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Ho-'omalamalama: Building a Sustainable Infrastructure in the Asia Pacific Region

Innovative Approach to Validation of Ultraviolet (UV) Reactors for Disinfection in Drinking Water Systems

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Disclaimer

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Background: Evolving Use of UV for Drinking Water Disinfection in U.S.

- State credited UV systems are third-party validated for Dose-Inactivation operating range, consistent with source water, and require continuous monitoring

- 2006-UVDGM is 'Guidance' on recommended approach for UV Validation, installation, & monitoring but alternative approaches may be acceptable to States
- EPA not planning formal update of UVDGM or UV dose tables in near future, but issues persist with interpretation of UVDGM by State permitting agencies

- Since 2006, UV research and commercial validation experiences have provided significant lessons-learned, modified validation practices, and identified new implementation challenges

	UV Dose (mJ/cm^2) Required for a Log Inactivation of:							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Crypto	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Virus	39	58	79	100	121	143	163	186

Evaluation Objectives of EPA Study

- Practical approach for validating LP and MP UV reactors for *Adenovirus & Cryptosporidium* inactivation using various test microbes, i.e., *MS2, B. pumilus, AD2, T1*
- Apply UV dose algorithms based on theory vs empirical that predict log-I and RED as a function of the UV sensitivity of the microbe (combined variable criteria), flow, lamp-sensor output, DL, w/wo UVT
- Assess capabilities of test microbe for predicting target pathogen, assess credibility with second test microbe vs bracketing
- Evaluate UV lamp sensor technology that accounts for germicidal contributions of low-and high-wavelength UV light within MP reactors

Evaluation Objectives of EPA Study

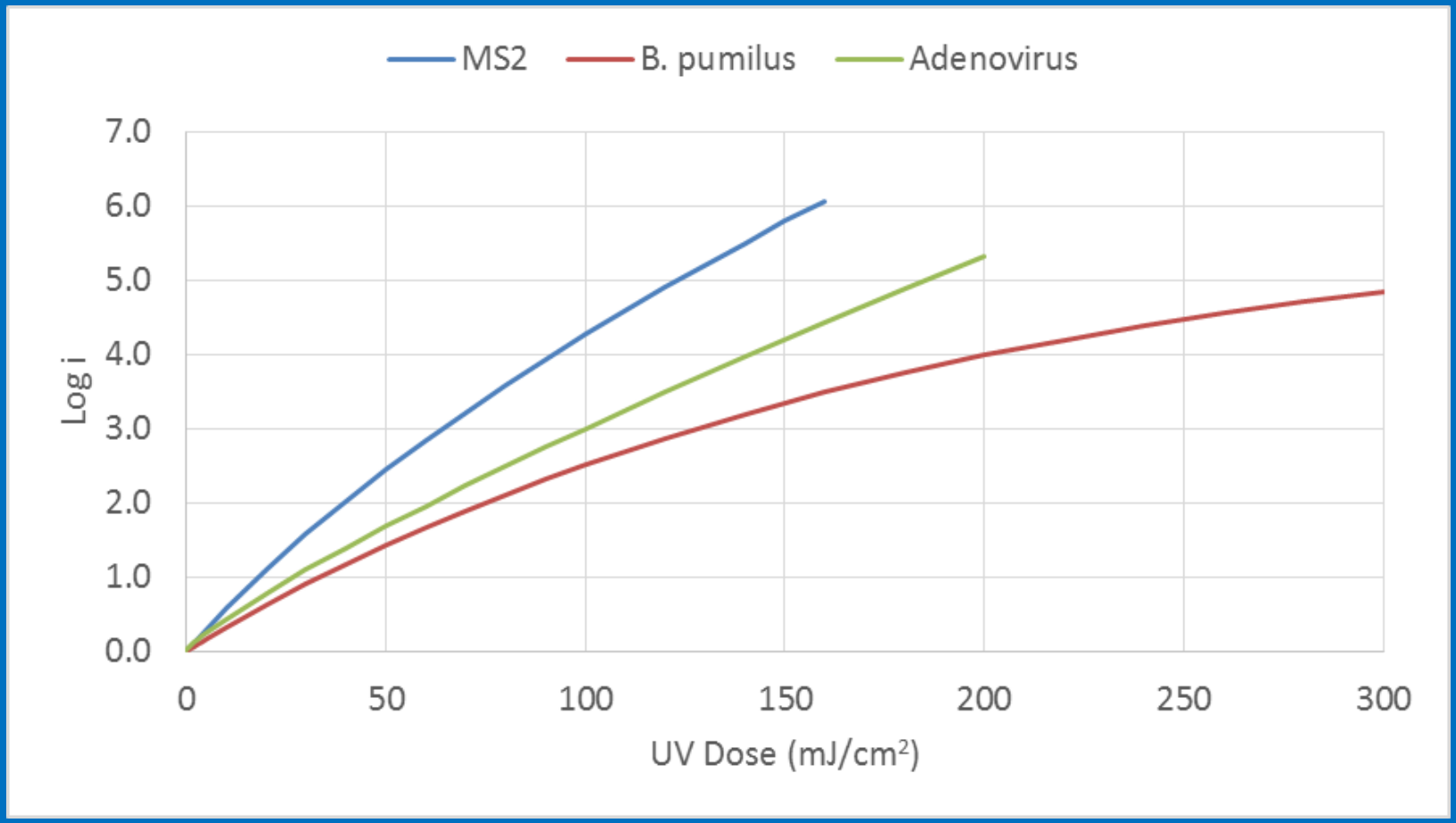
- Address approaches for propagating and assaying *AD2, B. pumilus, MS2*, and methods for determining low and high wavelength ASCFs using collimated beam LP & MP UV lamps
- Determine & apply low and high wavelength ASCFs to predict *Cryptosporidium* and *Adenovirus* credit using *MS2, B. pumilus, or T1* test data
- Simplify Validation-Factor (VF) analysis of uncertainties/biases
- Develop recommendations document from recent lessons learned applicable to GWR / SWTR describing alternative approaches for UV validation and implementation, and changes needed from previous UVDGM

Full-scale UV Reactor Testing – EPA Study

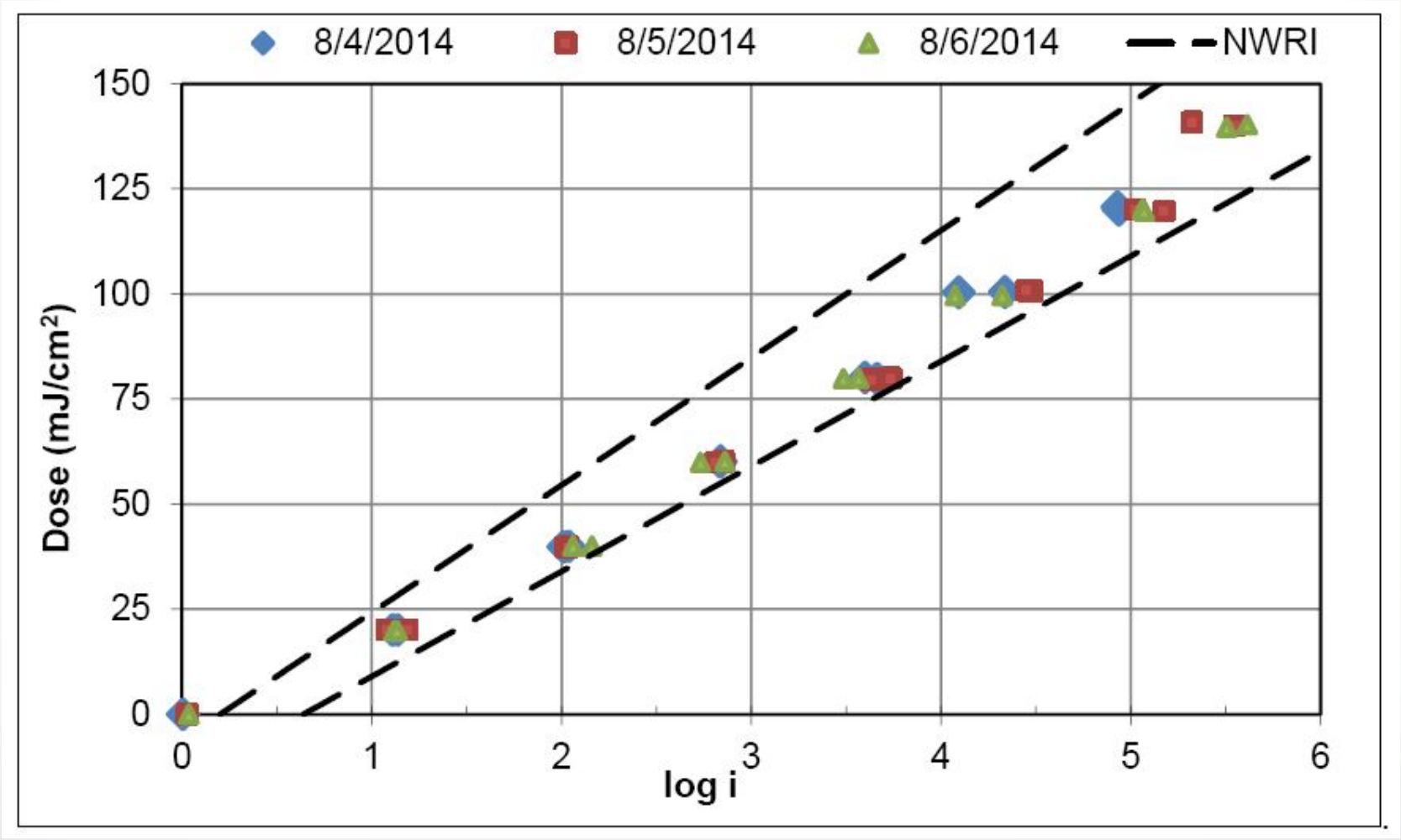
- LPHO UV Reactor:
  - 60 test conditions, *MS2, Adenovirus, Bacillus pumilus*
  - 25-700gpm flows; UVTs 70, 80, 90, 98; Lamp power 60-100 %

- MP UV Reactor:
  - 103 test conditions, *MS2, AD2, B. pumilus*
  - 17-400gpm flows; UVTs 70, 80, 90, 98; Lamp power 0.9-2KW
  - Synthetic & type 219 quartz sleeves, superhume-LSA
  - Sensors: low wave 200-240nm; ONORM high wave 240-300nm

UV Dose-Response of *MS2* and *B. Pumilus* Brackets Adenovirus



UV Dose-Response *MS2* & QA/QC Bounds



UV Dose-Response *B. pumilus*

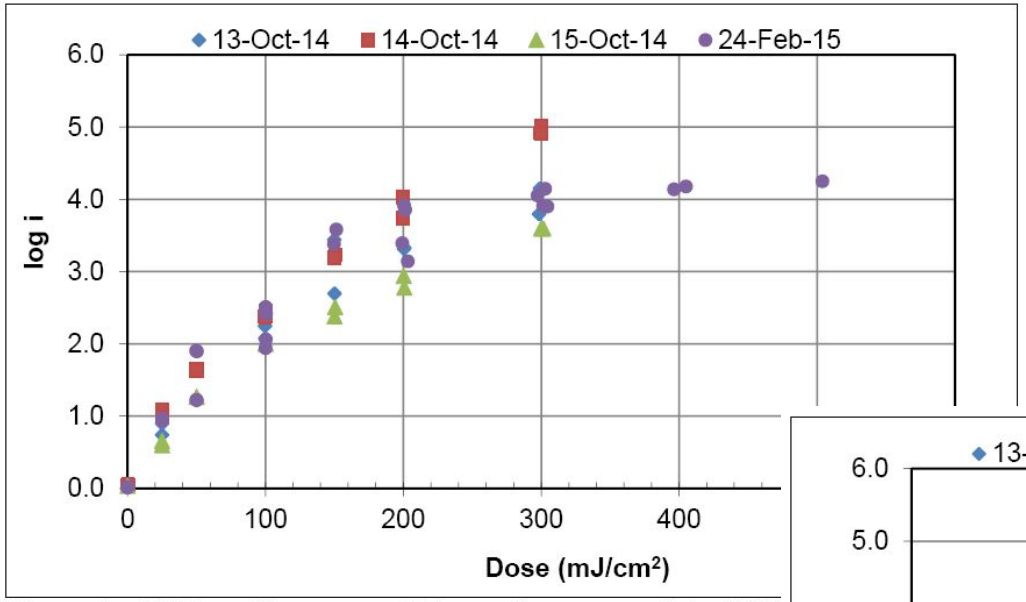


Figure 4a UV Dose Response of *B. pumilus* spores (lab: GAP

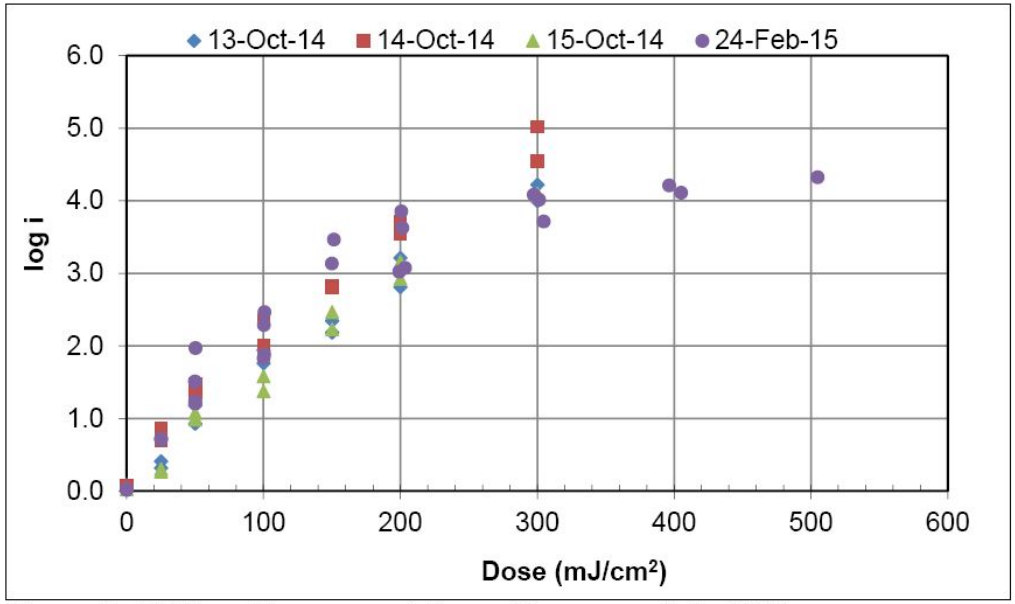


Figure 4b UV Dose Response of *B. pumilus* spores (lab: EPA)

UV Dose-Response *Adenovirus AD2*

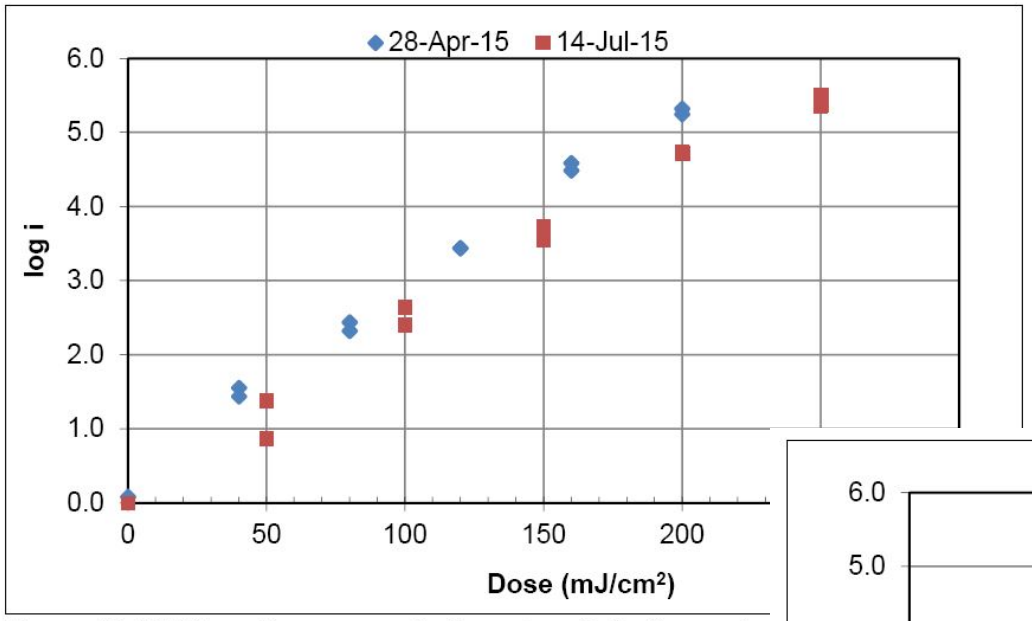


Figure 5b UV Dose Response of adenovirus (lab: Corona)

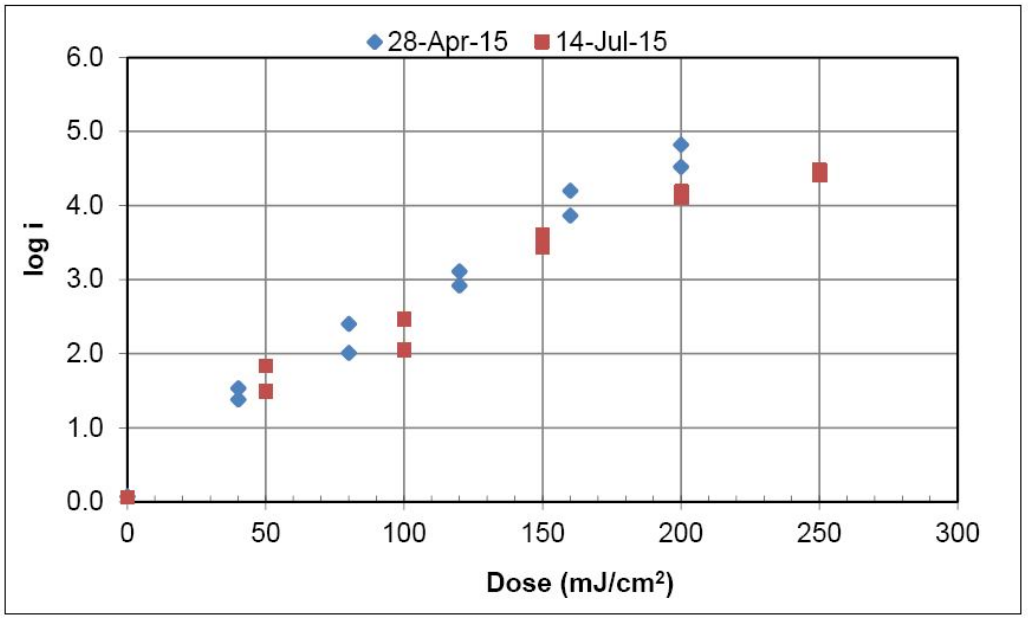


Figure 5a UV Dose Response of adenovirus (lab: EPA)

New UV Dose Algorithm

$$\log I = 10^{A} \times UVA_{254}^{B \times UVA} \times \left(\frac{S_H / S_{0H} \times ASCF_H}{D_L \times Q} \right)^{C + D \times UVA_{254} + E \times UVA_{254}^{2}}$$

$$+ 10^{F} \times UVA_{220}^{G \times UVA} \times \left(\frac{S_L / S_{0L} \times ASCF_L}{D_L \times Q} \right)^{H + I \times UVA_{220} + J \times UVA_{220}^{2}}$$

Low wavelength UV dose monitoring component uses low wavelength UV sensor and UVT at 220 nm

LP UV: Relationship between Measured log Inactivation and $S/S_0/Q/D_L$

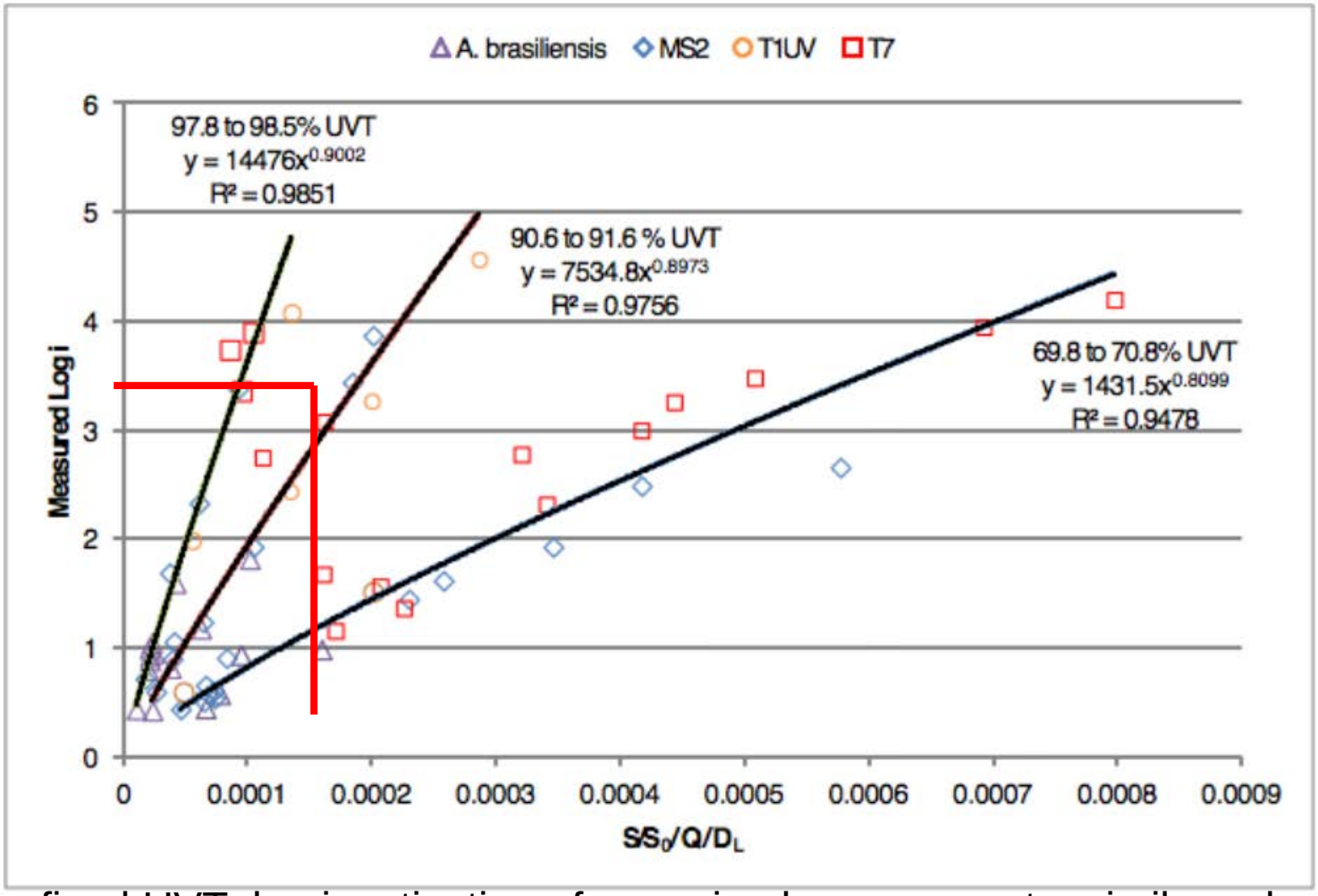
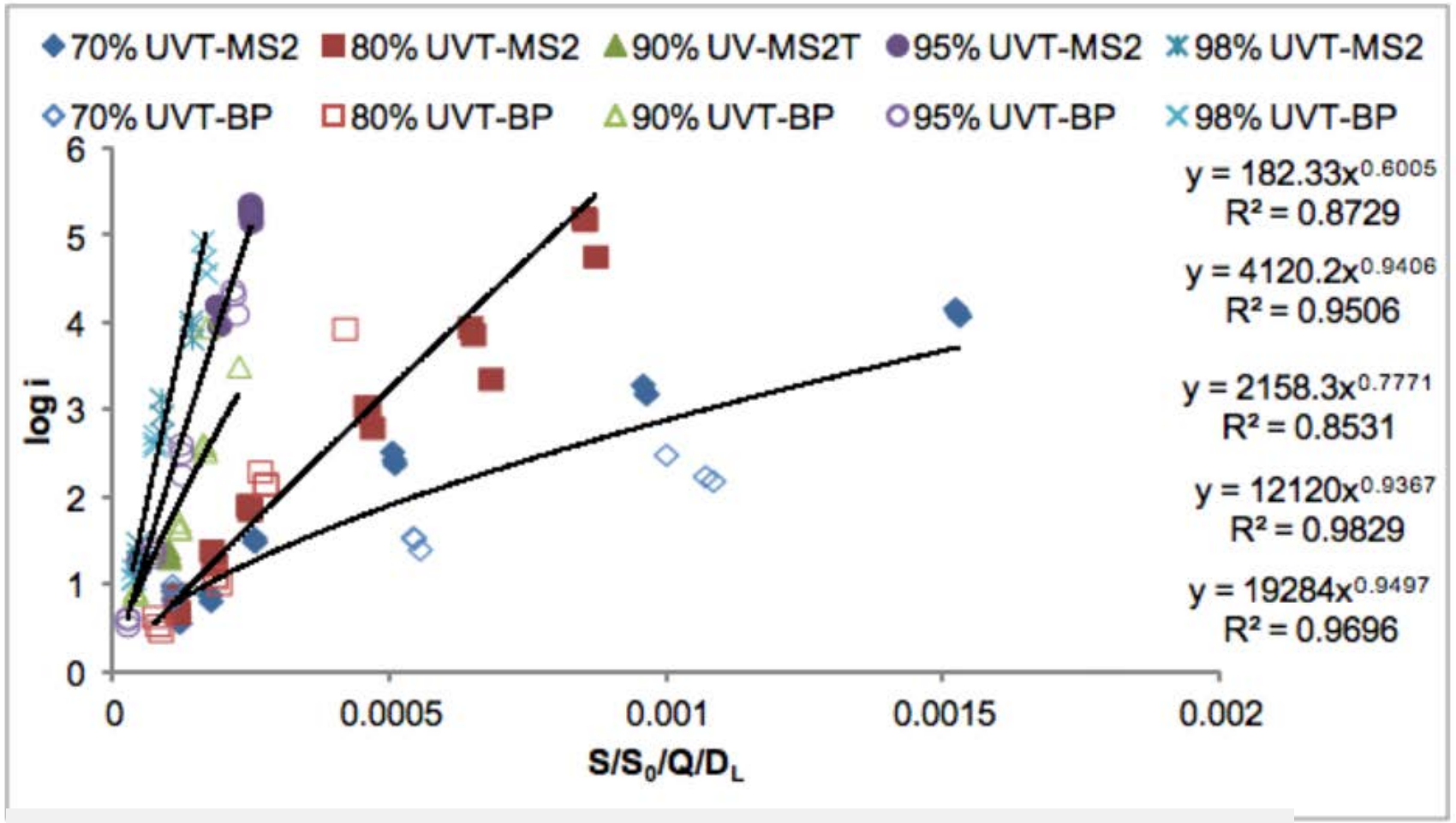


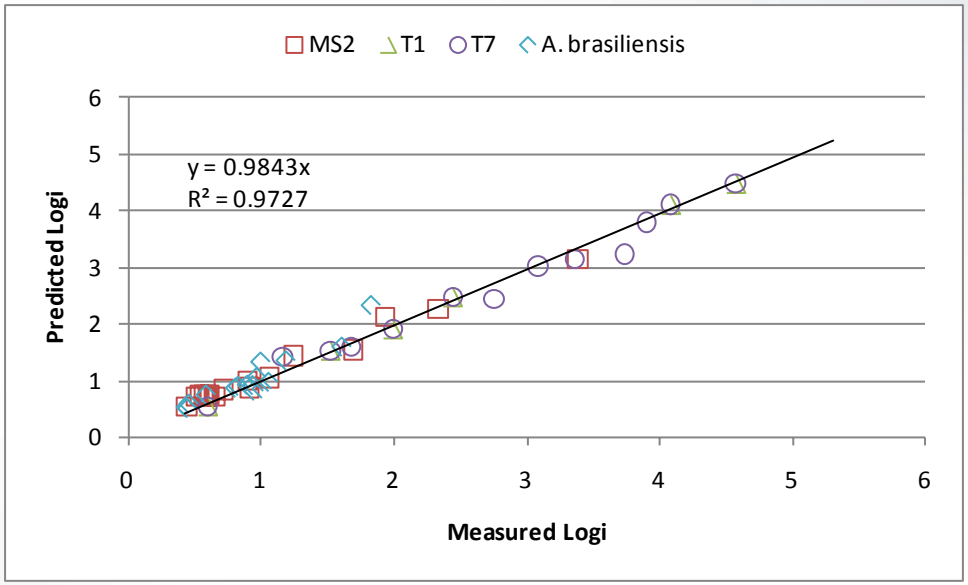
Figure 4 Relationship between Measured log Inactivation and $S/S_0/Q/D_L$

At a fixed UVT, log inactivation of any microbes occurs at a similar value of S/S0/Q/DL

LP UV: Relationship between Measured log Inactivation and $S/S_0/Q/D_L$

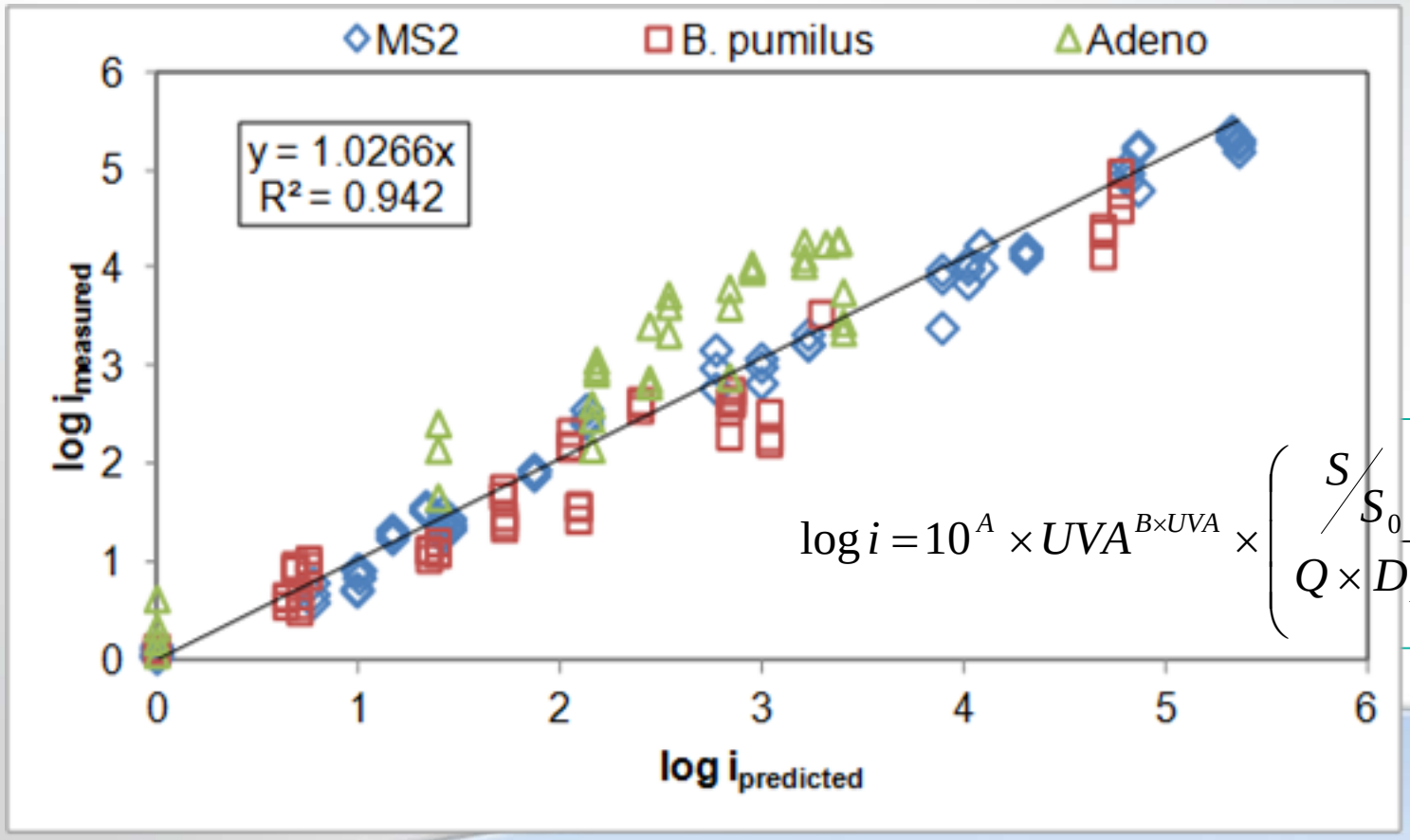


LP UV: algorithm calibrated with *T1* Predicts *MS2*, *T7*, and *A. Brasilienis*



Predictions Limited to Validated Range of $S/S_0/Q/D_L$ defined by T1

LP UV: Measured vs. Predicted log I Calibrated Using *MS2*



$$\log i = 10^{A} \times UVA^{B \times UVA} \times \left(\frac{S / S_0}{Q \times D_L} \right)^{C + D \times UVA + E \times UVA^2}$$

LP UV: Algorithm Fit to *MS2* & *B. Pumilus* Data Predicts *Adenovirus* No Better Than *MS2* Alone

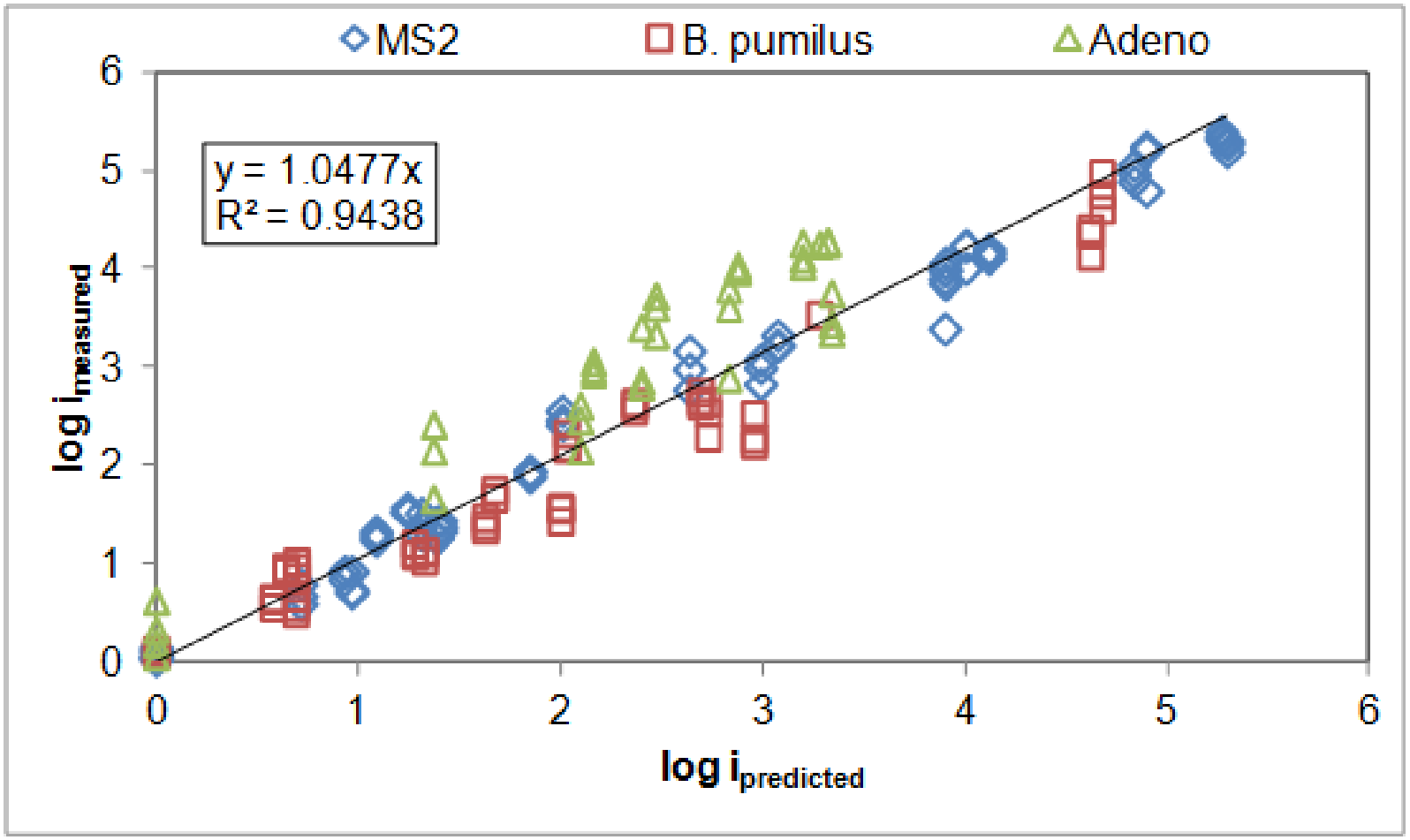
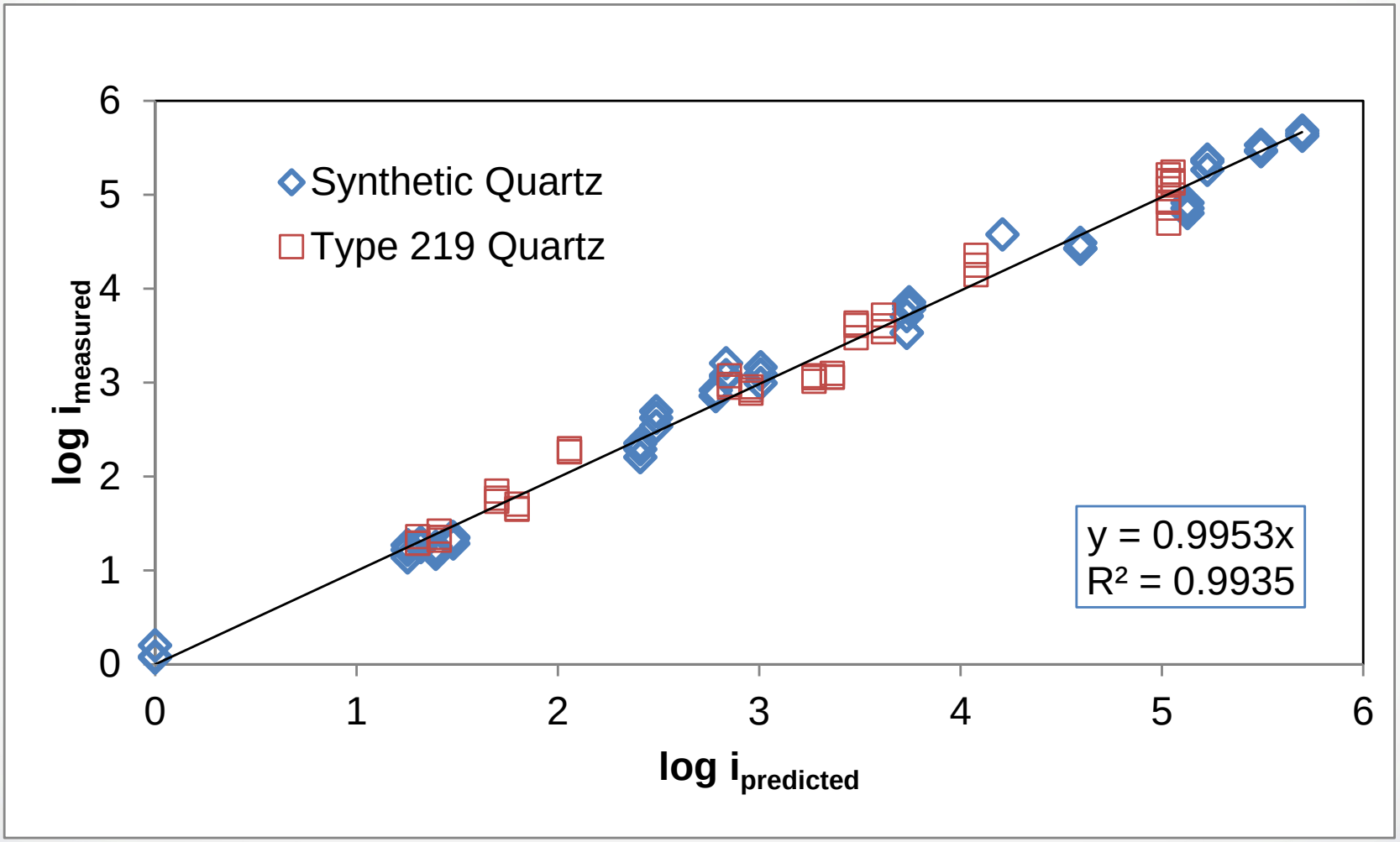
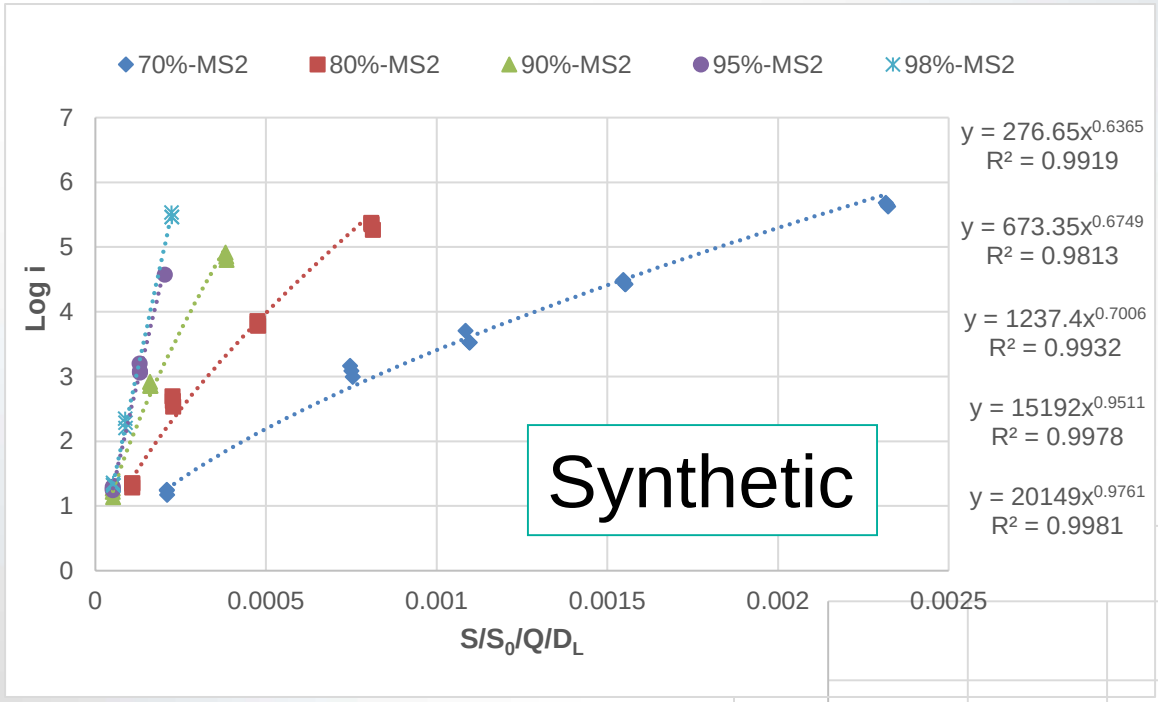


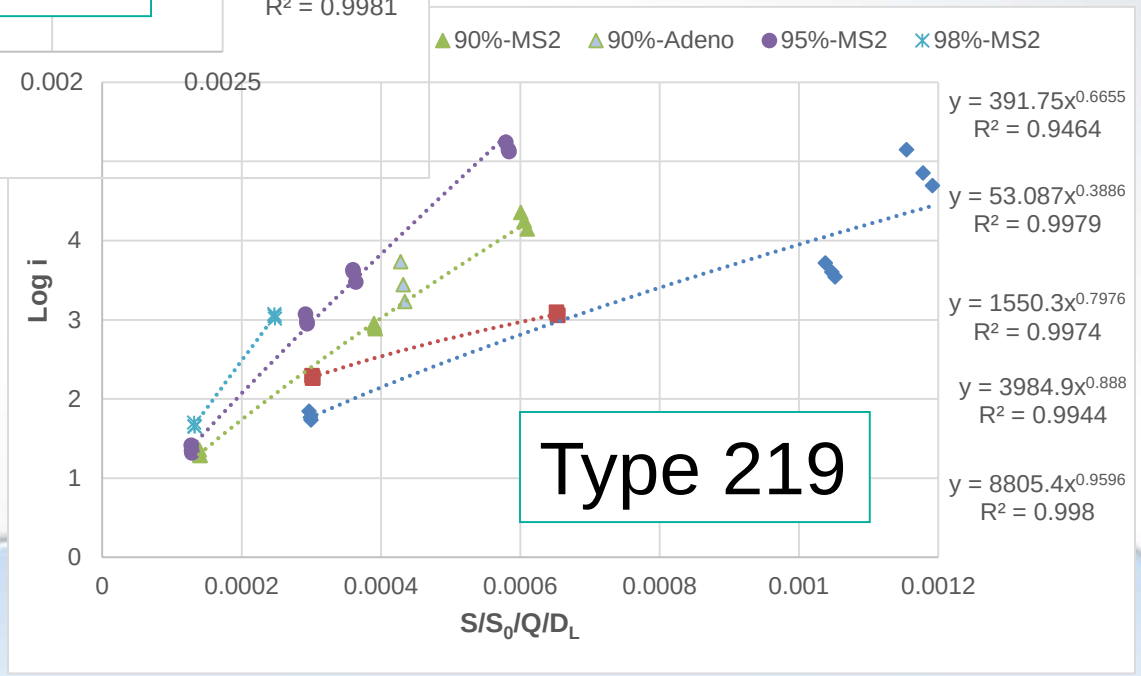
Figure 20 Measured vs. Predicted Log Removal: MS2 and *B. pumilus* data

MP Predictive Algorithm w/ high & low wavelength sensor and UVA measurements maps *MS2* data well

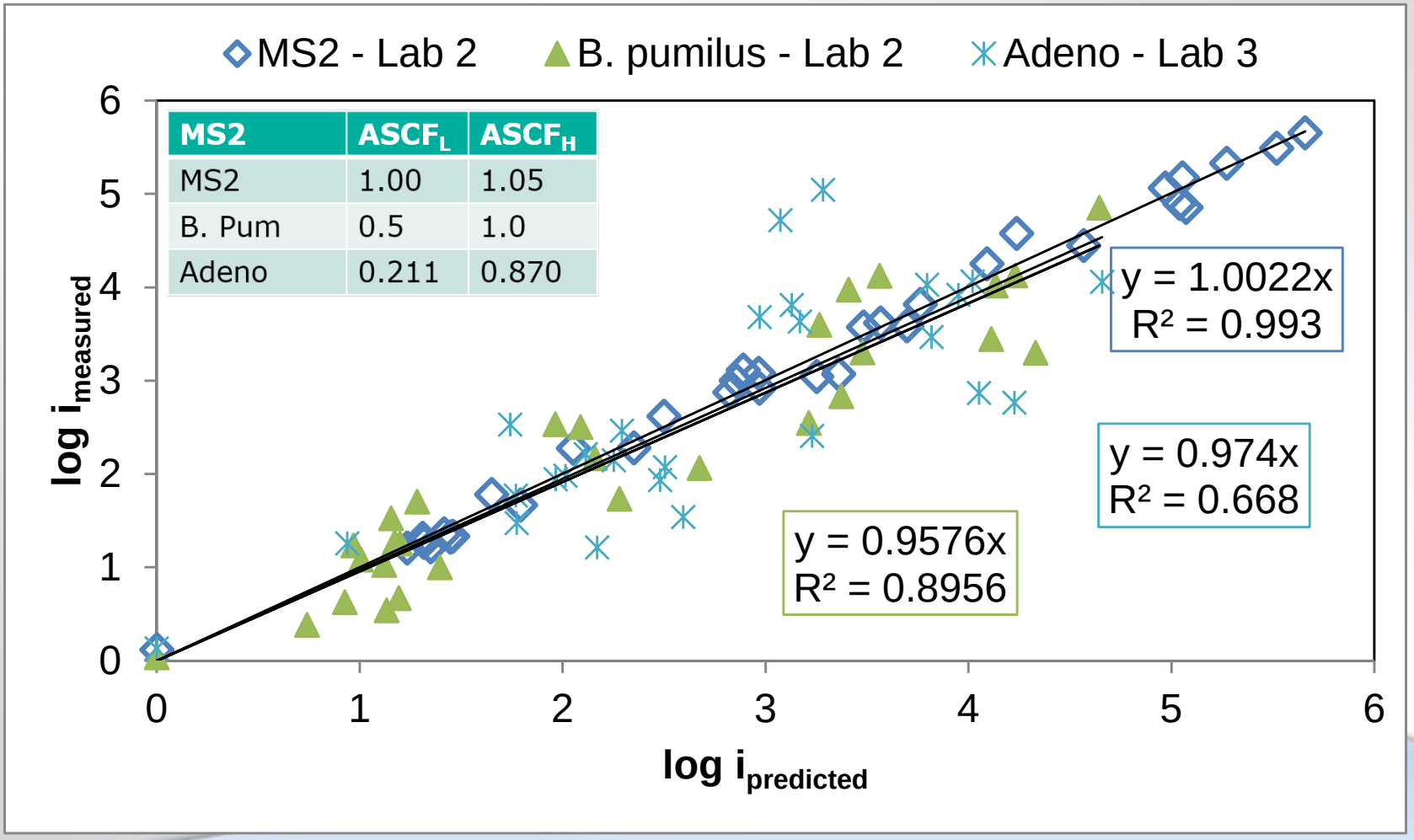


MP UV: *MS2* Log I vs. $S_H / S_{0H} / Q / D_L$

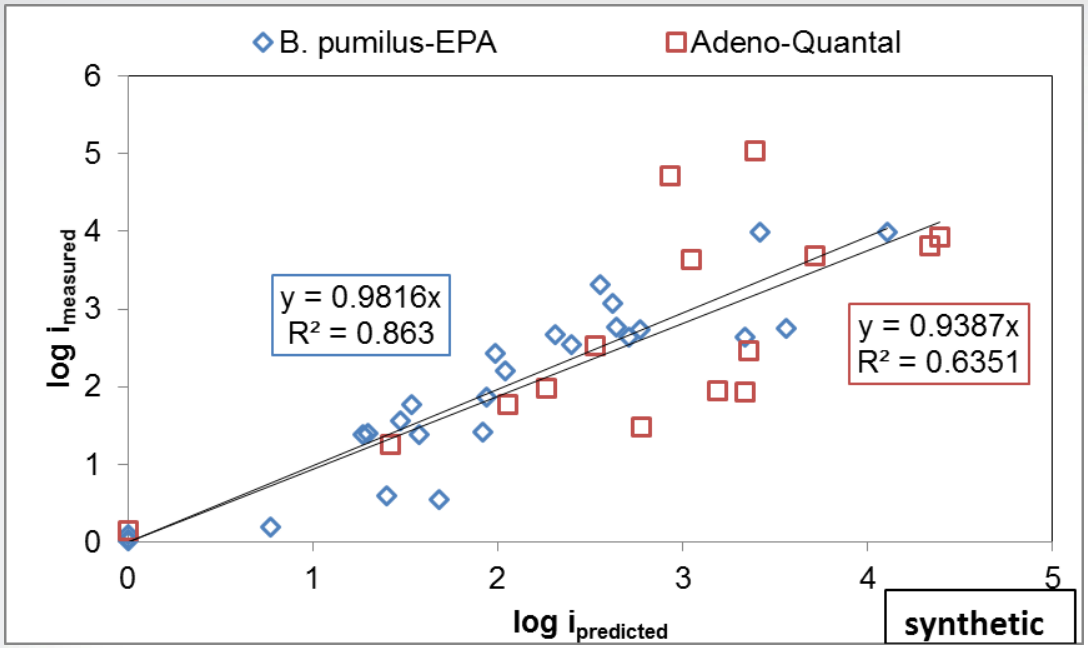


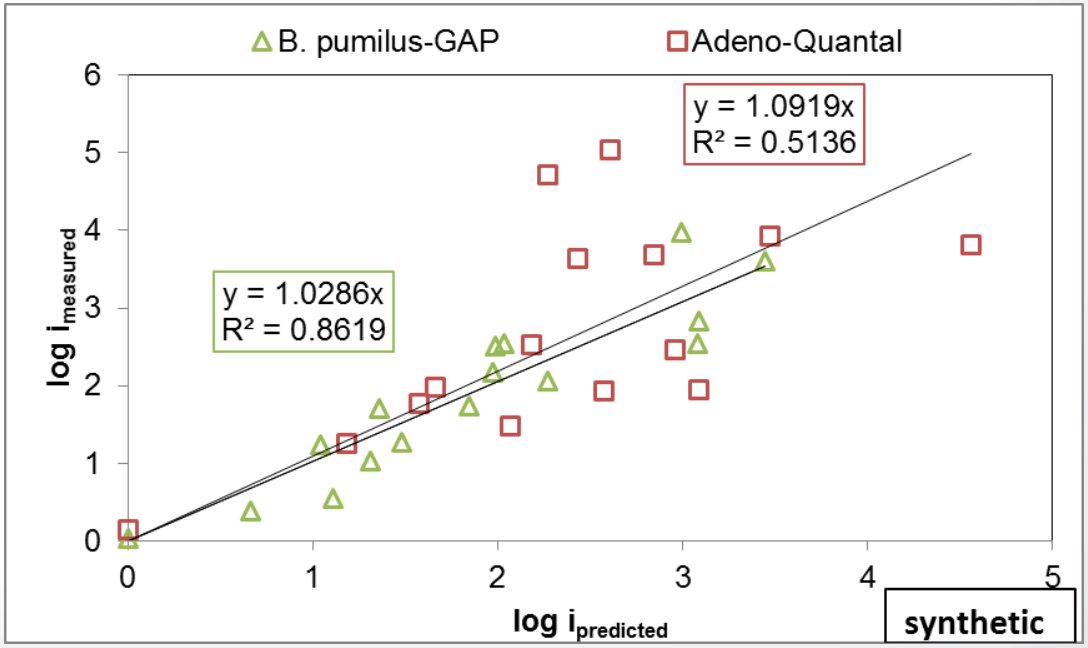


MP UV: Measured vs. Predicted log I Calibrated Using *MS2*



MP UV:
B. pumilus Predicts *Adenovirus*





Lessons-Learned To-Date

- Use of *Adenovirus* microbes in conventional validation is impractical; if used the dataset should be large to assess high point-to-point variability/uncertainty

- In both LP & MP analyses, *MS2* microbes alone provided good correlations and conservative predictions of *AD2* inactivation, better than *B. pumilus* alone or combined with *MS2*

- Low-wavelength sensor paired with typical ONORM sensor can be effective for monitoring UV full germicidal range

Lessons-Learned To-Date

- The UV industry will need to develop verification & calibration standards for low-wave sensors

- Credit for low-wave UV contributions results show 2-3X lower REDs than LP *AD2* RED=186 (4-log kill) so benefits of MP vs LP demonstrated in UV reactor scenarios

- Combined Variable S/Q/DL algorithm variants & ASCFs, map UV reactor- validation datasets well, useful for predicting *Crypto & AD2* scenarios with test microbes, and simplifies uncertainty/bias factors for VF

Questions & Discussion

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