Hydrogen ventilation in a geological disposal facility

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Introduction

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- Nuclear energy provides one fifth of the UK's electricity.
- 60 year old technology
- Legacy poses one of the biggest engineering challenges.
- How should we safely store the intermediate level waste in the long-term?
- The UK's first Geological Disposal Facility will provide a vault deep underground where the waste can safely decay.

The problem

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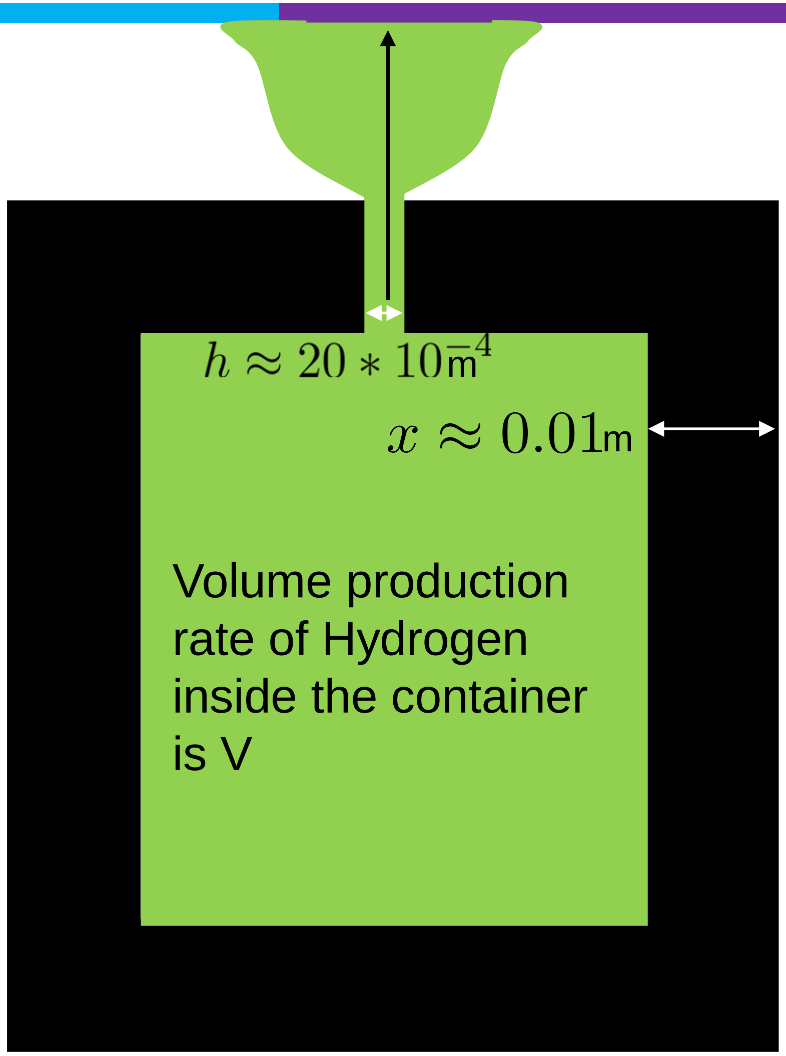
- Hydrogen in air is combustible from 4%-75% and explosive from 18%-59%.

The proposed approach to studying the accumulation of hydrogen gas will involve:

- A study into slow leakage flows.
- Estimating vault circulations and concentrations.
- Studying the risks of mechanical ventilation failure.

Scoping and scaling

$l \approx 20 * 10^{-4}$ m	Orifice size
$V_c \approx 8$ m^3	Volume of container
$T \approx 303$ k	Temperature
$\alpha \approx 135$	Thermal diffusivity
$R \approx 8.3$ m^2/s	Gas constant
$\mu \approx 10^{-3}$ kg/ms	Dynamic Viscosity
$g \approx 10$ ms^-2	Gravitational Constant



$\rho_H \approx 0.09$ kgm^-3 $\rho_{air} \approx 1.29$ kgm^-3

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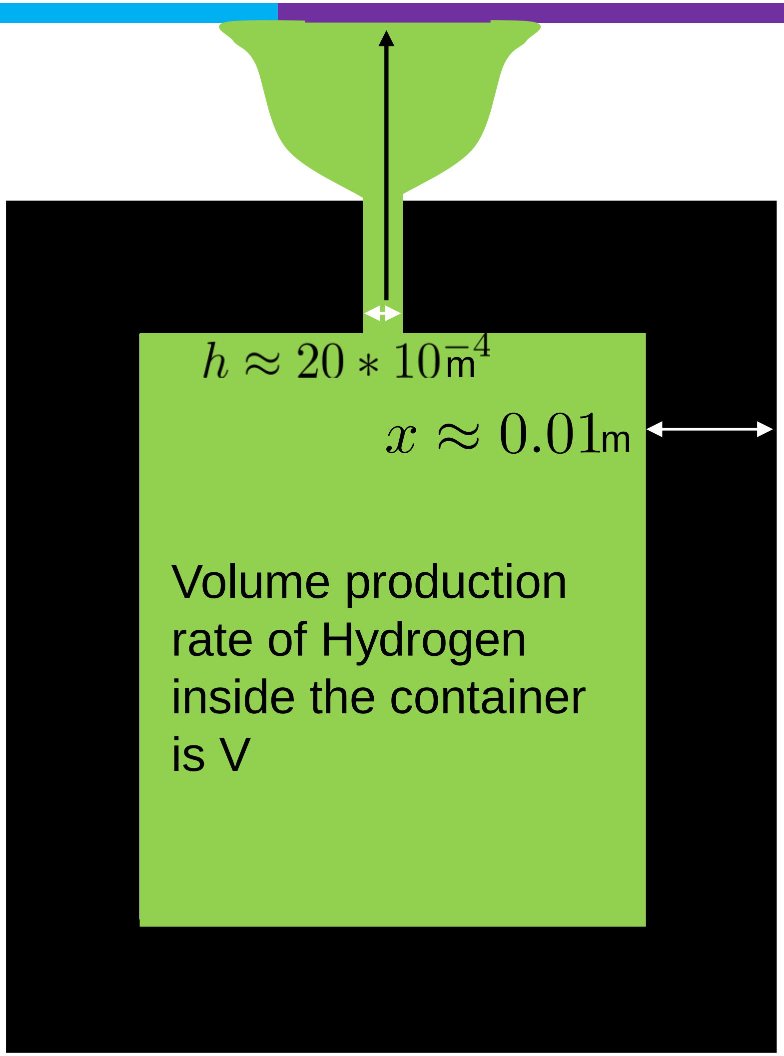
Scoping and scaling

- Using the ideal gas equation

$$P = \frac{\rho V t R T}{V_c} \approx 28 \text{ Pa}$$

- Approximate the flow through the vent to be a Poiseuille flow

$$u \approx \frac{-1}{2\mu}\frac{dP}{dx} y(h-y) \approx 1.4 \text{ m/s}$$



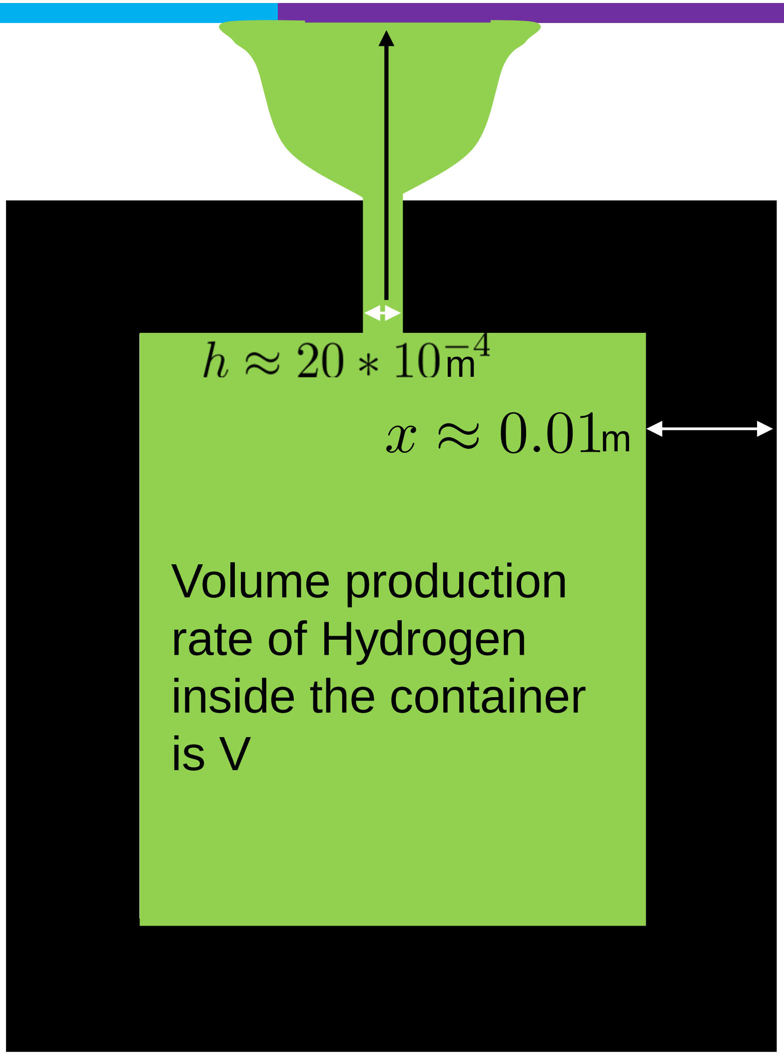
Scoping and scaling

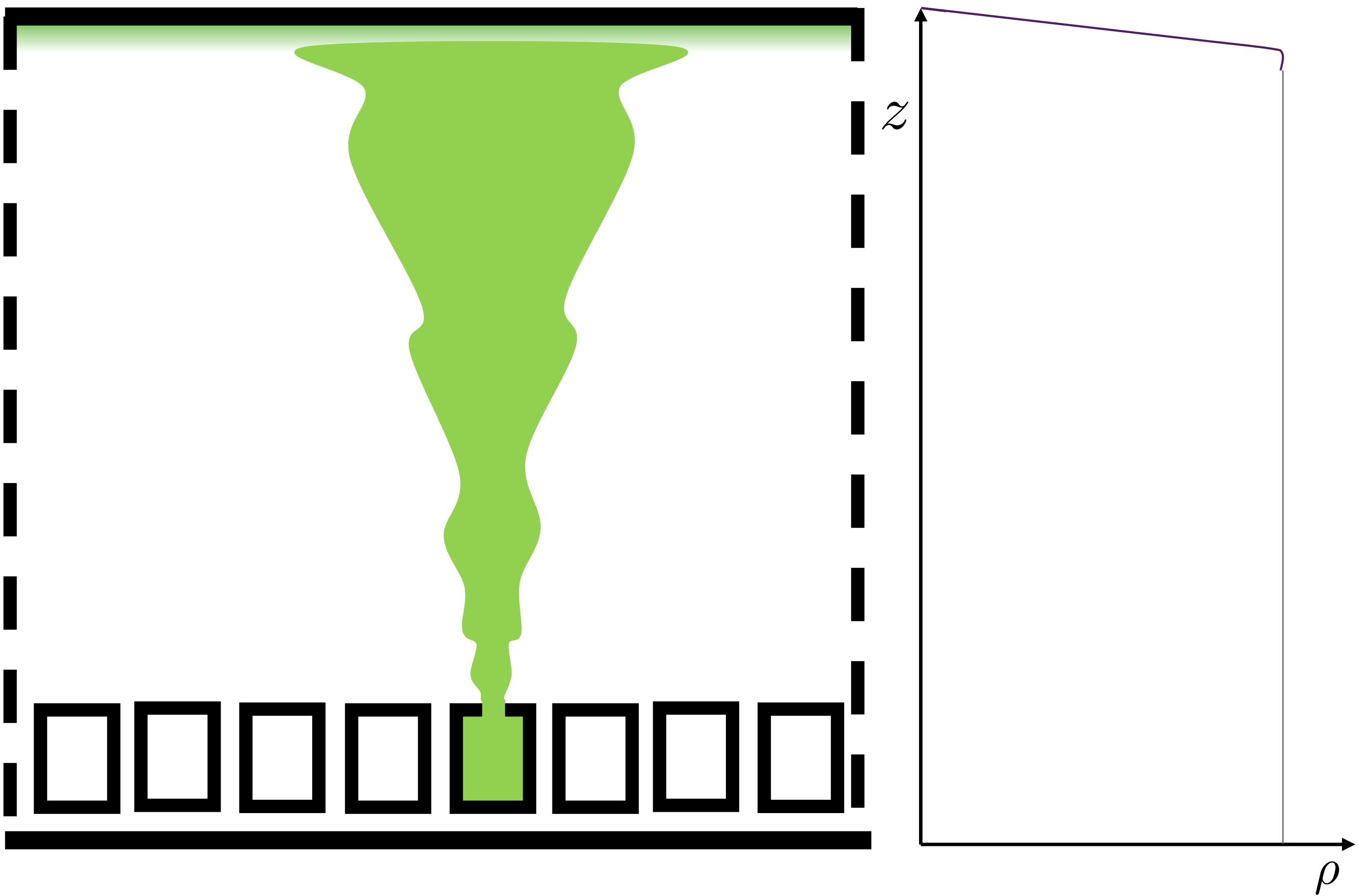
- Rayleigh Number

$$Ra = \frac{\Delta \rho l^3 g}{\mu \alpha} \approx 7.11 * 10^{-7}$$

- Reynolds number

$$Re = \frac{u l \rho}{\mu} \approx 0.25$$

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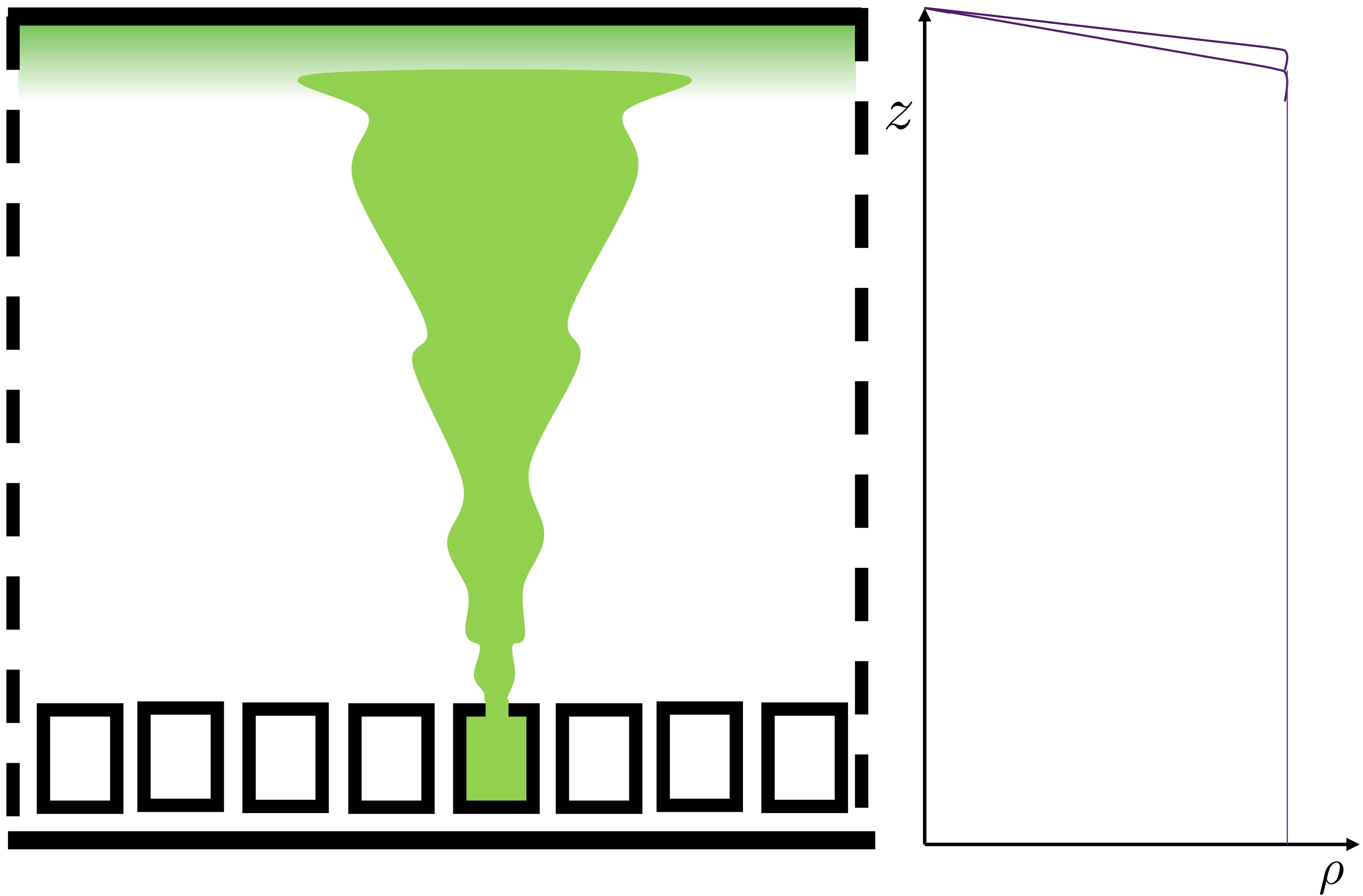
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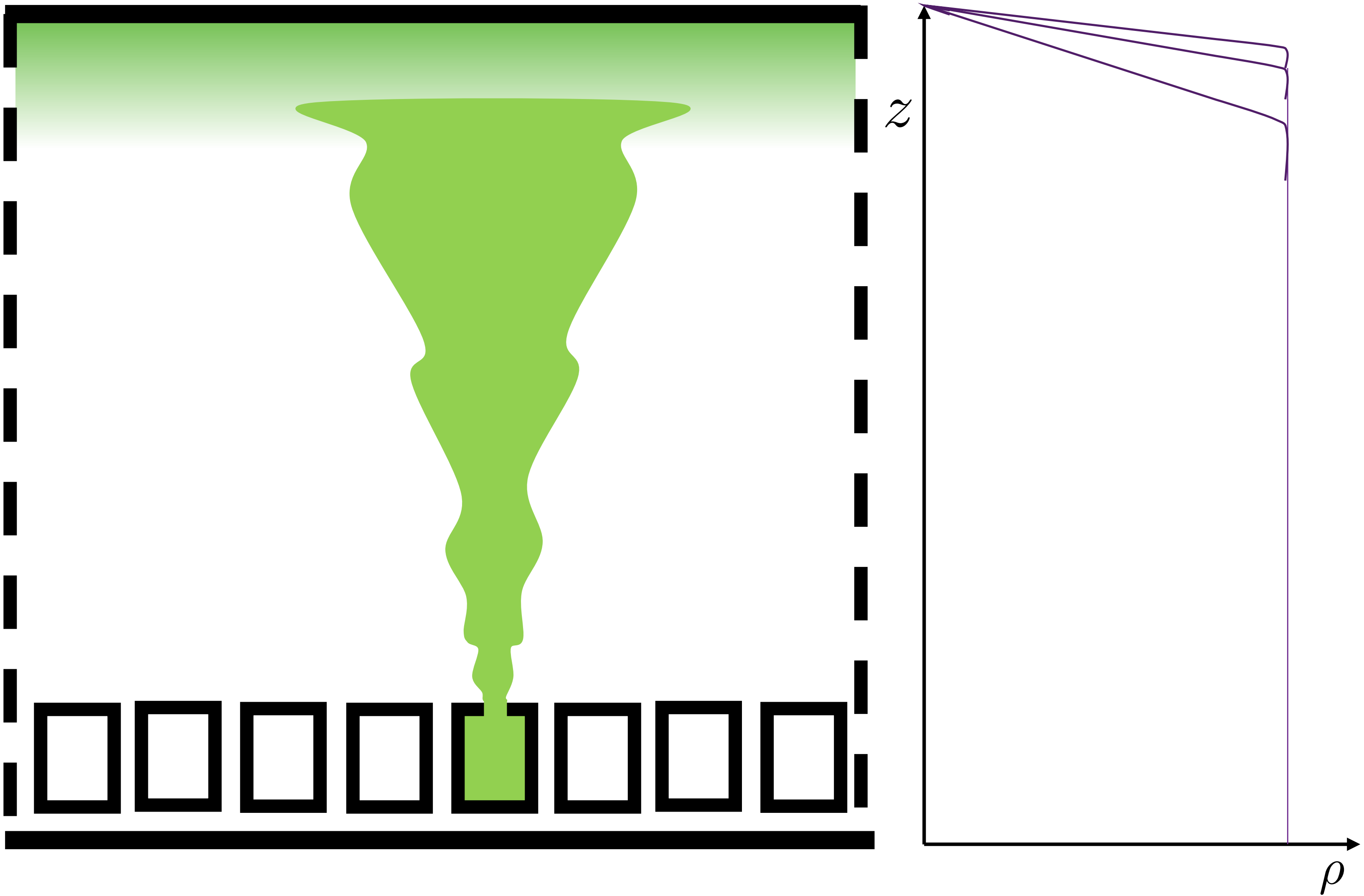

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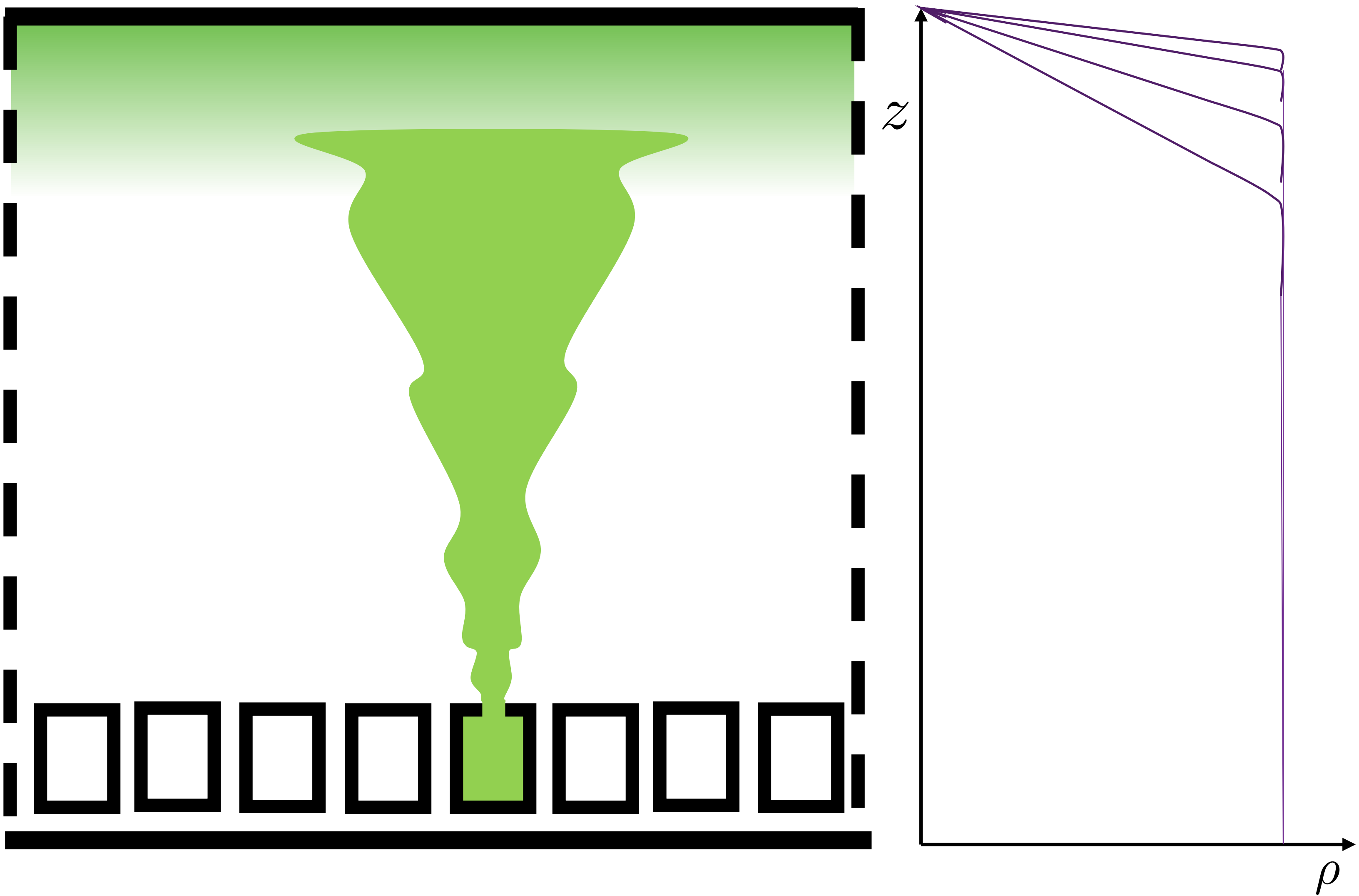
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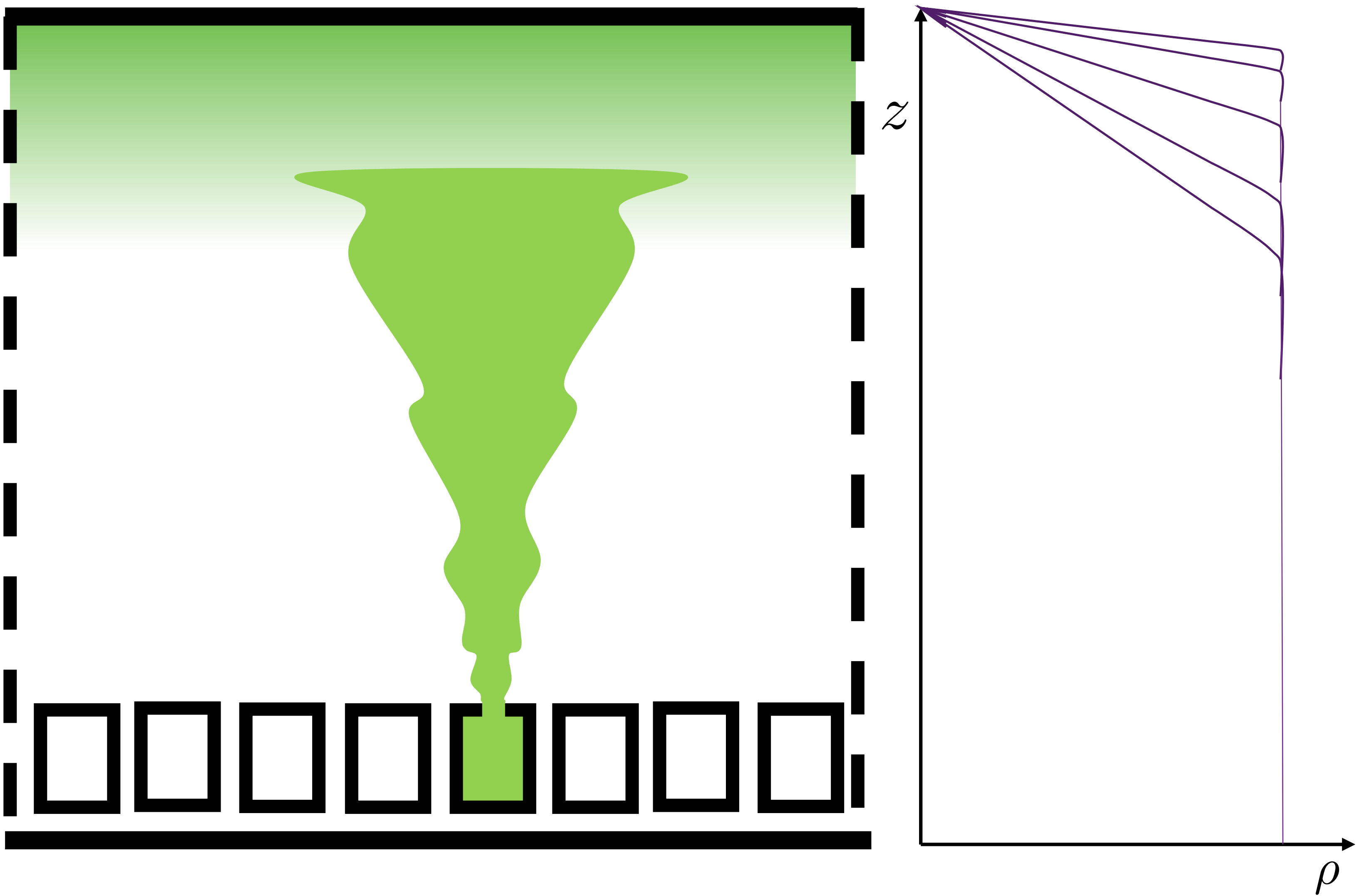

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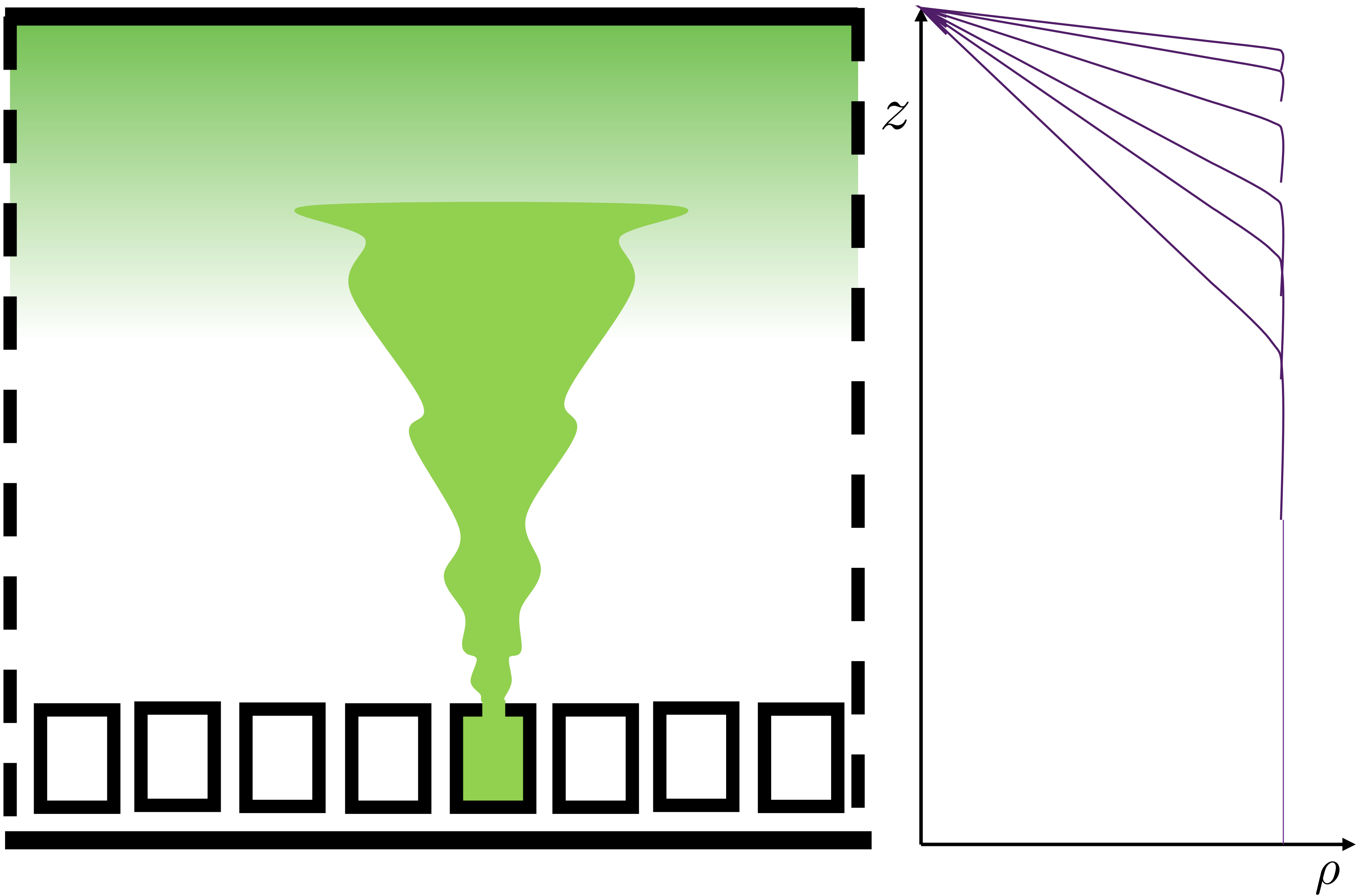
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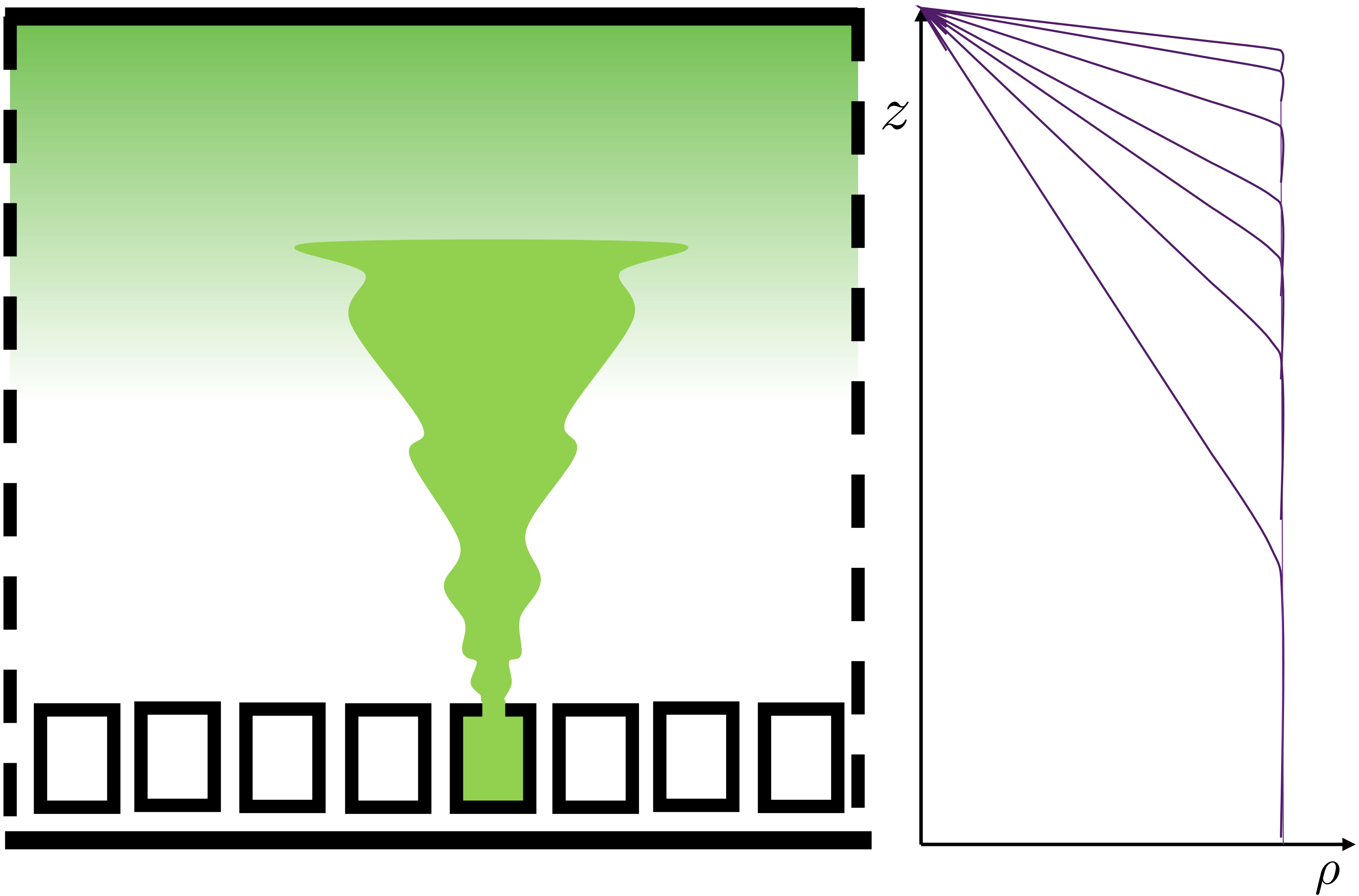

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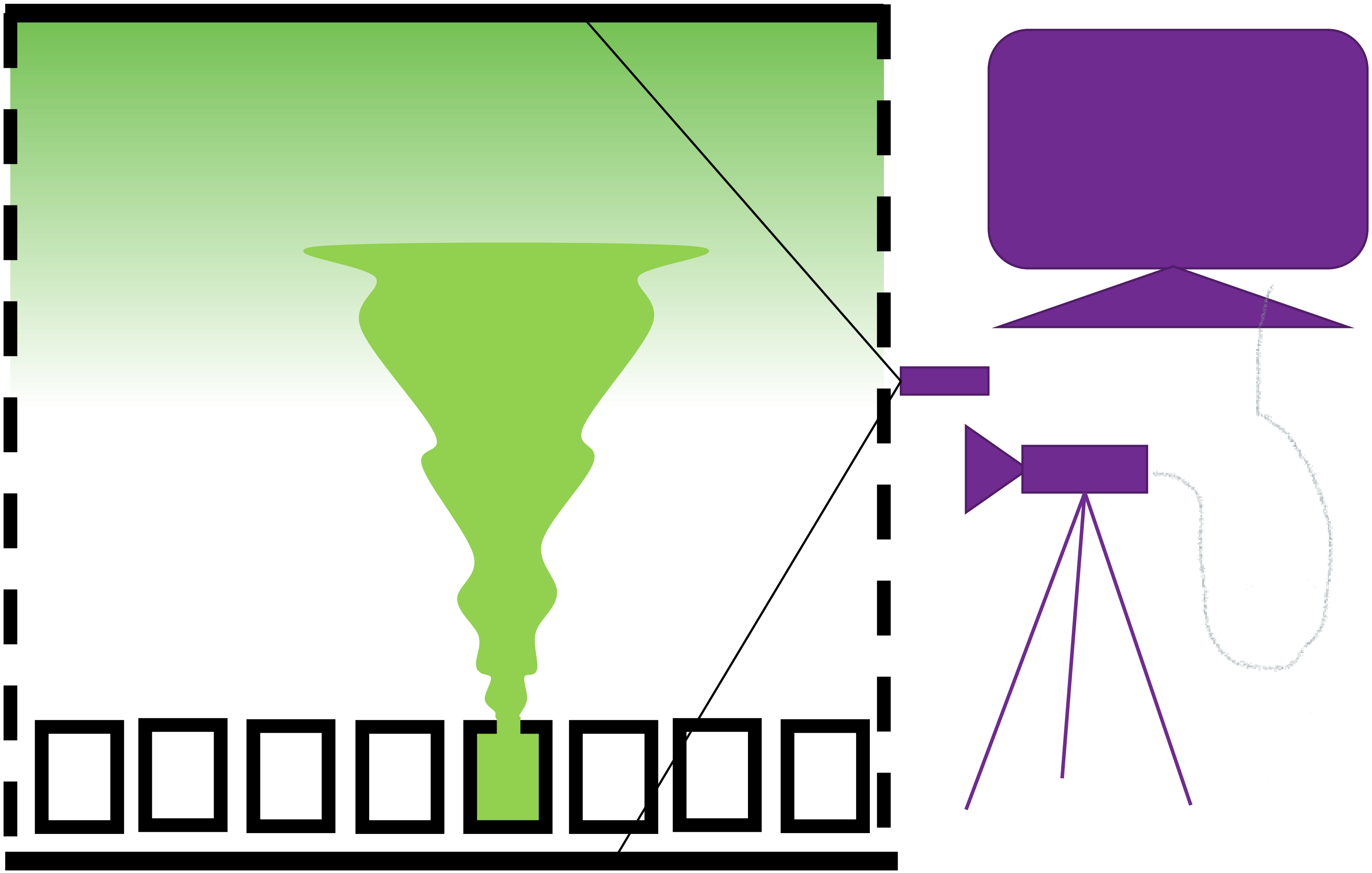
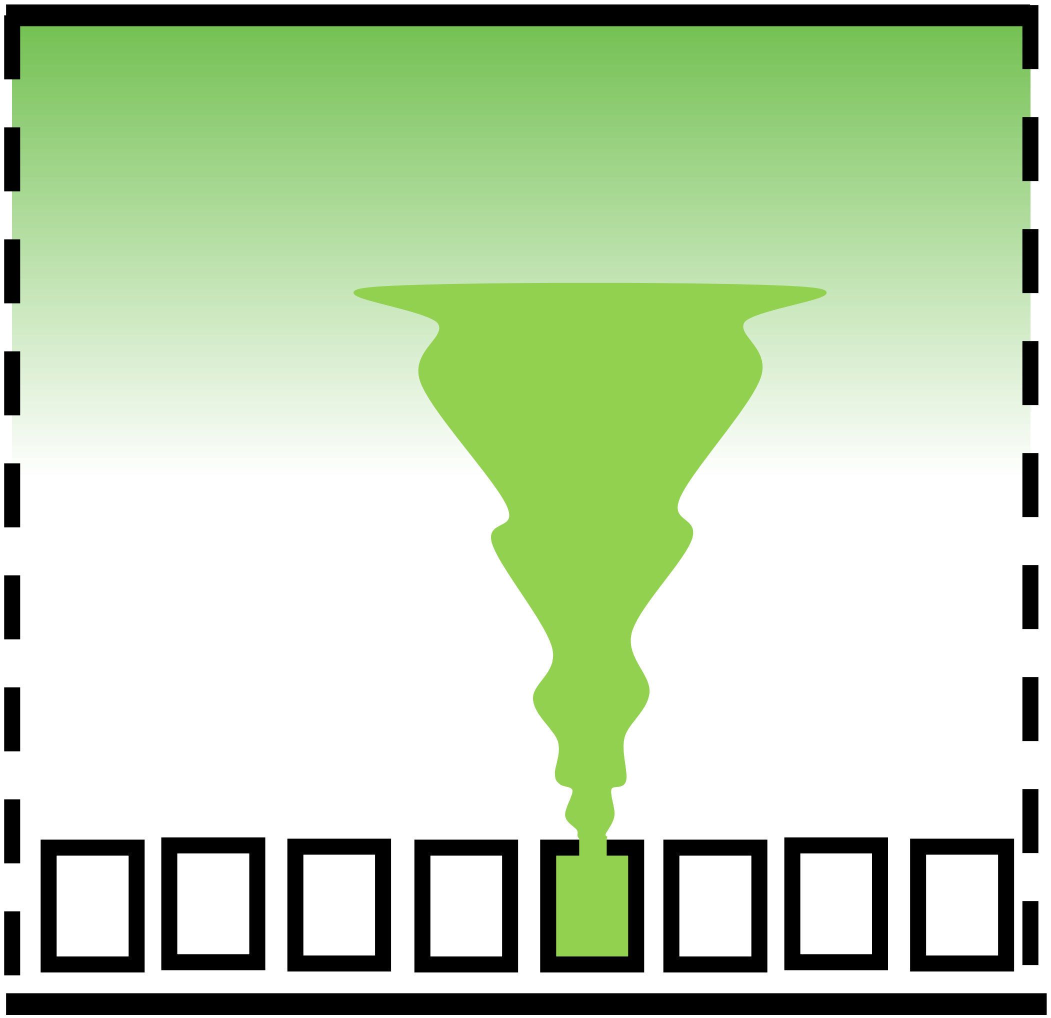
The experiments

- Desktop-scale laboratory experiment.
- Density differences between fresh and salt water will be exploited.
- Primarily using a non-invasive technique.

Proposed Experiment



Proposed Experiment



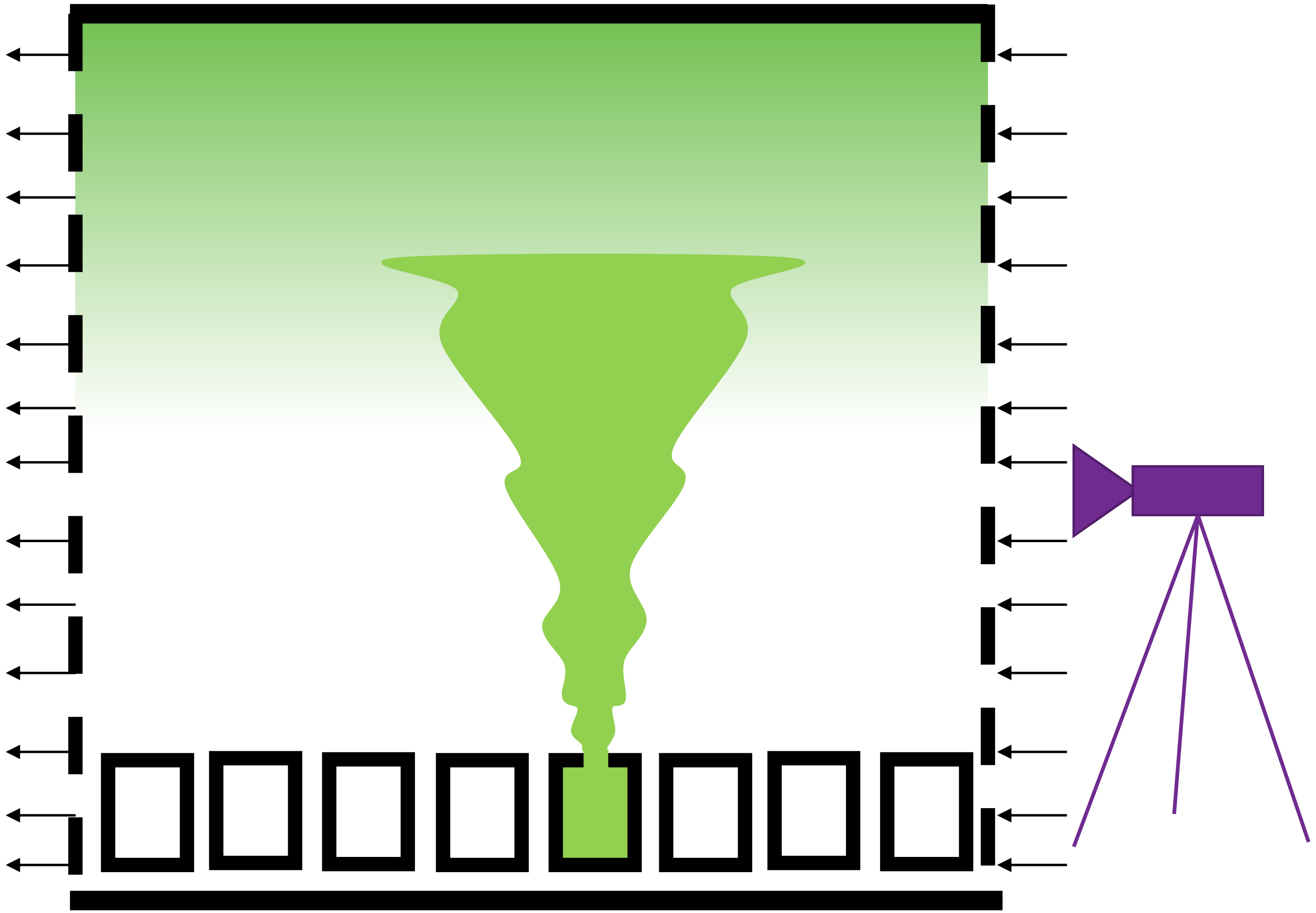
Frame rate 1fps

Resolution 4MP

Leakage flow rate = ???

L x W x H
400 x 200 x 200mm

Ventilated vault



Challenges

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- Estimate rate of molecular mixing in viscous plume.
- Determine suitable positioning for a network of leakage detectors.
- Quantify uncertainty in leakage source location, given detector time-histories: inverse problem.
- Determine long-term time-evolution of the vault stratification.

Finding differential equations

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Morton, Taylor, Turner (1956) experiments corresponding to the case where a lighter fluid is discharged into a heavier, stably stratified fluid. 3 equations are outlined detailing consequences of:

- Conservation of volume
- Conservation of momentum
- Conservation of density deficiency

An appropriate differential equation for the mixing rate could be developed by adjusting these equations to account for the lack of momentum behind the hydrogen plume.

Next steps

- Stratification evolution is the long-term question
- Dynamical system in its own right
- Underlying PDE
- Analysis required!