Minimizing Environmental Infectious Agent Transmission in the Built Environment: A Holistic Approach



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WATER & ENERGY SUSTAINABLE TECHNOLOGY

Studies on Transmission and control of infectious Microbes in the Built Environment

- Identifying most contaminated sites
  - Microbiome of toilets
- Targeting sites for maximum benefit of cleaning/disinfectants
  - Frequency of cleaning/disinfecting
- Assessing impact of cleaning/disinfecting interventions in exposure reduction to pathogens
- Quantifying reduction in risk of infection from interventions- QMRA
- Transport/dissemination of viruses in the indoor environment
  - Re-suspension of viruses
  - Human activities

What is a Healthy Home – Can we define to minimize the Risk of Environmentally Transmitted Diseases?

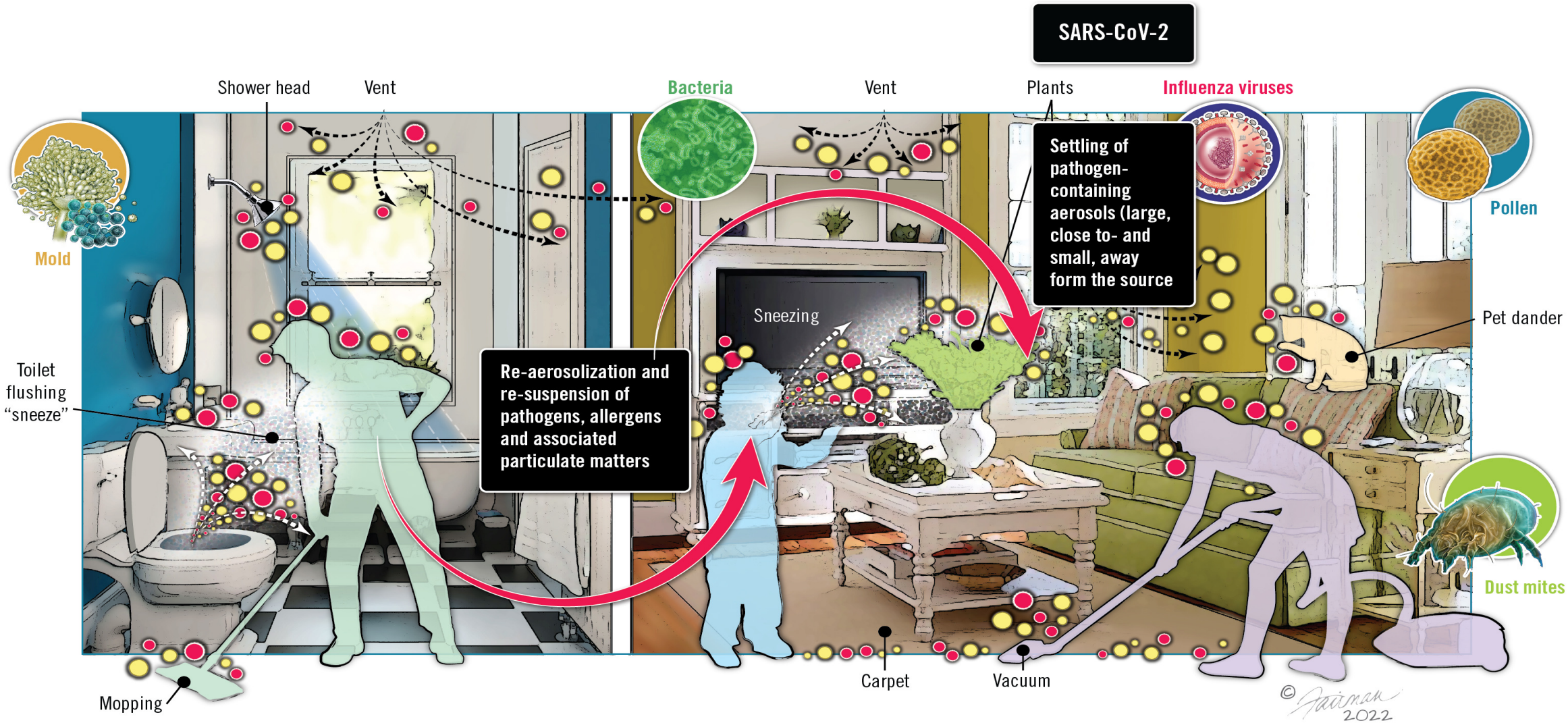
- Can we use QMRA to quantify risk of infection?
  - Should we look at individual site risks or integrate all risks from all sites and routes of exposure? (fomite + aerosol?)
- Exposure is complex
  - Human behavior
  - Building design
  - Nature of materials (fabrics, vinyl, porcelain, etc.)
  - Activities (cleaning, walking, food preparation, etc.)
- What is our goal (acceptable risk)
- Should we only focus on the greatest risk or the or the ones we can have the most benefit with the least cost/environmental impact

Examples of QMRA Targets

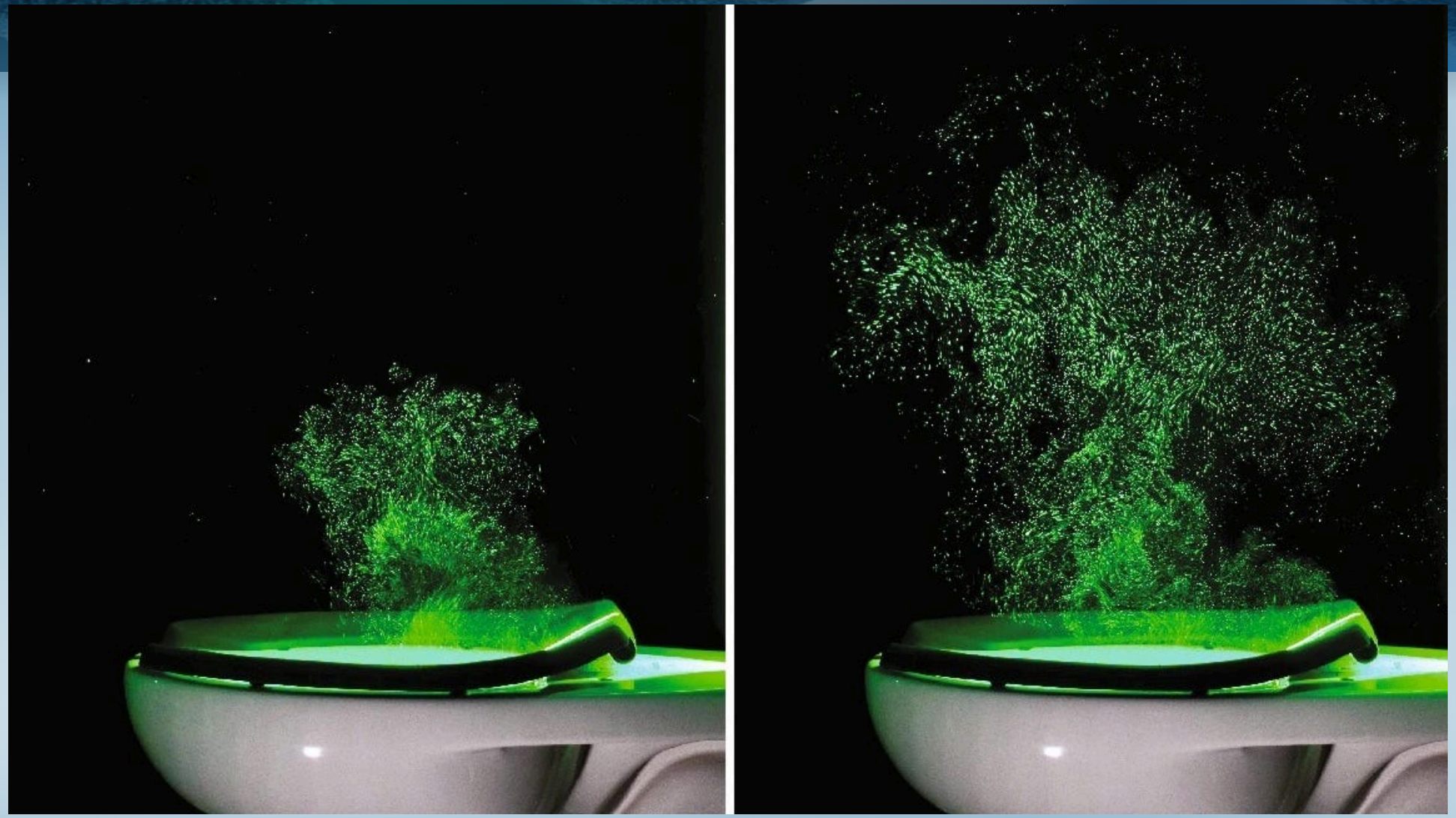
(Wilson et al 2024 J. Occup. Environ. Hygiene)

Risk Threshold		Scenario Details
Annual Risk	1/10,000 annual risk	• Used in drinking water contexts, including DPR in Arizona, California, Texas, and Colorado • US EPA, WHO, Health Canada, USDS-ARS
Per Event	1/100 1/1,000	• Exploring contamination of hands by handwashing water, using a risk threshold of 1/1,000 for the main analysis and additional comparison thresholds of 1/100 and 1/10,000
	1/10,000	• Used in QMRAs as a reference point for single fomite touch • Used in CDC communication about COVID-19 risks posed by fomites relative to other transmission routes
	1/1,000,000 per event risk	• Risk associated with contaminated fomites in healthcare – used to determine level of cleaning needed
Per Day	2.7×10^{-7} Daily infection risk	• Used in California to inform log removal values for direct potable reuse water

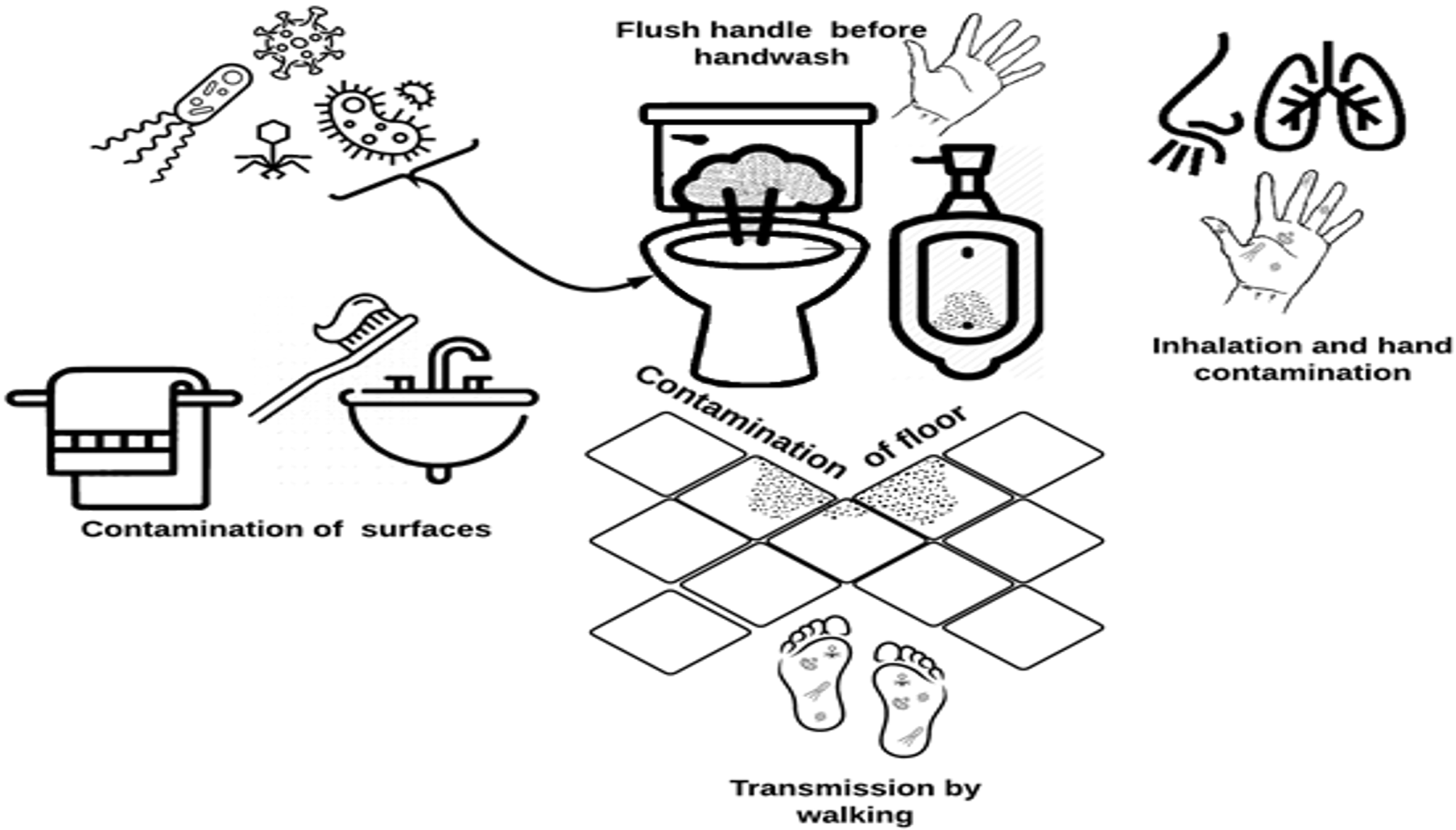
Pathogen movement in the built environment is complex



Why are we Focused on toilets?



Exposure from pathogens by toilet flushing



Objectives:

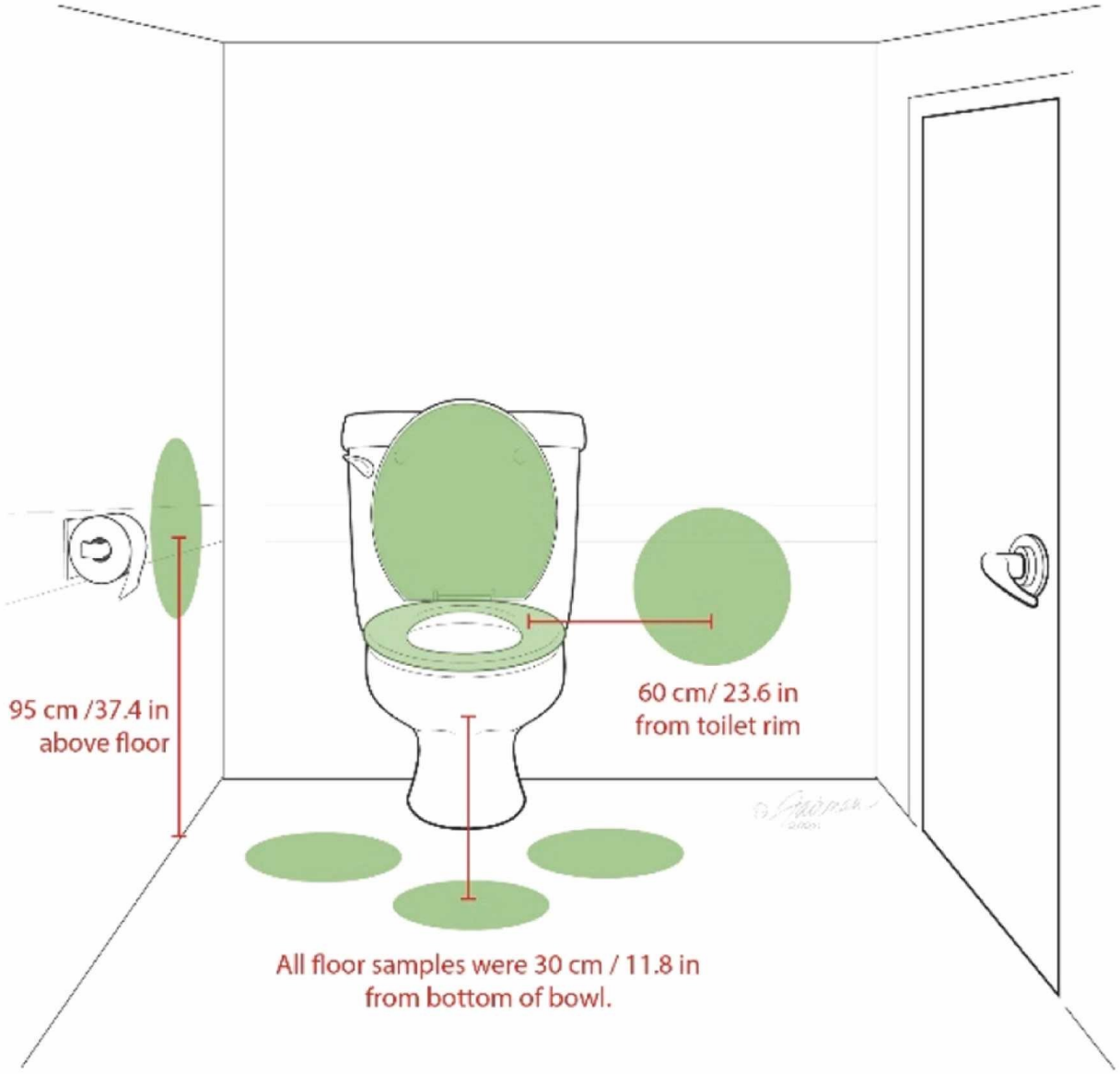
- Determine impact of lid closure on fomite contamination in the restroom

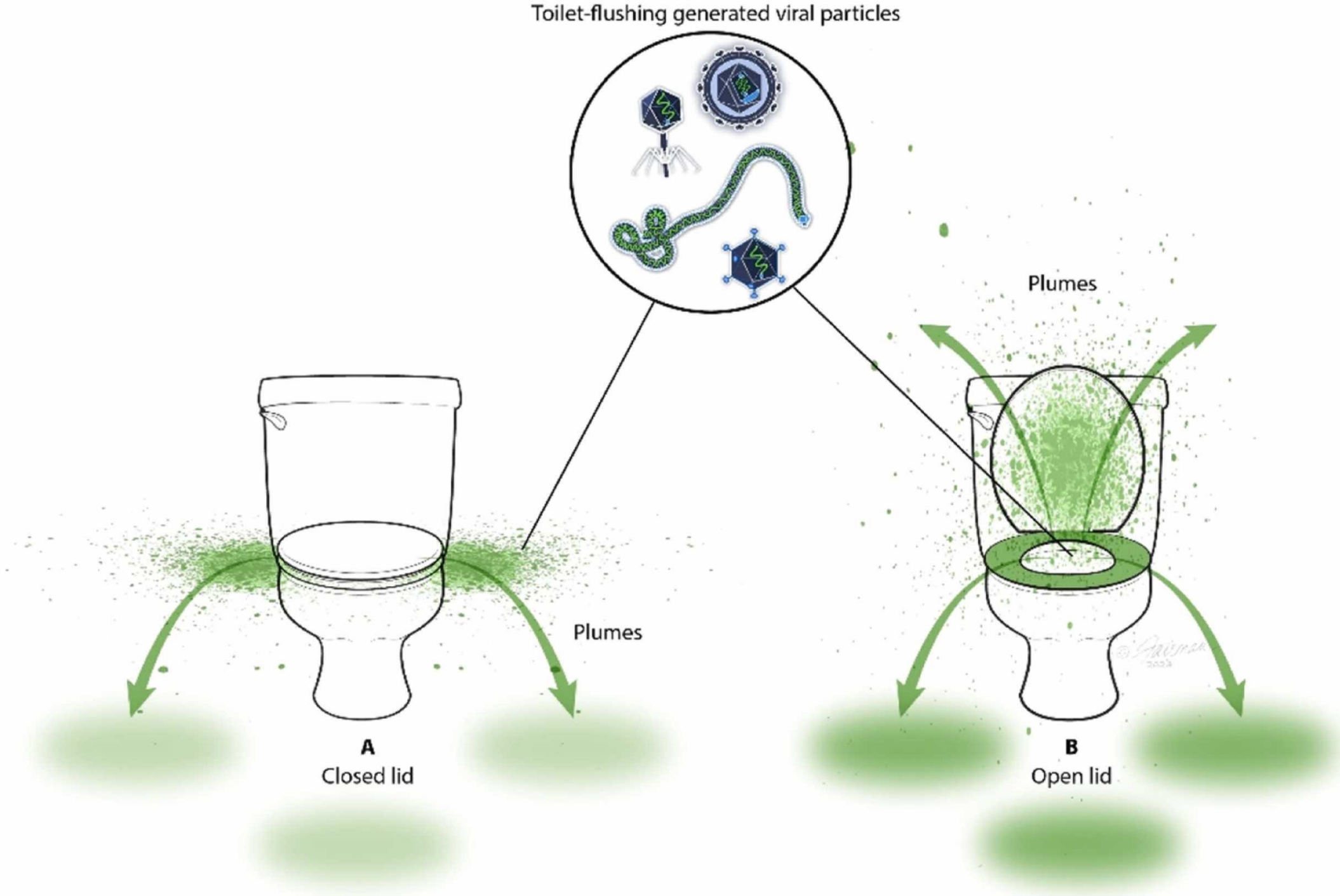




- Determine impact of cleaning toilet with and with out a disinfectant cleaner

Fomite Sample Locations in Restroom




Toilet-flushing generated viral particles
Plumes
Plumes
A
Closed lid
B
Open lid

Impact of home toilet lid position prior to flushing on MS2 virus contamination of toilet surfaces

Lid Position	Toilet Lid PFU/ 100 cm^2		Toilet Seat PFU/100 cm^2	
	Top	Bottom	Top	Bottom
Up	1.70	1.70	6.80	7.85
Down	1.72	1.65	5.62	7.62

10^{14} PFU added to bowl before flush

Note: no statistical difference on contamination with lip up or down

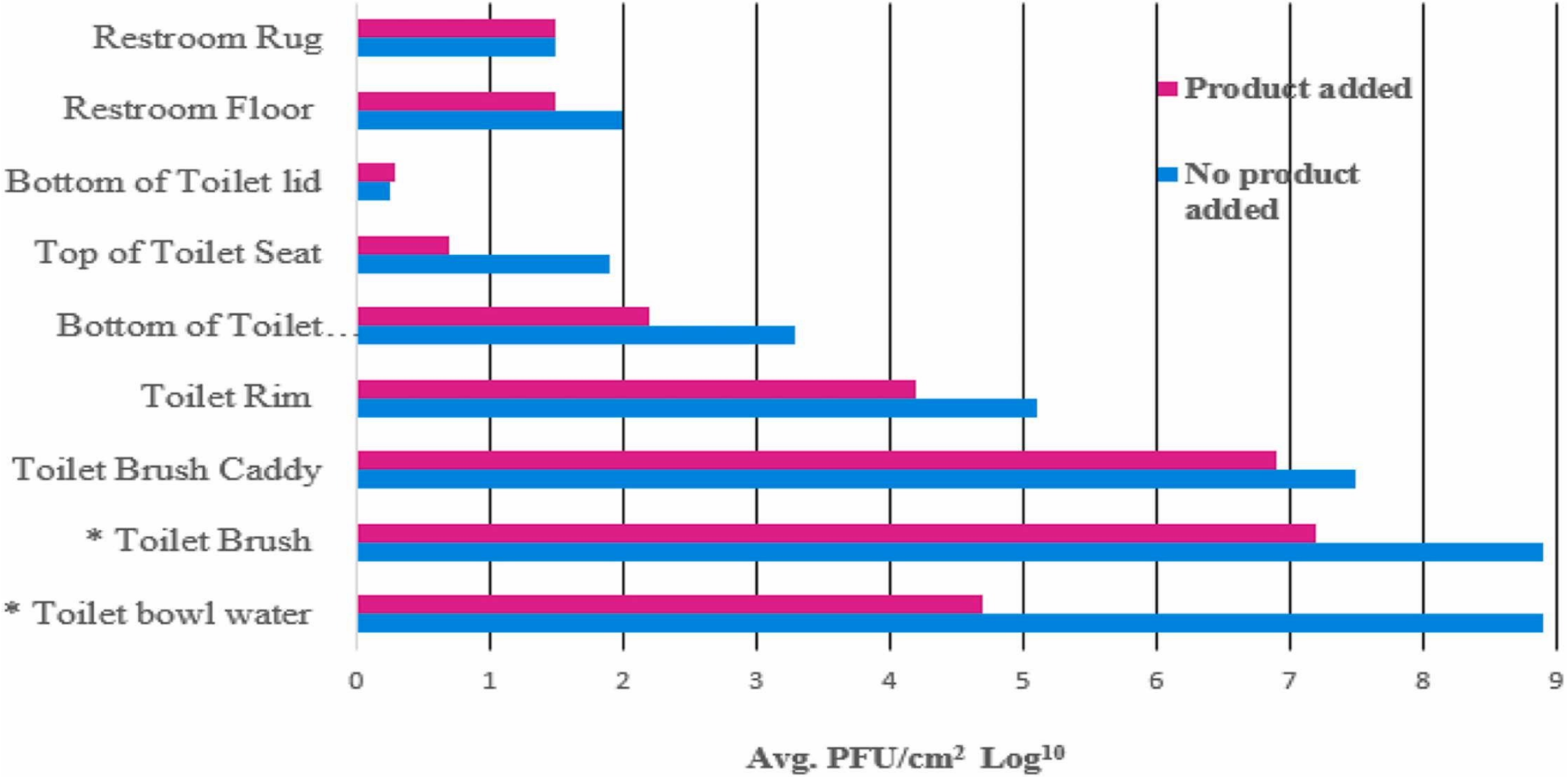
Impact of home toilet lid position prior to flushing on MS2 virus contamination of floor and restroom walls

Lid Position	Floor PFU/ 100 cm^2		Wall PFU/100 cm^2	
	Left of toilet	Right of toilet	Left of toilet	Right of toilet
Up	3.64	6.23	2.31	1.77
Down	5.11	4.81	1.61	1.86

10^{14} PFU added to bowl before flush

Note: no statistical difference on contamination with lid up or down

Impact of toilet bowl cleaning with and without a disinfectant product on virus contamination of restroom



Conclusions

- Closure of toilet lid had no significant impact of viral contamination of the toilet seat, lid or surrounding areas (floor, walls)
- Cleaning the toilet bowel with a brush resulted in contamination of the toilet seat, lid or surrounding areas (floor, walls)
- Contamination was reduced if a disinfectant was used during toilet bowl cleaning

What is the Optimal Cleaning Frequency for a home Restroom?

- Compared using one product vs. multiple products.
- Cleaning frequency
  - Every 1, 2, 3 and 7 days.
- Measured total bacteria, *E. coli*/coliform levels as reference for fecal contamination.

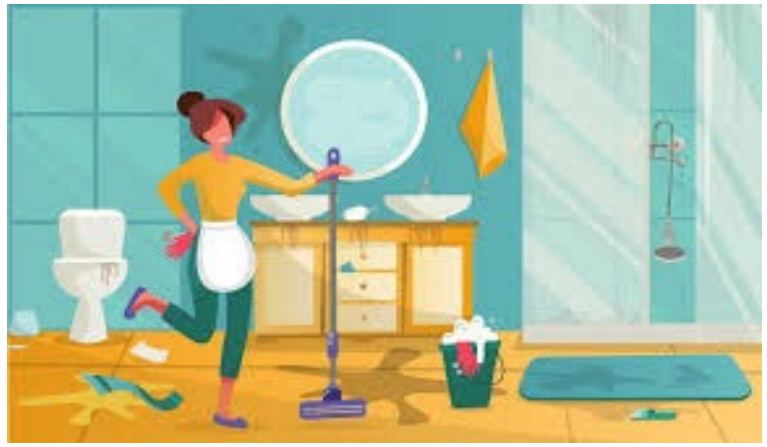
Cleaning Phase and Products Used*: Toilet Surfaces

Cleaning Phase/ Intervention	Toilet Water	Toilet rim	Toilet bowl	Toilet bowl seat Bottom	Toilet bowl seat top	Toilet Bowl lid	Toilet Bowl Handle
Single product	Lysol Power Toilet Bowl Cleaner (LPTBC)	Lysol Power Toilet Bowl Cleaner (LPTBC)	Lysol Power Toilet Bowl Cleaner (LPTBC)	No Cleaning/ Disinfectant	No Cleaning/ Disinfectant	No Cleaning/ Disinfectant	No Cleaning/ Disinfectant
Multi-Product/Bundle	Lysol Power Toilet Bowl Cleaner (LPTBC)	Lysol Power Toilet Bowl Cleaner (LPTBC)	Lysol Power Toilet Bowl Cleaner (LPTBC)	Lysol Disinfectant Wipes (LDW)	Lysol Disinfectant Wipes (LDW)	Lysol Disinfectant Wipes (LDW)	Lysol Disinfectant Spray (LDS)
Bundle Product used							

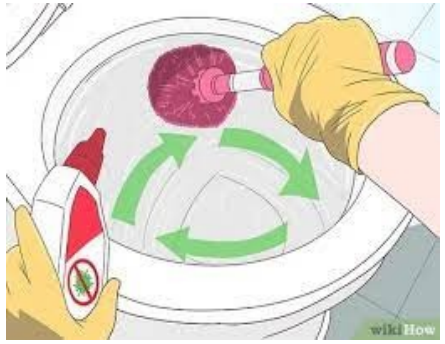
*Applied as per use-directions provided

Cleaning Phase and Products Used: Restroom Surfaces

Cleaning Phase/ Intervention	Vanity Counter top	Vanity Sink Faucet Handle	Restroom Floor	Door Handle
Single product	No Cleaning/ Disinfectant	No Cleaning/ Disinfectant	No Cleaning/ Disinfectant	No Cleaning/ Disinfectant
Multi-Product/Bundle	Lysol Power Foamer Bathroom Cleaner (LPTBC)	Lysol Power Foamer Bathroom Cleaner (LPTBC)	Lysol Clean & Fresh Multi-Surface Cleaner (LCFMSC)	Lysol Disinfectant Wipes (LDW)
Bundle Product used				



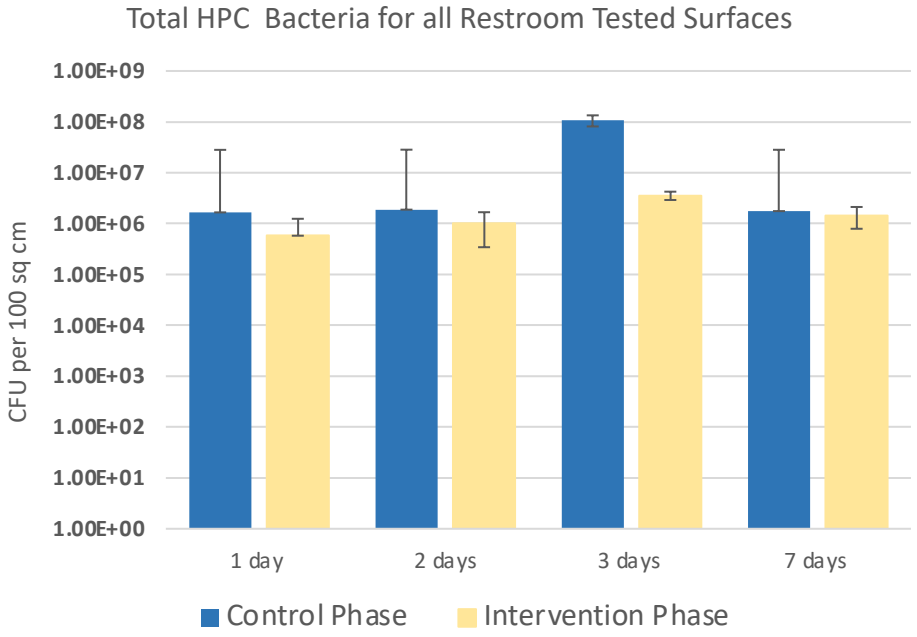
94.5% risk reduction

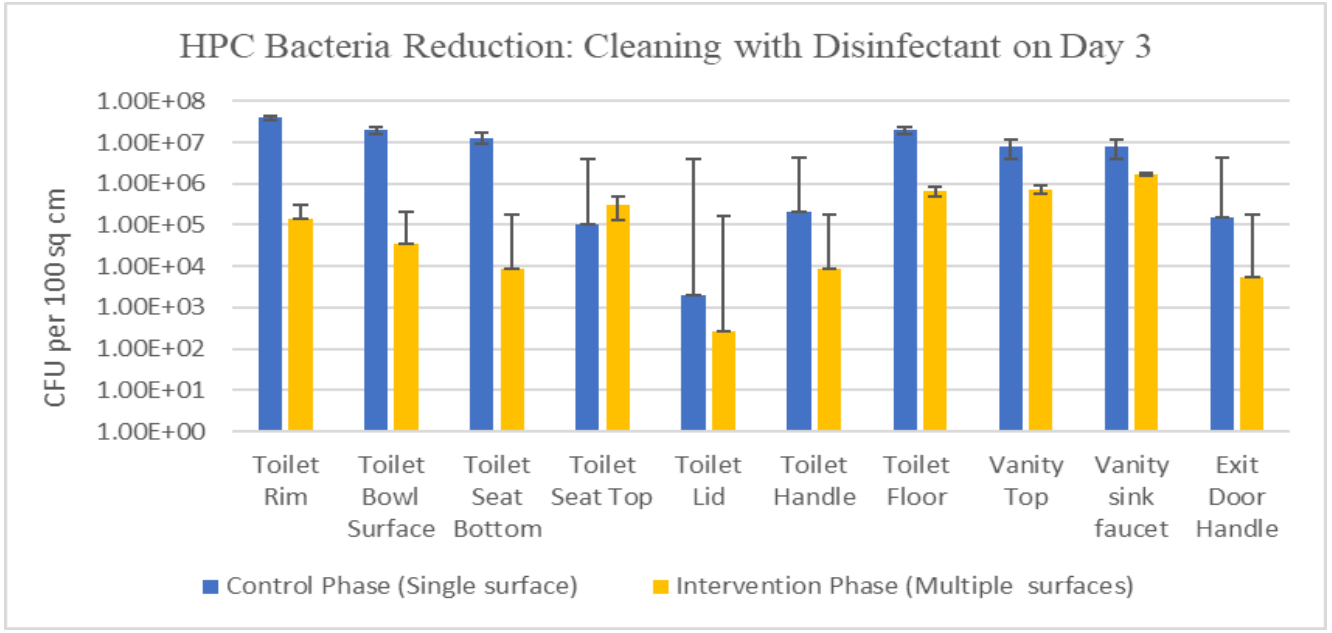


99.7% reduction risk reduction – 2X per week



For optimal microbe reduction, use multiple disinfectants to clean multiple bathroom surfaces twice a week.





Risk of norovirus infection after cleaning twice a week with Bundle approach of cleaning products

Site	One touch event		Percent reduction in risk
	Before*	After**	After bundle use
Vanity countertop	1.14×10^{-1}	$\leq3.30\times10^{-4}$	≥99.7
Toilet seat	5.8×10^{-3}	$<3.30\times10^{-4}$	≥94.3

Summary

- Toilet flushing results in both air and fomite microbial contamination in the restroom
- Closing the toilet lid does not result in significant reduction in restroom contamination
- Best control of microbial contamination resulted from cleaning/disinfecting the restroom twice a week with a selected bundle of products
- Probability of infection by norovirus was reduced by greater than 90% by touching the toilet seat and vanity top following intervention.

Future Work/Questions

- Is cleaning/disinfecting frequency influenced by
  - Toilet design
  - Flushing mechanisms (water pressure)
  - Products used for cleaning/disinfection
  - Design of Restroom (materials – vinyl vs. porcelain)
  - Number and age of household inhabitants
  - Environmental factors (relative humidity & temperature)