Extinction Tomography for Sprays

An Overview

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En'Urga Inc.

innovations in quality control

SETscan®

Outline

- **Optical Patternator**
- **X-Ray Patternator**

Optical Patternator

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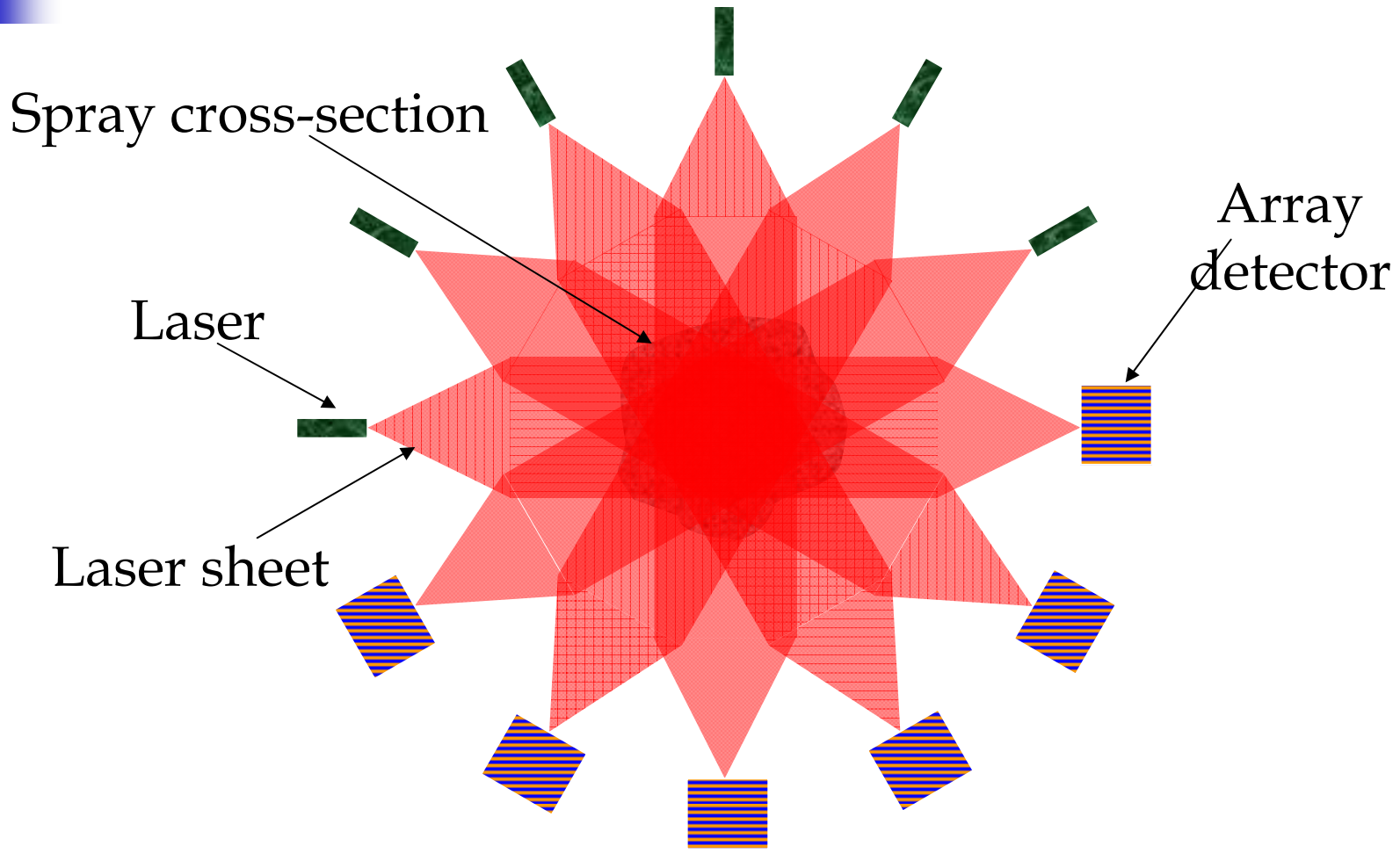
Why Optical Patternation

- Fast, capable of obtaining transient data
- Greater reproducibility than mechanical devices
- Does not interfere with the spray
- Greater spatial resolution
- Low maintenance and operational cost

The SETScan Patternator



Principle of Operation

- **Path integrated extinction of laser sheets**
- **Multiple view angles for non-axisymmetric turbulent flows**
- **Multiple slices to obtain high spatial resolution**
- **Local extinction coefficients obtained by statistical tomography (MLE method)**
- **For liquid sprays, the local extinction coefficients is equal to the drop surface areas per unit volume**

Performance Highlights

- **Fast ⇒ Up to 10 KHz, transient patternation of fuel injector sprays**
- **Extinction ⇒ Well developed technique**
- **MLE Deconvolution ⇒ Accurate (+/- 2%)**
- **High repeatability (+/- 2% on patternation number)**
- **Six-axis ⇒ Angular resolution up to 5 degrees**
- **512 element array ⇒ Spatial resolution up to 0.2 mm**

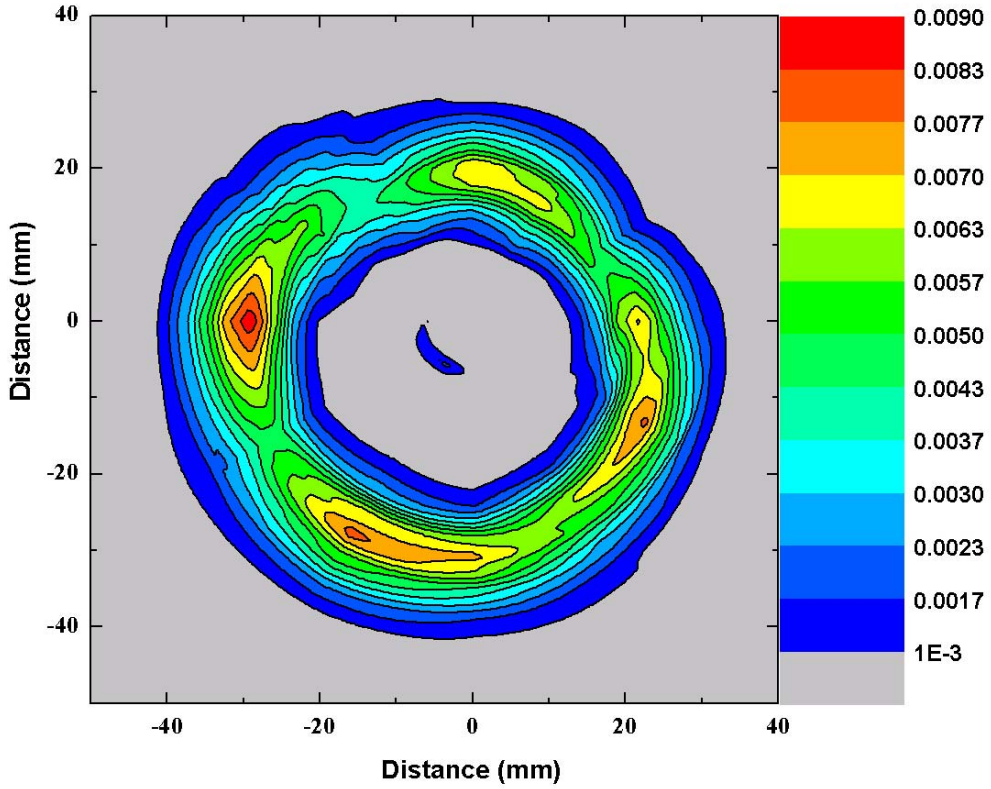
Comparison with Competitive Technology

- Extinction ⇒ Immune to environmental lighting
- Diode lasers ⇒ Class II, No safety issues
- Monolithic ⇒ Out-of-box factory floor deployment
- Adaptive grids ⇒ Alignment of nozzle not critical
- Advanced GUI ⇒ Easily operated by technician
- Reliable ⇒ 100% quality assurance of nozzles

Only quantitative (+/- 2% on absolute values, +/- .5% repeatability) patternator on the market

Sample: Aircraft Engine Nozzle

- Struts signature seen in drop surface area map
- Hollow cone seen as hollow
- Drip from nozzle seen at the center
- High flow rate ~ 200 kg/hr

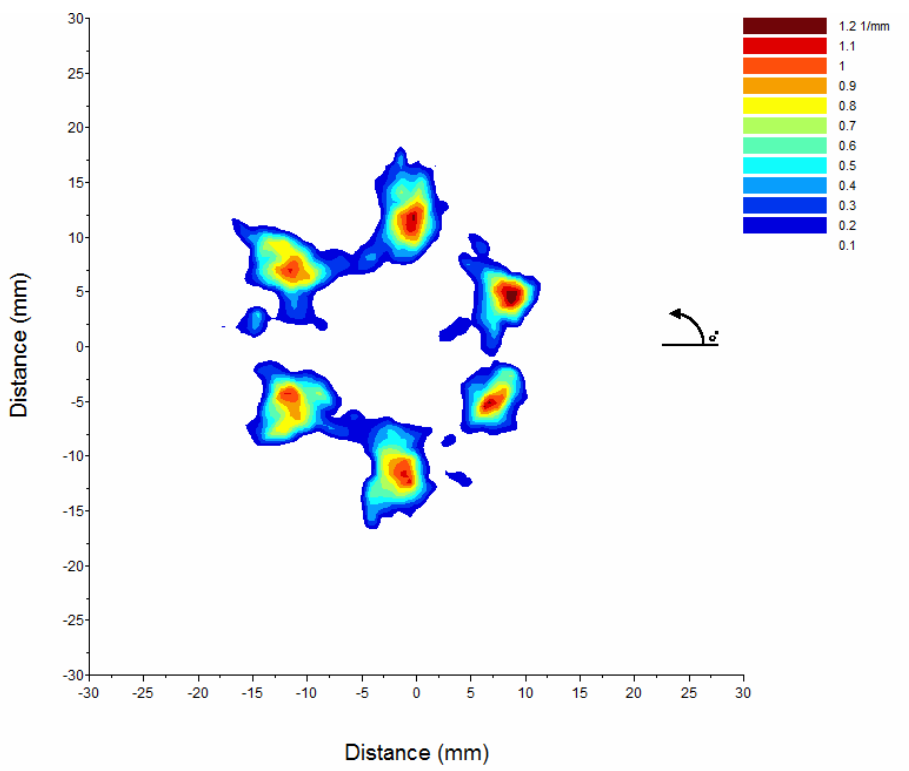


Interpretation of Data

- The data is the ensemble average of drop surface area per unit volume
- Differs from mechanical patternator (which is time average of mass flux)
- High surface area indicates streaks
- Low surface area indicates voids
- 95% ring typically used for spray angle

Automotive Injector

Mean plume angles (deg.)	% area in plume
10.89	19.32
5.73	4.69
11.53	21.71
10.48	17.91
11.51	23.06
9.35	12.93
Mean centroid (x, mm)	**Mean centroid (y, mm)**
3.26	-5.69
-4.84	14.28
-22.13	1.97
-29.04	-10.75
-15.37	-18.49
0.10	-20.01



Reliable data with multiple orifice injectors

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Selected Patternator Customers

Abbott	General Motors	Hitachi
Bend Research	Cummins	AVL
Pfizer	Emcom Technologies	FEV
S.C. Johnson & Son	Faurecia	Nordson
Catalytica Energy	Donaldson	Delavan
Delphi	Proctor & Gamble	Woodward
Ricardo	Honeywell	Tenneco
Continental	Bombardier	Synerject
Eaton	Rolls Royce	Danfoss
Columbian Chemical	General Electric	Boston Scientific
United Technologies Aerosapce System	Dow Agrosciences Laboratories	Vertex Pharmaceuticals
Toyota	Bosch LLC.	3M

X-Ray Patternator

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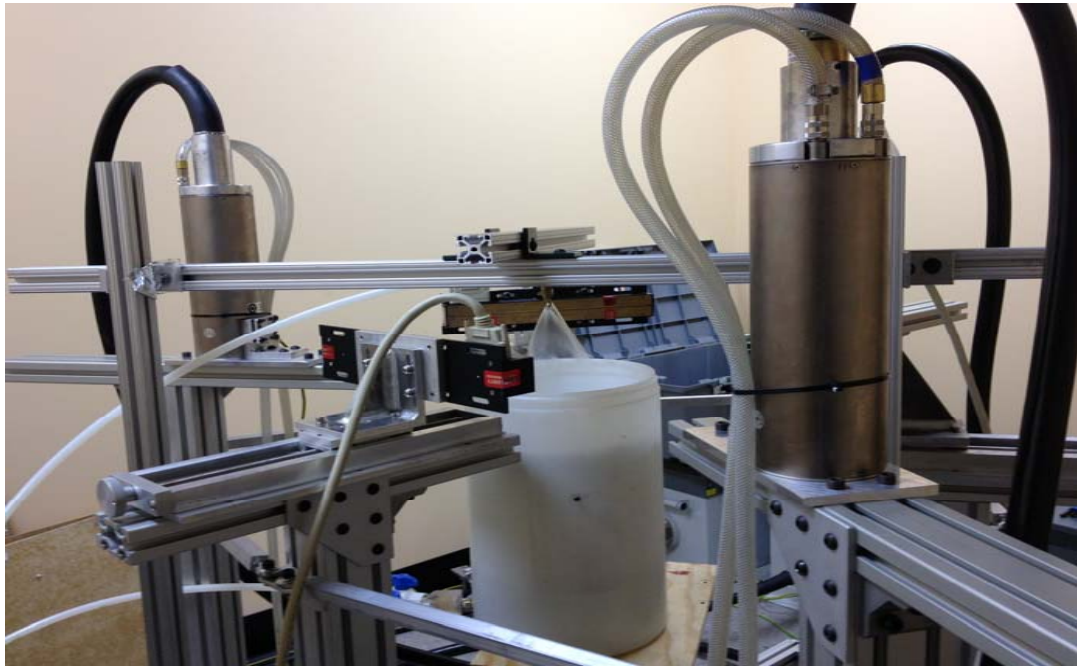
Open Source Design

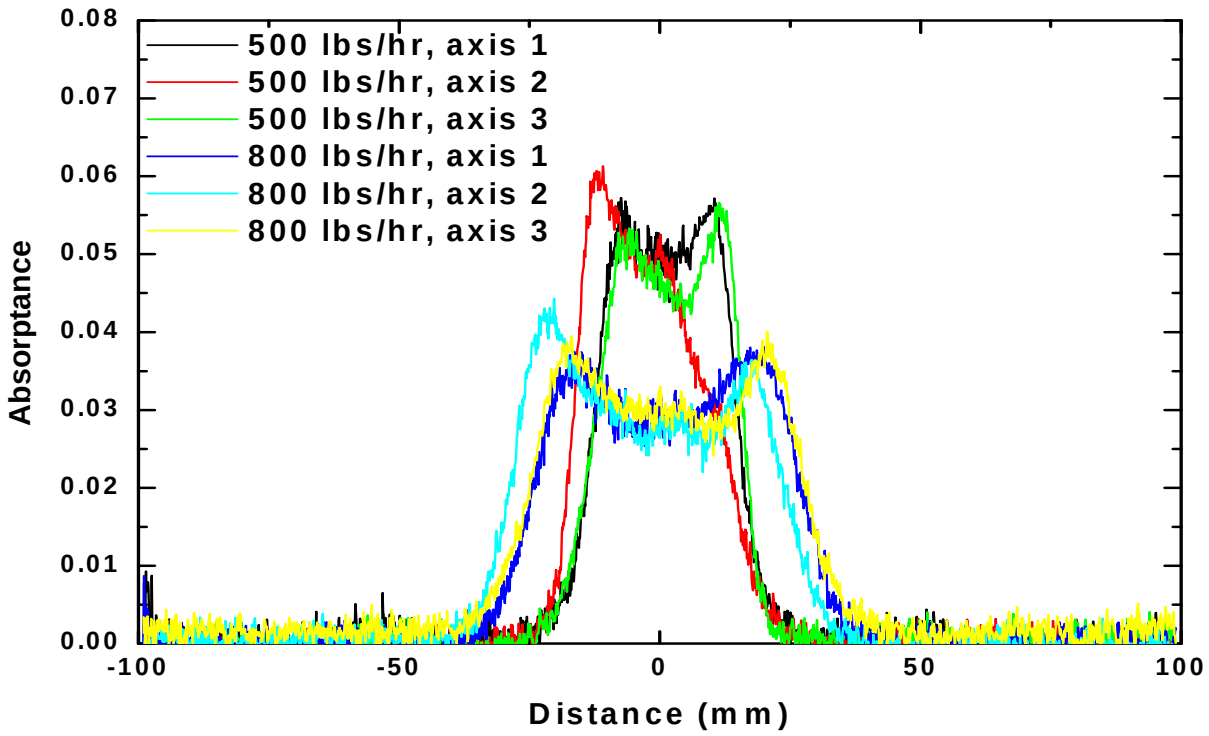


Three sources in fan beam configuration within a 12 ft x 12 ft x 6 ft lead lined chamber

Basic Description

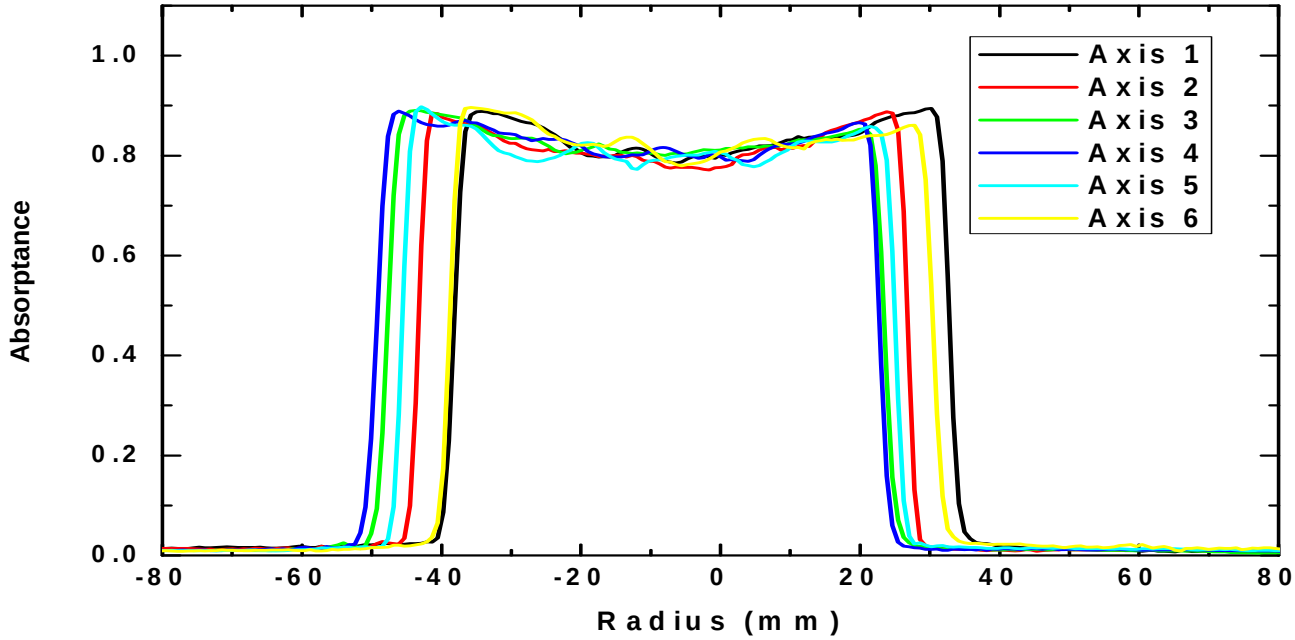
- Three 20 degree sources with 200 micron spot diameter
- Three linear arrays with 1560 elements each
- High Speed Data acquisition (1,000 Hz)
- Fan Beam Deconvolution algorithm

Absorptance Measurements



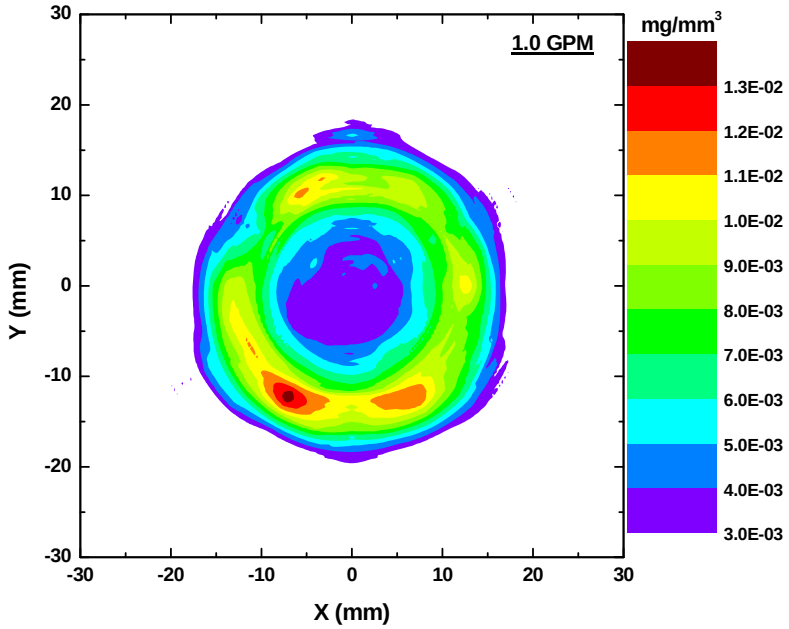
- Peak absorptance < 10% implies can measure tons/hr
- Larger flow rate has wider spread

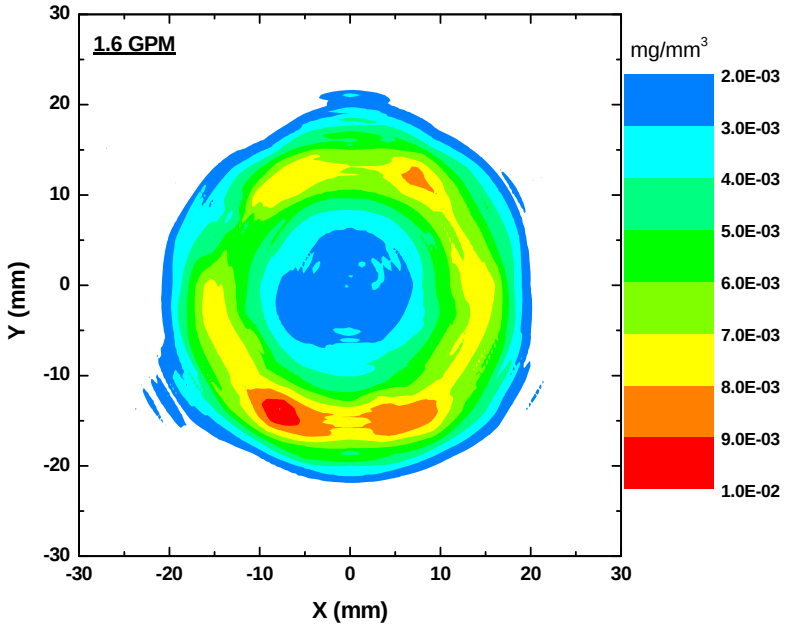
Comparison with Optical Patternator



- 500 lbs/hr
- Mean peak value at 0.92
- Instantaneous value exceeds 0.99 occasionally
- If drops are smaller, even this flow rate is not feasible

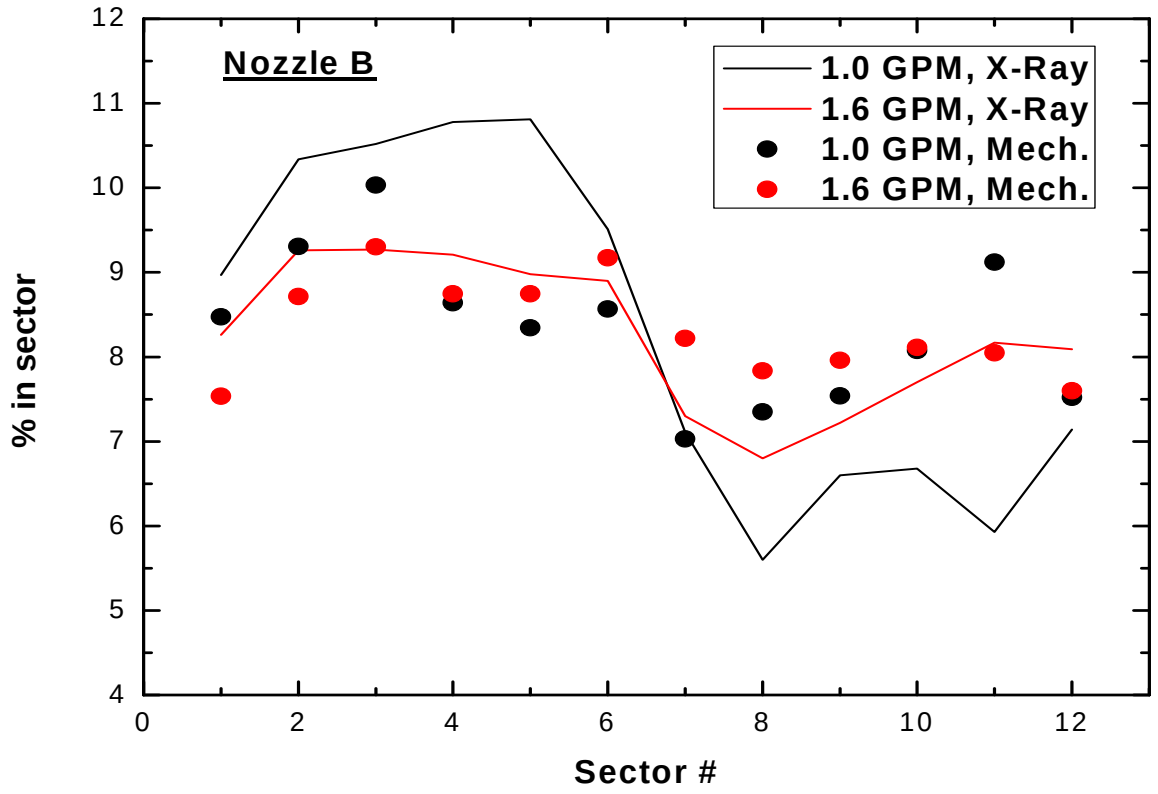
Concentration Maps





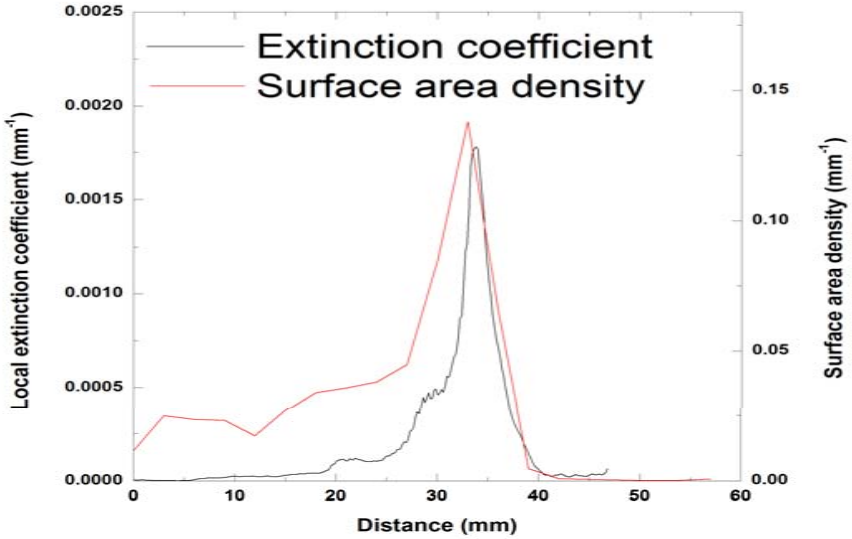
- Deconvoluted results of mass fraction of water
- Lower flow rate has higher local concentration
- High flow rate had larger footprint

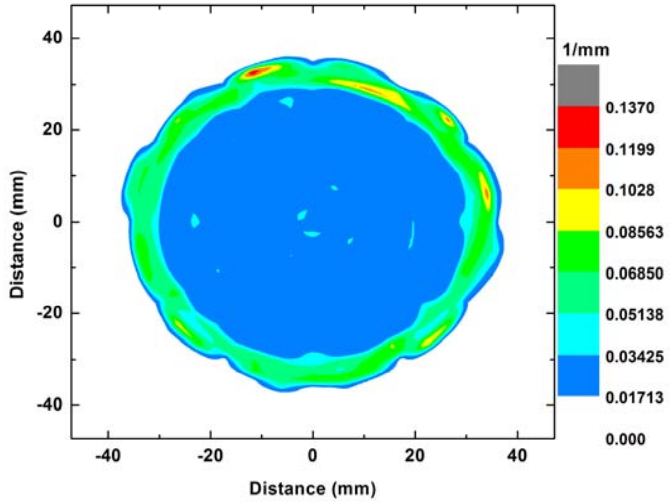
Validation (Mechanical Patternator)



- Similar trends with flow rates and angle
- Results agree with uncertainty of mechanical patternator

Validation (Optical patternator)



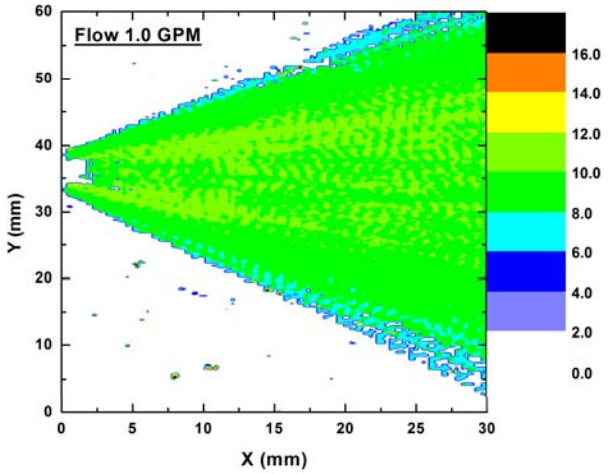


- Radial peak location very similar (only one condition)
- SMD (from mass concentration/surface area) is 141 μm (nozzle specification is 125 μm)

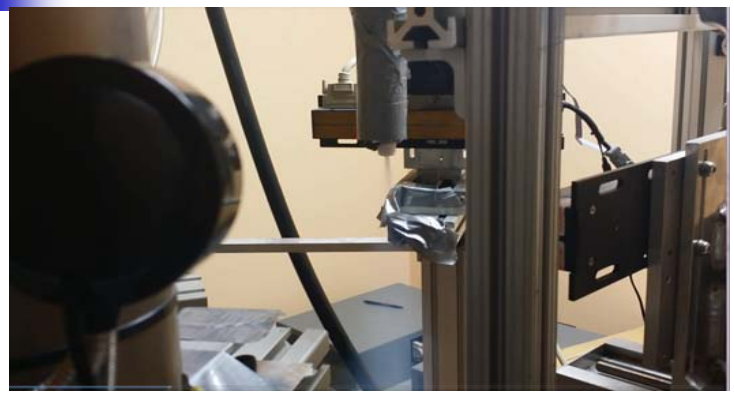
Validation (Total flow)

Nozzle	Input Flow (kg/hr)	Total planar mass (mg/mm)	Mean velocity (m/s)	Planar mass flux (kg/hr)
A	227	10.2	5.72	211
A	363	11.1	8.86	353
B	227	7.20	9.44	245
B	363	7.52	14.5	392

- Velocity measured using Statistical Pattern Imaging Velocimeter
- Nozzle A results match flow meter reading to within 5%
- Nozzle B results match flow meter reading to within 10%
- Results validate X-Ray measurements within the uncertainty of flow meter and velocimeter

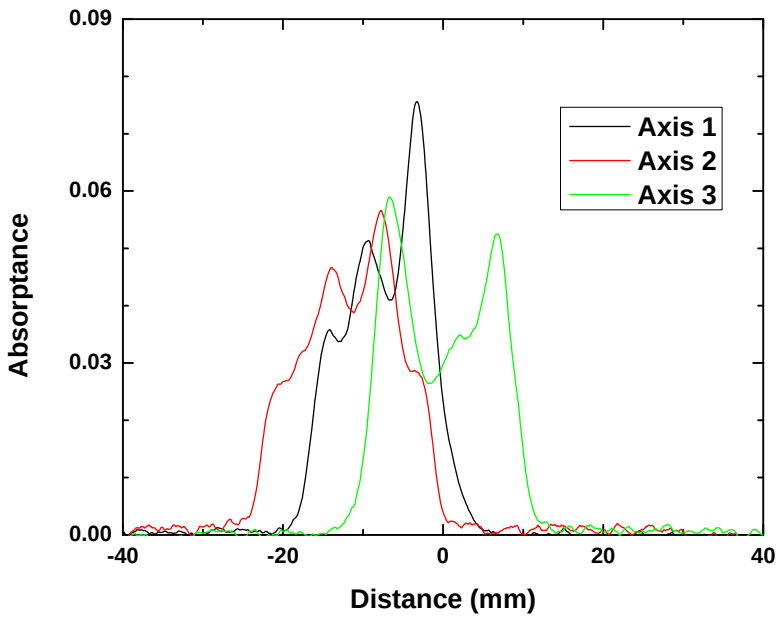


Cryogenic Flow (unconfined)



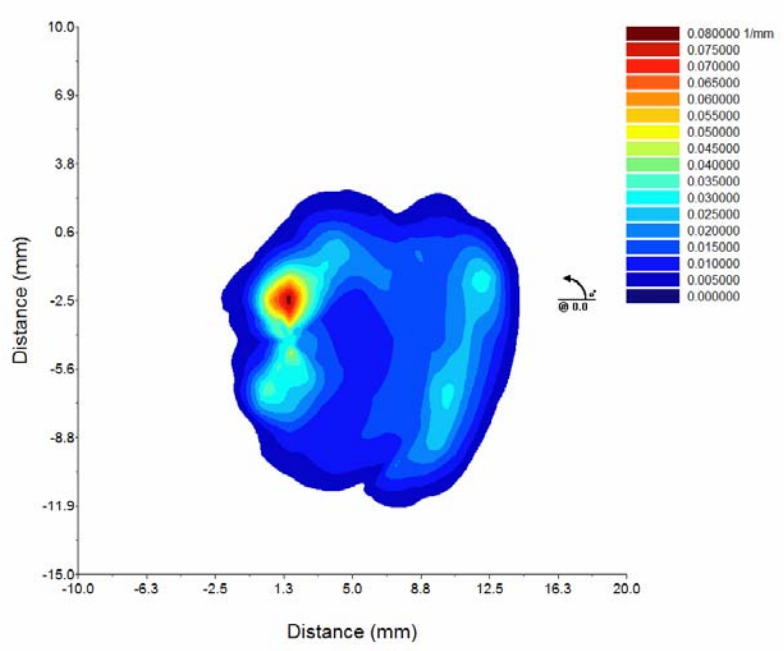
Liquid nitrogen with a flow rate of > 4 GPM
Atomization quality is not very good
Cloud of water vapor quickly forms in measurement zone
Clear for about 1 minute
Drop size/velocity too dense for optical patternator
Flow rate does not stay constant

Extinction at 30 KeV (unconfined)



- 10 mm from injector exit
- Peak absorptance ~ 8%
- Can handle higher flows
- Very narrow spray
- Wider spray would provide better spatial resolution
- Only three view angles (commercial system has 6 view angles)

Result (30 KeV unconfined)

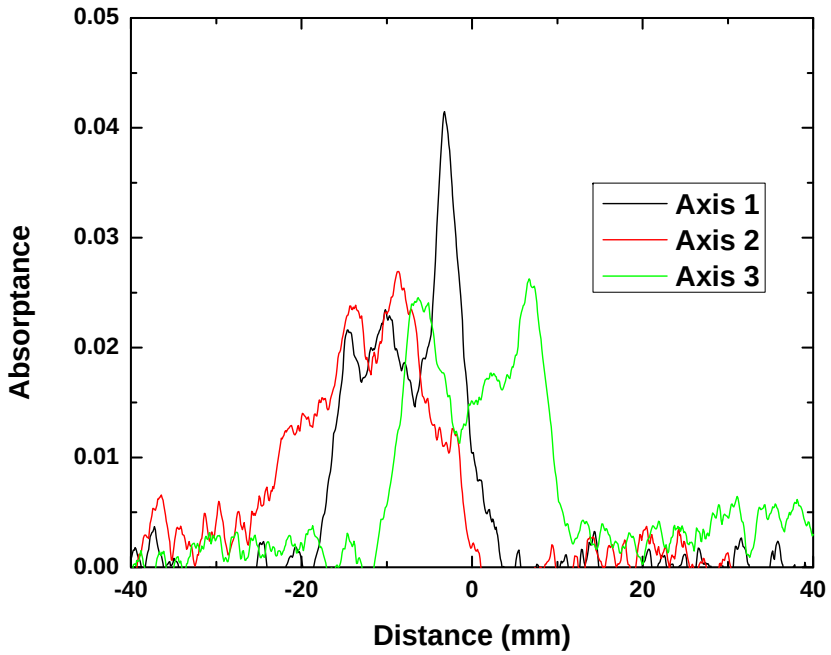


- Not very symmetric
- Deconvoluted with center of extinction
- High extinction values near left side
- Calibration required to convert to mass
- Small footprint as noted

Cryogenic Flow (confined)

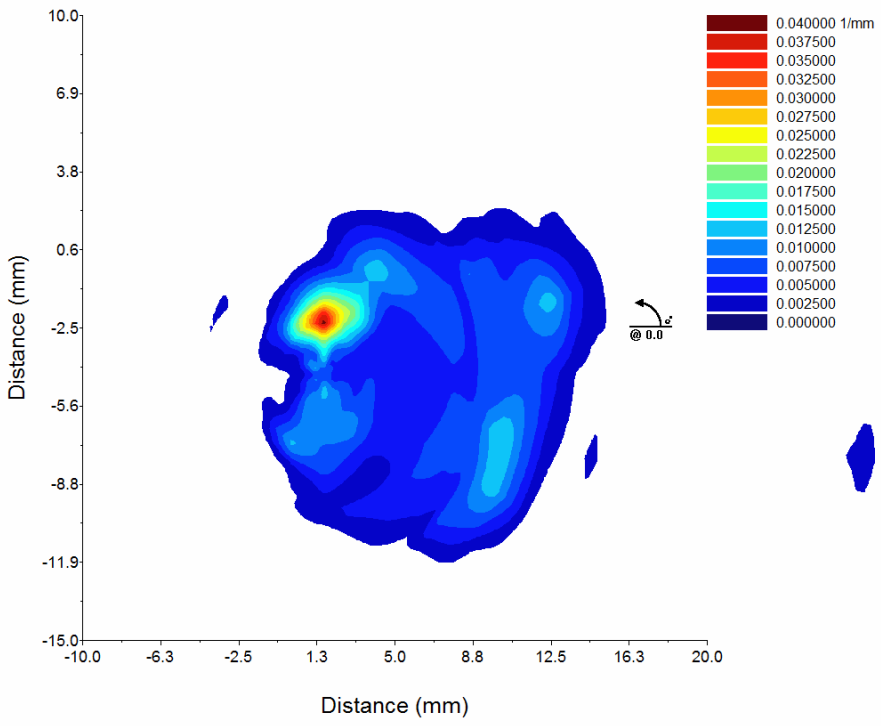
- Initial trails using a metal shroud was unsuccessful due to the lack of sufficient exhaust flow
- Returned to open configuration, but placed 2 mm thick aluminum pieces in front of the detector arrays to simulate metal jacket
- This arrangement work sufficiently well to show proof of concept

Extinction at 30 KeV (confined)



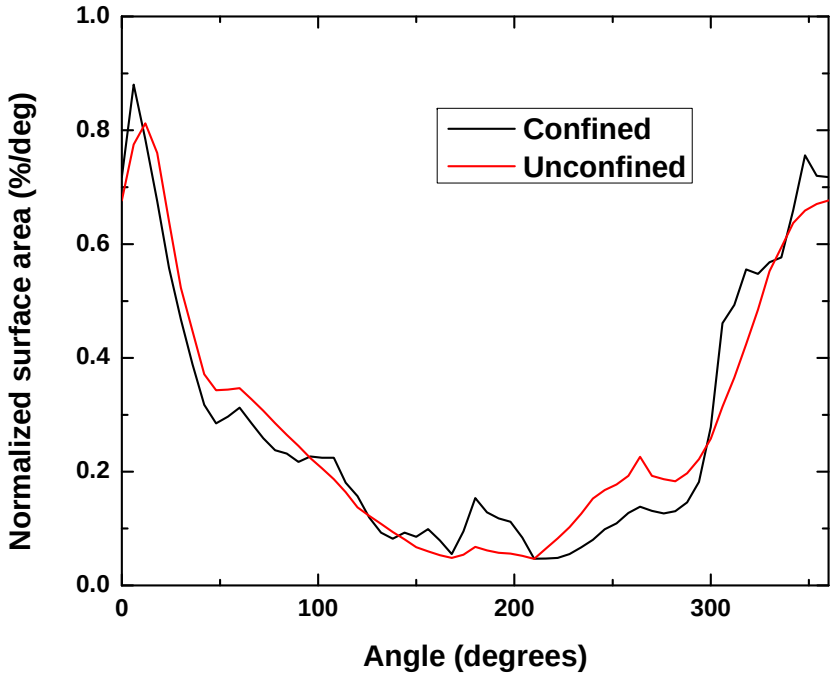
- 10 mm from injector exit
- Peak absorptance ~ 4%
- Very similar to unconfined
- Shows capability to view spray through 2 mm thick aluminum even at 30 KeV
- Slightly higher noise due to low extinction levels expected to improve at high flow rates and new sensors

Result (30 KeV confined)



- Almost identical pattern with and without confinement
- Peak local extinction value approximately 40% lower due to beam hardening
- Calibration will provide same mass concentrations with and without confinement
- Can compare angular profiles

Angular Distribution



- Almost identical pattern with and without confinement
- Slightly higher noise for the confined case due to lower signal levels
- Fully proves concept for confined cryogenic flow

Six Axis Commercial System

Mass concentration profiles in 2 phase flows

- **Sprays**
- **Solid powders**
- **Bubbles in water**
- **50 KeV system, six sources and six cameras**
- **200 mm interrogation area**
- **1,000 Hz data full flow pattern**
- **1 mm spatial resolution**

Custom lead lined rooms to house system

Specification of Custom Room

- 12 x 12 x 8 feet
- 3 mm lead-lined drywall on all four sides and roof
- 3 mm lead lined plywood on floor
- One observation window with lead impregnated acrylic
- Safety interlock for door
- Red rotating light during operation outside chamber
- System controlled by wireless Ethernet from outside