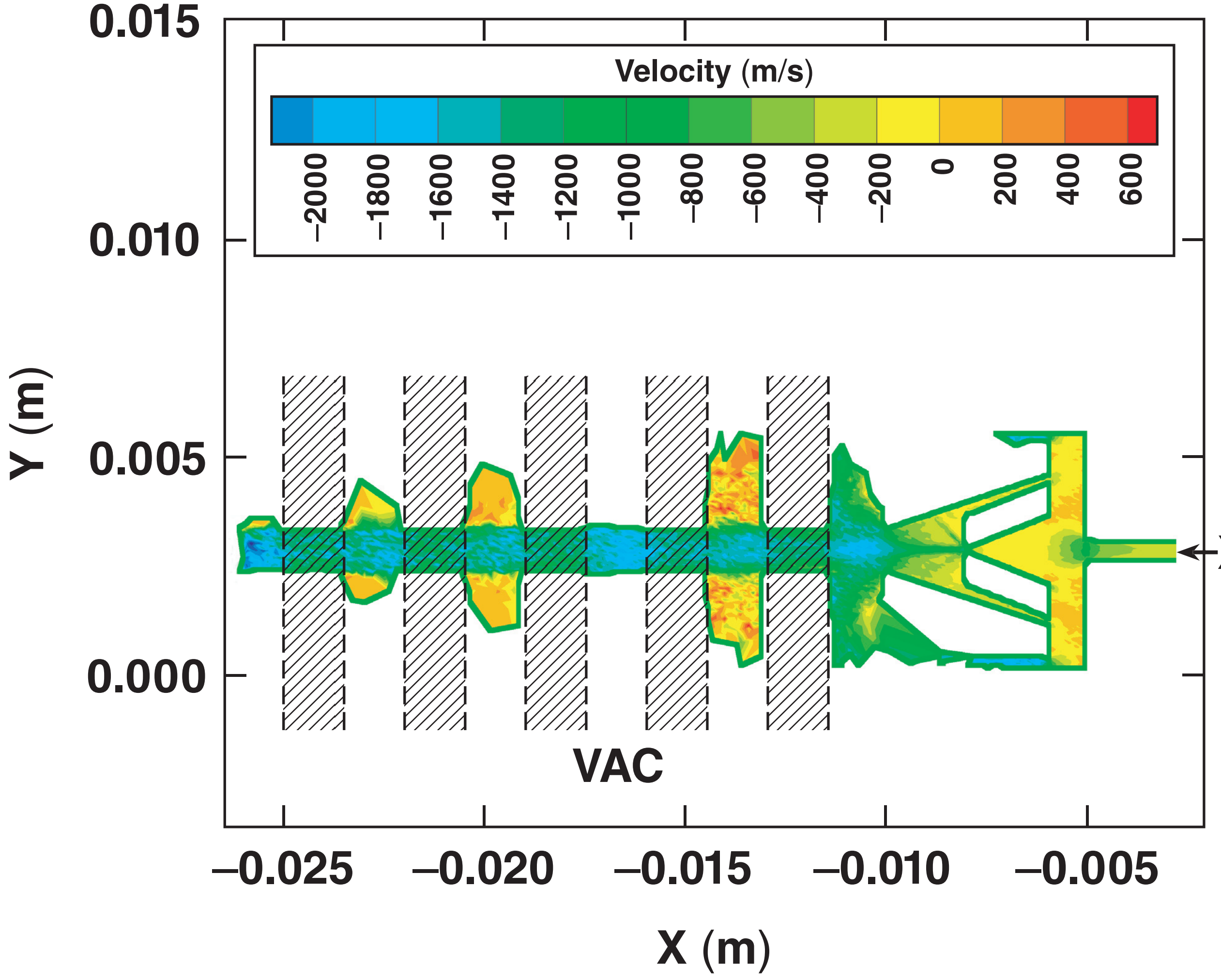
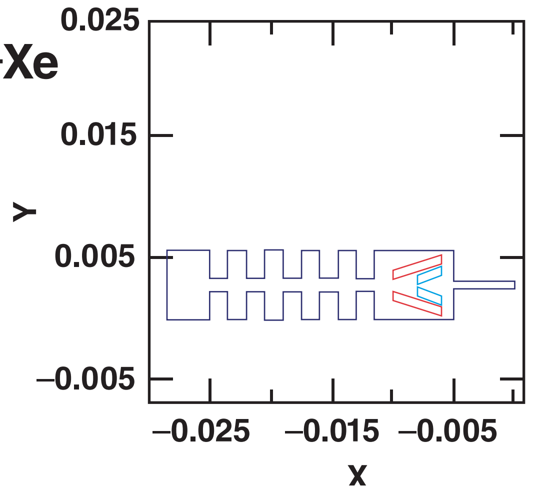
*D.G. Cahill, Rev. Sci. Instrum. 61, 802 (1990).

Modified nozzle design: Monte Carlo results



- **Velocity at target: 1500 m/s**
- **Velocity inside modified nozzle: 400–800 m/s**

Complex nozzle geometry



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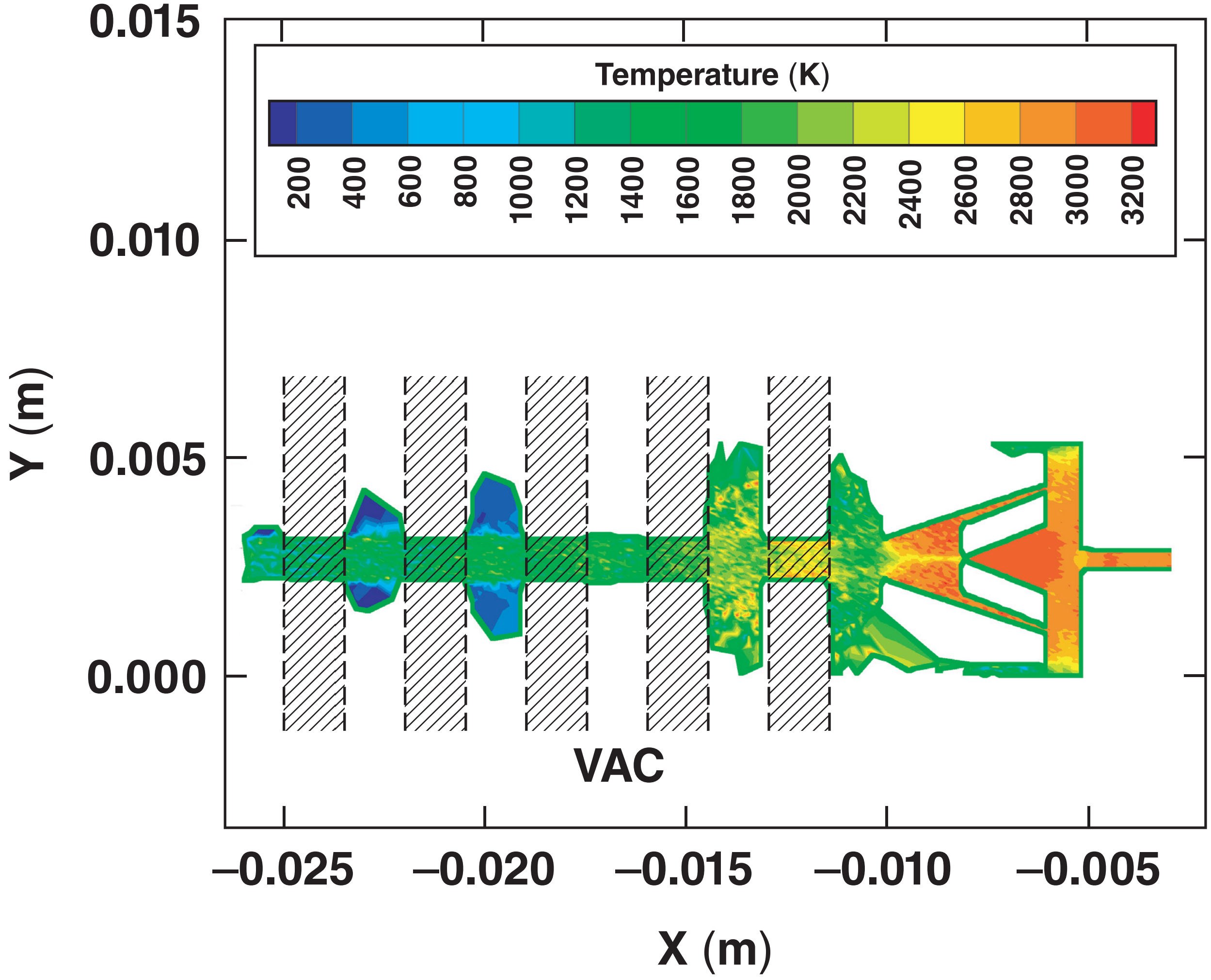
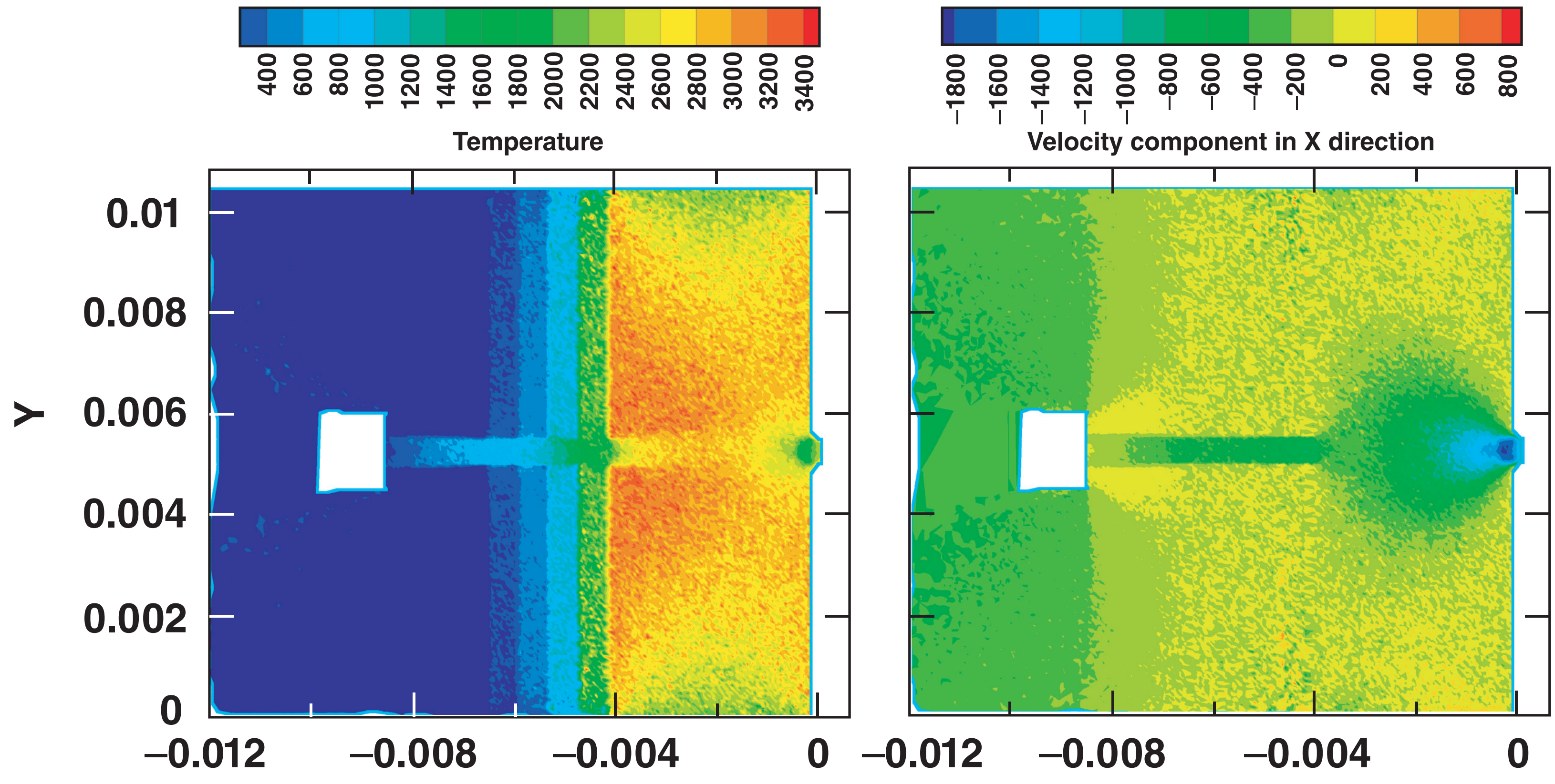
Modified nozzle design: Monte Carlo results

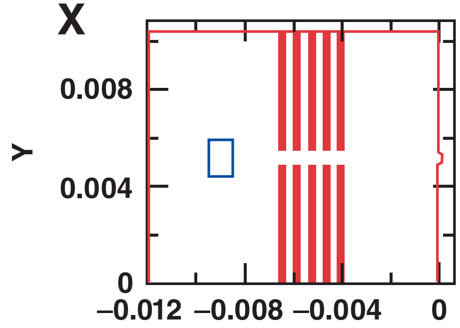


- Temperature at target: 1000 K
- Temperature before the first radiation shield: 2400 K

Thermal radiation shield design: Monte Carlo calculation
Future experimental directions: Optimize the temperature and velocity of Xe and optimize the thermal radiation shielding of the target



Thermal radiation shield geometry →



Velocity at target: 200/ms
Temperature at target: 400–600 K
Higher temperatures and velocities at target possible for a smaller number of shields and at different densities of Xe