

Photocatalytic Inactivation of Viruses Using Low-Pressure Ultraviolet Light in a Titanium Dioxide Suspension

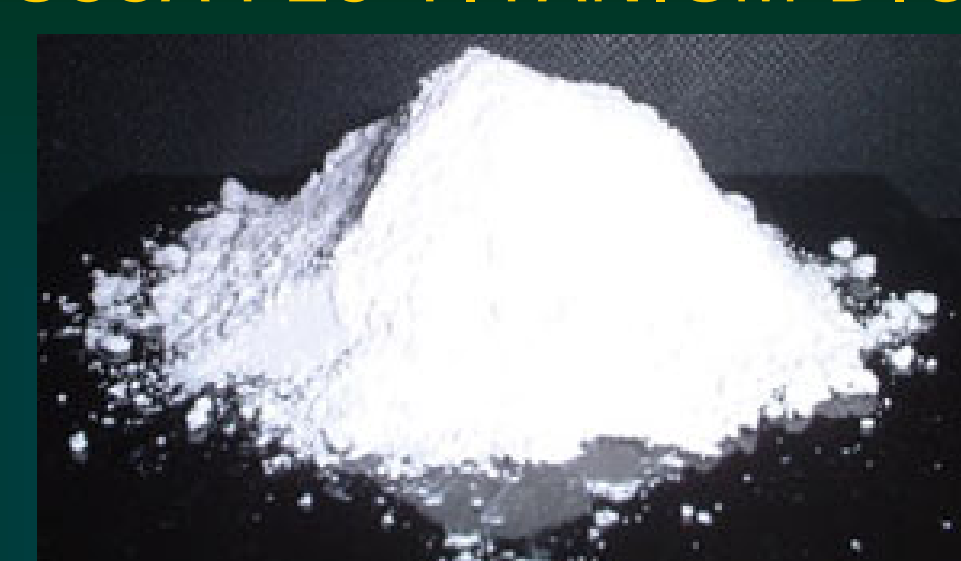
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Abstract

The carcinogenic potential of chlorine disinfection byproducts and recent changes in water quality regulations have led to a greater emphasis on alternative disinfection mechanisms. Although the inactivation of viruses using low-pressure ultraviolet (UV) light has been studied extensively, little research has been performed to demonstrate the efficacy of using UV light in conjunction with a photocatalyst for viral inactivation. The intent of this research is to explore the synergistic disinfection potential of ultraviolet light and titanium dioxide (TiO₂) with respect to four potential surrogate bacteriophages (MS2, PRD1, phi-X174, and fr) and adenovirus type 4. Although adenoviruses are highly resistant to UV disinfection, the reactive oxygen species generated by TiO₂ may provide a greater level of inactivation when added to typical UV reactors. A bench-scale collimated beam apparatus comprised of a 15-watt, low-pressure (254 nm) UV bulb and 1 mg/L Degussa P25 TiO₂ was used in each experiment. This setup achieved nearly 20% reductions in the UV doses required for four-log inactivation of the UV-resistant viruses (MS2, PRD1, and adenovirus 4). In addition to the standard setup, these dose reductions were achieved by changes in pH based on isoelectric points and pre-exposure of the TiO₂ nanoparticles to UV light. For the UV-susceptible bacteriophages (fr and phi-X174), the UV dose reductions ranged from 0-10%, respectively. In addition, this study demonstrated the application of an integrated cell culture quantitative polymerase chain reaction (ICC-qPCR) method for adenovirus disinfection studies. Using the primary liver carcinoma (PLC) cell line and a 24-hour incubation period, the ICC-qPCR method provided significant differentiation between standard spiking levels in addition to a negative control. Furthermore, the incubation period produced a 10-fold increase in viral quantity over the standard spiking levels. These results provide a proof-of-concept for the synergistic effects of UV light and TiO₂ in addition to substantiating further testing of adenovirus and other potential pathogens in water treatment applications.

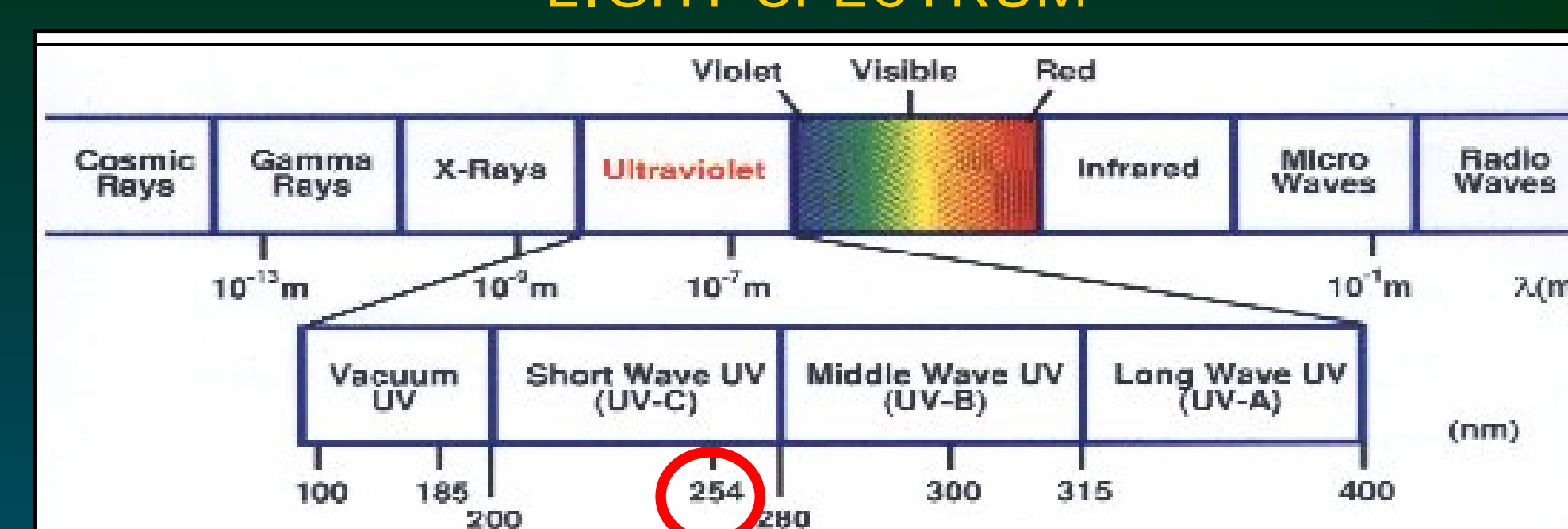
Background

DEGUSSA P25 TITANIUM DIOXIDE



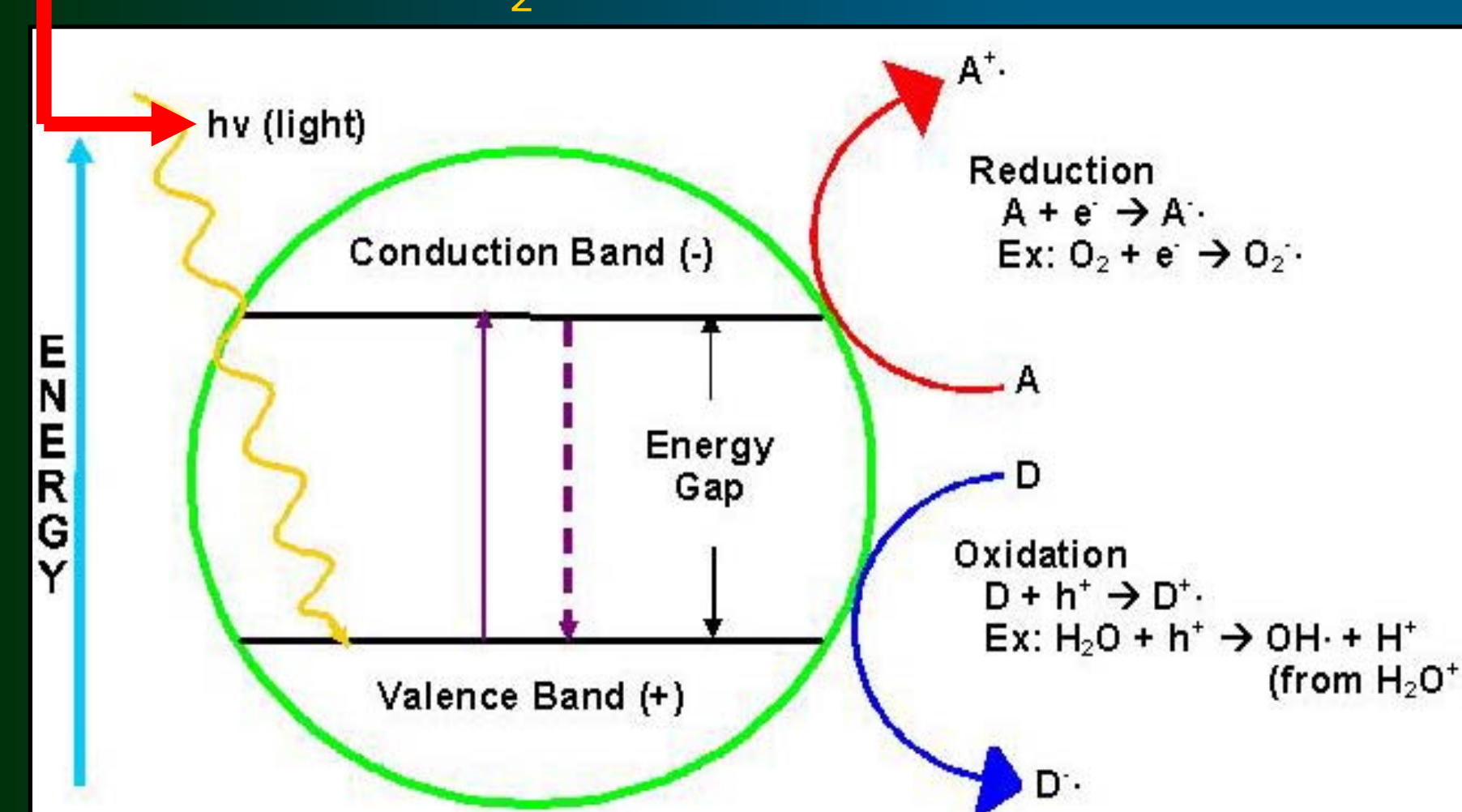
Bandgap Energy = $h\nu = 3.2$ eV
Activation Wavelength = $\lambda < 387$ nm
Optimal Dose = 1 mg/L
Sonication = 200 W/L for 15 minutes

LIGHT SPECTRUM



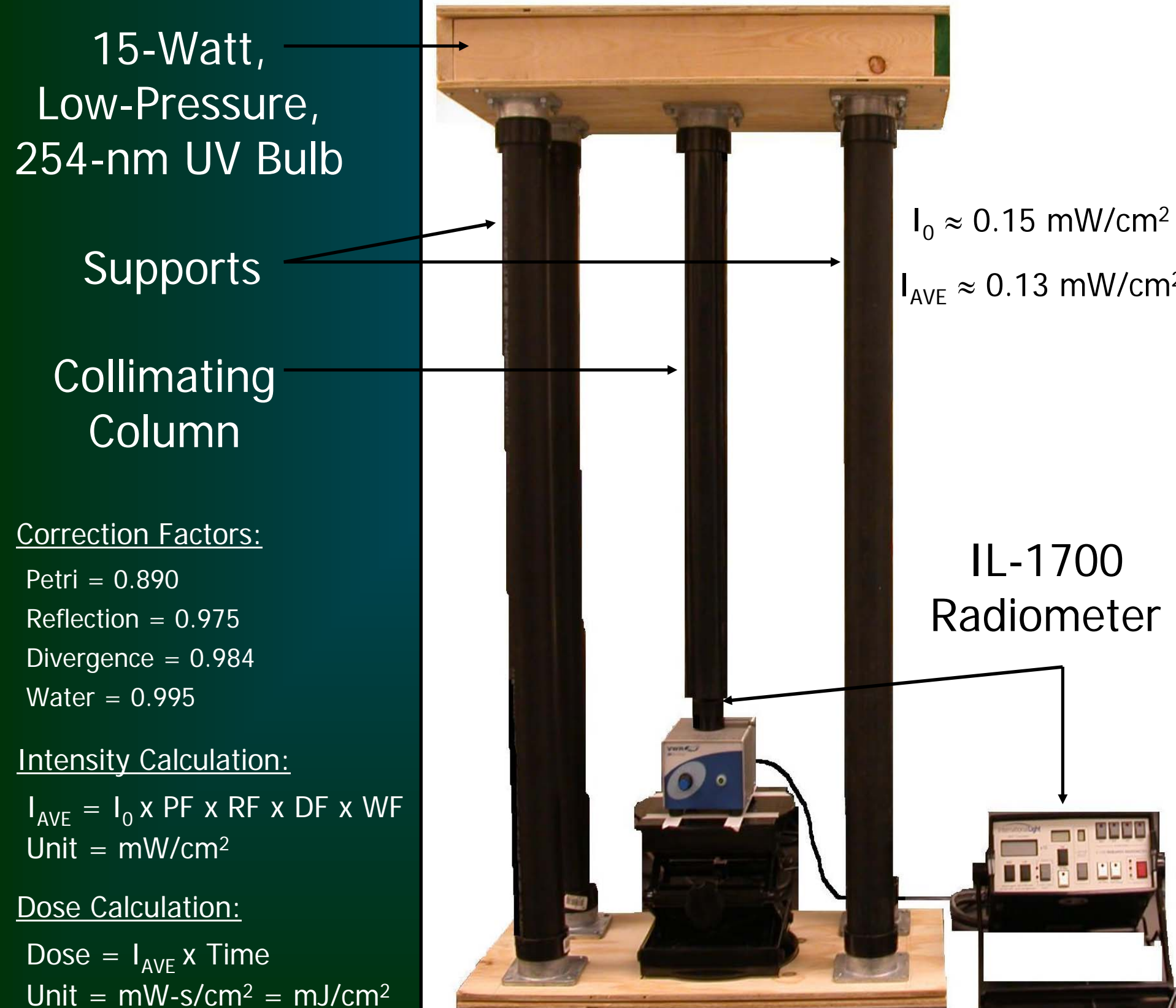
The monochromatic output (254 nm) of low-pressure UV bulbs is the most effective wavelength for disinfection purposes. Conversely, medium-pressure UV bulbs emit light over a wide range of wavelengths but at much higher intensities. Black-light bulbs (350-400 nm), which have been used in similar photocatalysis studies, are capable of activating TiO₂, but they are not sufficient for disinfection in water and wastewater treatment.

TiO₂ PHOTOCATALYSIS

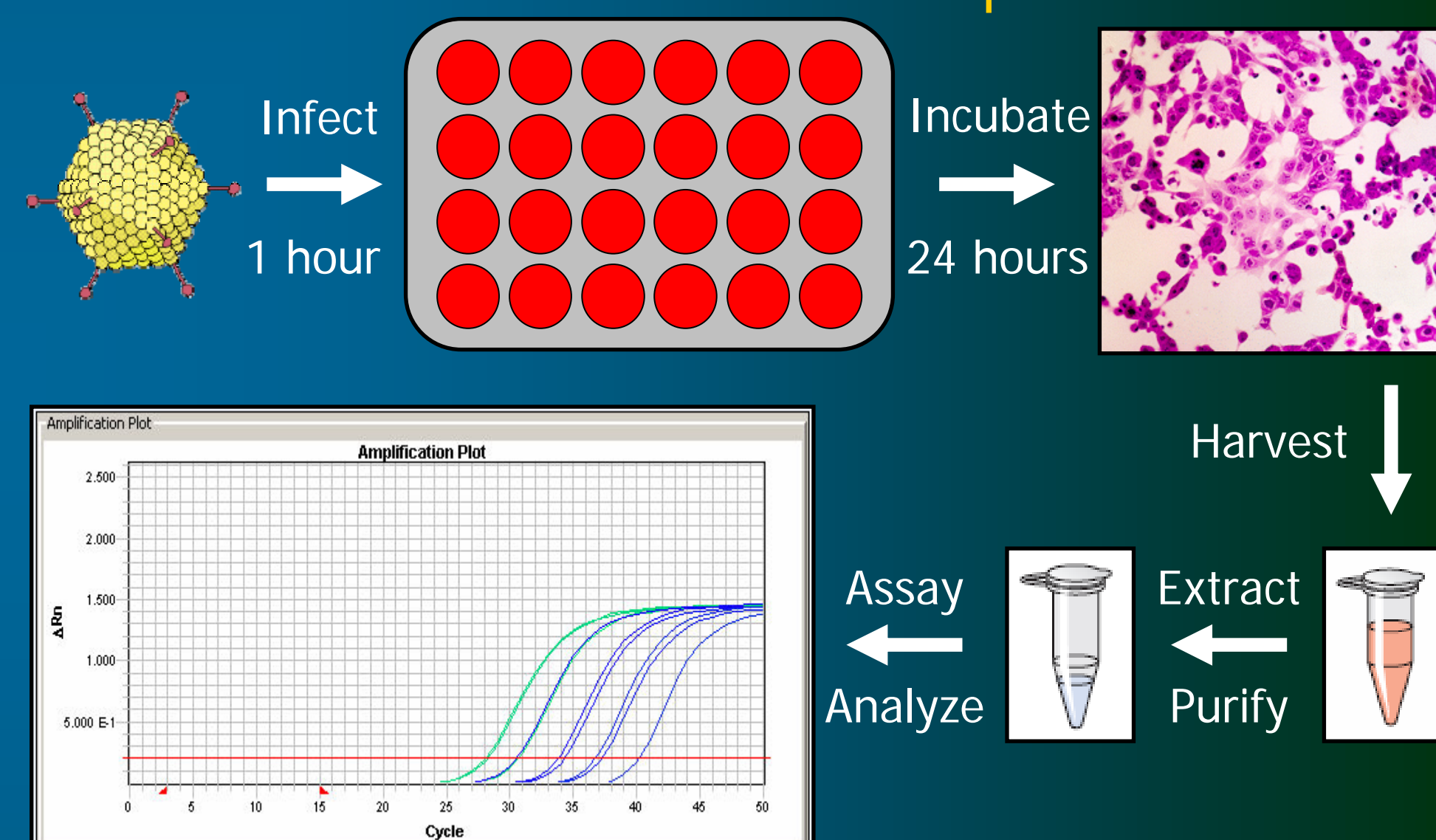


COLLIMATED BEAM DESIGN

The purpose of a collimated beam is to form parallel rays of light that strike the target surface at a right angle, thereby standardizing each irradiation experiment.

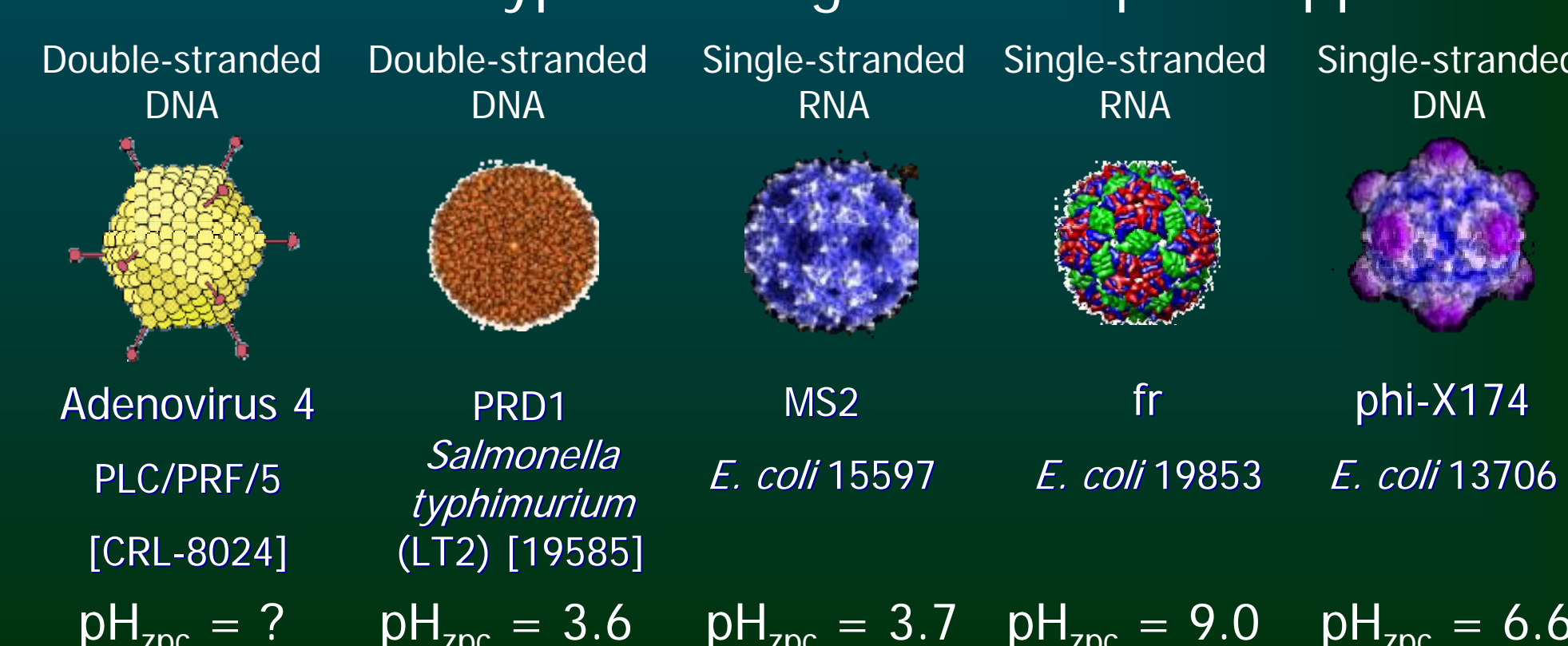


OVERVIEW OF ICC-qPCR



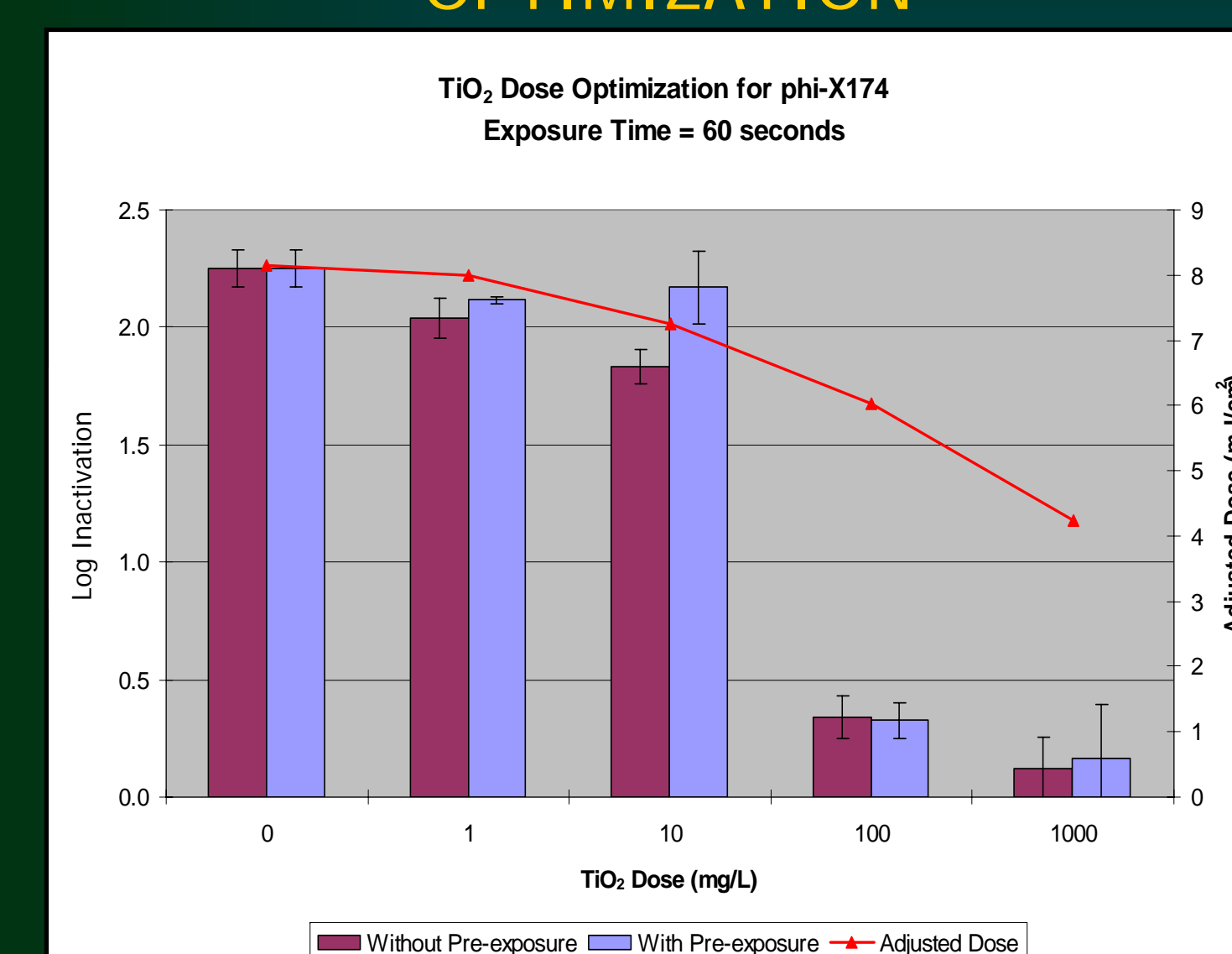
VIRUSES

Adenoviruses are highly resistant to UV inactivation. Four-log inactivation may require a UV dose of up to 200 mJ/cm². Using optimized TiO₂ parameters from previous bacteriophage experiments, photocatalysis may be able to reduce the dose requirements for adenovirus inactivation. The objective of this study was to quantify the UV and photocatalytic inactivation of adenovirus type 4 using an ICC-qPCR approach.



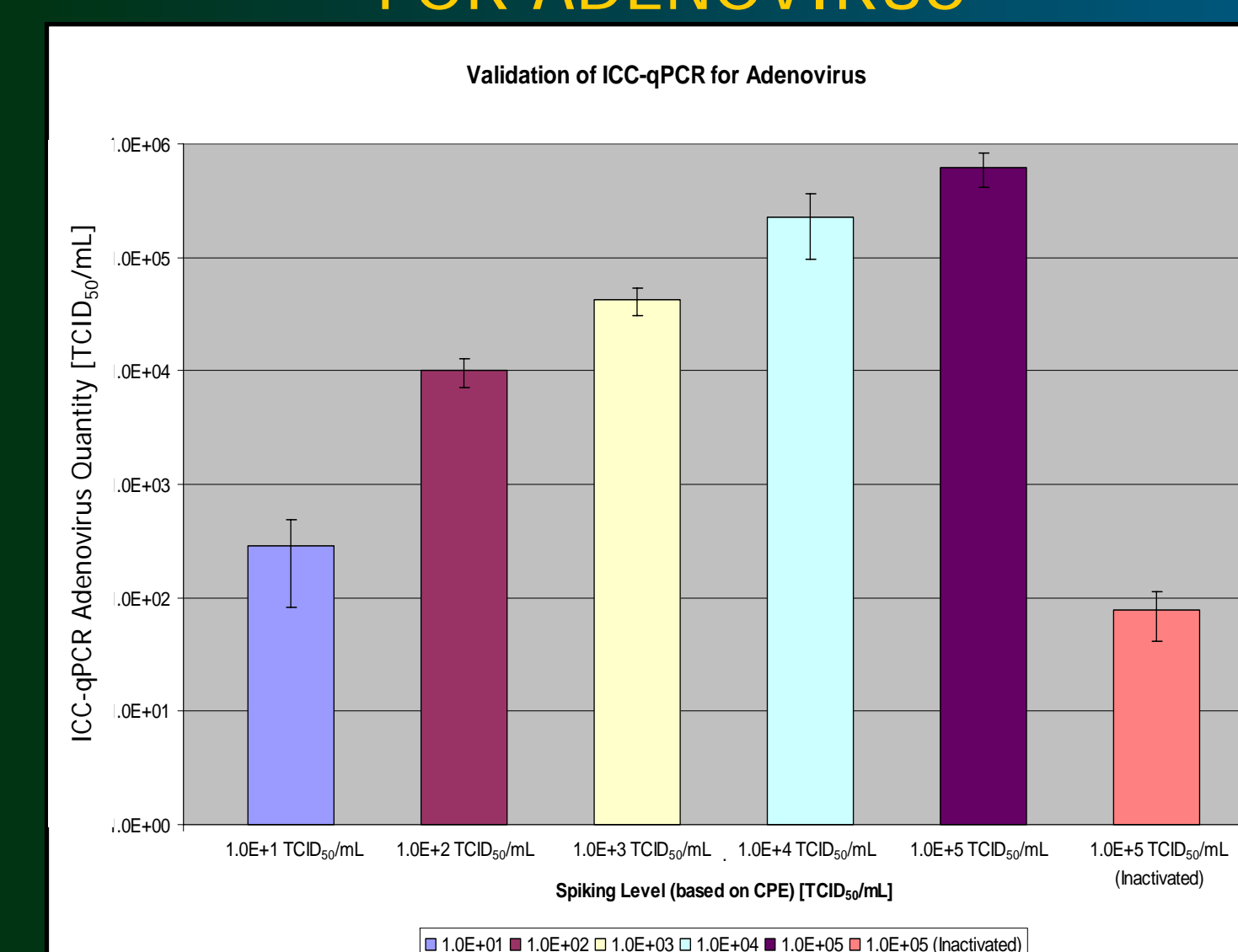
Results

TiO₂ DOSE OPTIMIZATION



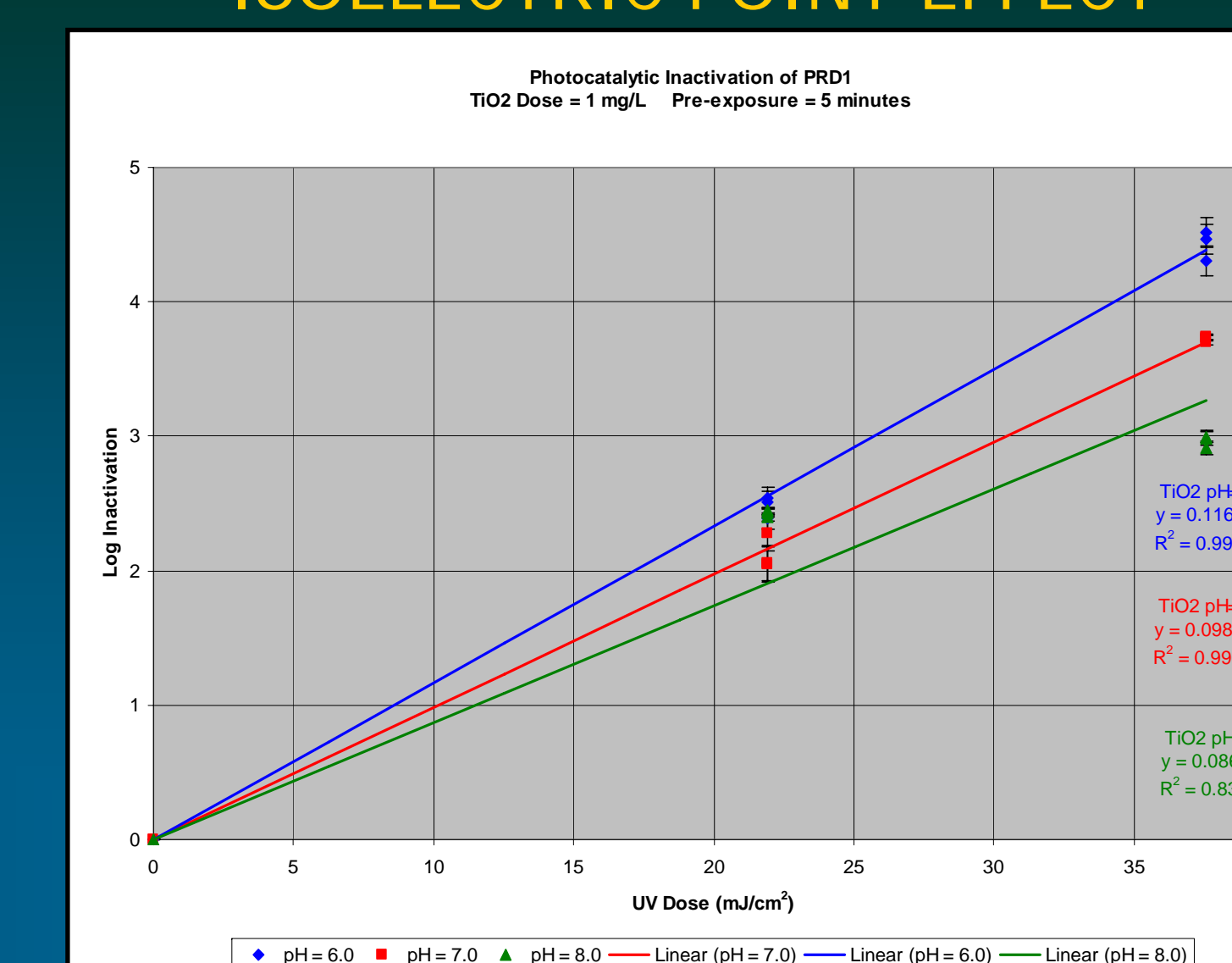
As the TiO₂ dose increases, the water becomes increasingly cloudy—approaching the color of milk—and inactivation decreases significantly. As a result, 1 mg/L was selected as the optimal dose to minimize light scattering and reflection.

ICC-qPCR VALIDATION FOR ADENOVIRUS



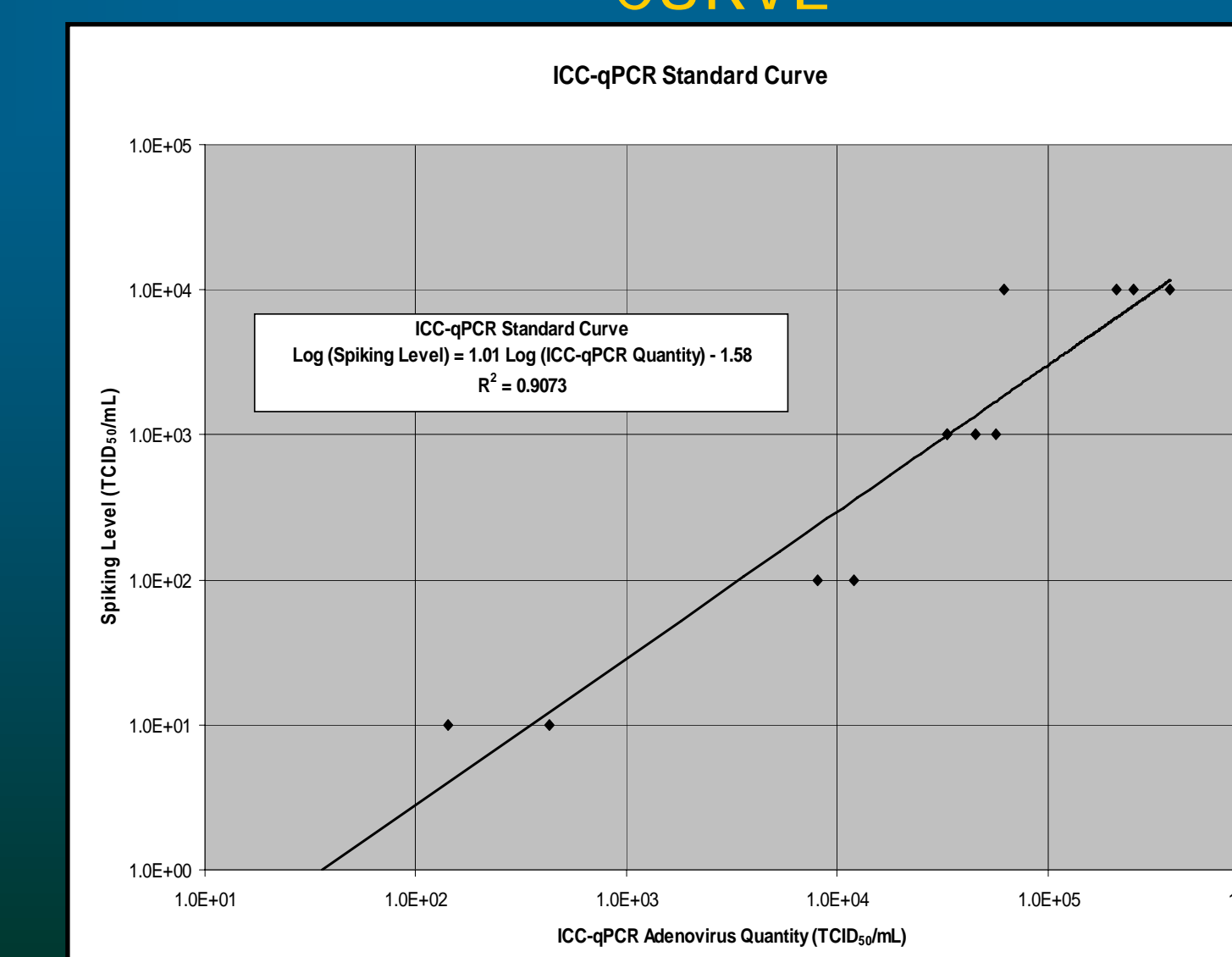
The ICC-qPCR validation graph illustrates the differences between the infectious spiking levels and the inactivation control.

pH OPTIMIZATION & ISOELECTRIC POINT EFFECT



The isoelectric point of TiO₂ is approximately 6.3. At a pH of 6.0, positively charged TiO₂ will be attracted to the negatively charged bacteriophages, thereby increasing the exposure of the bacteriophages to surface hydroxyl radicals.

ICC-qPCR STANDARD CURVE



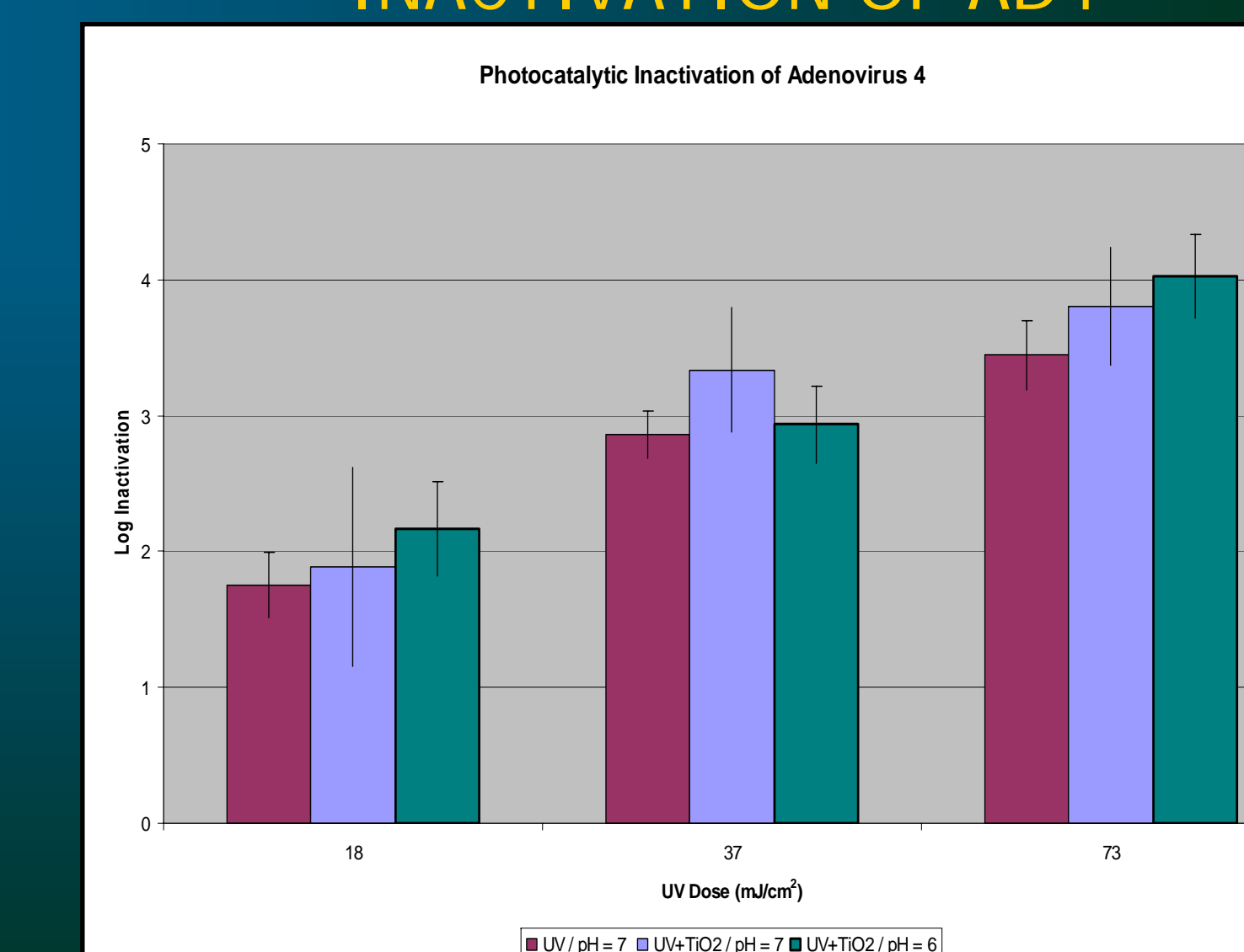
The ICC-qPCR standard curve can be used to calculate the original number of infectious adenoviruses in unknown samples.

DOSE REQUIREMENTS FOR 4-LOG INACTIVATION (mJ/cm²)

Bacteriophage	UV	UV/TiO ₂	% Reduction
MS2	46	39	15%
PRD1	41	34	17%
phi-X174	16	15	6%
fr	15	15	0%

The dose requirements and percent reductions are based on the optimized TiO₂ conditions: 1 mg/L of Degussa P25 TiO₂, pre-exposure of the TiO₂ nanoparticles to UV light, and pH adjustments based on isoelectric points.

PHOTOCATALYTIC INACTIVATION OF AD4



This graph illustrates the differences between the UV and UV/TiO₂ samples after calculating inactivation using the ICC-qPCR method.

Summary

- Due to light scattering, reflection, and absorbance at higher TiO₂ doses, 1 mg/L was selected as the optimal dose.
- pH adjustments based on isoelectric points increased the photocatalytic efficiency for some bacteriophages.
- Photocatalytic inactivation was more effective against the UV-resistant bacteriophages (MS2 and PRD1) than the UV-susceptible bacteriophages (phi-X174 and fr).
- TiO₂ photocatalysis does not seem to significantly improve adenovirus inactivation.
- Although the destruction of organics will likely drive the use of TiO₂ photocatalysis, this technology will also provide some level of microbial inactivation. More research is necessary to maximize the effectiveness of this technology and generate a better understanding of potential applications.