



Electrostatic Precipitation System for Radionuclide Particle Collection

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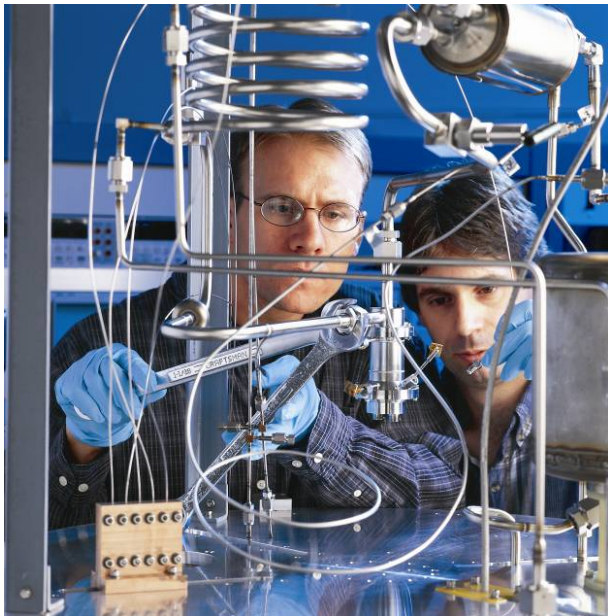
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Radionuclide Aerosol Collection

- **International Monitoring System Radionuclide Stations**
 - Each station includes Radionuclide Particulate Monitoring
 - Existing system is the Radionuclide Aerosol Sampler/Analyzer (RASA)
 - Samples captured in a filter-paper collector over 24-hour sample period (batch process)
 - Decay of fission isotopes are measured with gamma-ray spectrometry: provides positive proof of nuclear detonation
 - Samples are archived for physical analysis if desired
- **Challenges for Current Systems**
 - **Power Consumption**
 - During Fukushima incident, power stability was an issue for aerosol detection near the site
 - Filter-paper based approach requires high blower power due to large ΔP across filter
 - **Sensitivity**
 - Blower power limits air flow rate and total sample quantity
 - Collecting more particles per sample period will increase instrument sensitivity
 - Environments with high background radiation can limit instrument sensitivity (higher noise levels require more signal to overcome)



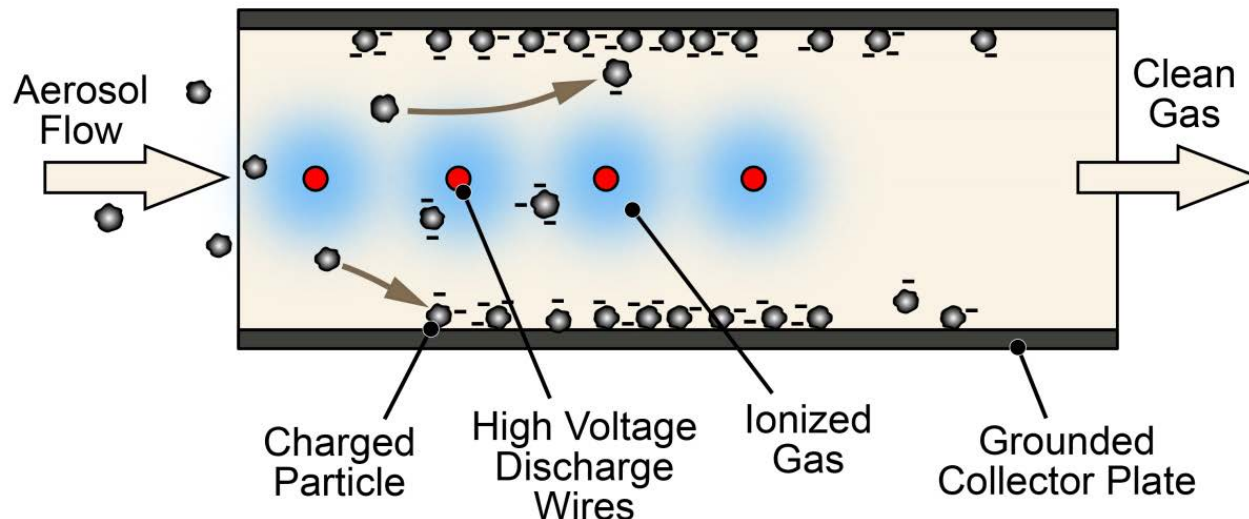
Radionuclide Monitoring Station Locations- 63/80 certified.
<https://www.ctbto.org/map/>

Radionuclide Aerosol Collection

- **A new collection system is desired that consumes less power**
 - Enable operation in power-limited locations/operating periods (existing system employs a 3 hp blower)
 - A system with a lower pressure drop may enable higher sampling rates
- **Electrostatic precipitation offers low power alternative to filter-based approaches**
 - Cross contamination of collected samples must be avoided
 - Commercial ESPs are not focused on sample preservation
 - Samples must be packaged for detector integration
- **System requirements**
 - Full-scale system flow rates: 500 m³/hr to 2,000 m³/hr of higher (current system samples at ~1000 m³/hr)
 - Particle collection efficiency
 - $\eta > 90\%$ for particle diameters 0.1 μm – 1.0 μm
 - $\eta > 50\%$ for particle diameters $> 10 \mu\text{m}$
 - Minimize system power $\ll$ 3 hp (2.2 kW) blower requirement for current RASA
 - Minimize sample cross-contamination
 - Compact system size

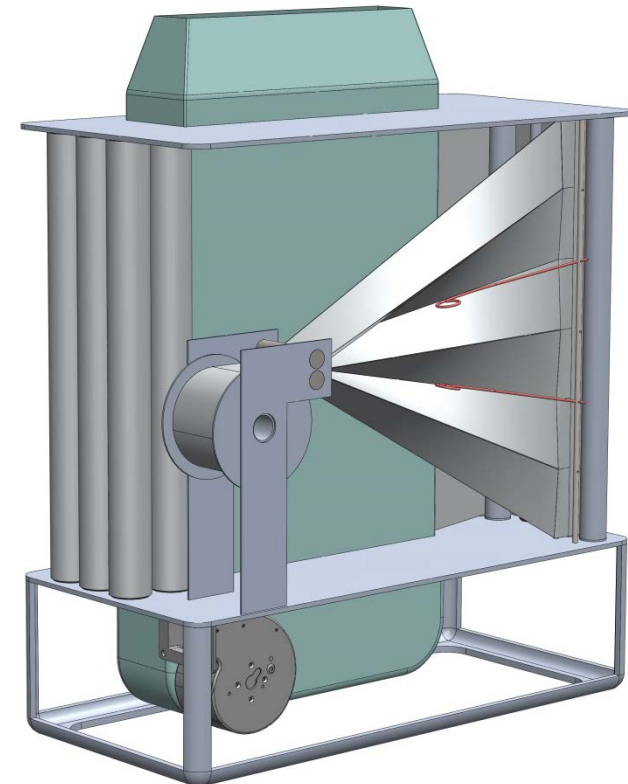
Electrostatic Precipitation

- **Electrostatic precipitation operation:**
 - A high voltage is applied between two electrodes (such as a thin wire and a flat plate) and the aerosol flow is passed between them
 - A corona is generated at the discharge electrode
 - The ionized gas molecules collide with the particles entrained in the flow, and charge builds up on the particles
 - The charged particles are drawn to the collector electrode by the electric field force where they stick, held by static and van der Waals forces
- **ESP systems can achieve very high collection efficiencies (>99.5%) across a wide range of particle sizes: 30 nm to >100 μm**



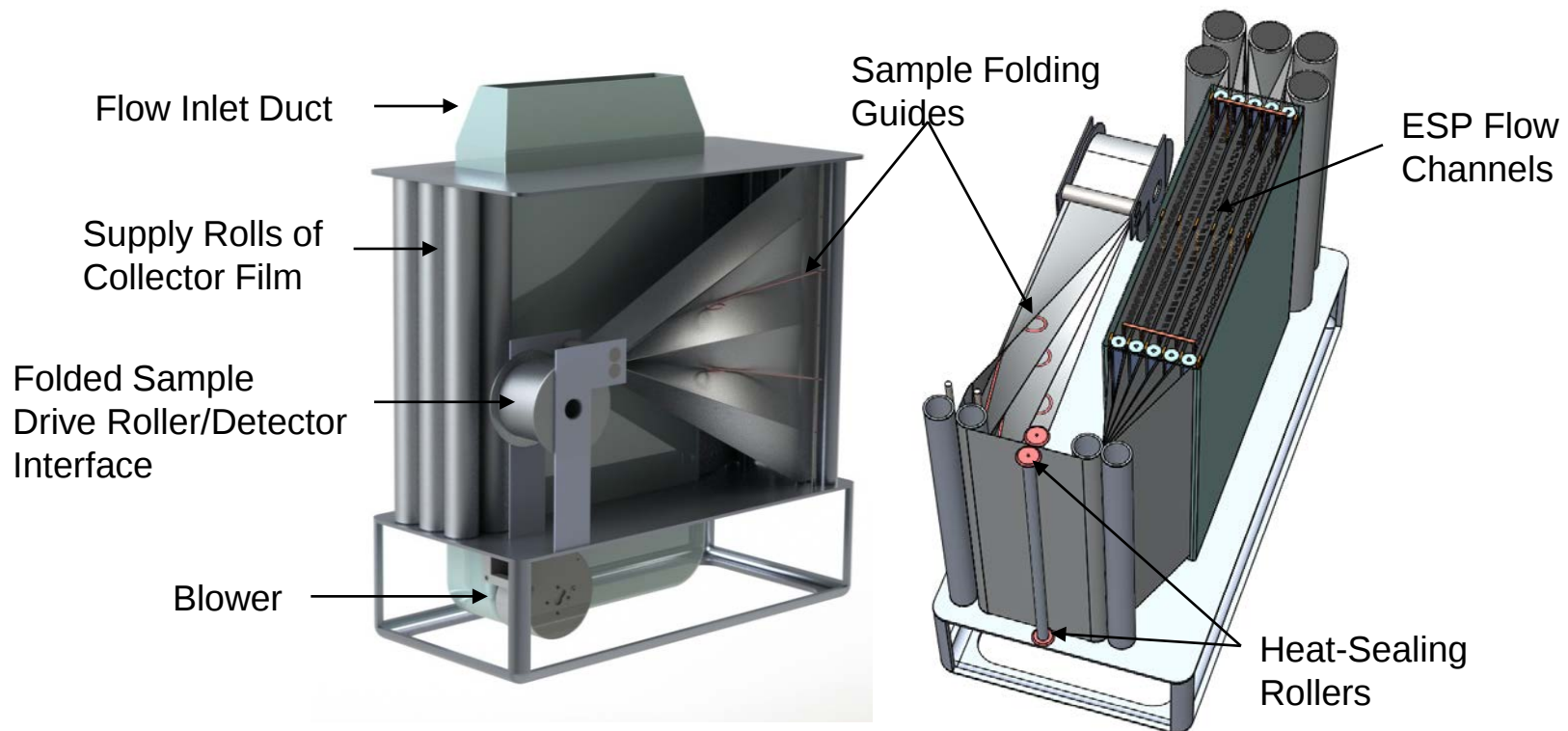
Phase I Design Concept

- **Full-scale system requirements:**
 - Fit within general RASA dimensions if possible $\sim(40\text{ cm} \times 60\text{ cm} \times 13\text{ cm})$
 - Maintain particle collection efficiency $>90\%$
 - Minimize power
 - Reduce sample to at least $10\text{ cm} \times 40\text{ cm}$ strip to interface with detector
- **ESP collector design:**
 - ESP form factor challenge—long and narrow
 - Longer flow-dimension increases collection efficiency
 - Goal to minimize system volume (length) while maintaining performance
 - Minimize system complexity for sample handling to support long-term, autonomous operation
 - Minimize cross-contamination between successive samples
 - Mode of Operation: Sample 24 hrs, Decay 24 hrs, Detect 24 hrs



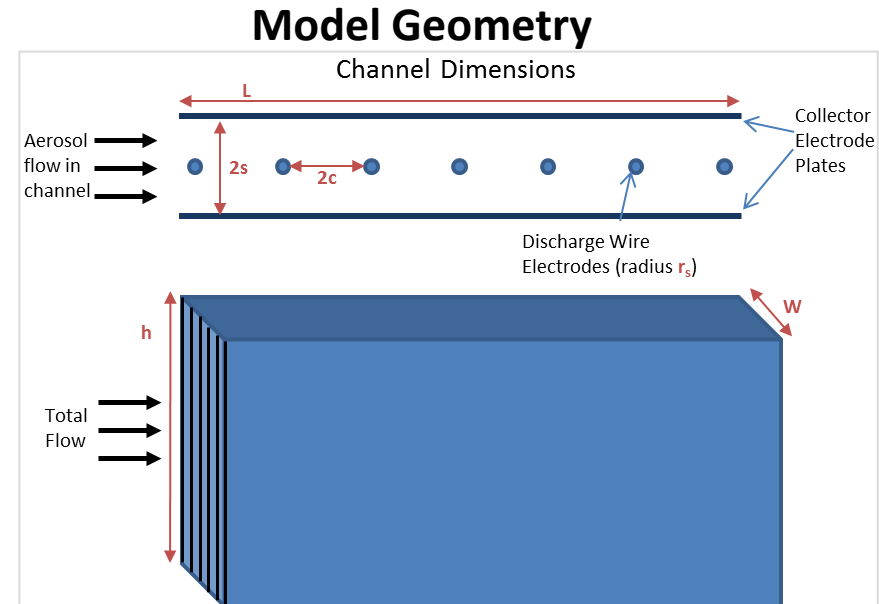
Phase I Design Concept

- **Wire-plate ESP design with multiple rectangular flow channels**
- **Layers of flexible, conductive collector sheets drawn through ESP crosswise to flow direction**
- **Layers are heat sealed at top and bottom edges**
- **Sample is folded in accordion-like fashion to reduce dimensions to detector interface (10 cm Height)**



Phase I Design Model

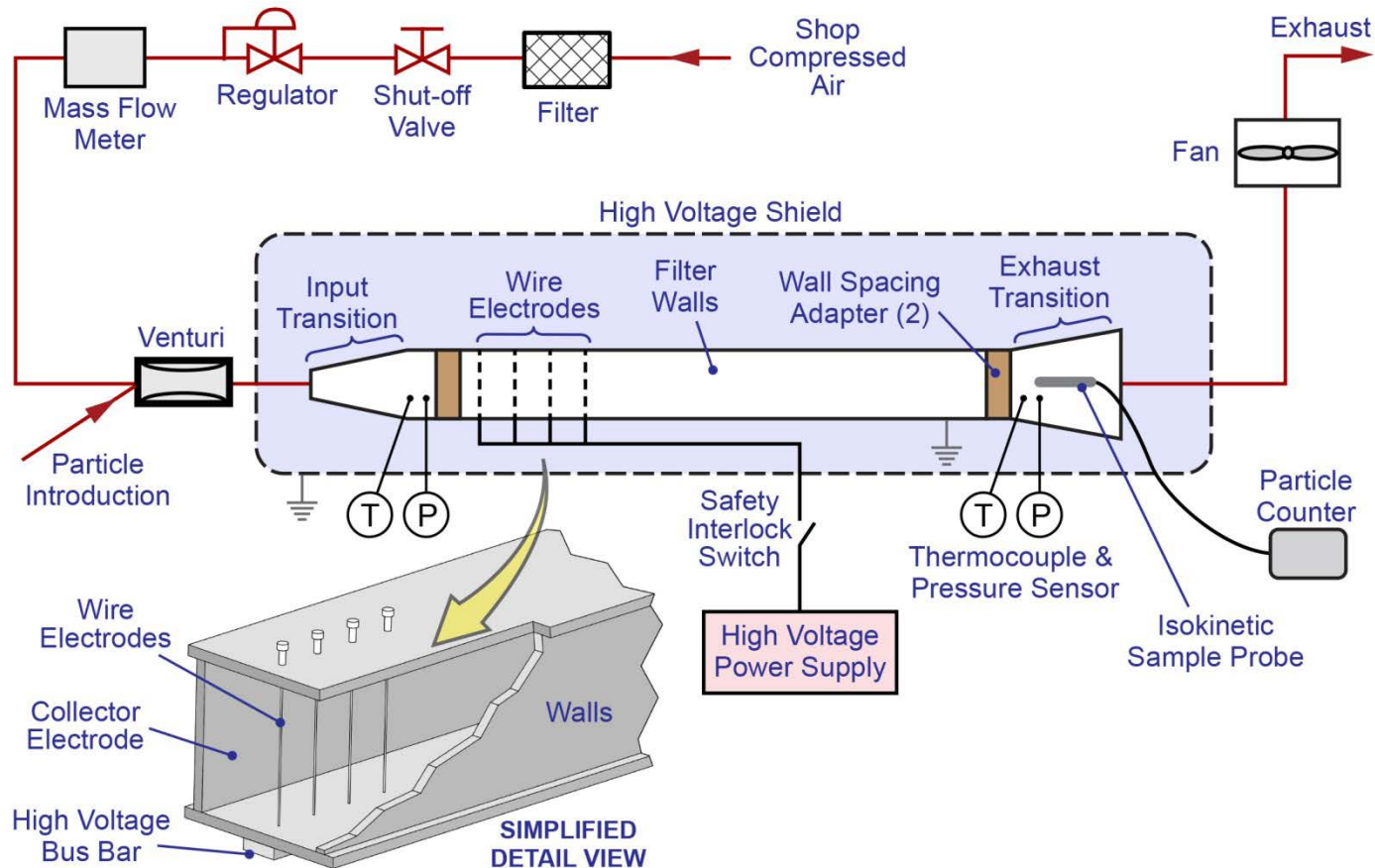
- Developed ESP design model for performance prediction and system sizing
- Explored sensitivity of key configuration parameters:
 - Discharge wire electrode spacing
 - Channel width
 - Discharge wire radius
 - Channel length
- Explored sensitivity of predicted ESP performance to applied voltage and air flow rate
- Compared model to subscale test results and used to generate full-scale design



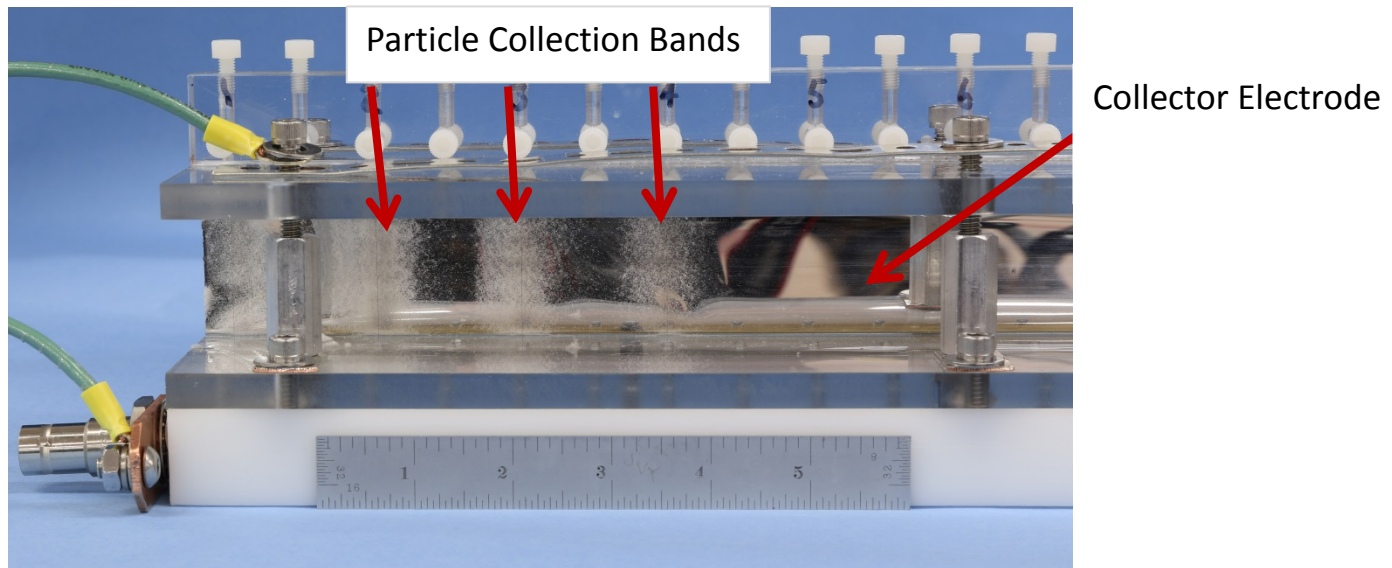
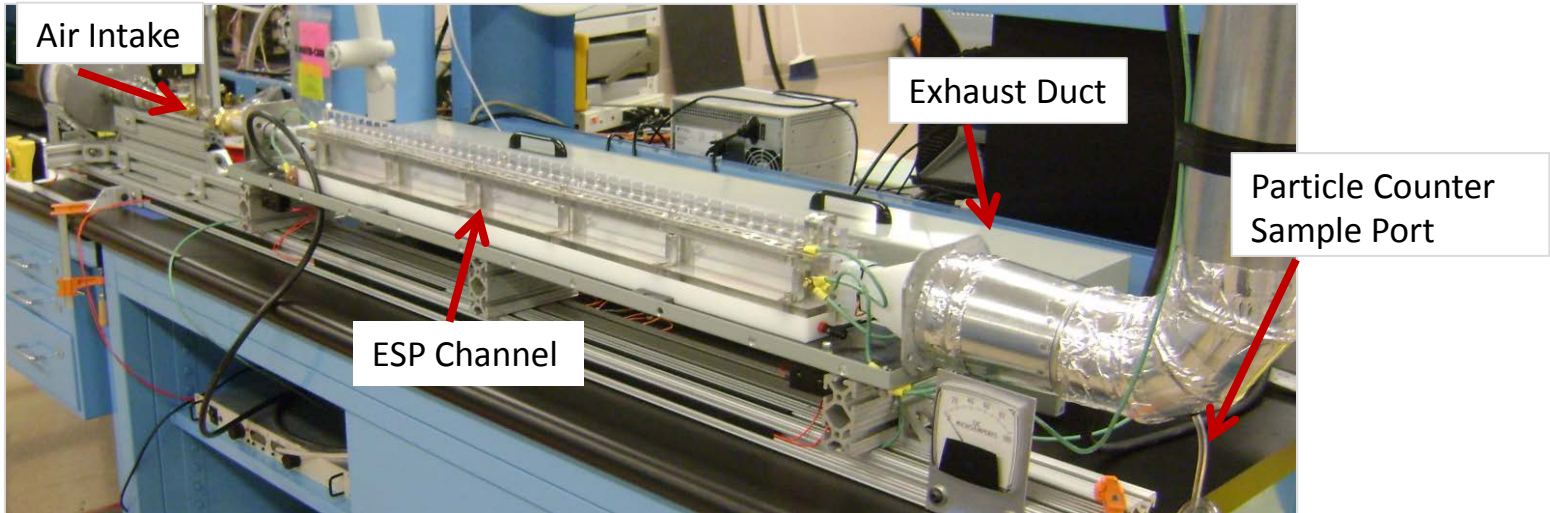
Model Parameters	
MODEL INPUTS	MODEL OUTPUTS
Number of Flow Channels	Particle Collection Efficiency
Channel Length (L)	ESP Power
Channel Width ($2s$)	Turn-On Voltage
Channel Height (h)	Pressure Drop
Discharge Wire Pitch ($2c$)	Blower Power
Discharge Wire Radius (r_s)	
Applied Voltage	
Total Flow Rate	
Particle Diameter/Properties	

Subscale Test Facility

Schematic of Single-Channel ESP Test Facility (1/50th of full-scale size)

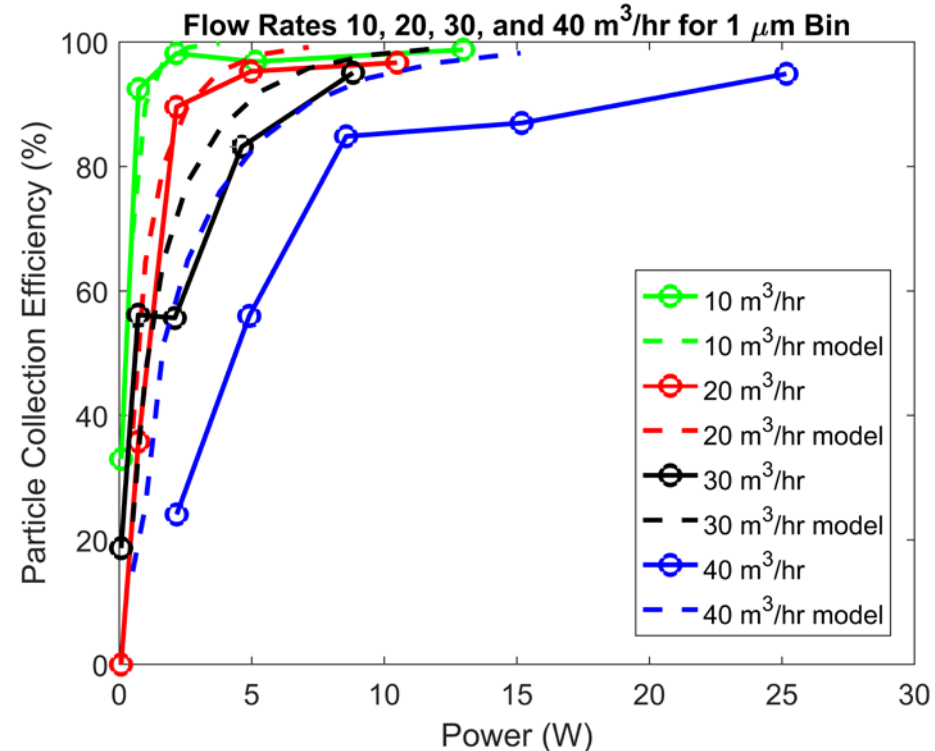


Phase I Subscale Tests – Test Facility



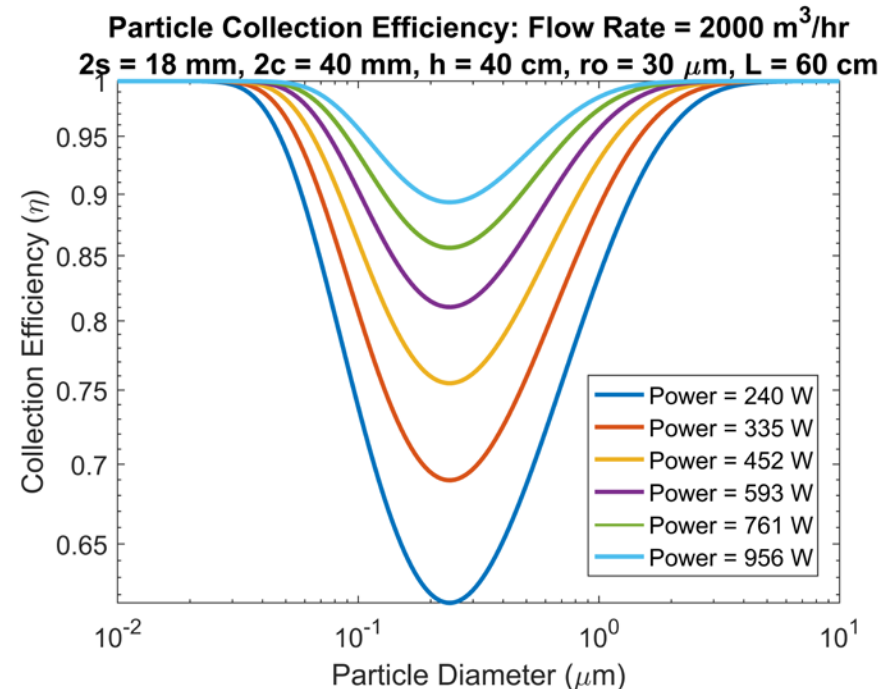
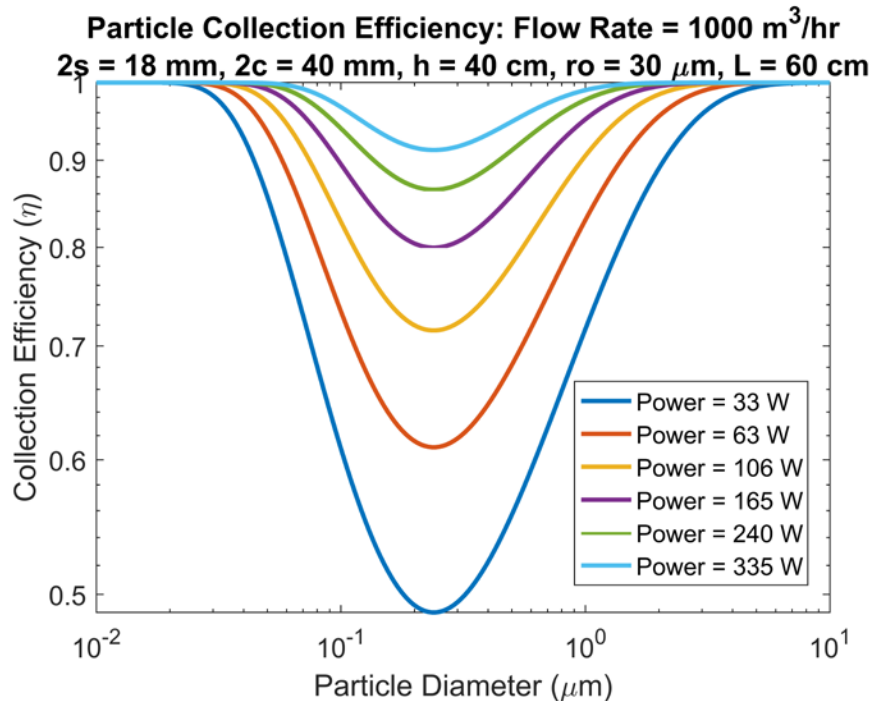
Phase I Subscale Test Results

- Comparing model results for the test channel geometry:
 - Shows good agreement to data at the lower flow rates (40 m³/hr equivalent to 2000 m³/hr full-scale)
 - Over-predicts collection efficiency at higher flows
 - Differences can be due to particle re-entrainment, particle sensor errors, and test particle properties
 - Refining subscale test facility in Phase II with better particle generation and detection capabilities
- Performance vs. flow rate
 - High flow goal of >90% collection achieved
 - Test channel is not an optimized design



Phase I Modeling Results

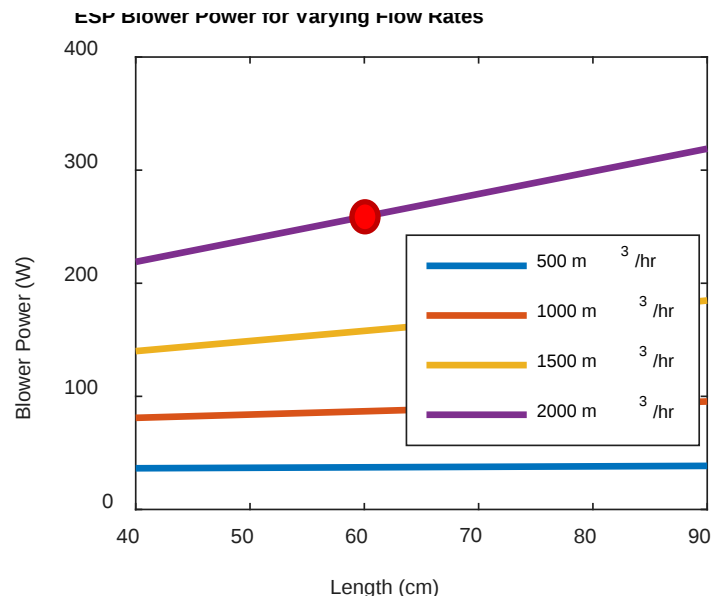
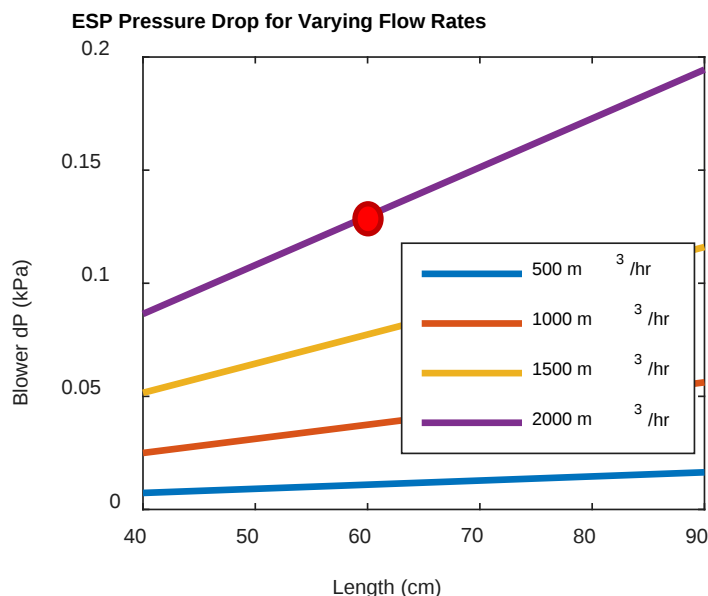
- **Collection efficiency for all particle sizes for varying ESP power input**
 - Shown for 1000 m³/hr (nominal flow) and 2000 m³/hr (target high flow)
 - ESP can be dynamically tuned to:
 - Maintain the collection efficiency at a given value
 - Maximize flow for a given power budget and efficiency
 - Maximize sample collection mass and decrease sampling time during rapidly evolving events



Phase I Modeling Results

- **Blower power**

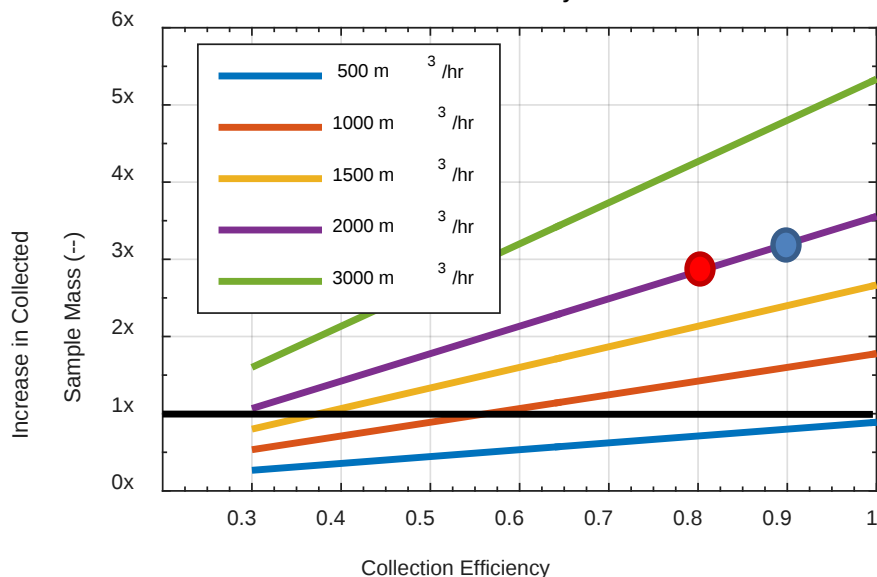
- Primary reason for power savings with an ESP over conventional filter
- Open channels have very small pressure drop
- Ducting to and from ESP will be main contributor to overall pressure drop
 - Included additional 0.15 kPa (0.6 inches H₂O) to ESP dP to account for ducting losses in estimating blower power
 - 2000 m³/hr through 50 ft of 10 inch-diameter ducting with two 90° bends
- Target high flow rate of 2000 m³/hr needs ~260 W blower power (includes 60% blower efficiency)
- Nominal operating point of 1000 m³/hr requires ~90 W (compared to 1-2 kW of RASA blower)



Phase I Modeling Results

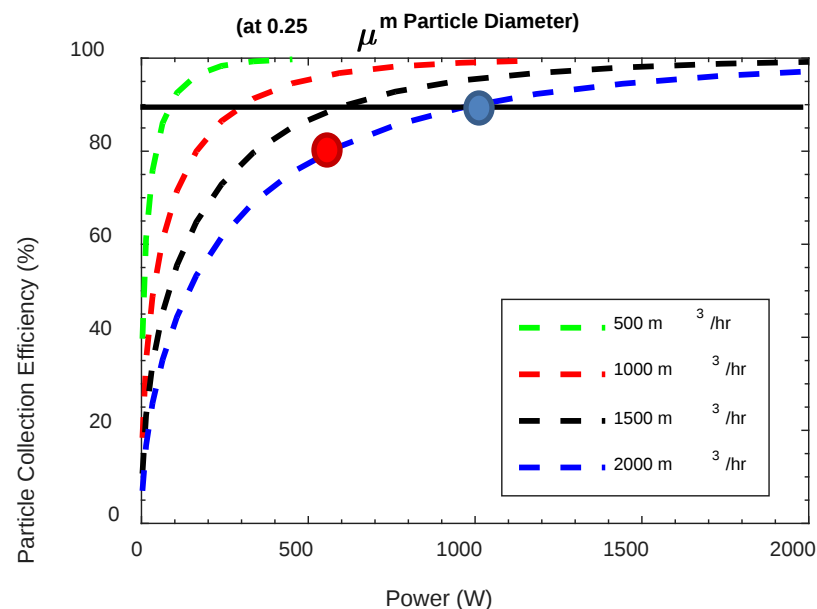
- Instrument sensitivity is a function of collection efficiency AND flow rate (sample volume)
- Optimization of sensitivity vs. power is better if collection efficiency target is reduced (90% is goal, IMS requirement is 80%):
 - At 90% and 2000 m³/hr need 1000 W: gain in sample mass is 3.2x
 - At 80% and 2000 m³/hr need 590 W: gain in sample mass is 2.9x → 41% less power

Increase in Sample Mass as a Function
of Flow and Collection Efficiency



Using 15,000 m³ as nominal sample volume

Full-Scale ESP Performance for Varying Flow Rates



Phase I Conclusions

- **Key results of Phase I:**

- **Developed ESP design model, validated against experiments**
- **Demonstrated ESP operation with flexible collector material**
- **Developed full-scale MESP design that meets all requirements for radionuclide collection**
 - **>90% particle collection efficiency for flows up to 2000 m³/hr**
 - **Total system volume 81 cm x 84 cm x 38 cm**
 - **Sample folding concept to produce sample size reduction to 10 cm x 40 cm**
- **Significant power savings over current RASA system**
 - **~440 W at nominal flows (1000 m³/hr), 1.4 kW at high-flow target (2000 m³/hr)**
 - **Up to 5x power reduction from 2.2 kW RASA**
- **Improvement in instrument sensitivity with higher flow rates**
- **Relaxation of the 90% collection efficiency will result in even larger reductions in power, while still improving instrument sensitivity**
- **Demonstrated feasibility of multi-layer sample folding and sample compaction**

Phase II Plans

- **Technical challenges and tasks:**
 - **Advanced subscale testing**
 - Facility improvements with particle generator and detection and inlet and outlet of ESP volume
 - Explore ESP improvements and power optimization in charging region
 - Test performance across range of operating conditions (particle resistivity, humidity, etc.)
 - Determine collected particle layer thickness limitations (will impact system sizing)
 - Long-term efficiency testing and materials verification
 - **Develop sample handling system**
 - System to hold collector sheets in ESP volume during sampling, remove, seal, and fold/compress to size necessary for detector integration
 - Maximize instrument sensitivity
 - Maximize reliability
 - Include concept of operations (“re-threading” collector sheets, sample storage, material costs, etc.)
 - **Design, build, and test full-scale prototype**
 - Measure performance of particle collection and power consumption for varying flow rates/test particles/and atmospheric sampling
 - Design to accommodate future integration with a detector
 - Control scheme for system monitoring, high-voltage safety interlocks, and eventual remote operation

Questions?