Methods for Reducing UHP Gas Usage in Fabs

Task 425.036: Customized Project, Sponsored by Intel

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Cost Sharing:

- **$55k (AZ-TRIF); $32k (membership funds); Equipment (Tiger Optics)**

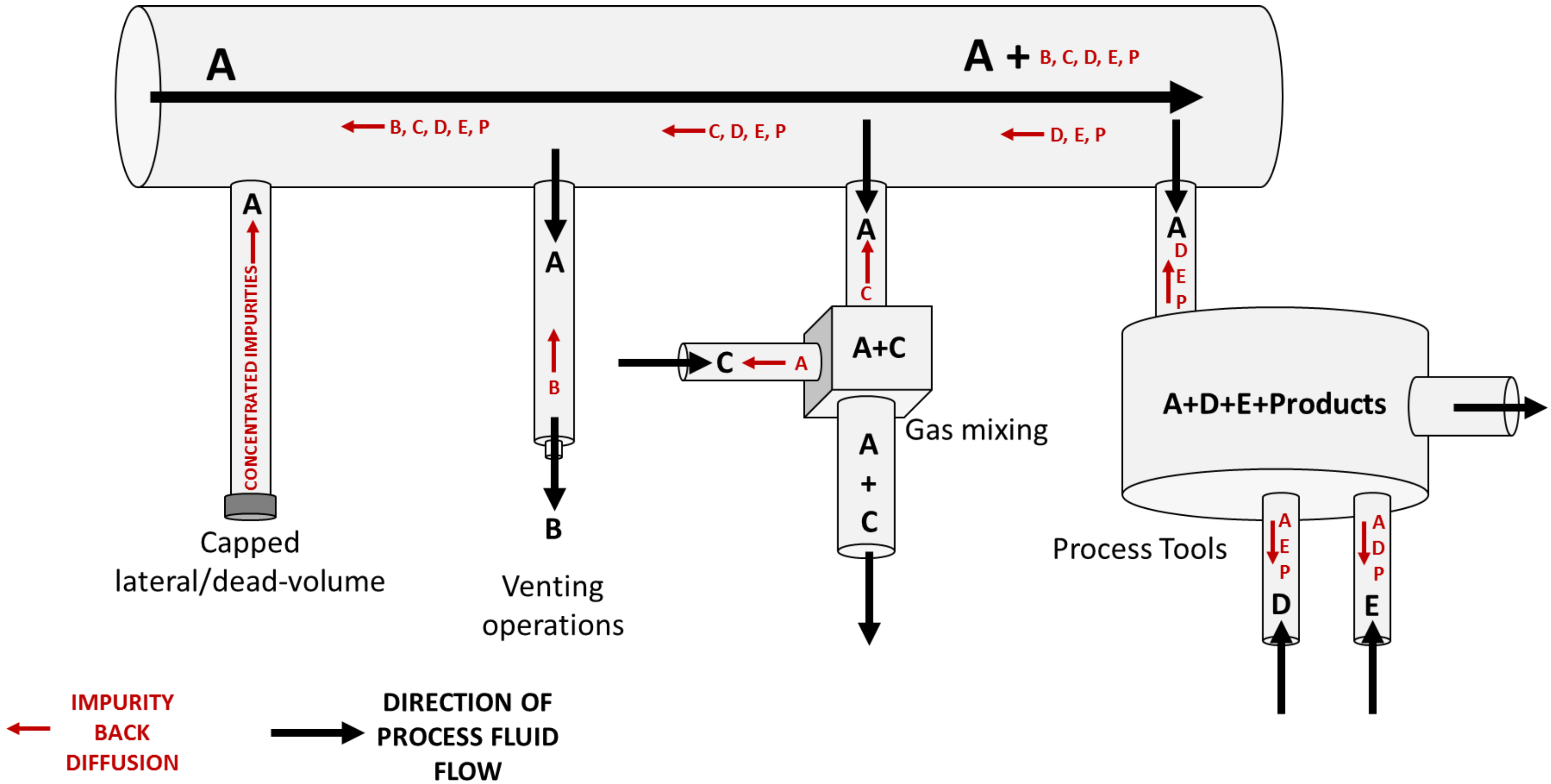
Objectives

- **Develop techniques for reducing UHP gas usage in fabs:**
  - **Subtask 1: Elimination of "*back diffusion*" as a major source of contamination**
  - **Subtask 2: Novel purge methods to remove contaminants during steady operation, start-ups, or recovery from system upsets.**

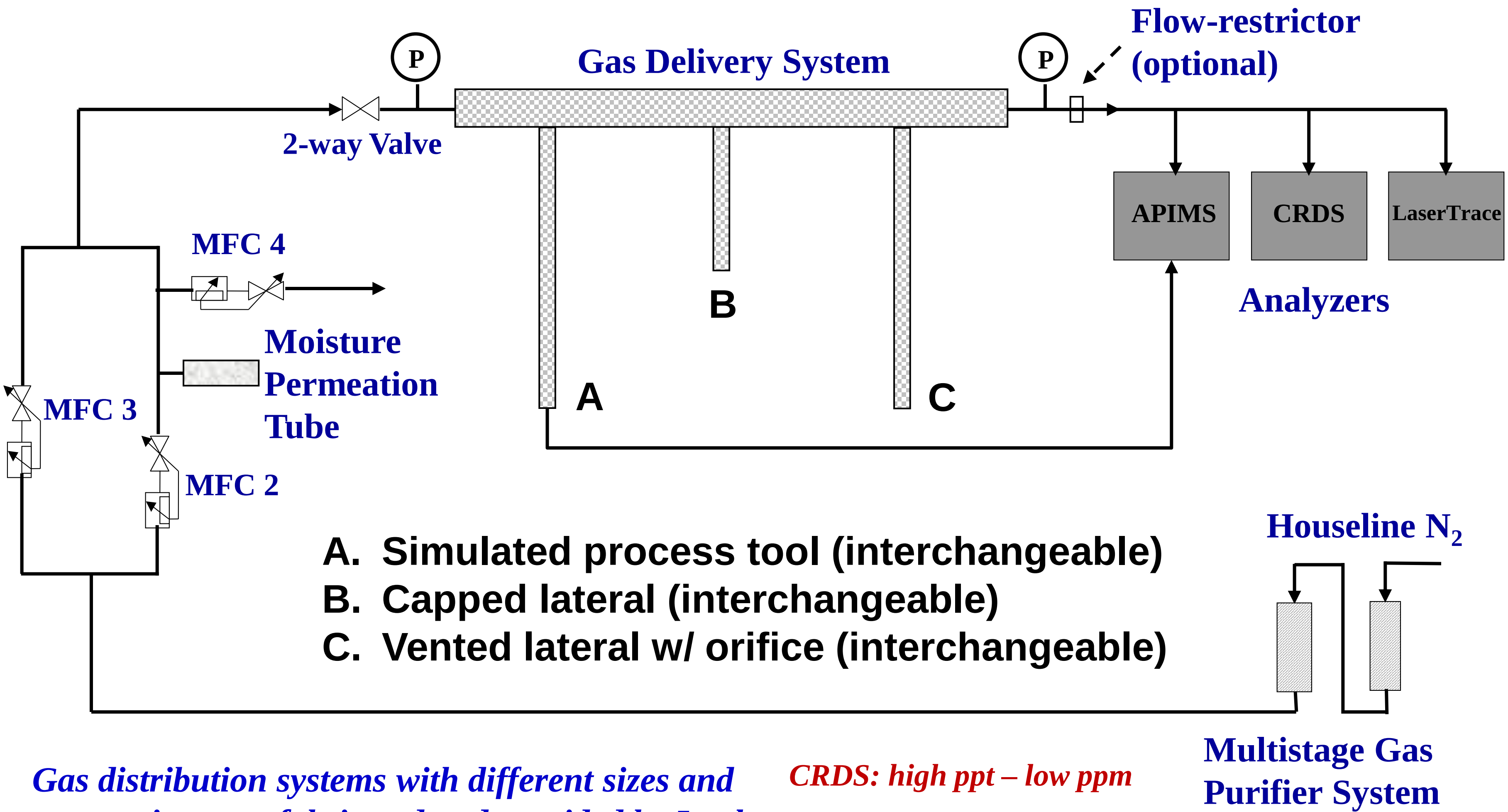
Motivation and ESH Impact

- **Contamination of gas distribution systems during operation or at start-up results in wasting of expensive UHP gases and valuable tool operation time.**

Subtask 1: Back Diffusion



Experiment Testbed



A. Simulated process tool (interchangeable)
B. Capped lateral (interchangeable)
C. Vented lateral w/ orifice (interchangeable)

Gas distribution systems with different sizes and geometries were fabricated and provided by Intel

CRDS: high ppt – low ppm

APIMS: low ppt – low ppb

Comprehensive Simulator

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0$$

Navier–Stokes equation:

$$\rho \left(\frac{\partial V}{\partial t} + V \cdot \nabla V \right) = -\nabla P$$

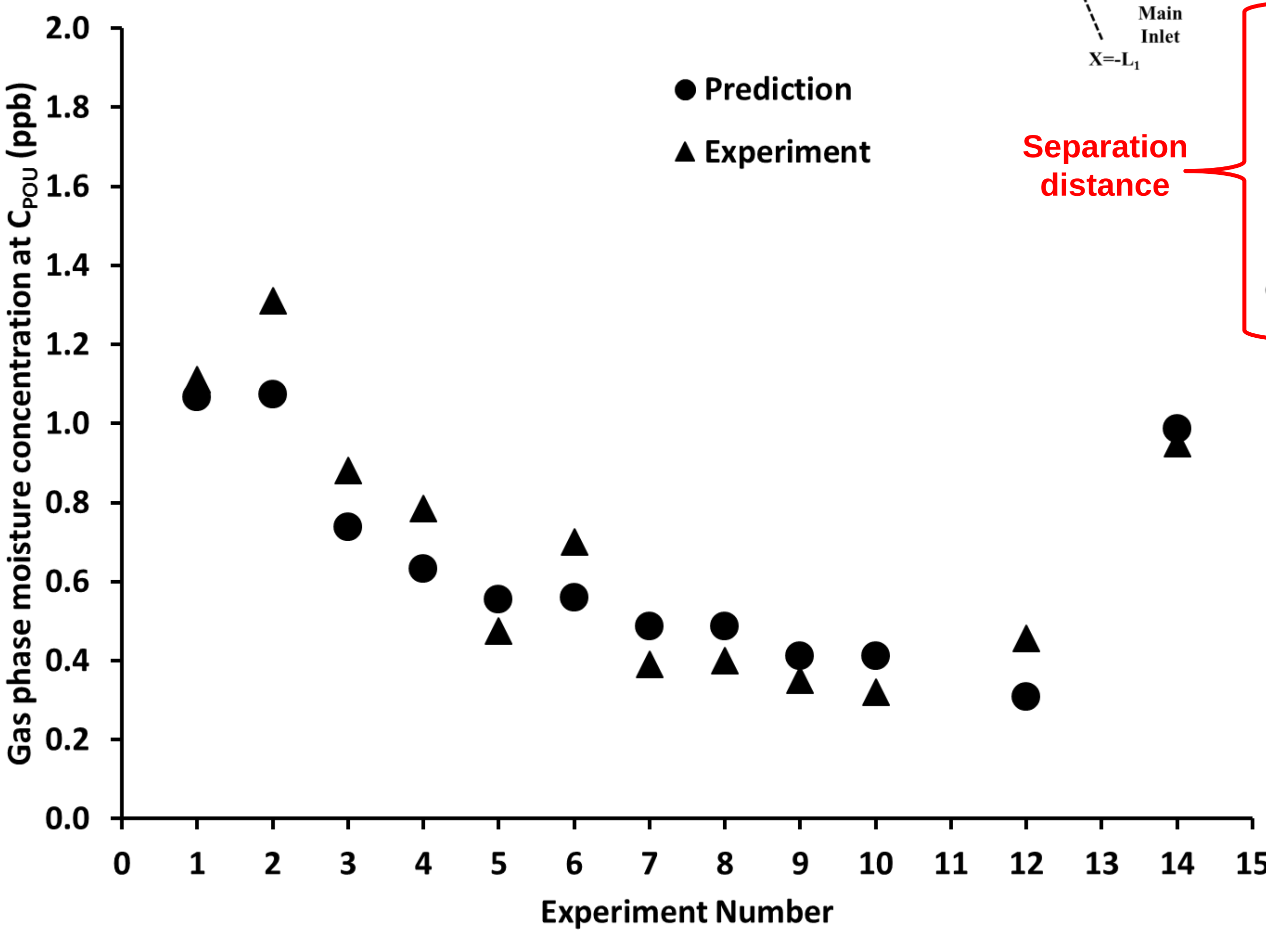
Moisture concentration in the gas phase:

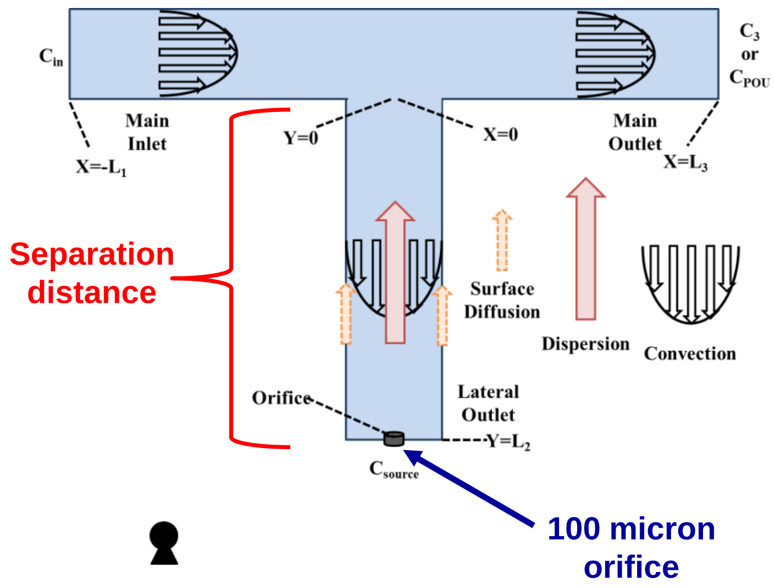
$$\frac{\partial C}{\partial t} = \underbrace{-\nabla \cdot (VC)}_{\text{Diffusion}} + \underbrace{\nabla \cdot (D \nabla C)}_{\text{Convection}} + \underbrace{\frac{4}{d} [k_d C_s - k_a C (S_0 - C_s)]}_{\text{Adsorption and desorption}}$$

Moisture concentration on the pipe surface:

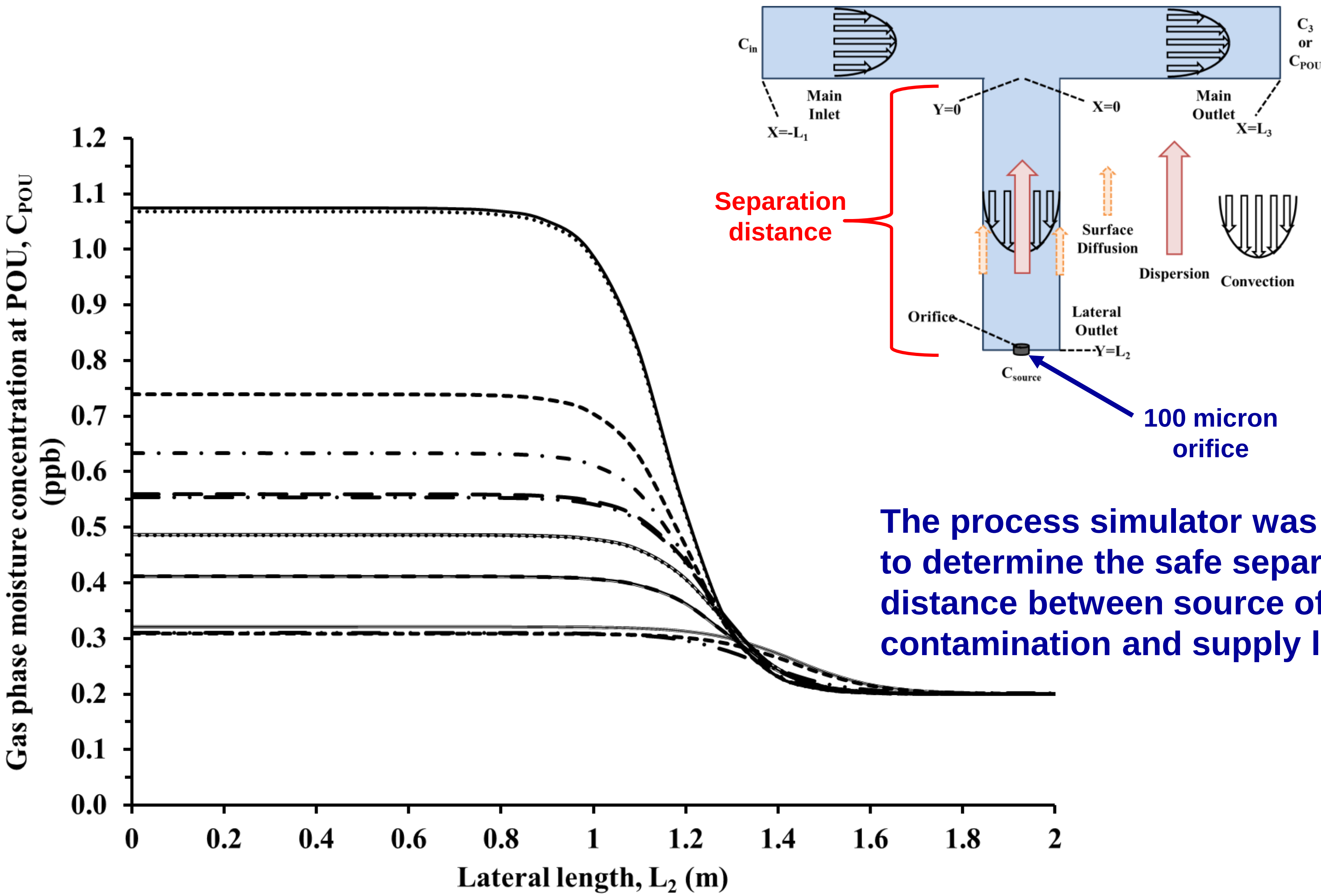
$$\frac{\partial C_s}{\partial t} = \underbrace{\nabla \cdot (D_s \nabla C_s)}_{\text{Diffusion}} + \underbrace{k_a C (S_0 - C_s) - k_d C_s}_{\text{Adsorption and desorption}}$$

Back Diffusion Simulator Verification



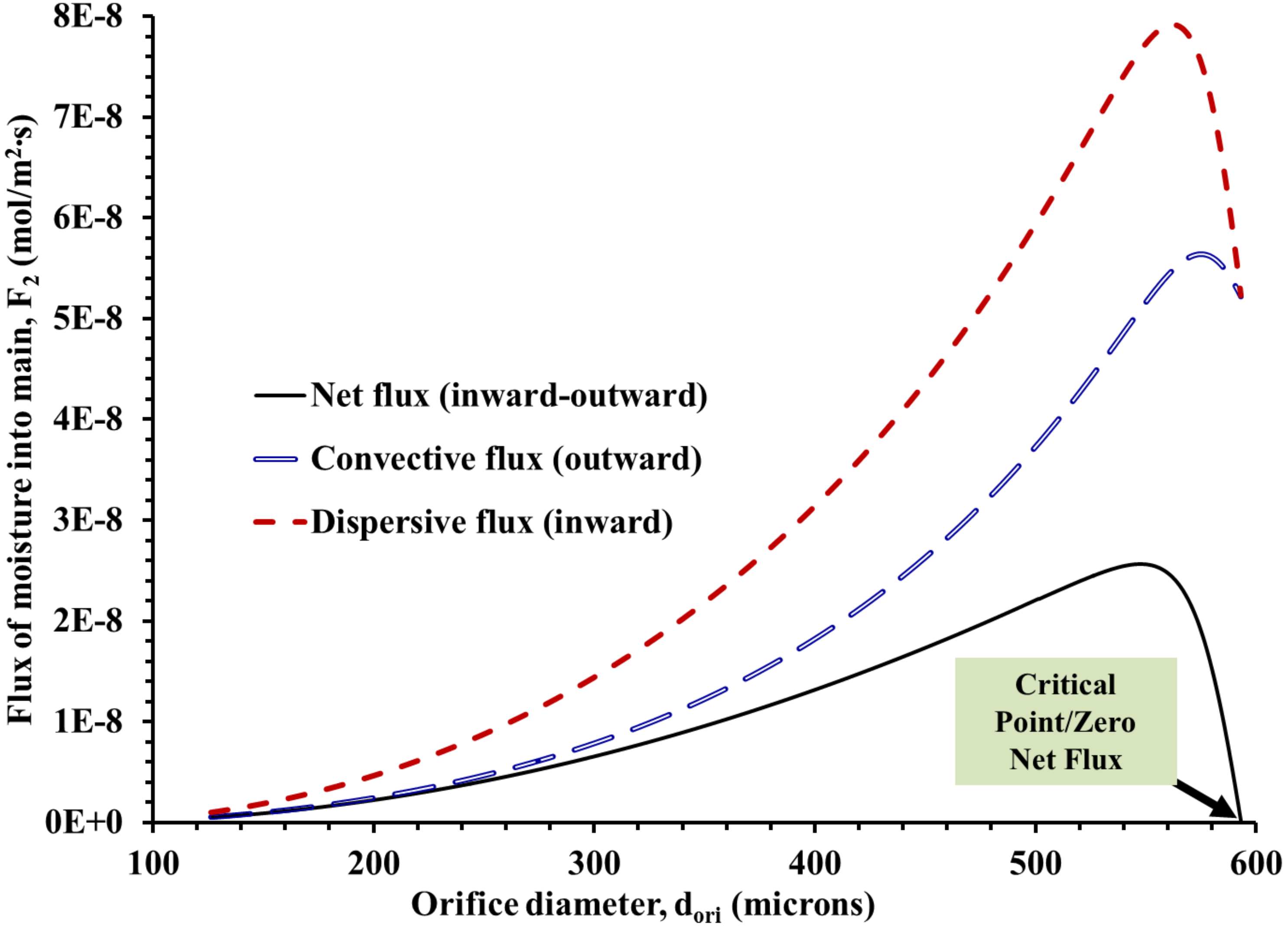


Back Diffusion Simulator Application

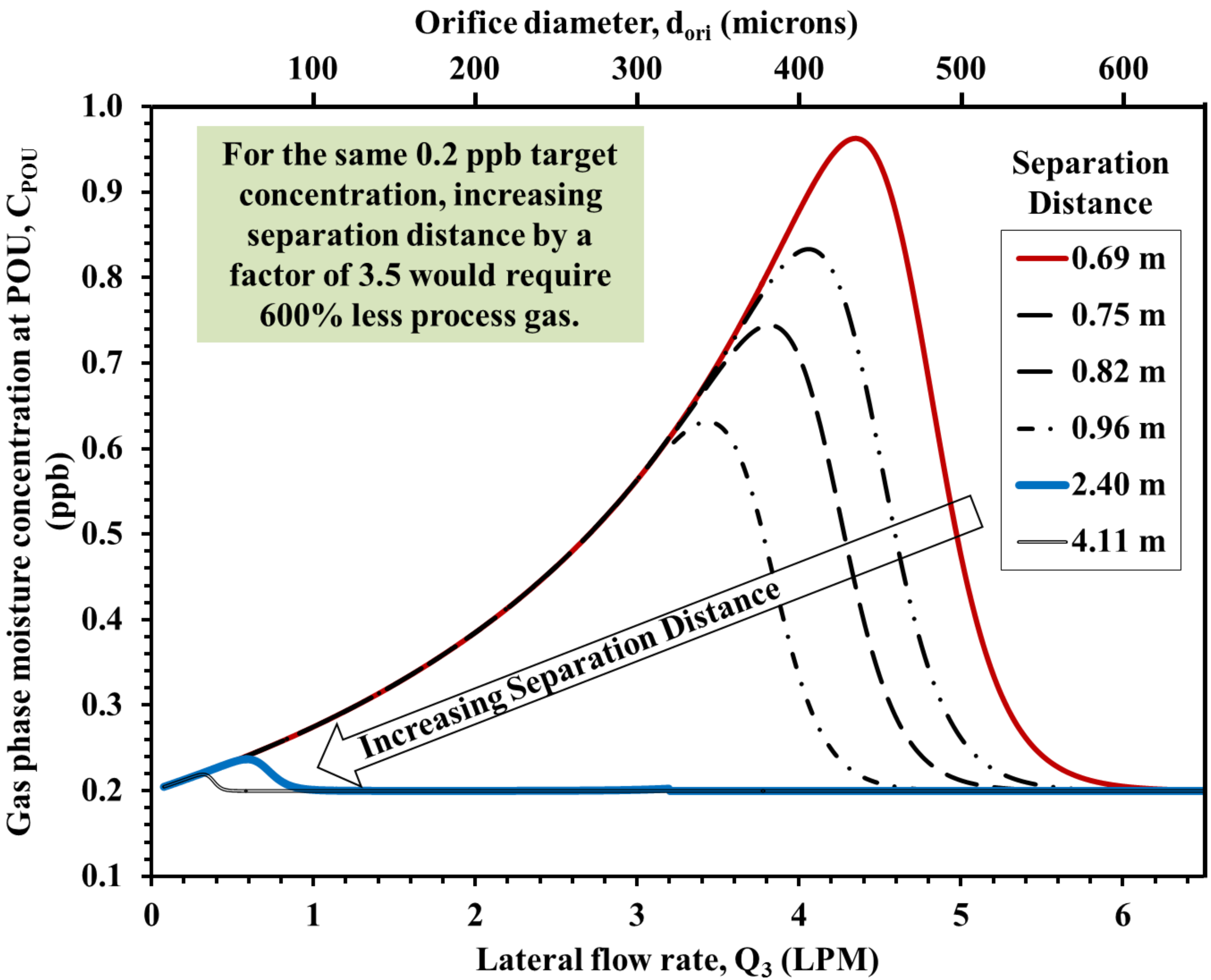


The process simulator was used to determine the safe separation distance between source of contamination and supply line

Back Diffusion: Sample Results

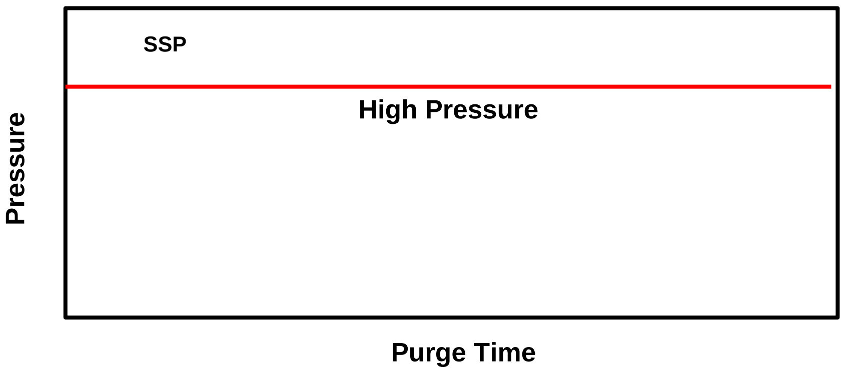


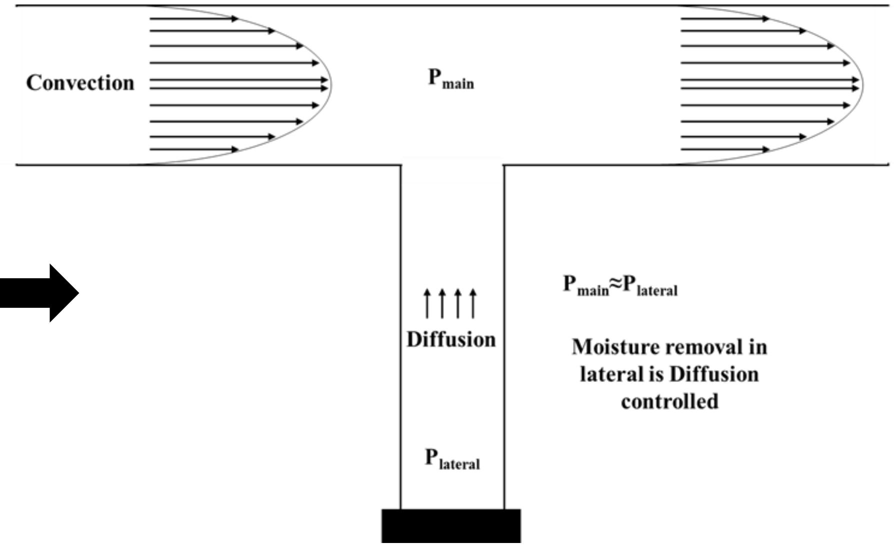
Back Diffusion: Sample Results



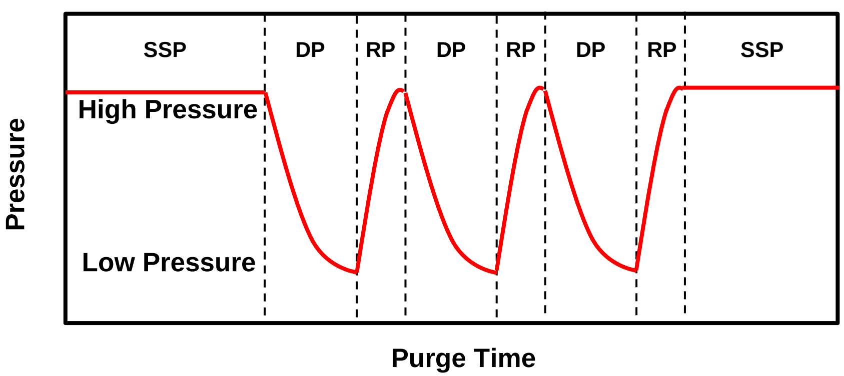
Subtask 2: Novel ESH-Friendly Purge Methods

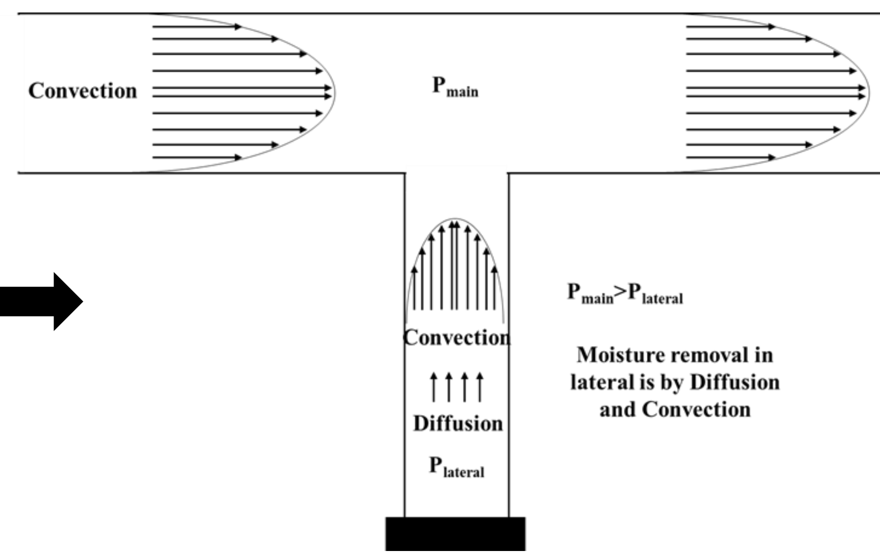
Steady State Purge (SSP)



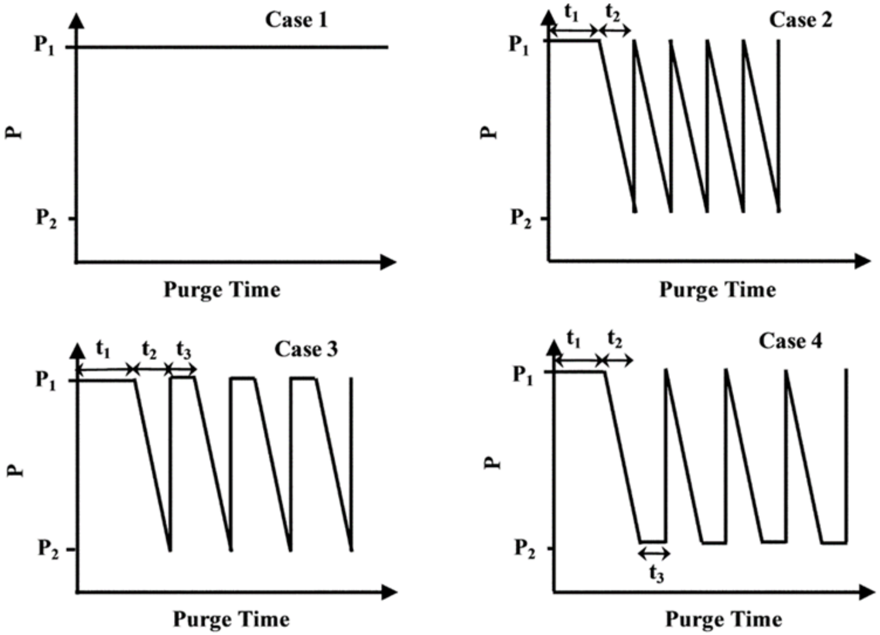


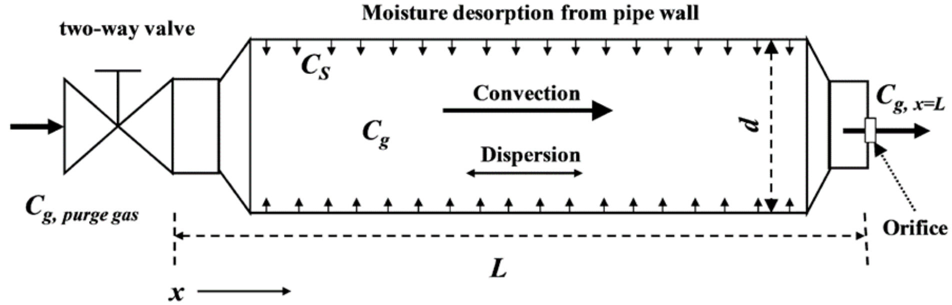
Pressure Cycle Purge (PCP)





PCP Cycle Composition Comparison



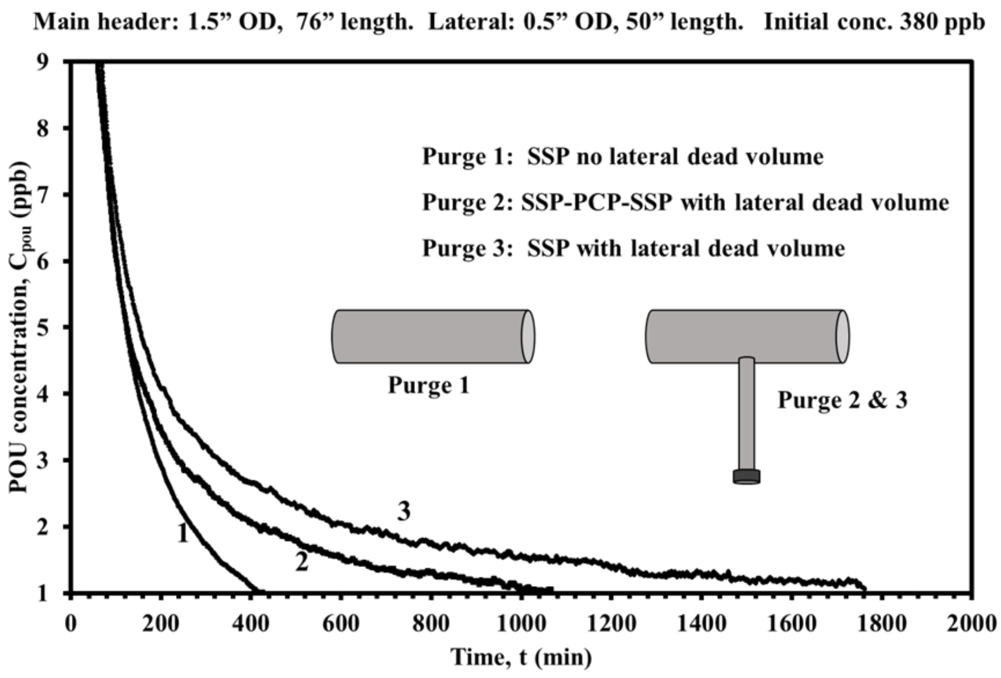


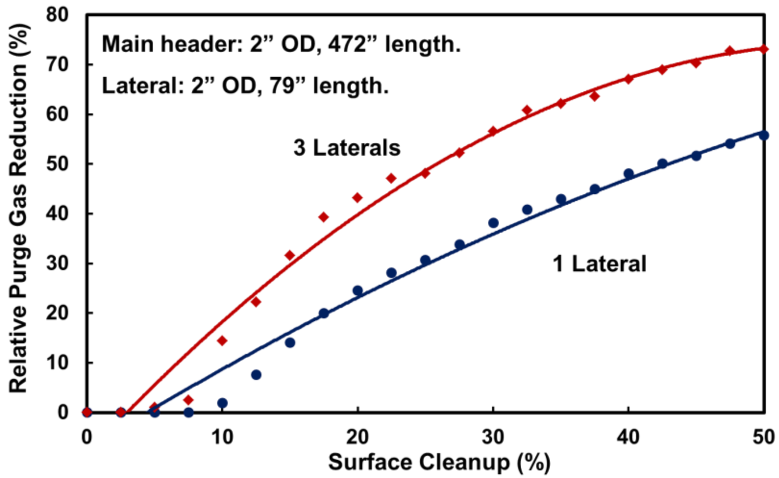
$P_1 = 8.27\times10^5$ Pa (93 psi), $P_2 = 1.93\times10^5$ Pa (28 psi);

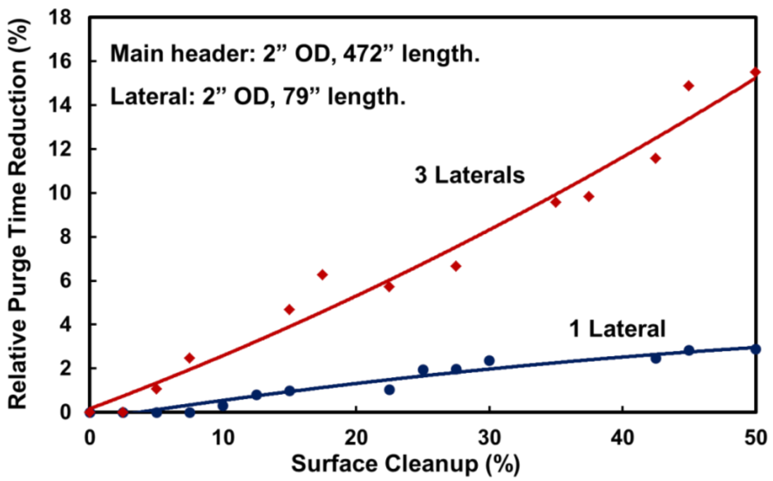
t_1 = 20 minutes, t_2 = 15 minutes, t_3 = 10 minutes

	Purge time (min)	Dry purge gas consumed (sl)
Case 1	200	1835
Case 2	135	655
Case 3	170	1100
Case 4	185	670

PCP Experiment Results and Model Verification







	Purge time (min)	Purge gas usage (sl)
SSP w/o lateral	425	850
SSP w/ lateral	1760	3520
SSP-PCP-SSP w/ lateral	1065	2070

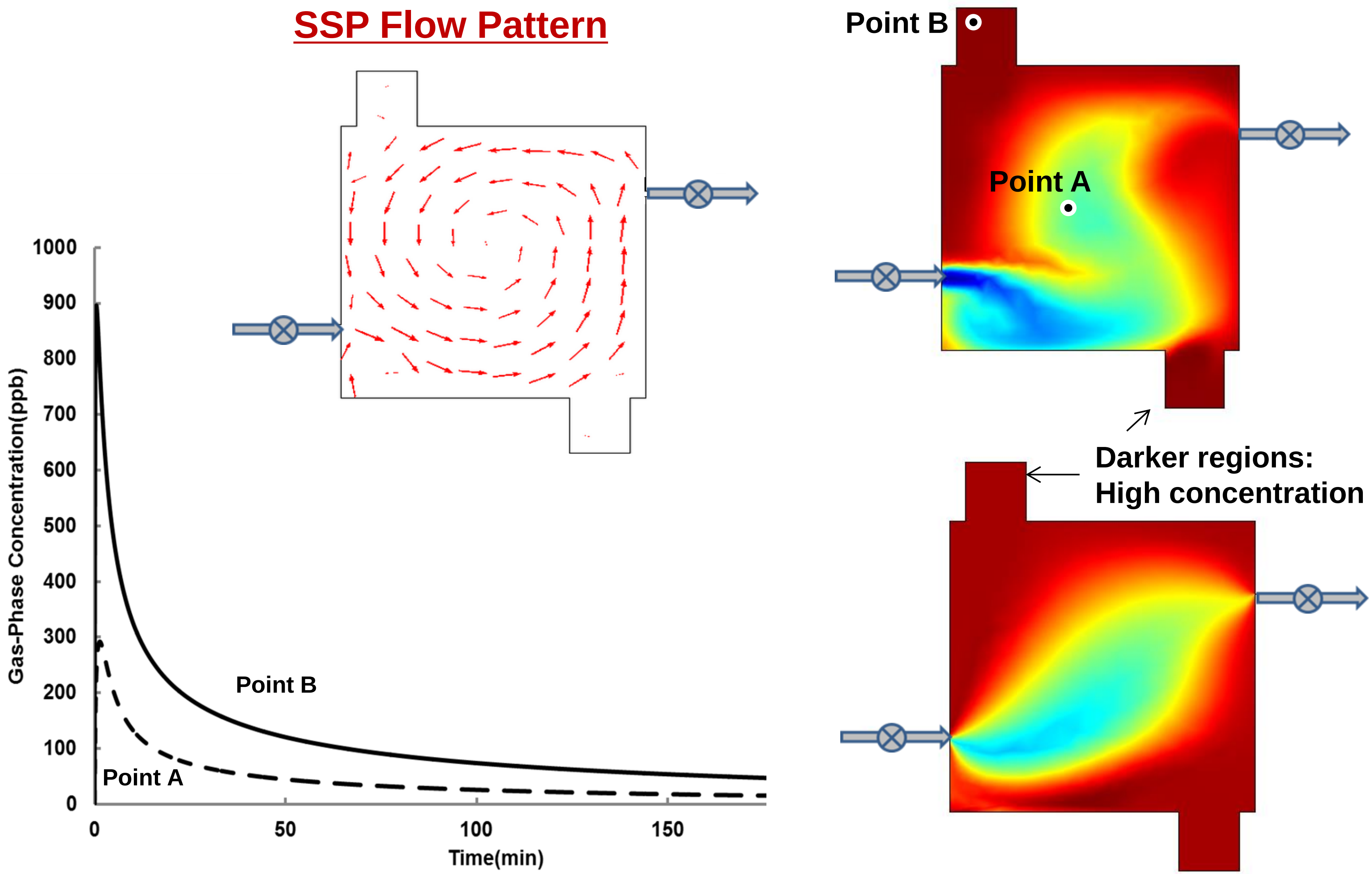
Pressure Cyclic Purge (PCP)

for Purging Tool Chambers

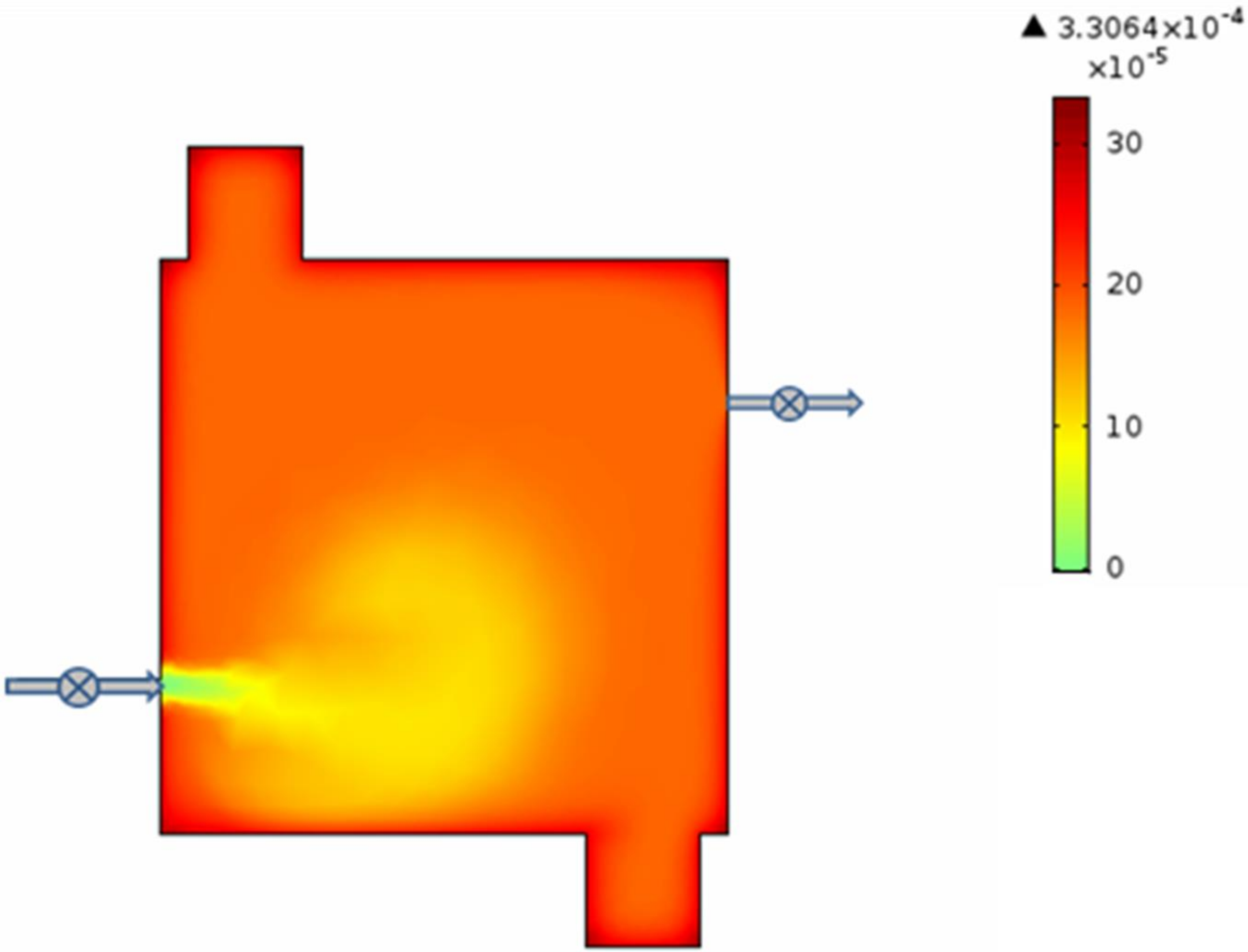
Purging tool chambers (outgassing and removal of adsorbed impurities such as moisture) is a major user of expensive UHP gases and other resources.

Lower Gas Usage + Lower Down Time
Means
ESH Gain + Lower Cost

Conventional Steady State Purge (SSP)



Conventional Steady State Purge (SSP)



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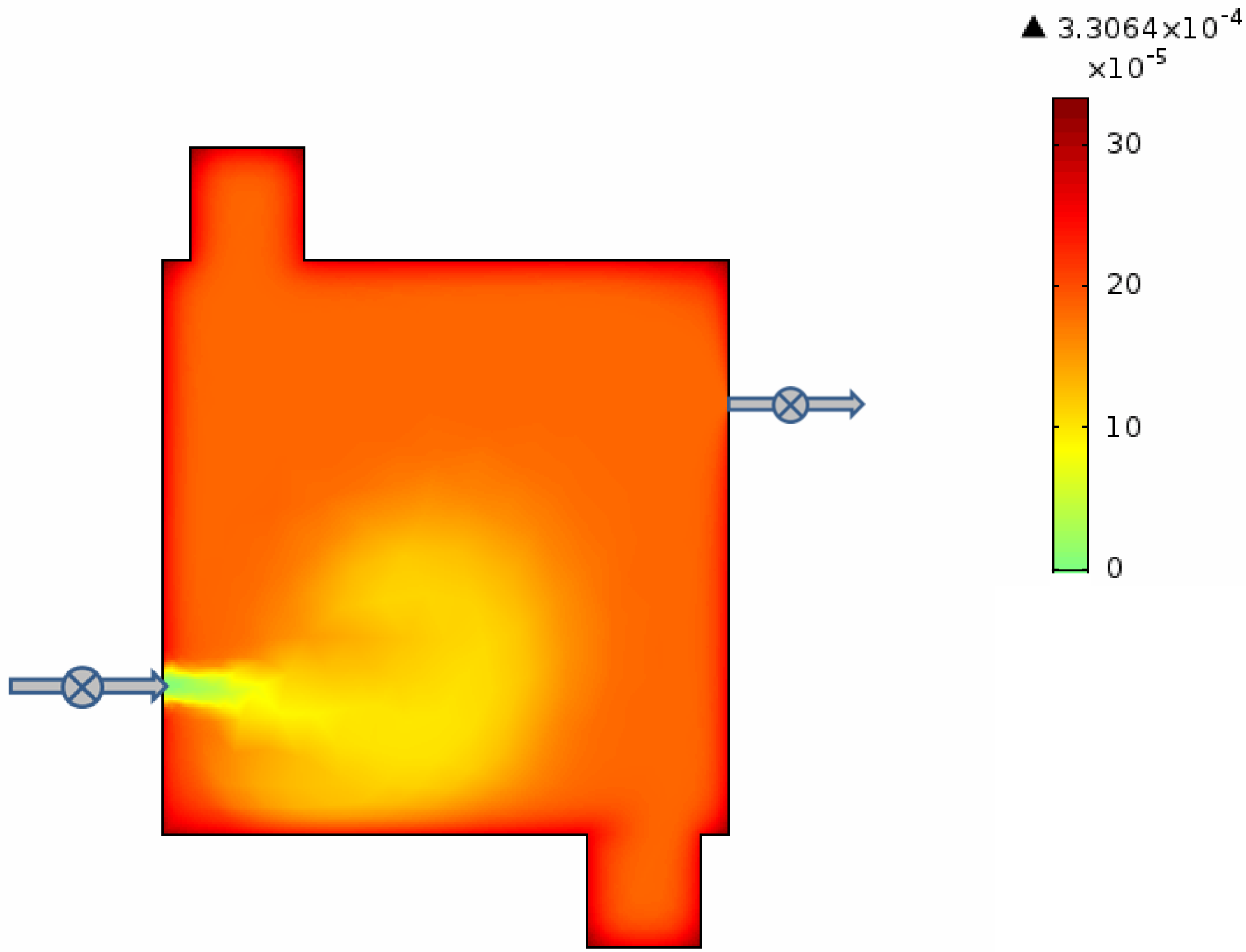
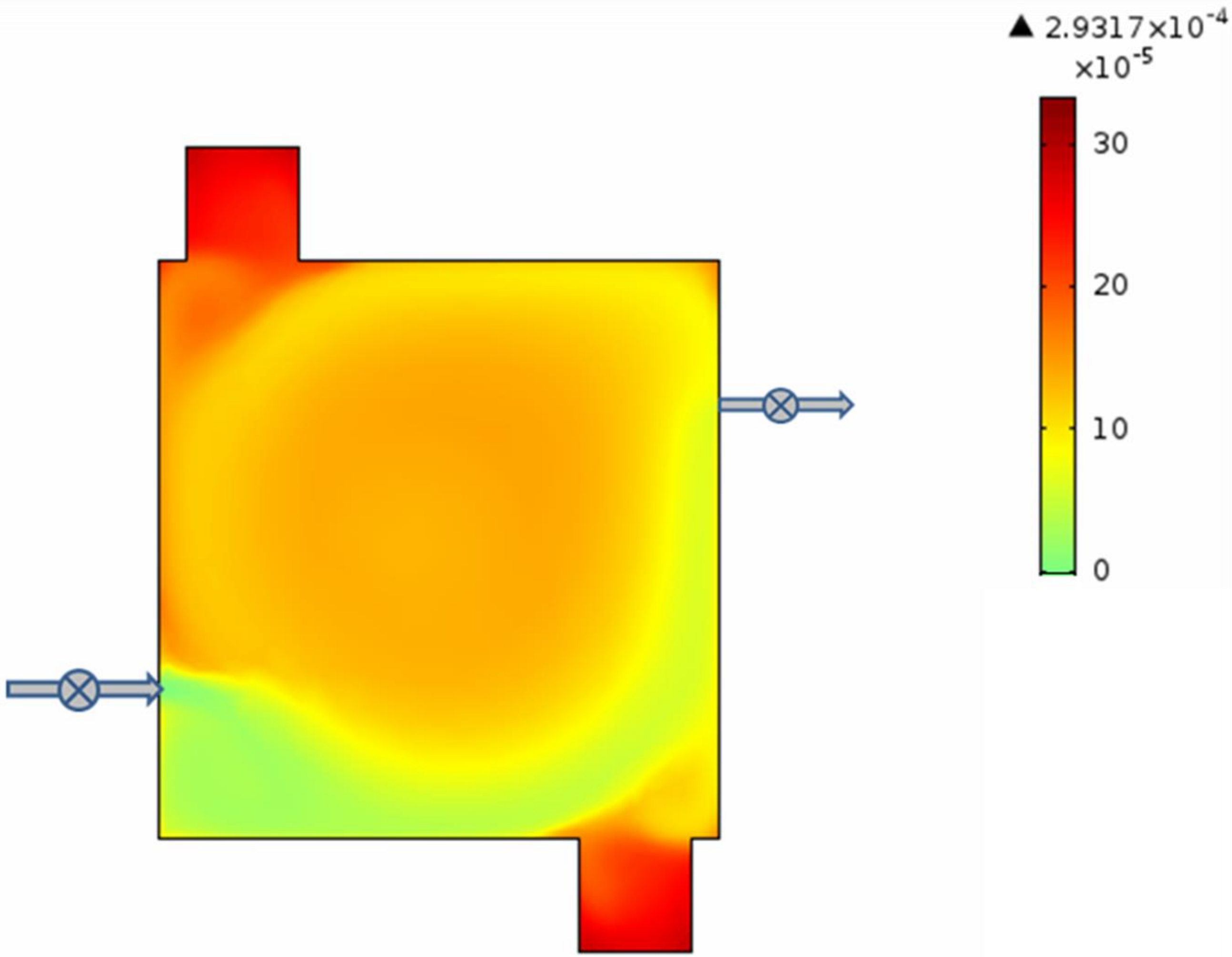
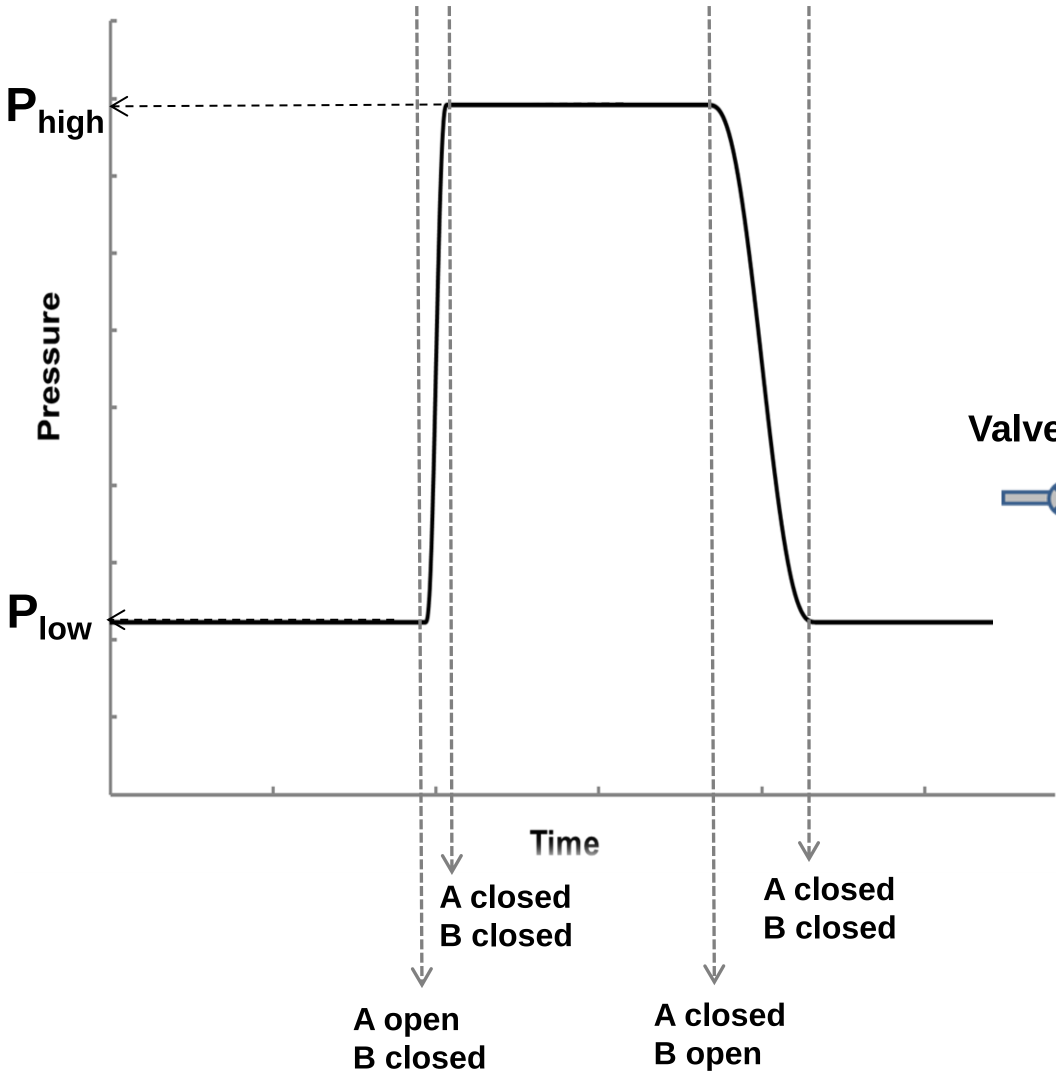
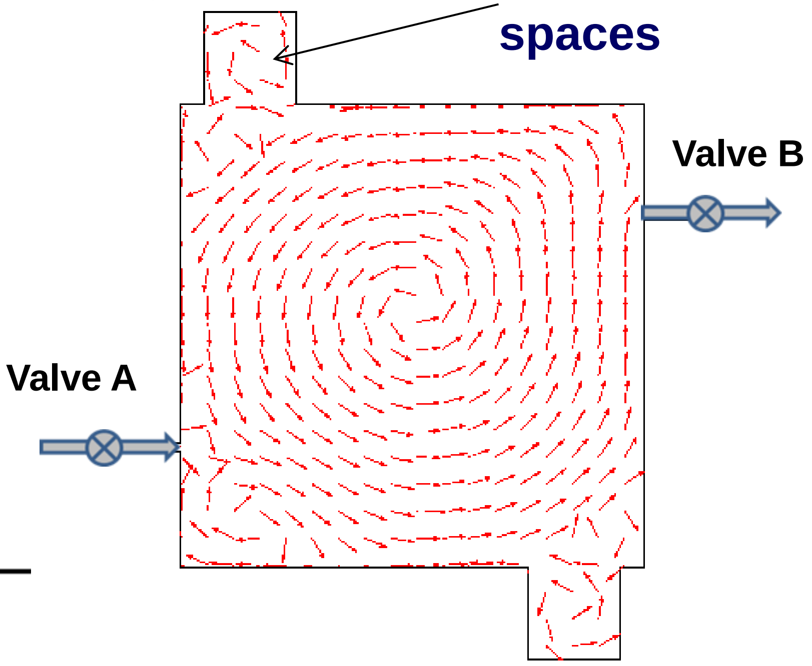


Conventional Steady State Purge (SSP)



Pressure Cyclic Purge (PCP)





Velocity vectors during PCP depressurization

The Comprehensive Chamber Purge Simulator

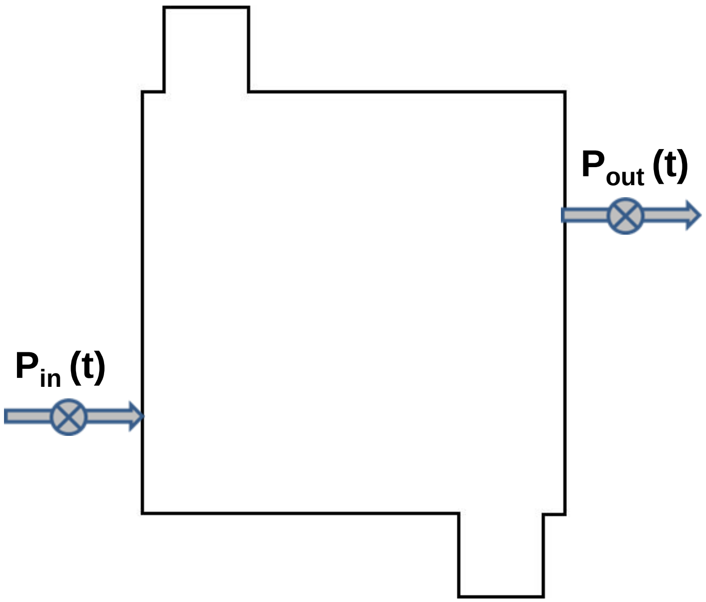
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho V) = 0$$

$$\rho\left(\frac{\partial V}{\partial t} + V \cdot \nabla V\right) = -\nabla P$$

$$\frac{\partial Cs}{\partial t} = R_s$$

$$\frac{\partial C}{\partial t} = -\nabla \cdot (VC) + \nabla \cdot (D\nabla C) + S/V \cdot R_s$$

$$R_s = k_d Cs - k_a C(S_0 - Cs]$$



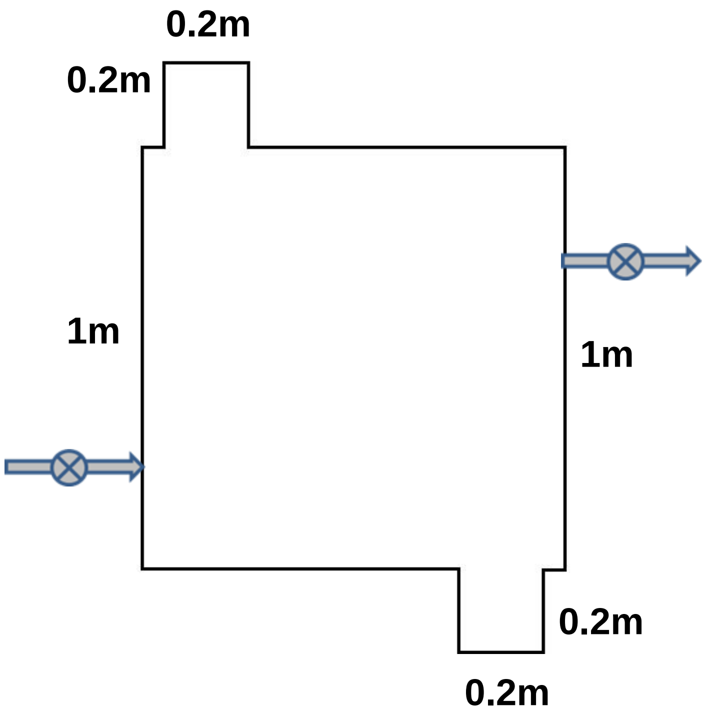
Pressure at inlet and outlet are given functions of time

$$P_{in} = P_{in}(t)$$

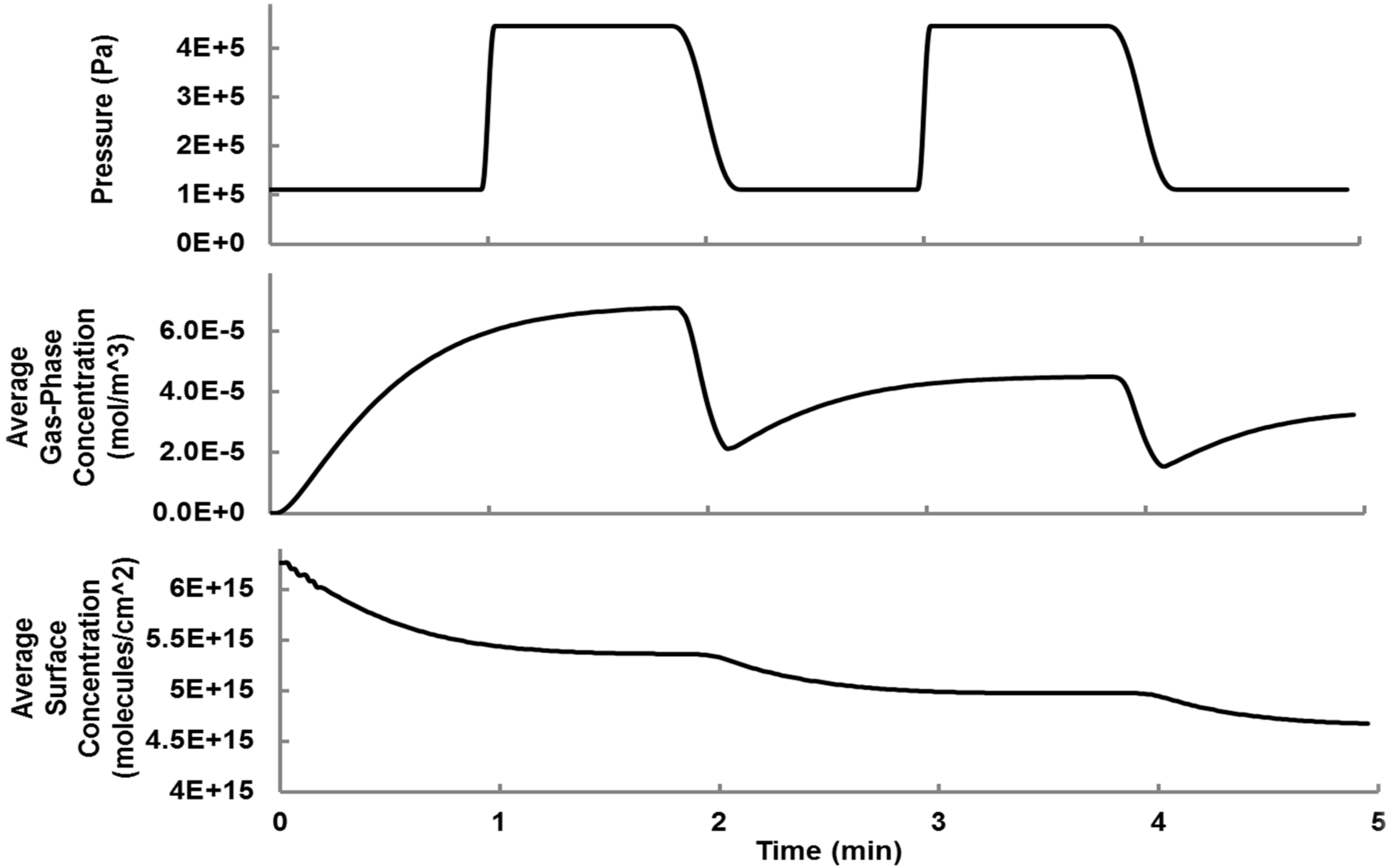
$$P_{out} = P_{out}(t)$$

Example for Application of PCP: Dry-Down of a Tool Chamber

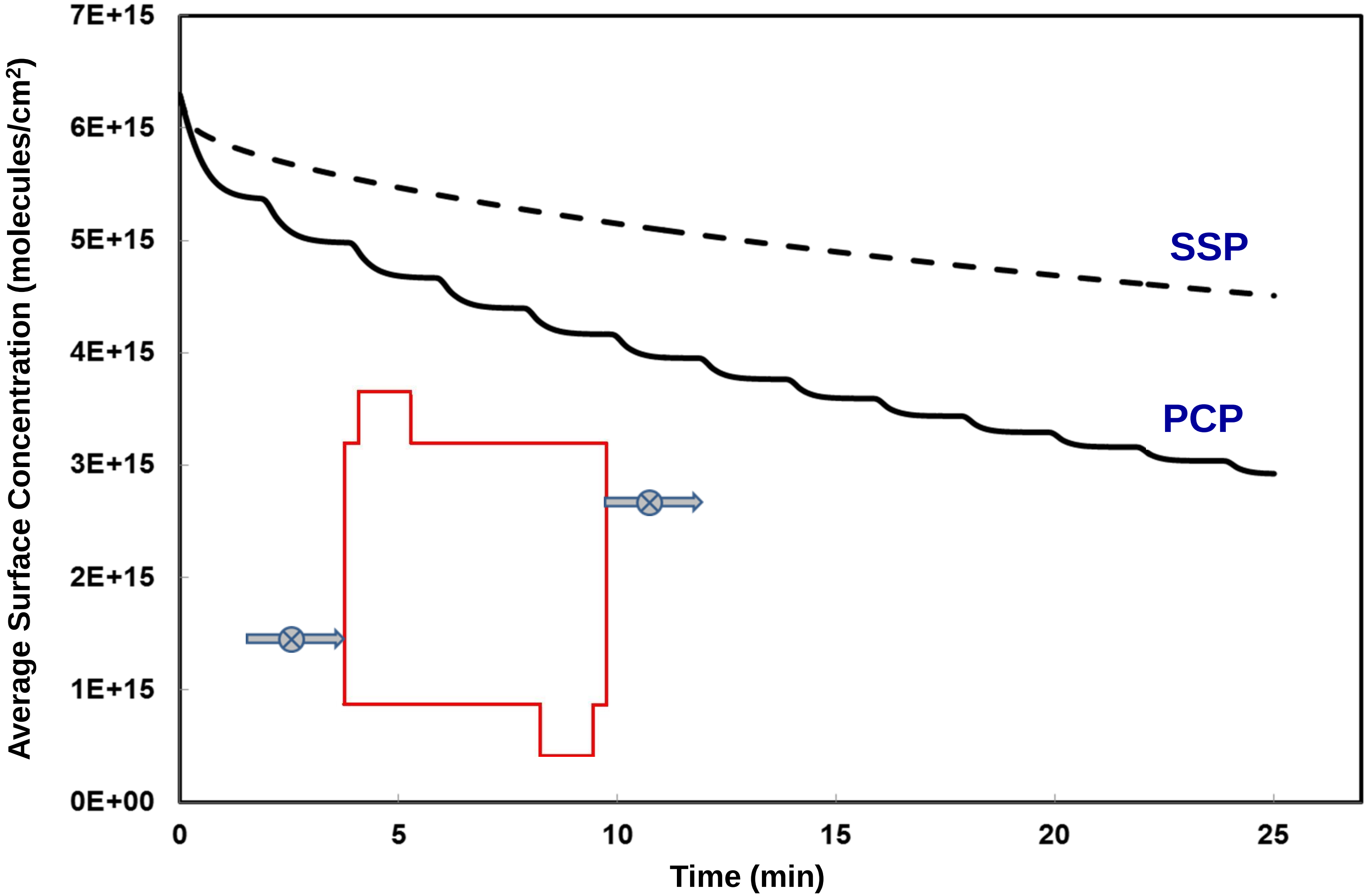
Parameters of EPSS chamber	
Length of chamber	1 m
Width of chamber	1 m
Purge gas concentration	0.2ppb
Initial surface concentration	1.045E-4 mol/m^2
Surface capacity	1.045E-4 mol/m^2
Lower operating pressure	111460 Pa
Higher operating pressure	445830 Pa
Time in low-pressure stage	60 s
Time in high-pressure stage	60 s
Depressurization time	16 s
Adsorption rate constant	335.9 m^3/(mol*s)
Desorption rate constant	4E-3 1/s



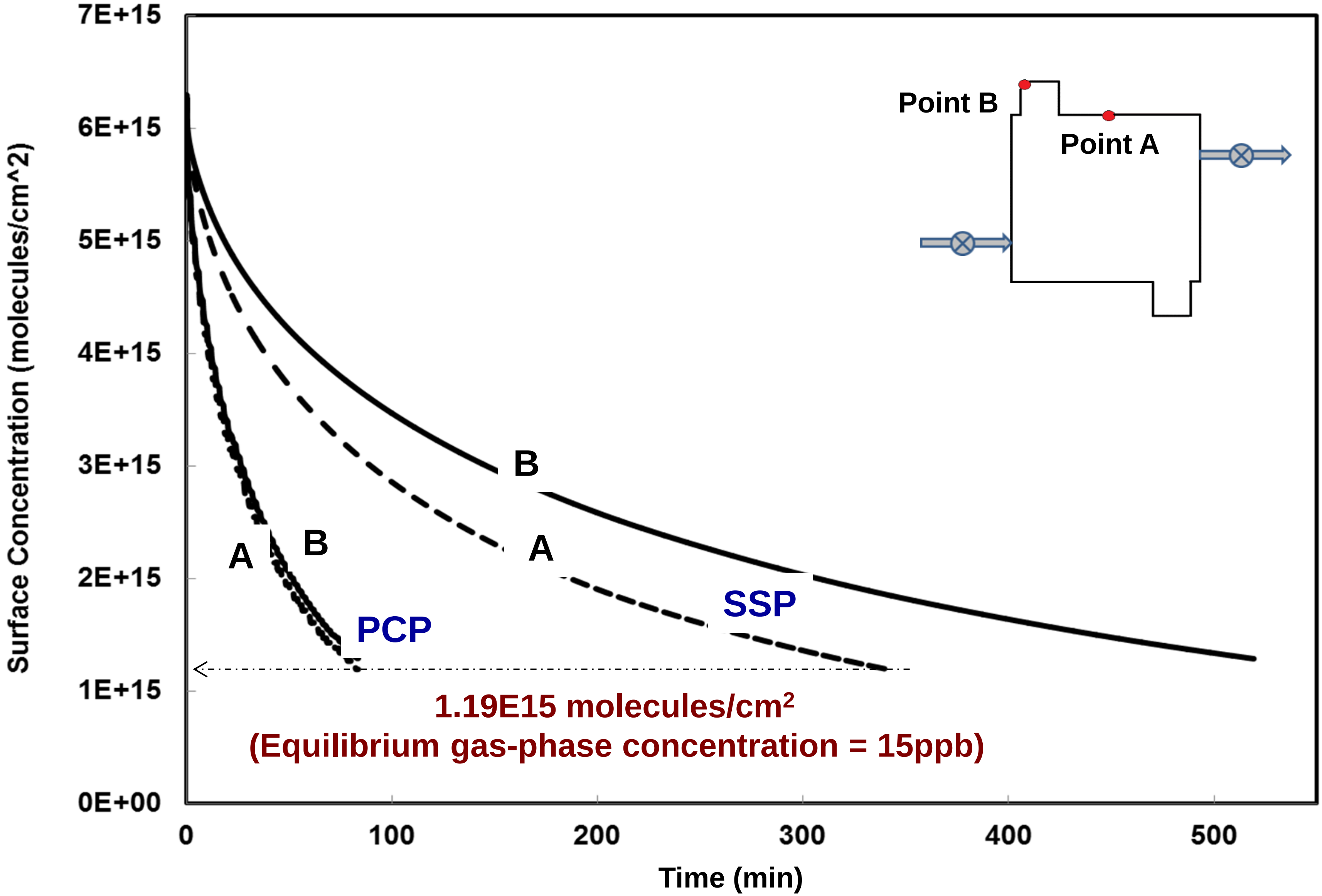
Pressure and Concentration Cycles in PCP



Overall Chamber Cleaning Profiles



Surface Cleaning: PCP vs SSP



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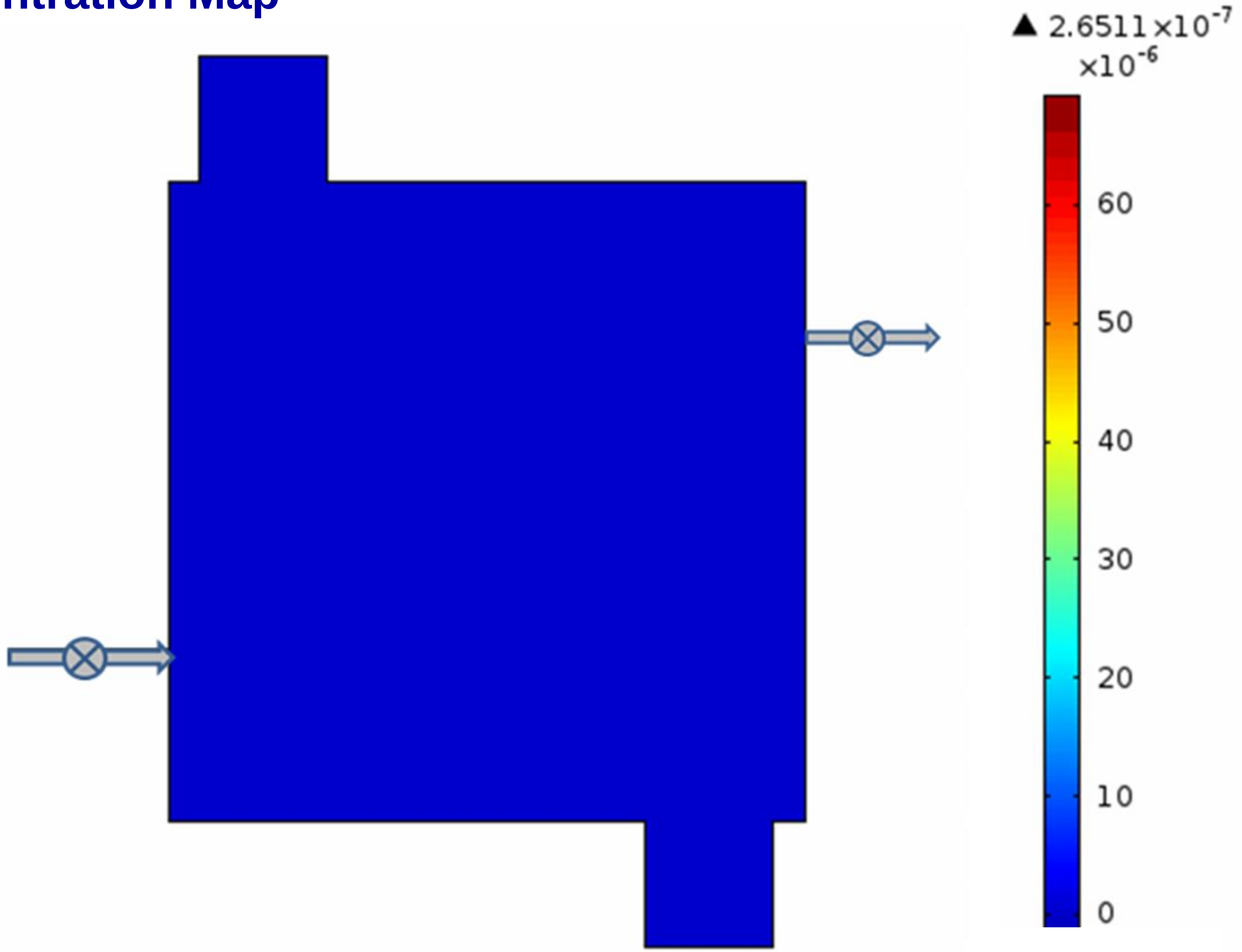
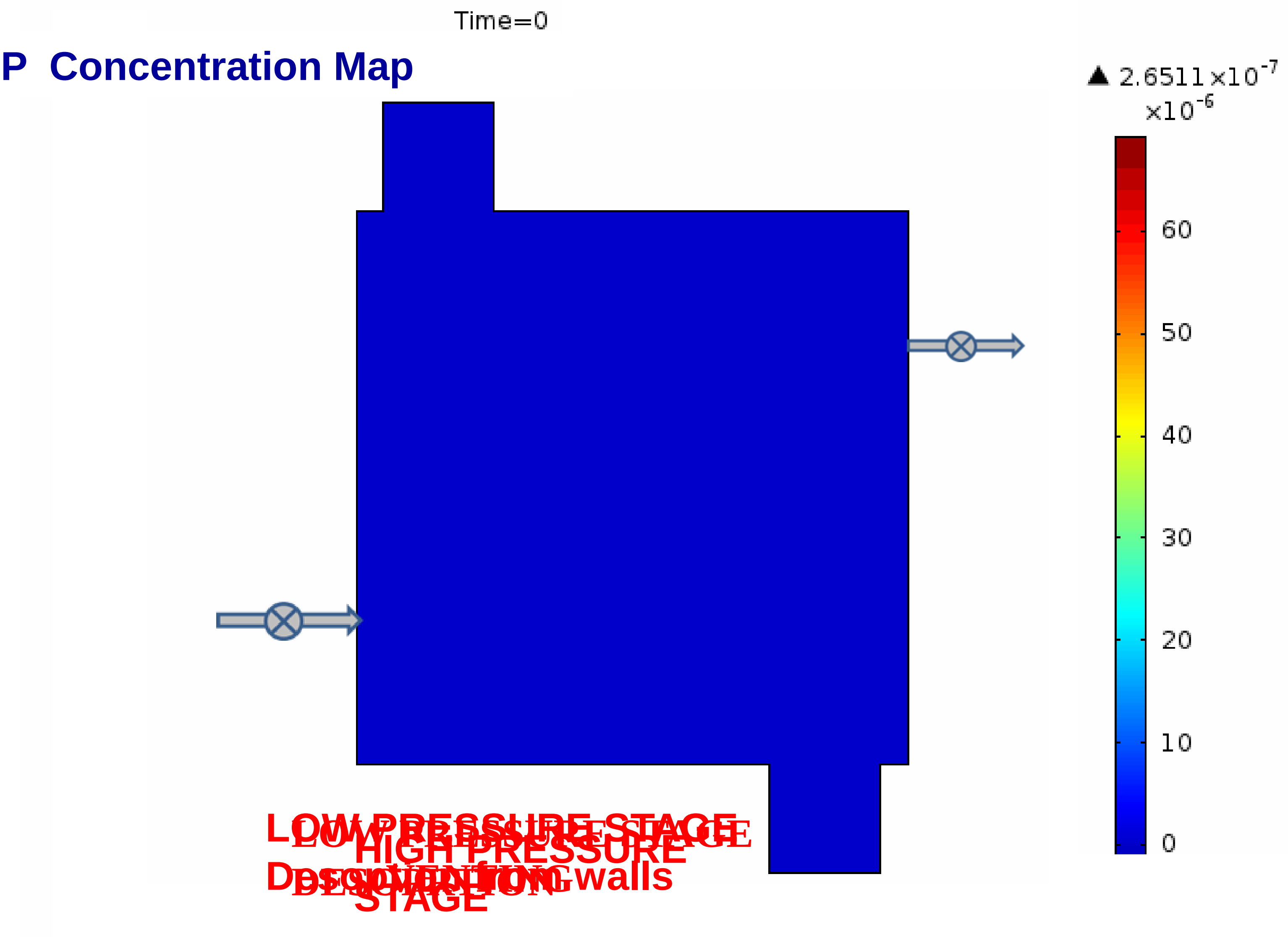
PCP Simulation

PCP Concentration Map



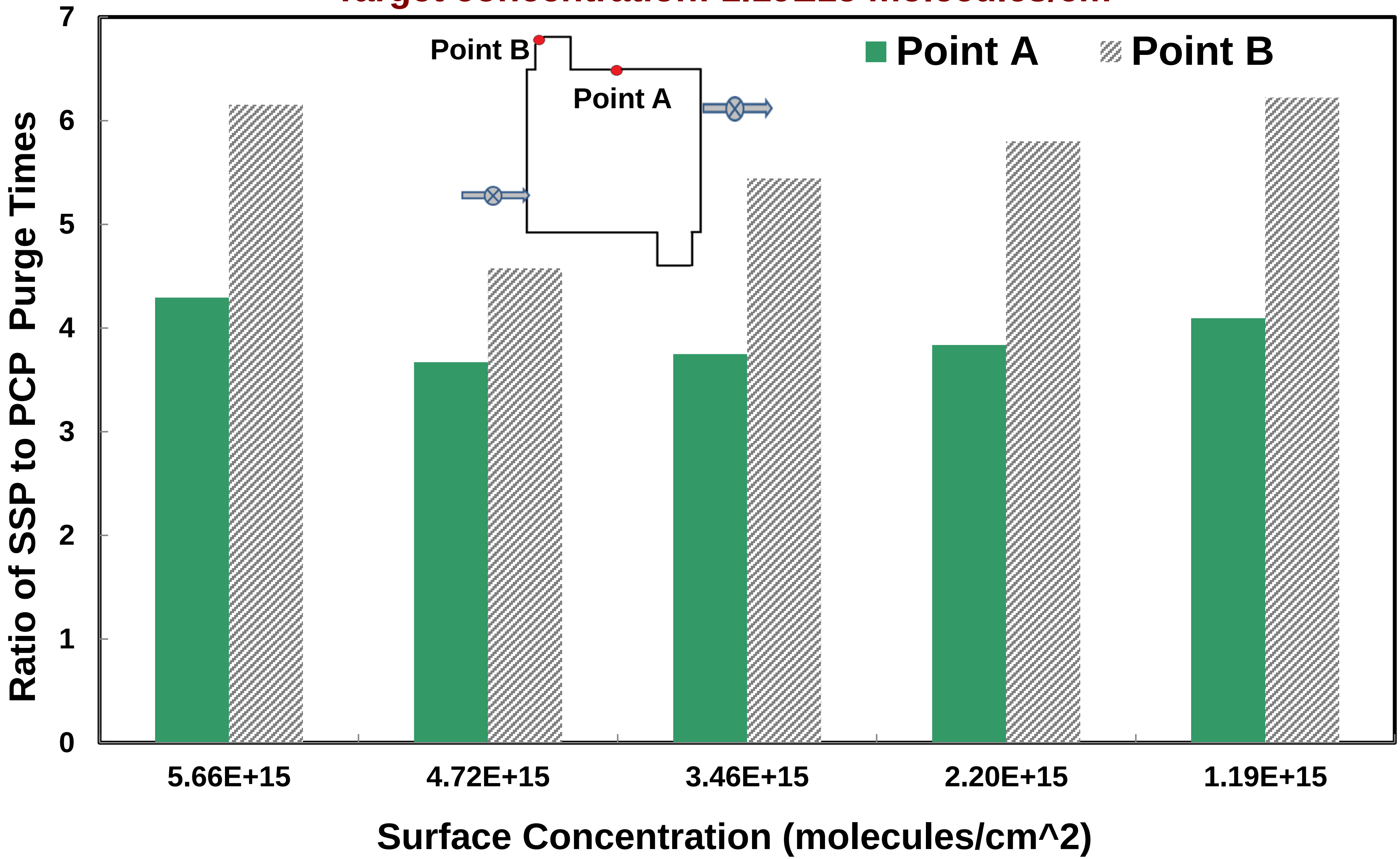
PCP Simulation

PCP Concentration Map



Purge Time Saving by PCP

Target concentration: 1.19E15 molecules/cm^2



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Summary and Conclusions

- A combination of experiments and process modeling was used to study the mechanism of impurity back diffusion in UHP systems.
- Back diffusion of contaminants can be minimized (and even eliminated in most cases) by proper choice of flow rate and spacing parts and vent opening.
- Pressure Cyclic Purge (PCP) process showed significant advantage over Steady State Purge (SSP) for gas distribution systems.
- A new form of PCP was developed for purging of tool chambers.
- PCP in chamber cleaning introduces beneficial convective flow in regions that do not see flow during conventional SSP purge.
- Typical case studies show up to 80% reduction in gas usage and required purge time.
- The process simulator can be used both for both new design and purging of a new gas distribution networks as well as for the efficient operation and dry-down of an existing systems.
- User-friendly simulators are now available for tech transfer.

Industrial Interactions

- **Continue joint work with Intel; some technology transfer and implementation of results at Intel fabs have already taken place.**
- **Process simulator was requested by and sent to AMAT**
- **Comprehensive version of both simulators (distribution systems and tool chambers) will be available by Fall 2014**

Publications and Presentations

- **Roy Dittler, Jivaan Jhothiraman, Carl Geisert, Farhang Shadman. "Contamination of Ultra-High-Purity (UHP) Gas Distribution Systems by Back Diffusion of Impurities." *Journal of the IEST* under review 2014.**

- **Hao Wang, H. and Shadman, F. "Effect of Particle Size on the Adsorption and Desorption Properties of Oxide Nanoparticles" *AIChE Journal 59(5), 1502 (2013).***

Acknowledgements

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