RESEARCH & DEVELOPMENT

Electrostatic Precipitation System for Radionuclide Particle Collection

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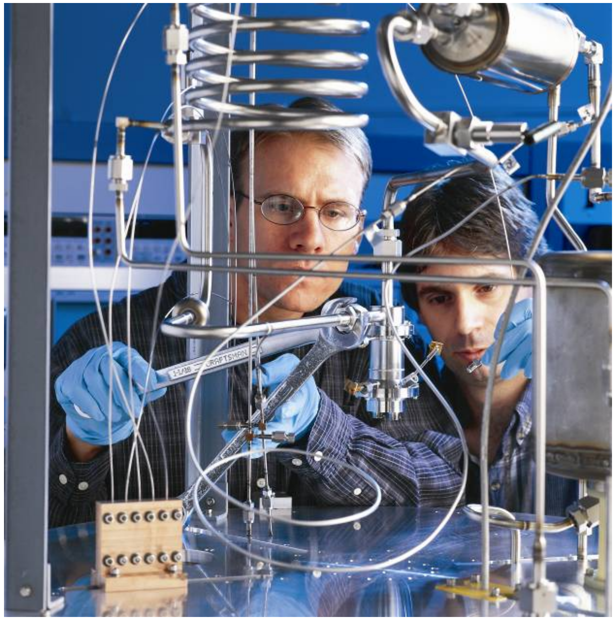
Creare

- **R&D Engineering Services**
  - Diverse technical expertise
  - Over 70 engineers including mechanical, electrical, materials, aerospace, and software
  - Highly skilled technicians, machinists, and designers
  - Industrial and Federal Clients
- **Core Competencies**
  - Thermal & Fluid Engineering
  - Technology Innovation
  - Cryogenics and Power Systems
  - Innovative Fabrication and Manufacturing



- **Our Facilities**
  - 80,000 Sq. Ft. Laboratory, Shop, and Office Space
  - Capabilities range from micromachining to running large outdoor experiments
  - Wide range of in-house fabrication facilities include precision machining, laser welding, vacuum brazing, EDM, and thin-film deposition
  - Electronics Lab, Clean Room, Environmental Chambers, Inspection Lab, Thermal Vacuum Systems
- **Established Record of Technology Transition**
  - Hubble Space Telescope Cryocooler
  - Mars Curiosity Rover Miniature Vacuum Pumps
  - Catapult Gap Instrument for Aircraft Carriers
  - Multiple Spin-off Companies and Technology Licenses

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)**

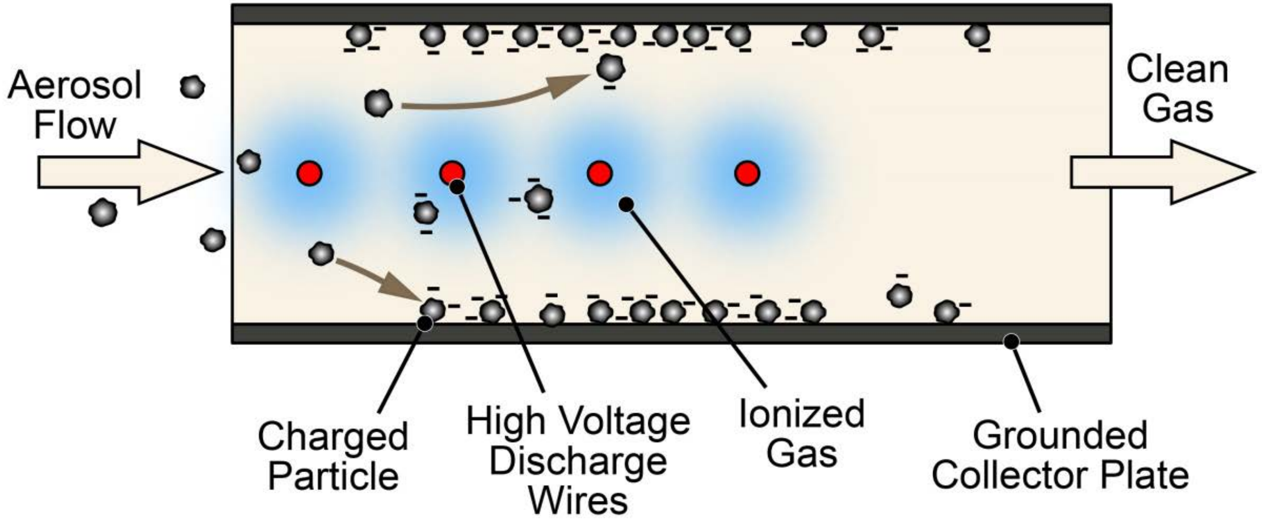
Radionuclide Monitoring Station Locations- 63/80 certified.
https://www.ctbto.org/map/

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 m^3/hr to 2,000 m^3/hr of higher (current system samples at ~1000 m^3/hr)
  - Particle collection efficiency
    - η > 90% for particle diameters 0.1 μm – 1.0 μm
    - η > 50% for particle diameters > 10 μm
  - Minimize system power << 3 hp (2.2 kW) blower requirement for current RASA
  - Minimize sample cross-contamination
  - Compact system size

Electrostatic Precipitation

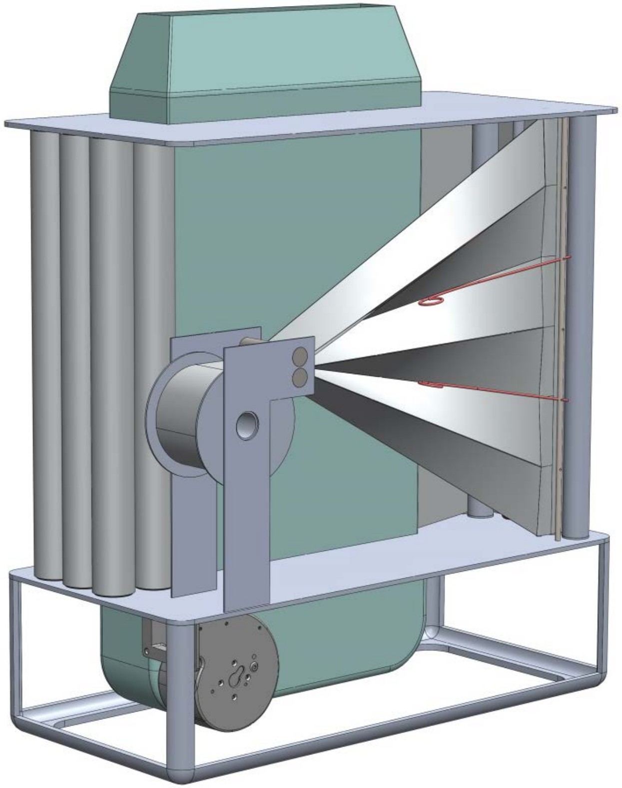
- **Electrostatic precipitation operation:**
  - A high voltage is applied between two electrodes (such as a thin wire and a flat plate) and the aerosol flow is passed between them
  - A corona is generated at the discharge electrode
  - The ionized gas molecules collide with the particles entrained 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 Walls 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

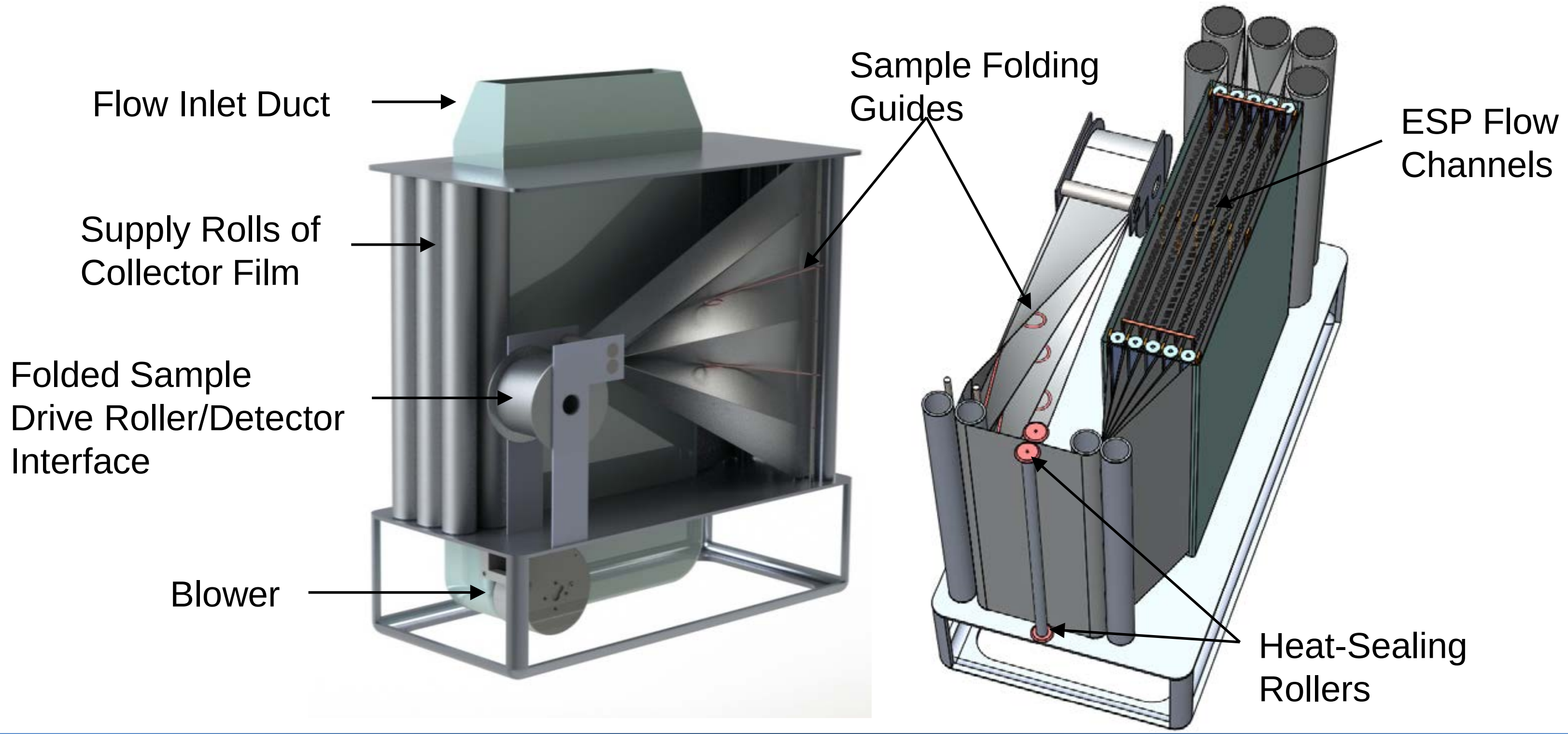
- **Full-scale system requirements:**
  - Fit within general RASA dimensions if possible ~(40 cm x 60 cm x 13 cm)
  - Maintain particle collection efficiency >90%
  - Minimize power
  - Reduce sample to at least 10 cm x 40 cm strip to interface with detector

- **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

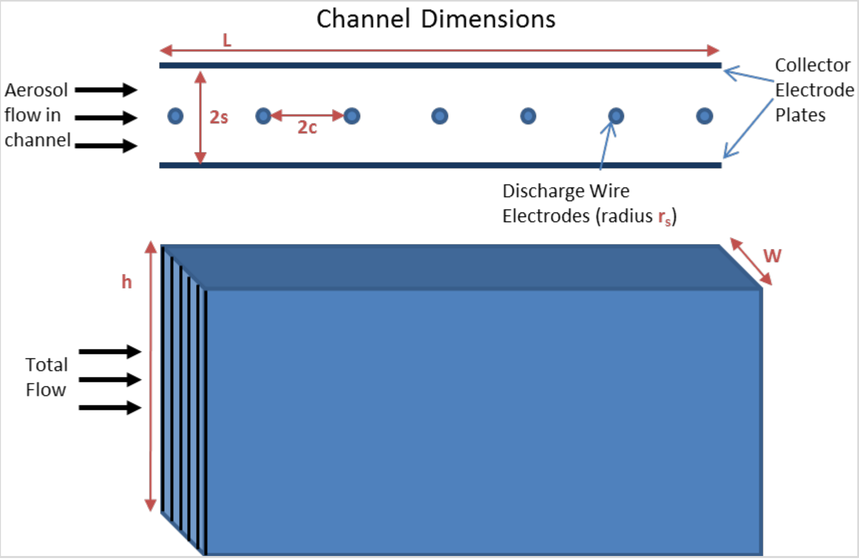
- **Wire-plate ESP design with multiple rectangular flow channels**
- **Layers of flexible, conductive collector sheets drawn through ESP crosswise to flow direction**
- **Layers are heat sealed at top and bottom edges**
- **Sample is folded in accordion-like fashion to reduce dimensions to detector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

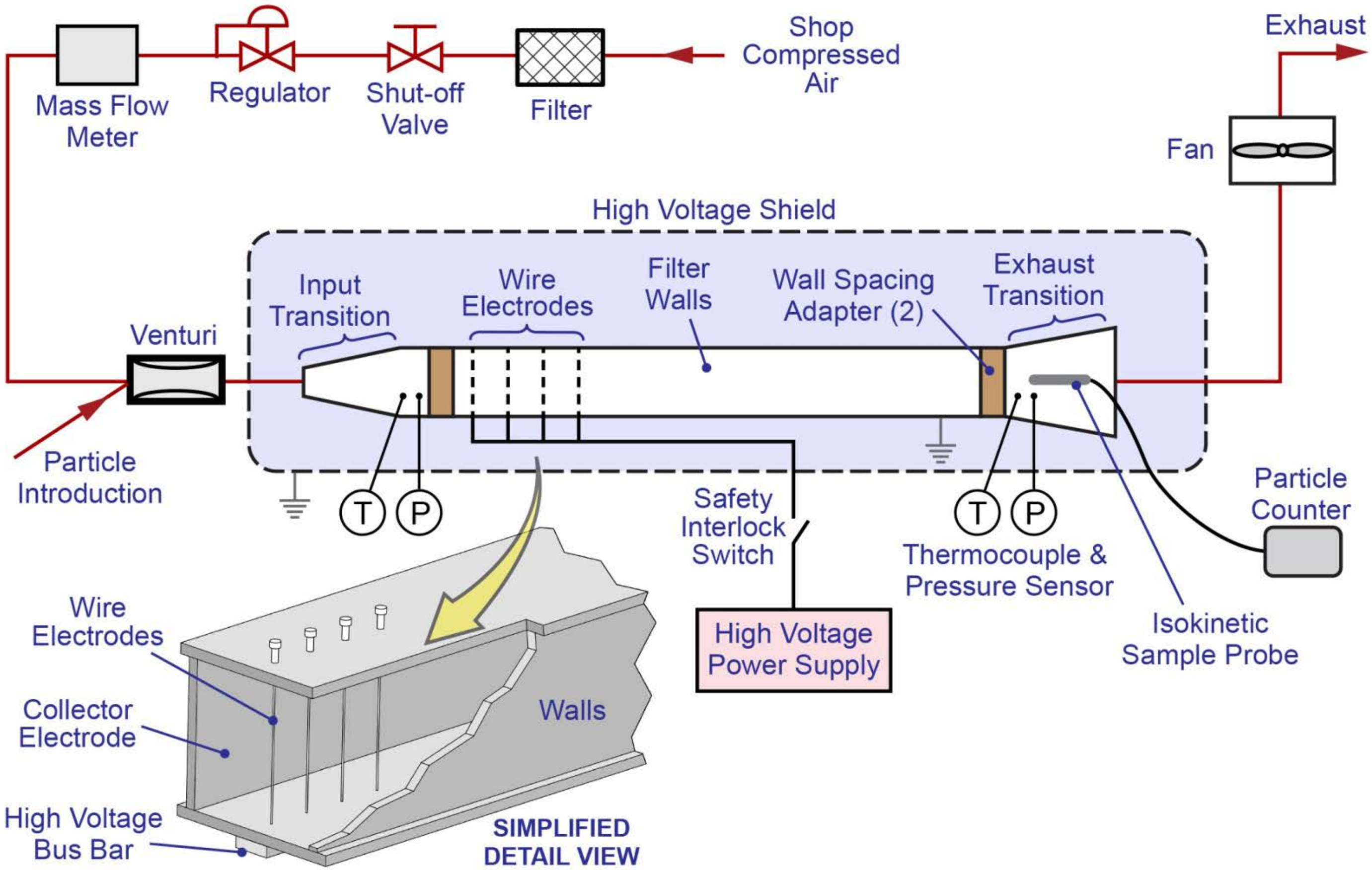
Model Geometry



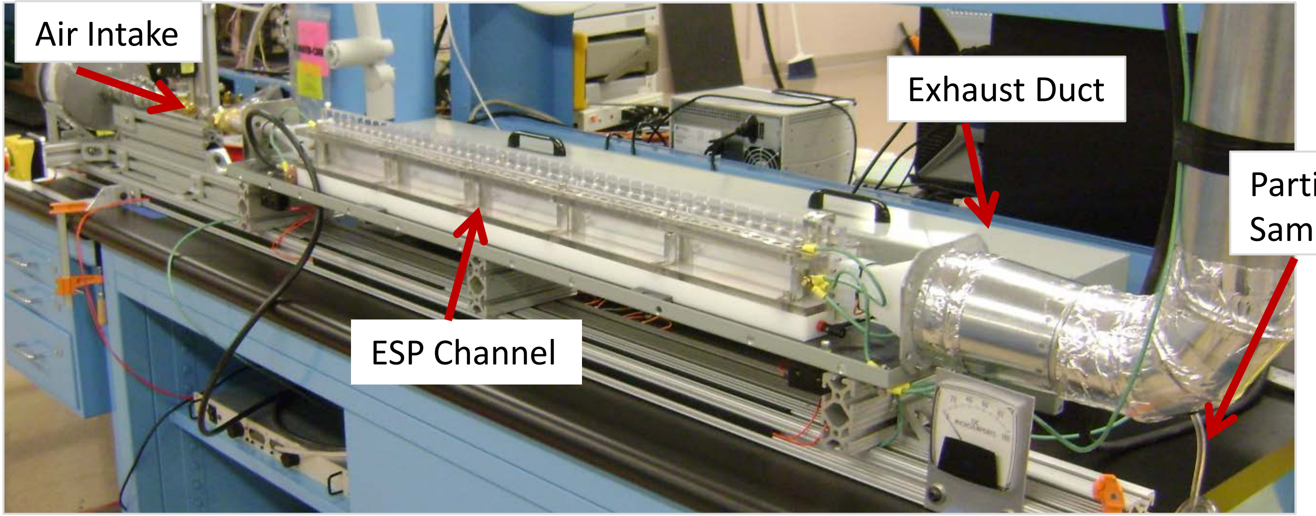
Model Parameters	
MODEL INPUTS	**MODEL OUTPUTS**
Number of Flow Channels	Particle Collection Efficiency
Channel Length (L)	ESP Power
Channel Width (2s)	Turn-On Voltage
Channel Height (h)	Pressure Drop
Discharge Wire Pitch (2c)	Blower Power
Discharge Wire Radius (r_s)	
Applied Voltage	
Total Flow Rate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

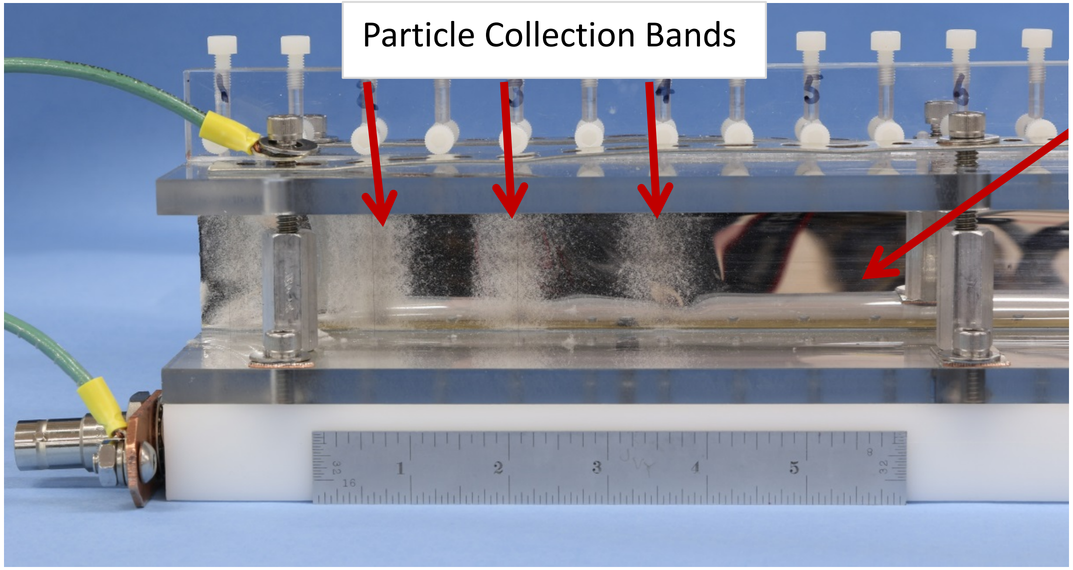
Subscale Test Facility

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



Phase I Subscale Tests – Test Facility

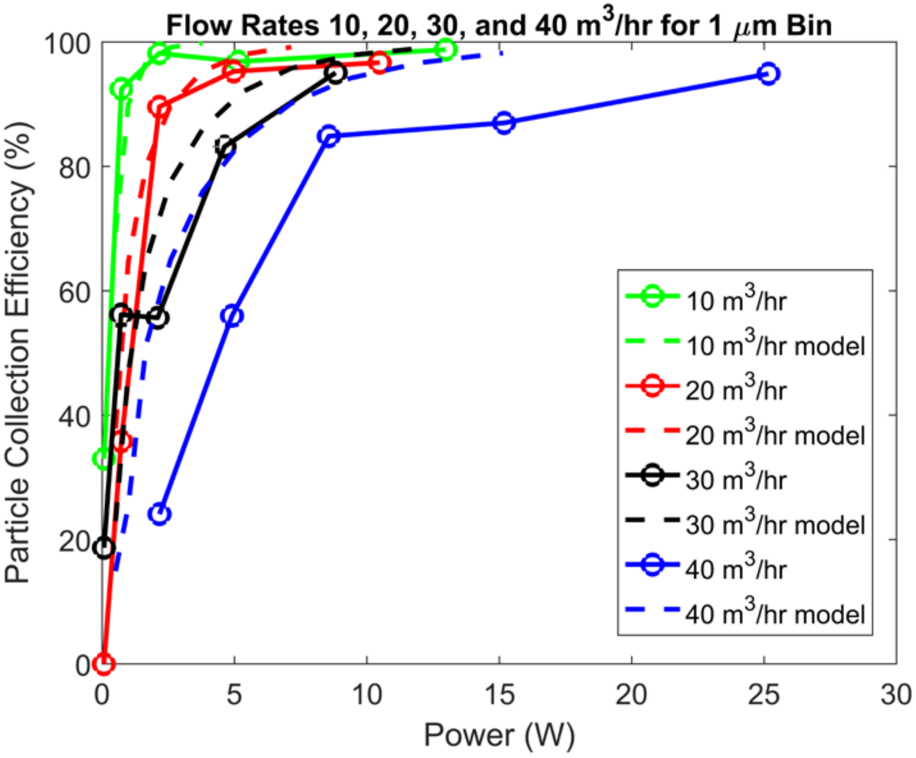




Collector Electrode

Phase I Subscale Test Results

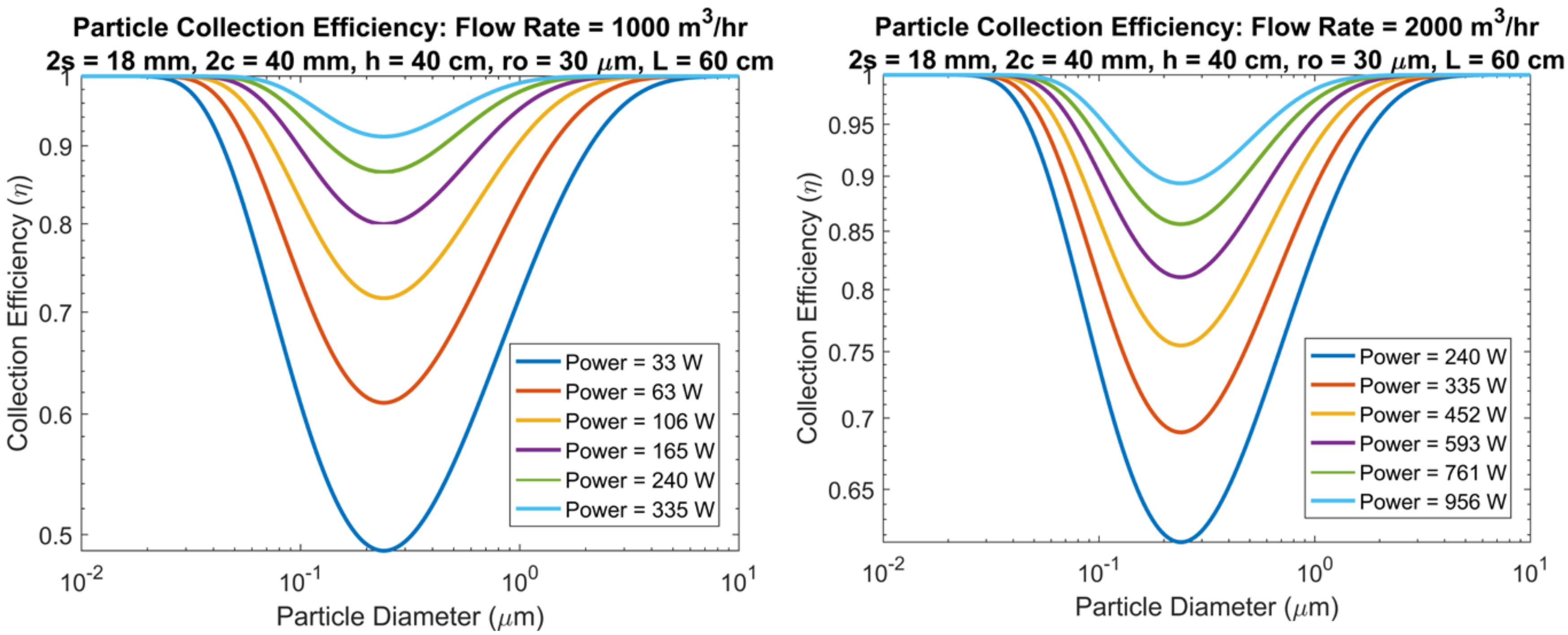
- **Comparing model results for the test channel geometry:**
  - **Shows good agreement to data at the lower flow rates (40 m³/hr equivalent to 2000 m³/hr full-scale)**
  - **Over-predicts collection efficiency at higher flows**
  - **Differences can be due to particle re-entrainment, particle sensor 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**

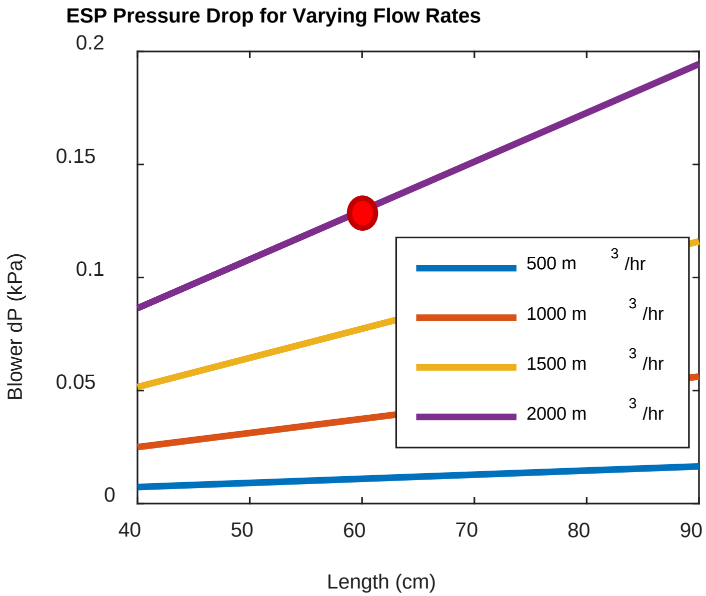
Phase I Modeling Results

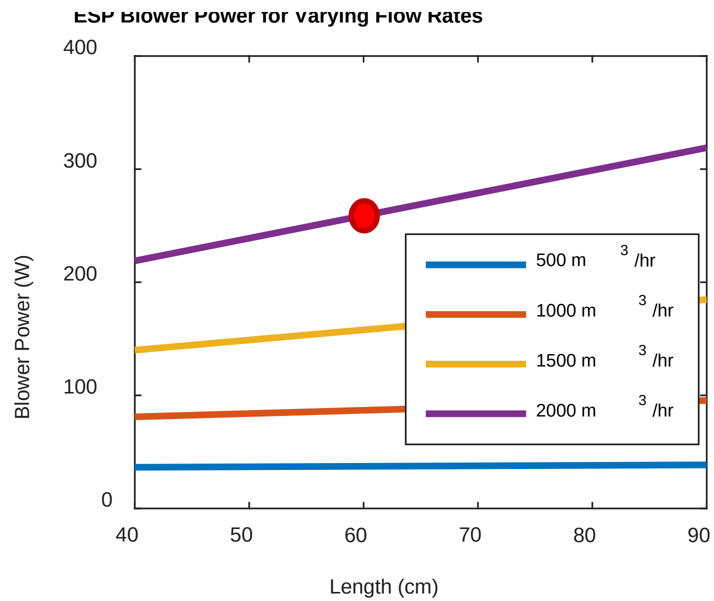
- **Collection efficiency for all particle sizes for varying ESP power input**
  - **Shown for 1000 m^3/hr (nominal flow) and 2000 m^3/hr (target high flow)**
  - **ESP can be dynamically tuned to:**
    - **Maintain the collection efficiency at a given value**
    - **Maximize flow for a given power budget and efficiency**
    - **Maximize sample collection mass and decrease sampling time during rapidly evolving events**



Phase I Modeling Results

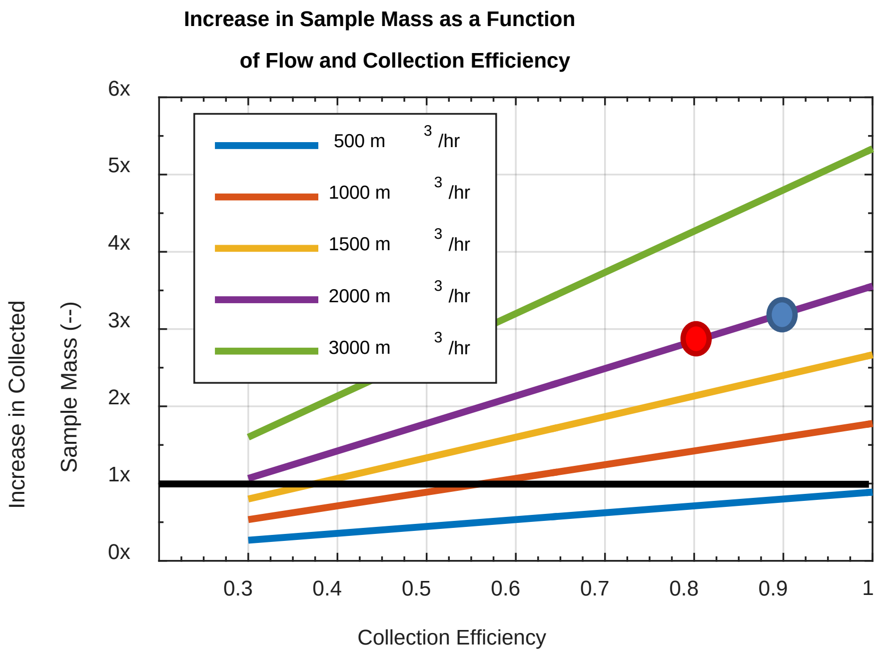
- **Blower power**
  - **Primary reason for power savings with an ESP over conventional filter**
  - **Open channels have very small pressure drop**
  - **Ducting to and from ESP will be main contributor to overall pressure drop**
    - **Included additional 0.15 kPa (0.6 inches H_2O) to ESP dP to account for ducting losses in estimating blower power**
      - **2000 m^3/hr through 50 ft of 10 inch-diameter ducting with two 90° bends**
  - **Target high flow rate of 2000 m^3/hr needs ~260 W blower power (includes 60% blower efficiency)**
  - **Nominal operating point of 1000 m^3/hr requires ~90 W (compared to 1-2 kW of RASA blower)**

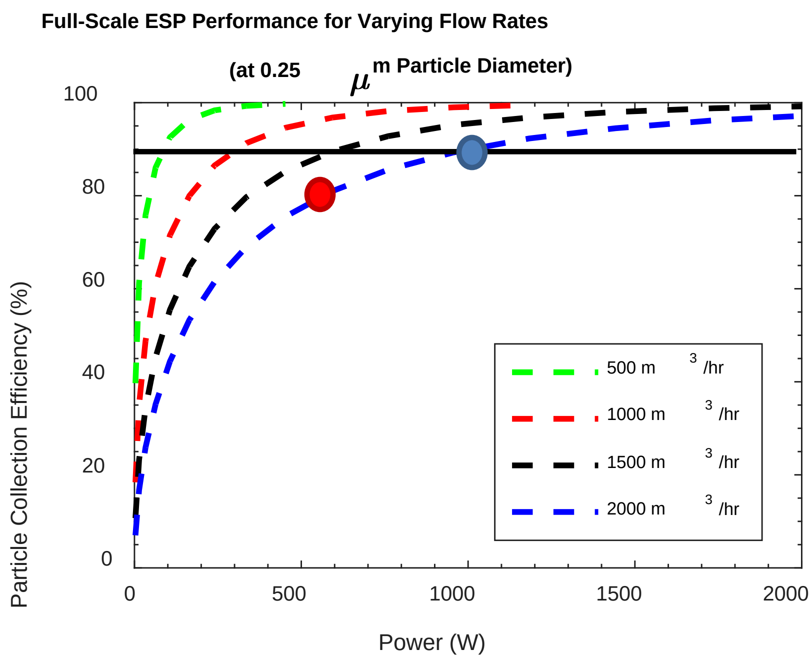




Phase I Modeling Results

- **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**





Using 15,000 m³ as nominal sample volume

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 m^3/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 m^3/hr), 1.4 kW at high-flow target (2000 m^3/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?