Thermal Management of Power Electronics Task at NREL

- **Goals**
  - Develop means to improve heat rejection from power electronics > 250 W/cm^2
  - Reducing system cost, increasing reliability, specific power, power density, and efficiency
- **Objectives for FY04**
  - Develop and demonstrate the viability and advantages of two-phase cooling techniques such as spray cooling, and Jet impingement
- **Deliverable for FY04**
  - Technical report on viability of spray-cooling and jet impingement for high heat flux heat removal

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- **Task Description: 2-phase heat management**

    - Investigation of spray cooling fluid dynamics: droplet size and pattern, orientation, surface treatment, spray behavior in critical system pressure, heat load, and vibration ranges.
    - Investigation of jet impingement fluid dynamics: Jet nozzle design, orientation, surface treatment, jet behavior in critical system pressure, heat load, and vibration ranges.
    - Surface preparation studies

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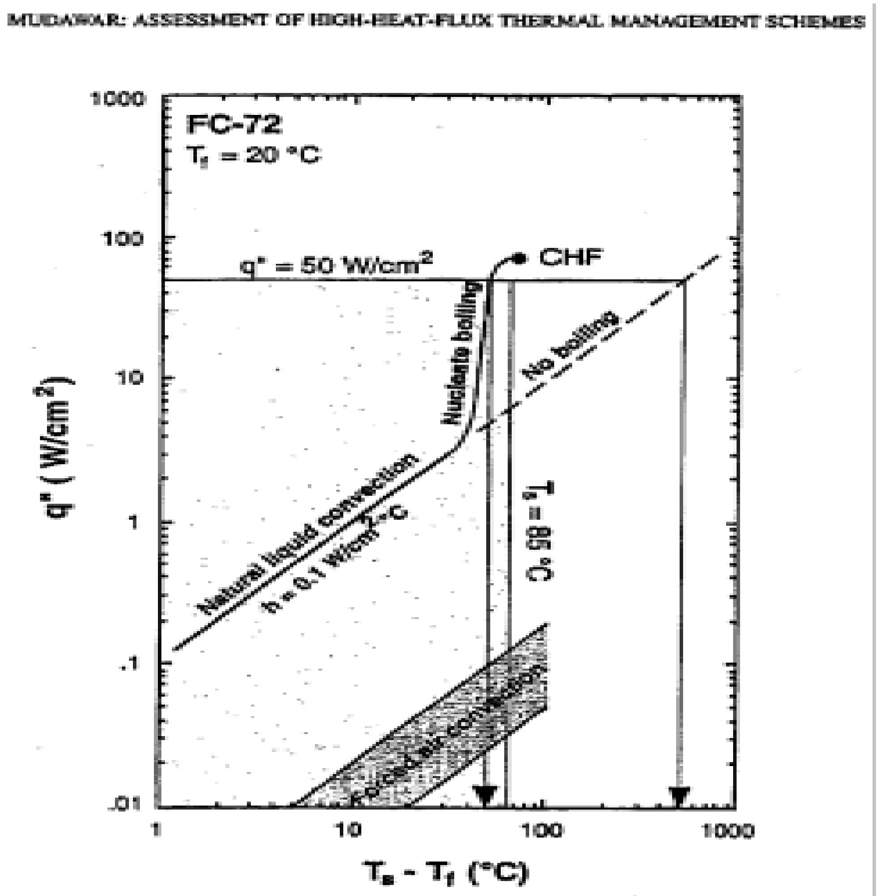
- **High Heat Flux Thermal Management Techniques**
  - Pool Boiling/Thermosyphons (30-70 W/cm^2)
  - 2-phase Microchannel/Minichannel Cooling (100-250 W/cm^2)
  - Jet Impingement Cooling (70-110 W/cm^2)
  - Spray Cooling (80-120 W/cm^2)
  - Surface Enhancement
  - Choice of Coolants



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- **Pool Boiling**
  - Coolant that boils 10 to 40 C below the operating temp.
  - 30-70 W/cm^2
  - Governing Parameters
    - Surface Enhancement
    - Surface Orientation
    - Nucleation Sites
    - Fluid Properties

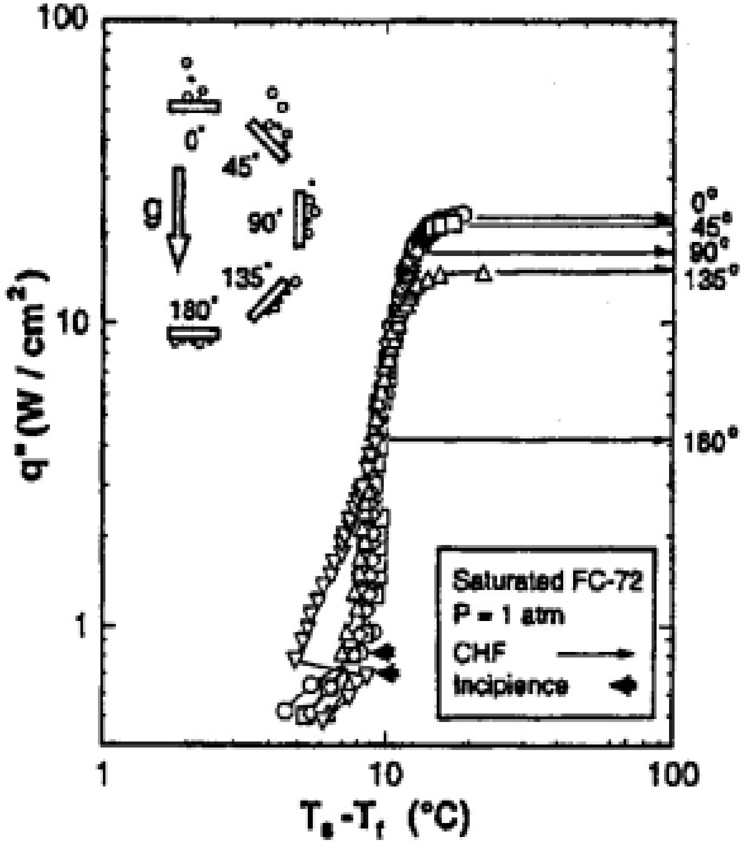

Fig. 8. Pool boiling curves for a 12.7-mm heated disc in saturated FC-72 at different surface orientations (adapted from [18]).

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- **2-Phase Microchannel/Minichannel Cooling**
  - Require minimal coolant flow rates
  - Flow channels with dimensions ranging from hundreds of microns tc few millimeters
  - 100-250 W/cm^2
  - Governing Parameters
    - Microfabrication methods
    - Pressure drop
    - Choice of hydraulic diameter
    - Fluid Properties

MUDAWAR: ASSESSMENT OF HIGH-HEAT-FLUX THERMAL MANAGEMENT SCHEMES

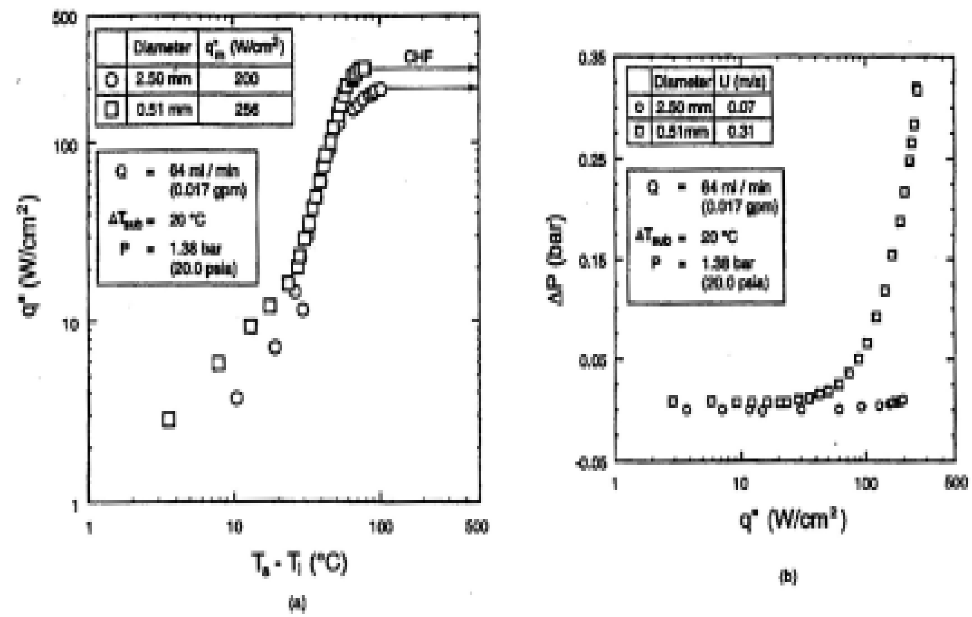

Fig. 18. Comparison of microchannel and minichannel heat sink characteristics relative to (a) cooling performance and (b) pressure drop (adapted from [

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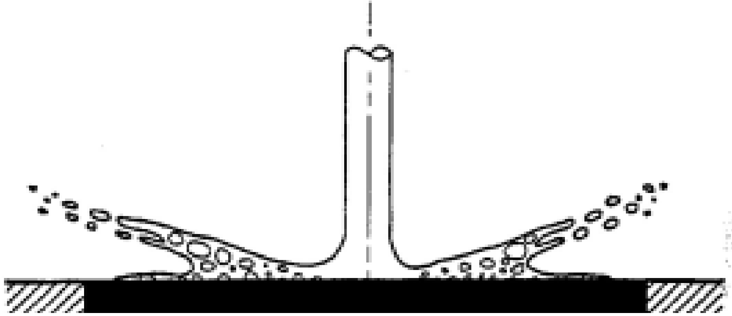
- **Jet Impingement Cooling**
  - Free jet (vapor or gaseous environment)
  - Submerged jet (liquid jet in liquid environment)
  - Confined jet (liquid jet confined between the nozzle and target)
  - Aggressive form of cooling (large impact momentum)
  - 70-110 W/cm^2
  - Governing Parameters
    - Jet velocity
    - Jet diameter
    - Subcooling of working fluid
    - Fluid Properties



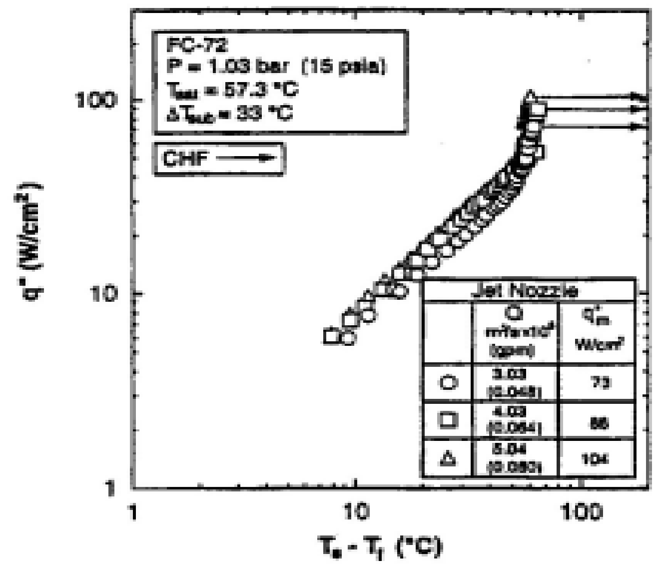


Fig. 21. Free circular jet boiling curves for different flow rates (adapted from [67]).

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- **Spray Cooling**
  - Water or FCs
  - 80-120 W/cm^2
  - Governing Parameters
    - Droplet Diameter
    - Surface Orientation
    - Surface Texture
    - Fluid Properties

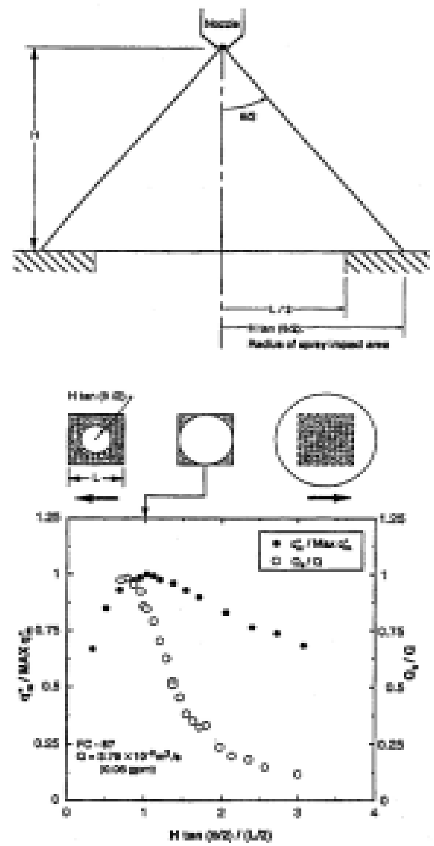
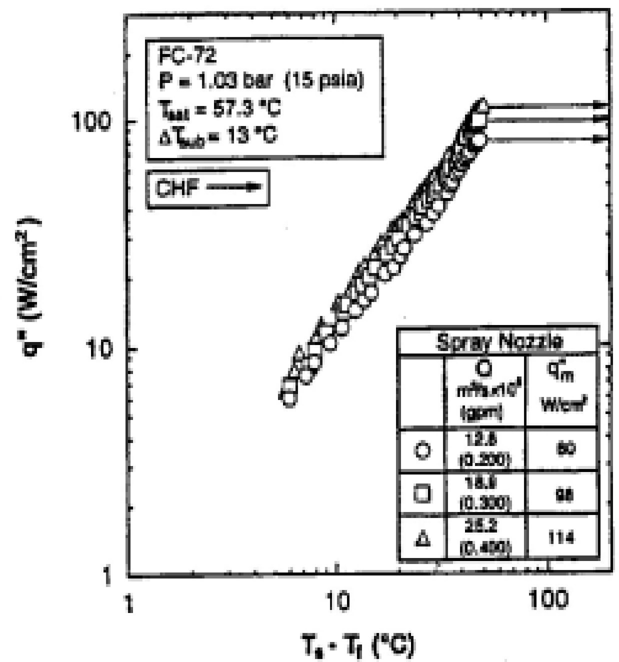


Fig. 24. Optimization of spray nozzle-to-wall distance to maximize CHF (adapted from [16]).



FC-72 boiling curves for different spray flow rates (adapted from

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- Surface Modification Investigations
  - Grooved Surface Configurations
  - Dimpled Surface Configurations
  - Patterned Structure Configurations
- Spray Orientation Effects on Modified Surfaces
- Generally Focus on Thermal Effects On Underside of Die/Substrate

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- FC-72 used in initial modeling
- Mass flow rate 0.0084 kg/s
- Chip surface area 161 mm^2
- Conditions match those in the literature
- Heat transfer now through droplet impingement, evaporation to be incorporated

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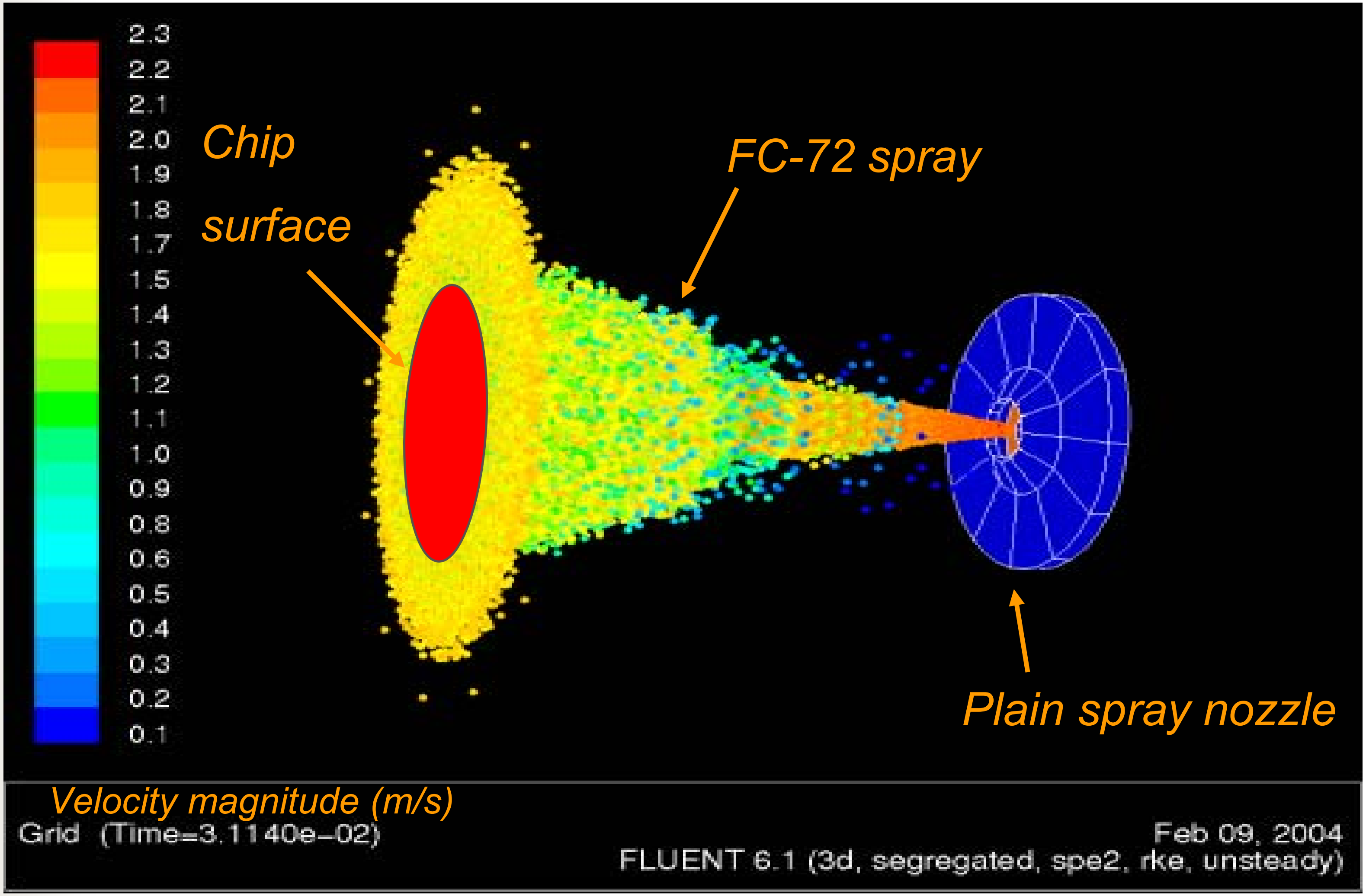

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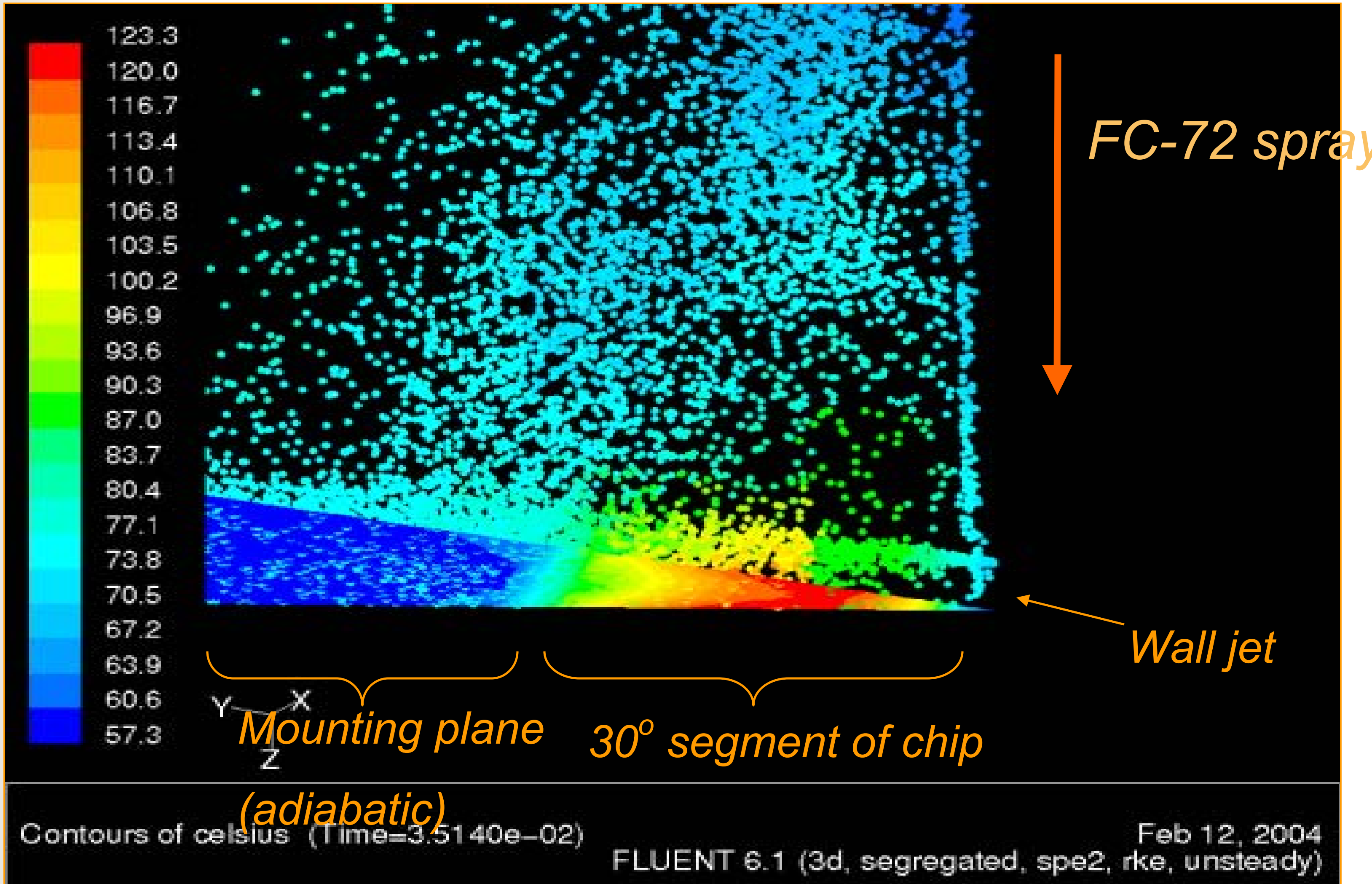

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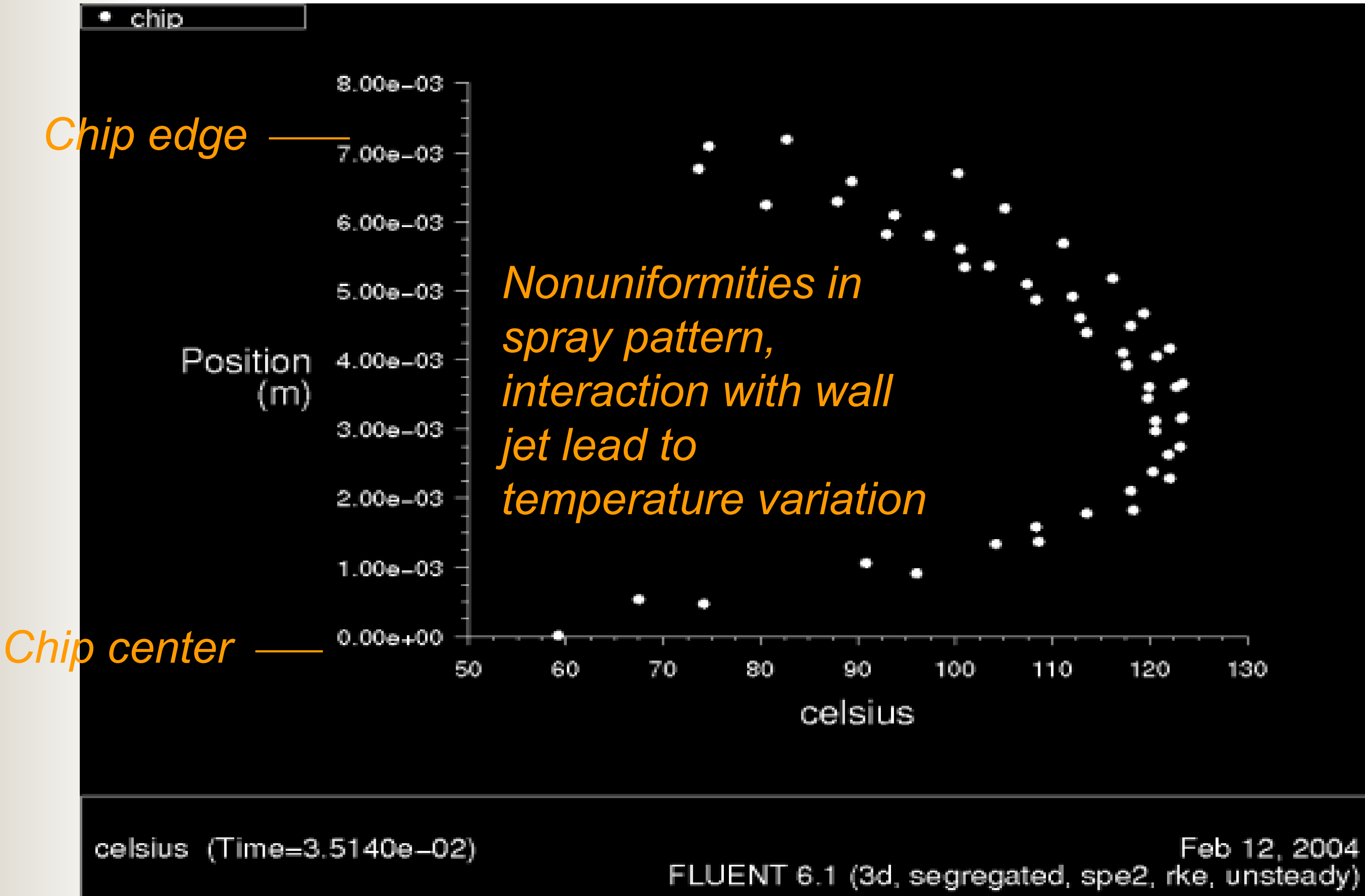

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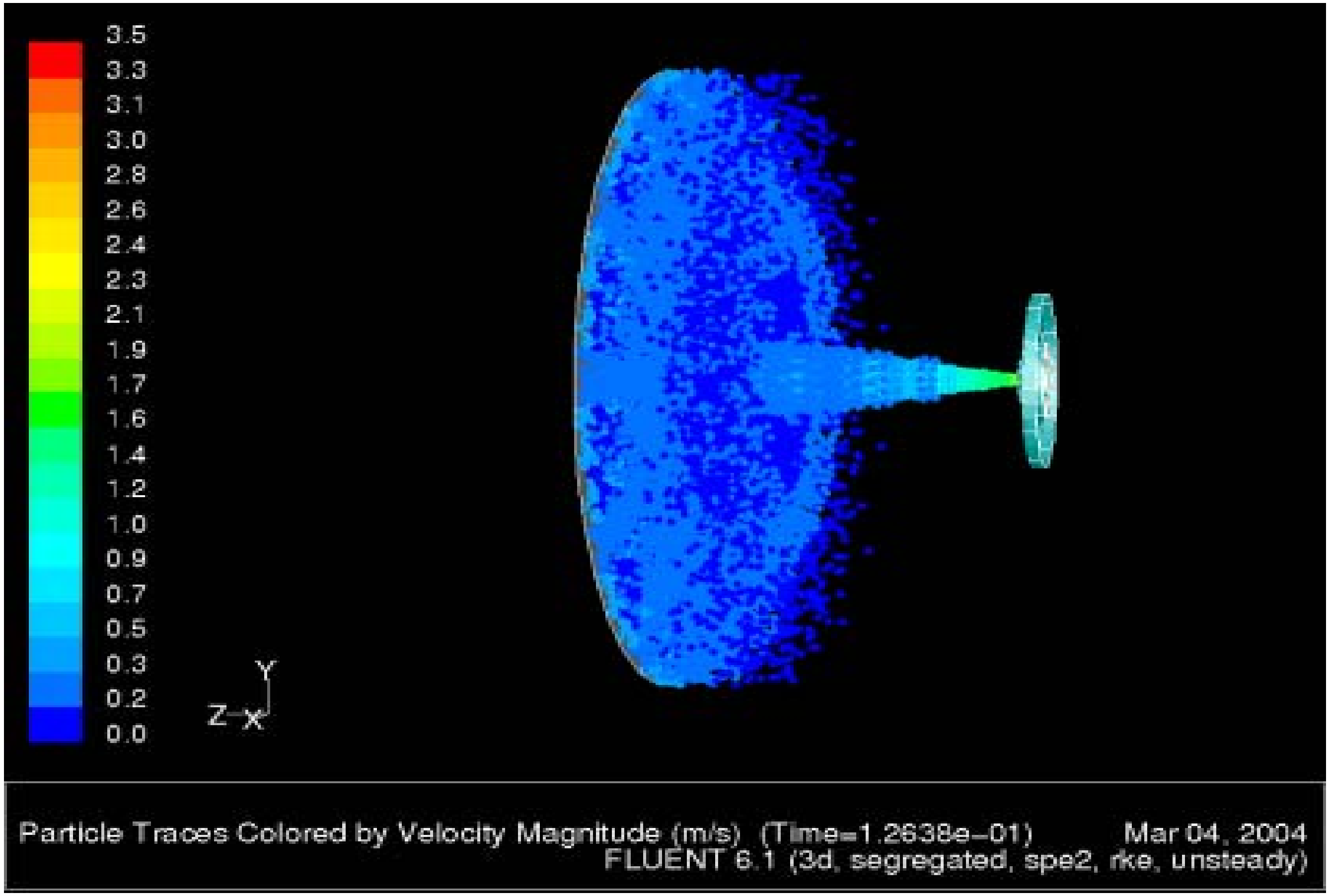

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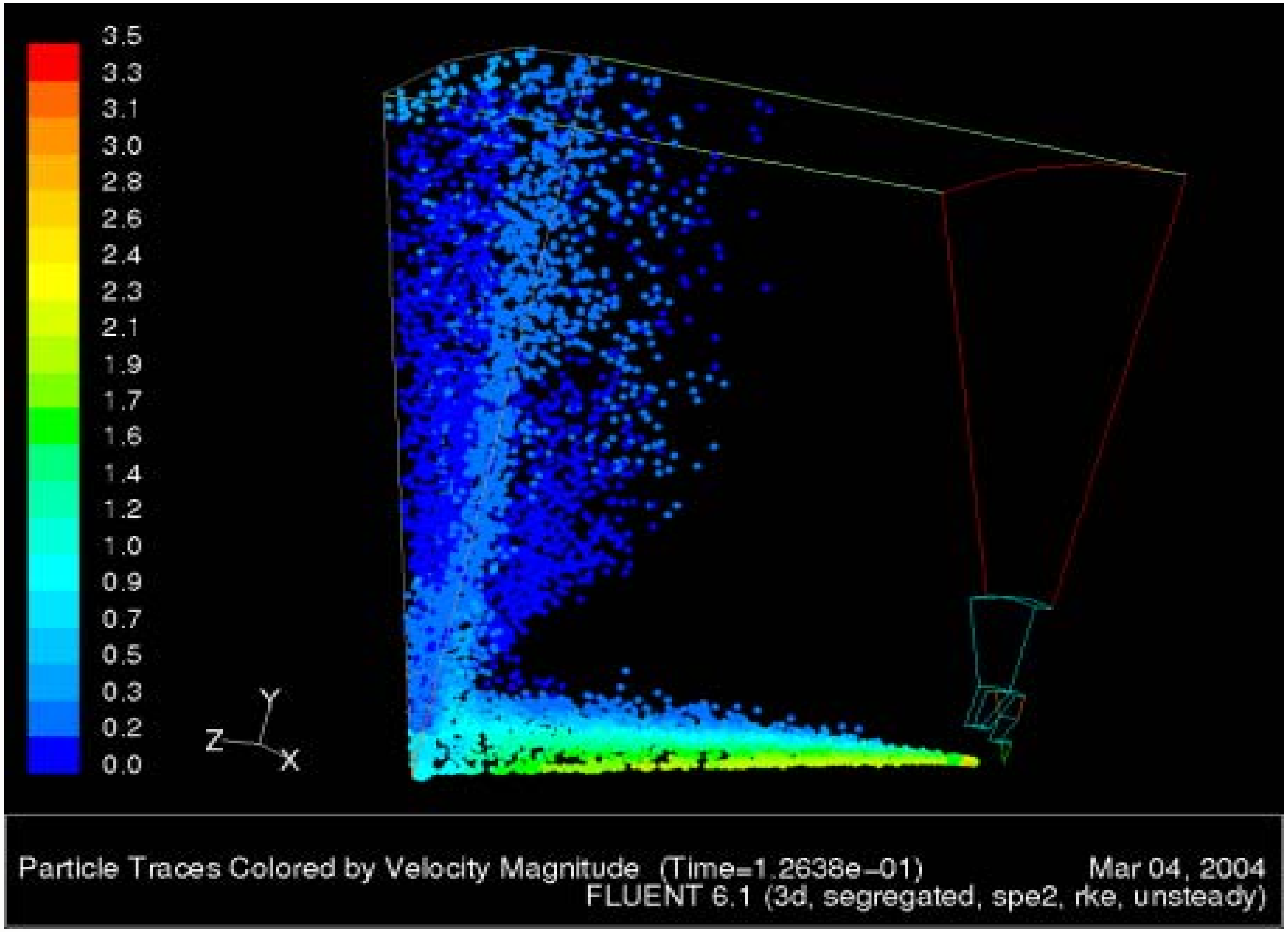

Thermal Management of Power Electronics Task at NREL

- **NREL's Experimental Capability**
  - Spray and jet impingement cooling testing capability, localized heat source and total inverter box
  - High speed camera for flow visualization
  - Infrared camera for temperature distribution