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Field-testing UV Disinfection of Drinking Water

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A recently invented device, "UV Waterworks," uses ultraviolet (UV) light to disinfect drinking water. Its novel features are: low cost, robust design, rapid disinfection (12 seconds), low electricity use (40W), low maintenance (every 6 months), high flow rate (15 l/min) and ability to work with unpressurized water sources. The device could service a community of 1000 persons, at an annual total cost of less than 10 cents US per person. UV Waterworks has been successfully tested in the laboratory. Limited field trials of an early version of the device were conducted in India in 1994-95. Insights from these trials led to the present design. Extended field trials of UV Waterworks, initiated in South Africa in February 1997, will be coordinated by the South African Center for Essential Community Services (SACECS), with technical and organizational support from Lawrence Berkeley National Laboratory (LBNL) and the Natural Resources Defense Council (both USA). The first of the eight planned sites of the year long trial is an AIDS hospice near Durban. Durban Metro Water and LBNL lab-tested a UV Waterworks unit prior to installing it at the hospice in August, 1997. We describe the field test plans and preliminary results from Durban.

UV disinfection of drinking water

As of 1994, more than 1 billion people in the world still lacked access to safe drinking water (WHO/ WSSCC/UNICEF, 1996). The problem of unsafe drinking water is recognized to be not an isolated technical problem, but interrelated to the problems of adequate water supply, community education in public hygiene, access to sanitation, and effective and safe disposal of human and animal wastes (USAID, 1990). Nevertheless, a device that offers affordable, simple, robust and low-maintenance disinfection of drinking water can be an important part of the solution.

The use of ultraviolet (UV) light to disinfect water of water-borne pathogens capitalizes on the germicidal properties of a narrow range of the UV spectrum. Given proper dosage, UV wavelengths ranging from 240 to 280 nanometers (nm) deactivate, or effectively kill, microorganisms by damaging their DNA so as to prevent the DNA, and the organism, from replicating (Harm, 1980). The UV dose, measured in microwatt-seconds per square centimeter, is the product of UV intensity and exposure time: dosages for a 90% kill of most bacteria and viruses range from 2,000 to 8,000 μW-s/cm^2, while dosages for Giardia, Cryptosporidium, and other large cysts and parasites are essentially an order of magnitude greater (approximately 60,000-80,000 μW-s/cm^2) at a minimum (Wolfe, 1990).

Most current UV systems use a low-pressure or medium-pressure mercury vapor lamp and expose water to UV by pumping the water around a sleeve within which the UV lamp is supported. Typical system designs deliver UV dosages of 25,000 to 35,000 μW-s/cm^2 and are adequate to deactivate only bacteria and viruses (Wolfe, 1990). UV systems can be coupled with a prefilter to remove those larger organisms that would otherwise pass through the UV system unaffected. The prefilter also clarifies the water to improve light transmittance and therefore UV dose throughout the entire water column.

Proper handling and storage of UV-treated waters are a critical part of any UV treatment system. UV treatment does not offer any residual disinfection, and treated bacteria can repair their DNA and reactivate in a few days when exposed to visible light (Harm, 1980).

UV systems compare favorably with other water disinfection systems in terms of cost, labor, and the need for technically trained personnel for operation and maintenance: (1) Deep tubewells fitted with handpumps, while perhaps the simplest system to operate, require expensive drilling rigs, are immobile sources, and often produce hard water that some communities find distasteful; (2) Chlorine disinfection treats larger organisms and offers residual disinfection, but systems are expensive with their need for special operator training and a steady supply of a potentially hazardous material; (3) Boiling water over a biomass cookstove is the most reliable treatment method, but it demands labor, and imposes high economic, environmental, and human health costs. UV treatment is rapid and, in terms of primary energy use, approximately 20,000 times more efficient than boiling.

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UV Waterworks (UVWw)

In the summer of 1993, prompted by the outbreak in India of a mutant strain of cholera ("Bengal" Cholera) against which there was no vaccine, we initiated a design effort for a low-cost, robust, and low maintenance device for drinking water disinfection. We found that one could disinfect water with a UV dose of 40,000 μW-s/cm^2 at an attractively low cost of 2 US cents per metric ton of water. However, the available UV water disinfection systems had two drawbacks: they all (1) required a pressurized source of water, due to various filters integral to the devices, and (2) used a UV-transparent sleeve to separate the UV lamp from the surrounding water stream. This sleeve fouled with biofilm and chemical deposits, reducing its UV-transparency, and thus required frequent mechanical and chemical cleaning. This was beyond the technical and time resources of the communities we hoped to help.

Our goal was to disinfect communities' drinking water collected by hand from surface sources, or with handpumps. The water entering the device might have a pressure of only a few cm of water column. Thus, we decided to do away with any integrated filter (and the need for pressurized water to push it through the filter). If filtering was necessary, it would have to be done outside the device, using a slow sand filter, or an in-line filter cartridge if one had a pressurized line. We circumvented the sleeve fouling problem with a design having a bare UV lamp supported below a reflector, above the free surface of flowing water. There are no solid surfaces prone to fouling between the water and the UV lamp. We set the maintenance interval of the design conservatively at 6 months. Our initial design was wholly of welded stainless steel sheet, consumed 40 Watts, disinfected 30 liters per minute (lpm), and cost about US$900.

Limited field tests of this design were conducted in India. The Indian communities informed us that the flow capacity of the device was higher than necessary, and that the devices were too bulky and costly. In response, we developed the present design (shown schematically in Figure 1) that still uses 40 Watts, but now disinfects 15 lpm, is much more compact, and has a substantially lower manufacturing cost. The unit is designed to treat water with a UV extinction coefficient of 0.3 cm^{-1}, equal to that of the average effluent from US municipal wastewater treatment plants.

The present design was tested at Lawrence Berkeley National Laboratory (LBNL) for its effect on a pure strain of *E.coli* in (a) clear and (b) turbid deionized water, and (c) on total coliforms in local creek water. The results are presented in Table 1. As expected, UVWw was most effective against bacteria in deionized water and least effective with turbid, unfiltered creek water.

Goals and work plan of field tests in South Africa

The primary objectives of the field-test are to: (1) identify and correct any design problems and unanticipated technical flaws in the device, and ensure its compatibility with the user preferences and requirements in South African communities; (2) evaluate and document the field performance of the device and its effectiveness in limiting the occurrence of waterborne biological contaminants in drinking water; (3) determine appropriate media and delivery systems for (a) community placement and acceptance of the device, (b) the necessary user education to assure sanitary and exclusive use of disinfected water for drinking and food preparation, and (c) relevant community education in public hygiene and sanitary practices; and (4) determine the content and delivery systems for technical training of maintenance personnel, local management systems for community ownership and operation of the

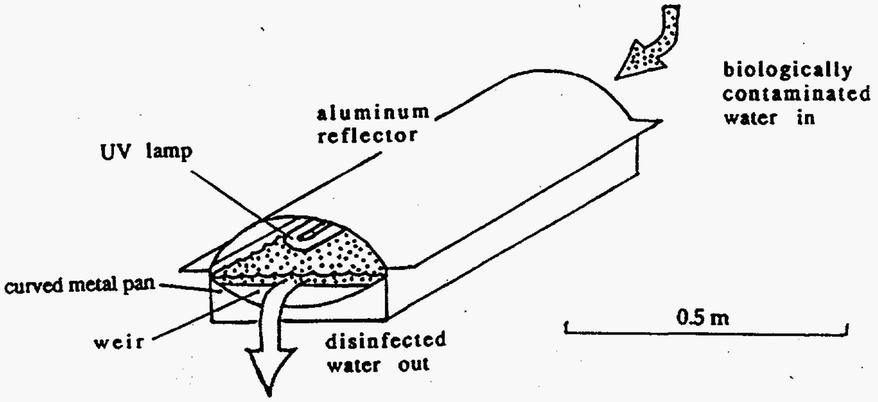

Figure 1. Simplified schematic of the interior of UV Waterworks. The housing (not shown) is made of rugged molded plastic or metal.

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device to ensure its ongoing functioning.

We plan to place UVWw at a total of 8 locations in a phased manner, thus enabling us to improve our approach in the later stages of the work from the lessons learned in the early stages. Of these 8 installations, 3 will be intensively monitored (about 50 samples a week for 50 weeks) for the bacterial contamination along the drinking water chain, from the outlet of the device, to the household storage cisterns, to the water in the drinking cups. The other 5 sites will be monitored less frequently (about 10 samples a week for about 20 weeks).

The community placement of the device, and community education and management of the technology will be organized by working with local NGOs who have the trust of the community and who understand the local customs, politics, and issues. We will document the outcome of various approaches to address these important dimensions of the problem.

Table 1. Disinfection of various water samples using UV Waterworks at LBNL

Sample description	Test description	Initial Concentration (CFU/100 ml)*	Final Concentration (CFU/100 ml)*	Final/Initial Concentration
(a) *E. coli* in deionized water (DI)	flow through unit at 15 l/min	5×10^5, 6×10^5, Colilert** test: yellow	< 1, < 1 Colilert** test: clear	$< 2 \times 10^{-6}$ $< 2 \times 10^{-6}$
(b) *E. coli* in DI made turbid with various concentrations of kaolinite	flow through unit at 15 l/min, 0.1 - 80 NTU			1 to 3×10^{-6}
(c) surface water from a local creek:	(i) flow through unit at 15 l/min (ii) 12 sec UV exposure of 210 ml of sample (iii) same as (ii), but after filtering through 2μm	(i) 10^4 (10 NTU), 10^3 (80 NTU) (ii) 10^5 (iii) 1.4×10^5, 8×10^4	(i) < 1, < 1 (ii) 9 (iii) < 1	(i) $< 1 \times 10^{-4}$, $< 1 \times 10^{-3}$ (ii) 9×10^{-5} (iii) $< 7 \times 10^{-6}$, $< 2 \times 10^{-5}$

* membrane filter method according to <u>Standard Methods for the Examination of Water and Wastewater</u>, 18th ed. (1992), Method 9222 B. Petri dishes prepared with HACH brand m-ENDO prepared broth, a total coliform broth, although some other varieties of bacteria may also form colonies. This count is therefore neither as limiting as a total coliform count nor as inclusive as a total heterotrophic plate count.

** Colilert (a product of IDEXX Laboratories, Inc.) turns sample from clear to yellow if any coliform bacteria are present.

Testing UVWw for South Africa installation

A UVWw production prototype was tested at Durban Metro Water prior to its installation at an AIDS hospice for infants near Durban. This hospice relies on untreated water from a nearby deep borehole. The performance of UVWw in Durban with reagent grade water spiked with *E.coli* was consistent with tests performed at LBNL (see Table 1). The unit reduced concentrations of *E.coli* and total coliforms from slightly above 10,000 CFU/100ml to less than 1 CFU/100ml (South African tests uses Chromocult growth media by Merck).

Durban Metro Water also wanted to test UVWw performance with water from their major surface source, Inanda dam (ID). A 2 liter sample of water from ID was tested at LBNL for both biological and physical characteristics to test its amenability to UV disinfection. We found the ID water samples had a UV extinction coefficient of approximately 0.3 cm^{-1} and had significant turbidity from suspended particles. A reduction in UV energy dose delivered to the bacteria from reduced transmittance and shielding by suspended particles can be expected to decrease biological deactivation. Using the same testing protocol as used for earlier tests of creek water (see Table 1, row c, column 2), the concentration of total coliforms (see first footnote beneath Table 1) was reduced from 20,000 CFU/100ml to 20 CFU/100ml. Filtering the sample through a 2μm filter led to an improved performance, with a 10^4 reduction after UV exposure.

UVWw performance at the first field site installation in South Africa

We measured the borehole water from the field test site to have a UV extinction coefficient almost identical to that of distilled water. It also was visually clear. In lab tests in Durban, exposing three 170ml samples in a 4 cm deep layer for ten seconds in the UV unit reduced initial coliform concentrations of 6 million CFU/100ml to an average of 6 CFU/100ml, a 10^6 reduction. With these results in hand, we installed the unit to disinfect the water supplied to the kitchen at the Lily of the Valley hospice. The flow rate was set at 8 liters/minute, which is adequate for the hospice needs (primarily preparation of baby formula and providing drinking water in feeding bottles). We measured 4,000 coliform (including 200 E. coli) CFU/100ml in the untreated water entering the unit, and no detectable coliforms in the treated water leaving the UV unit.

Concluding remarks

Deep borehole water from the Lily of the Valley AIDS hospice was found to be contaminated with fecal and total coliforms. The UVWw unit successfully treated this water and delivered drinking water that meets WHO and USEPA bacterial standards. As expected, we found that low UV transmittance and high turbidity of water reduced UVWw performance; hence it is important to test these characteristics of site water samples prior to unit installation.

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