MIT UV-Tube Project

1. Project Summary

Waterborne illness associated with unsafe drinking water and poor sanitation is still a major cause of death in the developing world (World Health Organization, 2002). These casualties could be avoided through improved water supply, water quality, hygiene education and sanitation. The MIT UV-Tube Project focuses on improving water quality for people in developing areas where other water treatment methods are not applied consistently because of their cost, inconvenience, complexity, or energy requirements.

We are seeking funding to develop and field test a simple, low-cost ultraviolet (UV) water disinfection system constructed from ferro cement. The UV-Tube Project at the University of California at Berkeley has been working on a similar system made from PVC and stainless steel since 1998. Most test results have been encouraging; however, degradation of the PVC when stagnant water is exposed to UV for extended periods leads to low but appreciable concentrations of disinfection byproducts and taste and odor problems in the outlet water. We are partnering with the Berkeley UV-Tube Project team to explore using ferro cement instead of PVC with the goal of eliminating byproducts, taste and odor. We also expect the ferro cement design to be less expensive and easier to maintain than the PVC and stainless steel design. This new design must be tested for microbiological effectiveness and materials stability under UV in the laboratory and for effectiveness, cultural appropriateness and acceptance by users in the field. We are asking for $8,330 to support this laboratory and field testing.

Pending laboratory test results, field tests are planned for June 2003 in Borgne, Haiti where manufactured, off-the-shelf UV disinfection systems have been previously introduced. The new Borgne Environmental Technology Center / Idea Exchange focuses on inspiring community involvement and creativity in environmental problem solving. The field test of the ferro cement UV-Tube will be the initial project of the center. We hope to build at least three prototypes to replace the three solar powered manufactured UV systems in Borgne (which have had maintenance issues). We also plan to test the microbiological effectiveness of the UV-Tubes in the field and to collect user feedback on the design. Finally, if there is community interest in the technology, we hope to begin a discussion about how the ferro cement UV-Tube might be incorporated into the local culture.

The nurses at the health clinic in Borgne indicate a reduction in diarrheal illnesses among those using UV treated water. A less expensive and more easily maintainable ferro cement UV-Tube will allow disinfected water to be made accessible to a larger segment of the population and will ensure that, when people come with their water jugs, the system is not out of order.

2. Background

2.1 Drinking Water Quality

The recent World Health Organization (WHO) report on worldwide mortality indicates that waterborne illness associated with unsafe drinking water and poor sanitation is still a major cause of death in the developing world (World Health Organization, 2002). Although a variety of methods are available for treating drinking water, many people do not have access to these lifesaving technologies. Central disinfection of piped water supplies is becoming more common;

however, these systems often fail to provide adequate disinfection due to inconsistent dosing and deteriorated distribution networks. In rural and peri-urban areas without water networks, people often obtain their drinking water from contaminated springs, wells, rivers, or man-made ponds. In both situations, safe drinking water can only be obtained by treating water in the household at the point of use (POU). Unfortunately, POU methods currently available are either expensive (commercial UV, reverse osmosis, buying bottled water), require an inconvenient wait time (chlorine addition, boiling, sand filtration) or are energy intensive (boiling), and for these reasons, are applied inconsistently. In response, we are developing a technology that makes household water disinfection with ultraviolet light accessible to those who need it most.

Haiti is not only the poorest nation in the western hemisphere, but it also ranks last on the Water Poverty Index according to a recent report that considered water supply, drinking water quality, water use and management, and the health of natural water bodies (CEH Wallingford, 2002). At the Haiti Outreach: Pwoje Espwa (H.O.P.E.) Health Clinic in Borgne, Haiti at least a quarter of all patients come to the clinic suffering from preventable waterborne illnesses. Improving drinking water quality in Borgne would significantly improve the quality of life, reduce childhood mortality rates, and lessen the load on the clinic staff so that can focus more time on other pressing issues such as AIDS treatment and prevention.

2.2 The UV-Tube Project at UC Berkeley

In the early 1990s, Dr. Ashok Gadgil, a Senior Staff Scientist at Lawrence Berkeley National Laboratory, designed a community-scale UV disinfection product called UV Waterworks for use in developing countries. Later in that decade, Dr. Lloyd Connelly, while installing several UV Waterworks devices in the Pátzcuaro region of Mexico, found that there was a need for a less expensive and simpler household treatment method. In response, Dr. Connelly downscaled and simplified the technology, creating the "UV-Tube" for which he later won the World Bank Development Marketplace competition. Design work and laboratory testing based around Dr. Connelly's stainless steel lined PVC version of the UV-Tube continued throughout 2000 and 2001. A preliminary field study was conducted in Pátzcuaro, Mexico during summer and fall 2001. The Pátzcuaro development organization *Grupo Interdisciplinario de Tecnología Rural y Apropiada* (GIRA) – Interdisciplinary Rural and Appropriate Technology Group – held a community workshop where three UV-Tubes were constructed and later installed in local households. Participants were instructed not to drink from the tubes, because at the time of the study, materials degradation tests were not complete. Design changes were made based on user feedback and field observations, and laboratory tests were repeated for the new design.

Results of the materials degradation testing led to concerns about disinfection byproducts, and the instructions for using the stainless steel lined PVC UV-Tube were subsequently altered to ensure safe operation. Unfortunately, the changes added some complexity to the operating procedure. A full scale field study of the stainless steel lined PVC UV-Tube using the altered operation instructions will be conducted in 2003 near Cuernavaca, Mexico by Instituto Mexicano de Tecnología del Agua, (IMTA), the Mexican Institute of Water Technology. Because of the materials degradation results, the UV-Tube Project has been looking for partners to explore making UV-Tubes from other common materials. Members of the MIT UV-Tube Team suggested using ferro cement. We hypothesize that ferro cement will prove inexpensive, available, and easy to work with in developing areas, and will not react significantly with UV light. Also, because some field work has already been completed in Mexico, we propose to field test the ferro cement tube in Haiti in order to investigate the cross cultural acceptance of the UV-Tube.

2.3 Haiti Outreach: Pwoje Espwa

Haiti Outreach: Pwoje Espwa (H.O.P.E.), based in Rochester, New York and Borgne, Haiti is a non-governmental organization that seeks to work in solidarity with the people of Borgne and to stand by them as they struggle to build a just and equitable community. H.O.P.E. has a number of projects in Borgne including a community health center, a mill, a microlending bank, a scholarship program and three solar powered community ultraviolet water disinfection systems. All three UV systems were purchased in the United States from companies that supply camps and motor homes with water systems. The cost of each UV unit was around $450. The first UV system was installed at the H.O.P.E. Health Clinic in June 2000, and, when operating, it provides approximately 200 families a week with free, safe drinking water. Two other UV systems were installed outside of Borgne in March 2001. These systems were built by teams of six neighborhood people who then selected three operators (sometimes referred to as "Doctor Water" in Borgne) from their ranks to run the UV units. Operators charge a small fee to fill their neighbors' five gallon buckets with disinfected water. The profits compensate the operator for cleaning, maintaining, and operating the system. He or she is also responsible for educating users about safe water storage and use habits.

Unfortunately, there have been some problems with the units. Because the parts are not available locally and shipping parts from the United States is often a lengthy process, the units do not operate consistently. H.O.P.E. is, therefore, very interested in finding UV units that can be built and maintained from locally available parts.

2.4 Borgne Environmental Technology Center / Idea Exchange

H.O.P.E. is currently planning to establish a new Environmental Technology Center / Idea Exchange in Borgne, Haiti beginning in May 2003. The purpose of the center is to build local confidence in the ability to understand, use, and modify technologies and to empower local people to work together to solve community environmental health problems. In the long term, the center will provide information and prototypes of environmental technologies used elsewhere in the world and will invite Haitian and international students to explore and test new design ideas. It will encourage (and possibly fund) local experimentation with new designs and design modifications to fit local circumstances. Finally, it will offer space for community discussion regarding which technologies to implement and how best to implement them.

The initial focus of the center will be on safe drinking water and sanitation. It will offer education, information, and prototype demonstrations on a variety of water disinfection and sanitation techniques. The field study of the ferro cement UV-Tube will be the first project of the center. Although UV will be a main focus, the center will stress the need for people to understand a variety of backup water disinfection techniques in case their primary technique is unavailable. The drinking water treatment methods explored will include UV disinfection, solar pasteurization using solar cookers or SODIS, pottery filters, boiling, and chlorine addition. Initially, sanitation projects will focus on development of an ecological dry toilet prototype for use in the center and community education and discussion about nutrient and pathogen cycles.

An anthropology student working with H.O.P.E. will explore social and cultural attitudes toward human wastes.

3. Project Description

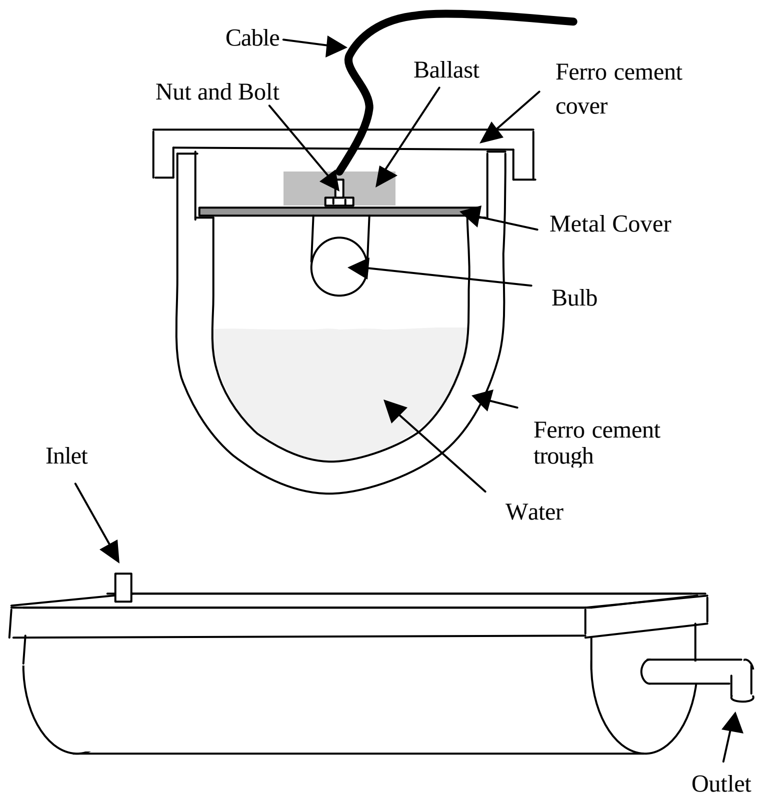
3.1 Design Innovation

The UV-Tube is a household (point-of-use) water disinfection device for people with limited resources. Similar to a number of water treatment plants in Europe and the United States, UV-Tubes use ultraviolet (UV-C) light to inactivate pathogens, including the waterborne bacteria, viruses and protozoa which cause dysentery, cholera, polio, typhoid fever, cryptosporidiosis and giardiasis. UV-Tubes, however, may be constructed from common, low-cost materials available in developing areas and are easy to use. Other household UV disinfection units on the market cost between about $300 and $1000, a price much too high for household use in developing countries. UV-Tubes have been made by local people in Mexico for as little as $40. They are also energy conserving devices that require less energy per liter than either boiling or transporting bottled water from a bottling plant – two common methods of obtaining safe drinking water. Finally, UV-Tubes are a community-level solution to the problem of contaminated drinking water. They are built by users in community workshops or by local entrepreneurs, and they are evaluated by users who provide feedback to the design process. Workshops also provide opportunities for community education on water quality, hygiene, and health and require the involvement of a variety of stakeholders including local non-governmental organizations, users, and community leaders.

UV-Tubes were originally constructed of stainless steel lined PVC tube by students at the Renewable and Appropriate Energy Lab (RAEL) at UC Berkeley. However, because of materials degradation problems, designs using different materials are needed. The MIT UV-Tube Project proposes to investigate using ferro cement as the main construction material.

The ferro cement UV-Tube consists of a ferro cement trough with two covers, one made from metal (preferably aluminum for its high UV reflectance) and a second made from any commonly available non-metal material such as wood, ferro cement, or plastic. The metal cover sits on an internal ledge in the top of the ferro cement trough (see figure 1). Bulb holders are attached to the metal cover to hold the germicidal (UV) bulb, and holes are drilled for the inlet, electrical cables, and window. The ballast sits on top of the metal cover. The second, external cover is

Figure 1: Cross Section and Side View of the Ferro Cement UV-Tube



raised about 2 inches above the metal cover to allow space for the ballast, and is used to protect users from the electrical connections. The second cover also has clearance holes for the inlet, cables, and window. During use, the water enters at one end of the trough through a copper elbow inlet in the lids. It then flows along the bottom (beneath the germicidal bulb) until it reaches an outlet at the opposite end of the trough where it exits. The height of the outlet sets the depth of the water in the trough and regulates the hydraulic retention time. Since the UV-Tube does not require water pressure to operate, it may be connected directly to a faucet or filled with a funnel and bucket.

In Mexico, 8, 15, and 30 Watt germicidal bulbs are available in hardware and lighting stores. UV-Tubes can be made from each size by altering the length of the trough and adjusting the flow rate to make sure a sufficient UV fluence (dose) is achieved in the chamber. We feel that the 15 Watt bulbs are most suited to household use. UV-Tubes made with the 30 Watt bulbs are about 120 cm long, too long to be easily incorporated into Mexican kitchens. The UV intensity of the 8 Watt bulbs is low, so the operating flow rate must be quite low—about 1 liter per minute. UV-Tubes made with the 15 Watt bulbs are about 75 cm long and can be operated at flow rates of 3 to 5 liters per minute. We do not currently know if germicidal bulbs are available in Haiti, but we expect that lighting stores in Cap Haitien that carry General Electric or Phillips brand florescent lights would be able to order them.

Based on January 2003 prices in Cuernavaca, Mexico, the cost of the stainless steel lined UV-Tube compares favorably with most other means of obtaining safe drinking water. Using chlorine disinfection is less expensive; however, it is difficult to achieve the correct dose—enough chlorine to inactivate the microorganisms without leaving a chlorine aftertaste. Chlorine also requires a wait time before the water is safe to consume. The energy use of the UV Tube also compares well with other methods.

Table 1. Comparison of UV-Tube with other disinfection systems *(based on January 2003 prices in Cuernavaca, Mexico)*

Option *(see appendix A for details)*	Initial Cost (dollars)	Monthly Cost (dollars)	Energy per Liter (kJ)
UV-Tube 	$41	$1.30	3
Bottled Water 	$3	$12 (8 bottles at $1.50 ea.)	70 (transportation only)
Purchased UV System	$300	$1.30	3
Boiling with Gas 	$20-30	$10	558
Adding Chlorine	$3	Minimal	Minimal

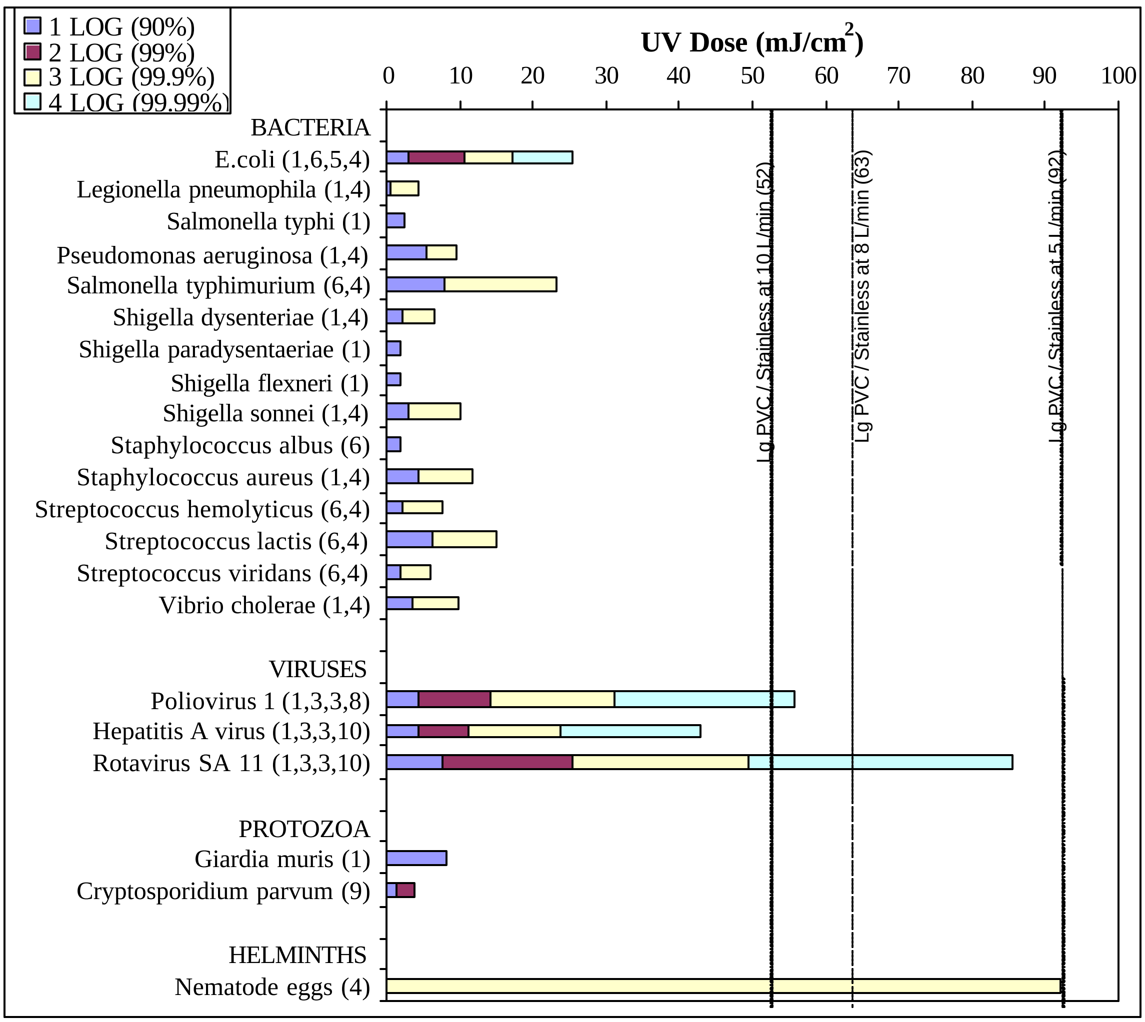
We expect the final cost of the ferro cement tube to be similar to or less than the cost of the stainless steel lined PVC tube. The monthly cost includes electricity and the annual purchase of a new germicidal bulb. The bulbs cost between $10 and $15 at lighting and hardware stores in Cuernavaca.

3.2 Laboratory Testing

In the laboratory the new ferro cement prototype must be tested for germicidal effectiveness and materials stability under UV light.

To determine the germicidal effectiveness of the prototype, MS2 bacteriophage will be used to establish the average fluence (dose) of UV light transmitted to water passing through the prototype at a specified flow rate. First, a fluence-inactivation curve will be generated for the MS2 by exposing samples to varied amounts of UV light using a bench-scale quasi-collimated beam apparatus. Water with a transmittance of about 70% will be inoculated with MS2 and then passed through the prototype at three flow rates. The log inactivation of the MS2 will then be compared with the fluence-inactivation curve to determine the fluence (dose). Results of similar tests completed on the 30 Watt stainless steel lined PVC UV-Tube prototypes developed at UC Berkeley are shown in Figure 2 on a plot of inactivation data for pathogens of concern (compiled from various sources).

Figure 2: Plot of UV-Tube prototype fluences (doses) compared with the pathogen resistances.



Even at a flow rate of 10 L/min, the stainless lined PVC UV-Tube inactivates more than three logs of bacteria and virus. The fluence (dose) delivered at 10 L/min, 55 mJ/cm^2 is significantly greater than 38 mJ/cm^2, as required by the National Sanitation Foundation standards (NSF/ANSI 55 "Ultraviolet Microbiological Water Treatment Systems"). At slower flow rates the fluence is even higher. We expect the ferro cement UV-Tube to provide similar fluences (doses) at the specified flow rates.

The stability of ferro cement under UV-light will be determined by simulating possible household operating conditions for the UV-Tube in the laboratory and by sending the outlet water out to a lab to be analyzed for metals and 59 common volatile organic compounds (VOCs).

If the ferro cement tube provides a fluence above the NSF standard of 38 mJ/cm^2 without producing outlet water concentrations of metals or VOCs above World Health Organization standards and tracer studies show approximate plug flow conditions, the field test will begin in early June 2003 in Borgne, Haiti.

3.3 Implementation in Borgne, Haiti

Borgne is a rural town on the north coast of Haiti about 30 miles from Cap Haitien, Haiti's second largest city. Borgne has a population of about 5,000 with 20,000 people in the surrounding areas who travel to the town for the market, shops, churches, schools, clinic, and other services. There are a number of community groups including women's groups (Gwop Fanm), church groups (Ti Legliz), and a community development group (MODEIB, Mouvement pour le Developpement Integral du Borgne).

3.3.1 Support Systems

Water: Water is piped into Borgne from a capped spring five miles away. The water flows into town by gravity trough a series of leaky pipes. A few houses have taps, but most people obtain water from the public spigots. During the dry season, there is insufficient water to supply the town continuously, and many days can pass without water flowing from the spigots. At these times, people obtain water from other unprotected springs near town, from shallow contaminated wells or from the river. Water quality testing conducted on some spigots and wells in 2001 showed the presence of fecal coliforms and *E. coli*. Although not always pathogenic themselves, these organisms are indicators of fecal contamination which may also contain pathogenic organisms. On a positive note, there was no indication of contamination from lead or pesticides and the water was generally not turbid. Most people do not treat their drinking water. Some, however, boil or add chlorine to the water they give to children, the elderly, or people who are ill. UV-Tubes can be used with any (non-turbid) water source because they can be attached directly to a household tap or can be used with a bucket and funnel. If the source is turbid, a 3-5 micron filter bag or another type of filter can be used to remove the larger particles from the water before it enters the UV-Tube.

Electricity: There is no electrical grid in Borgne. A few families and the church have generators. The H.O.P.E. health clinic and the three UV systems currently operating in Bornge run on solar power with battery backup. There is a growing trend for families to purchase rechargeable batteries and use them to power lights and radios in the house. These batteries are recharged for a fee by villagers who own generators. The UV-Tube requires about 20 Watts of power to operate which can be generated using solar panels, batteries, or possibly a human powered generator. Depending on the types of fluorescent ballasts available in Haiti, the UV-Tubes could operate on either AC or DC power. Initially, UV-Tubes will be installed with battery power and charged by a generator. As funds become available, solar panels will be purchased to charge the batteries. Another H.O.P.E. volunteer will also be exploring the possibility of using a human powered generator to operate the system.

<u>Tools and Supplies</u>: UV-Tubes can be built from common materials with common tools (See Appendix B). The H.O.P.E. clinic owns a variety of common tools and other groups in town also have basic tools. People are generally willing to lend their tools to help others complete their projects. Concrete and cement are common building materials, and many people in town are experienced in using them. Tools and supplies can be purchased in Cap Haitian (three hours away by truck), if necessary. Currently, we are not certain that germicidal bulbs are available in Haiti, but we expect that lighting stores that carry GE or Phillips brand florescent will be able to order them for the project.

<u>People:</u> The MIT UV-Tube Team will also be advised by members of H.O.P.E. and local community members in Borgne including Dr. Rose-Marie Chierici (Haitian-American professor of Anthropology at SUNY Genesseo), Dick Echols (small businessman and electrical systems expert from Alabama), Ben Georges (community leader, health agent, and member of MODEIB in Borgne), Monique Mondesir (nurse at the H.O.P.E. Health Clinic in Borgne), Shiller Monpremier (science teacher, community leader, and member of the water committee in Borgne.) MODEIB has worked with H.O.P.E. previously on a number of projects including building a cooperative mill, installing the manufactured UV units and conducting a demographic survey of the area. They have expressed interest in the UV-Tube project.

3.3.2 Plan and Timeline

March – May:	Construct a ferro cement prototype in the United States and test for germicidal effectiveness and materials stability.
May 20:	Sarah Brownell travels to Borgne to establish the Borgne Environmental Technology Center / Idea Exchange
May 21 – June 10:	Find suppliers for the ferro cement prototypes and solar panel, inverter, and electrical equipment. Persuade Cap Haitien lighting stores that carry GE or Phillips brand fluorescent lights to also stock germicidal bulbs.
June 10:	Xanat Flores and Melanie Pincus arrive in Borgne.
June 11 – 14:	Build the initial prototype with members of MODEIB and install solar panels at the Tech Center.
June 15 – 22:	Conduct disinfection tests (Hach Lauryl tryptose presence/absence tests for fecal coliforms and *E. coli* or H_2S tests) on the prototype using contaminated water and check for structural integrity.
June 23 – 25:	Write assembly, operating, and maintenance instructions in Kreyol and meet with local community groups to present the prototype and plan the field study.
June 26 - 28:	Hold a community workshop at the Technology Center to build and install three UV-Tubes and establish testing procedures.
June 28 – 30:	Train UV-Tube operators and testers selected by the community to participate in the field study.
July 1 – 3:	Set up a system to operate and test the tubes for one year through H.O.P.E. and the Technology Center. Train local people in conducting disinfection tests.

July 3 – July 2004: Local community members will field test the UV-Tubes

- Conduct monthly biological testing (fecal coliforms, *E. coli*, and possibly the H_2S test).
- Monitor for leaking or electrical problems.
- Record user feedback on water quality, health impacts, ease of use, and aesthetics.

3.3.3 Operation and Maintenance

Operation and maintenance procedures cannot be specified until laboratory testing is complete on the ferro cement UV-Tube and the community of Borgne has determined if and how they will use the UV-Tube (as a household, neighborhood, or community system, for example.) Examples of instructions for the stainless steel lined PVC UV-Tube are included in Appendix B.

4. Future Steps: Possibilities for Dissemination

The development of a local and sustainable dissemination model is an integral and integrated part of our project. It has been widely acknowledged that successful technology transfer projects rely on user involvement and investment (Agarwal 1983, Purdey, et al. 1994). We recognize that to be effective, the system not only has to be designed well technically and be socially practical and affordable, but also distributed and introduced in such a way to ensure continued use. Our design approach aims to incorporate indigenous local knowledge at every step and our dissemination strategy aims to provide the users with a sense of ownership of the product. Dissemination strategies in Borgne will depend on which methods are considered most appropriate by local leaders following the field study. However, distribution of the UV-Tube may proceed along one or more of the following paths: local organization of community workshops with non-profit support; for profit and non-profit based distribution of kits requiring no skill to assemble; or the establishment of new for-profit companies that would sell pre-assembled, ready-to-install versions of the technology. We will also make the ferro cement design and test results available on the Internet and in printed handbooks so that each household, community organization, or entrepreneur around the world can choose the UV-Tube design that is most suited to their location and preferences.

5. Community Impact

According to the local health clinic, UV water disinfection has already had some public health impact on the Borgne community and has increased community awareness of the need to drink clean water. Ferro cement UV-Tubes that can be easily built and repaired locally will ensure continued operation where the previously installed manufactured units failed to operate consistently. Since UV-Tubes are $1/10^{th}$ of the price of manufactured UV systems and cost less to purchase and use than most other drinking water treatment methods, disinfected water will be accessible to more people. Less than 20 UV-Tubes—run as neighborhood disinfection systems—could potentially serve the entire city of Borgne. As community awareness of waterborne illness prevention grows through educational programs, radio broadcasts on the local station, and promotion by the health clinic (all of which have been employed to some extent already), morbidity and childhood mortality rates due to typhoid, parasitic infections, and malnutrition should decline. The production of ferro cement UV-Tubes for nearby communities could become a source of jobs and revenue for Borgne and each UV-Tube could potentially be a small business for an operator who charges a small fee for the use of the disinfected water.

6. Team Members

Xanat Flores, Massachusetts Institute of Technology, M. Eng. in Water Quality and Environmental Engineering expected June 2003. Current research in water purification treatment techniques in developing countries: solar disinfection for Nepal, and design of a new prototipe. Social Service work at Regional Studies Center based on wastewater treatment and water quality control during 2000-2001.

Susan Murcott **(team advisor)**, Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, Lecturer [0]This appointment involves graduate students supervision and research on a variety of projects applying innovative technologies in water and wastewater treatment. Ecosystems Engineering, President. M. S. of Civil and Environmental Engineering, February, 1992. Areas of Specialization: Drinking water quality and treatment in developing countries (Nepal, Haiti, Nicaragua), innovative wastewater treatment technology (Brazil), arsenic remediation technologies, sustainable development.

Melanie Pincus, Massachusetts Institute of Technology, M. Eng, in Water Quality and Environmental Engineering expected June 2003. Current research includes innovative water purification technique for developing countries: intermittently operated slow sand (BioSand) filtration for Nepal.

7. Budget

Category	**No.**	**Item**	**Cost**
Equipment:	1	Conductivity Meter	$ 650.00
	1	Multimeter	$ 80.00
	1	Used laptop for writing instructions	$ 300.00
Supplies:		Solar panel system to provide electricity[i]	$ 1,200.00
		Materials for UV-tubes prototypes and molds	$ 1,000.00
		Tools for construction workshop	$ 100.00
		Laboratory supplies (lab and field)	$ 2,500.00
Travel:	3	Roundtrip tickets to Haiti ($700each)	$ 2,100.00
		Local traveling expenses	$ 400.00
Total			**$ 8,330.00**

[i] Solar panels will be installed in the Borgne Health Technology Center to run the initial ferro cement prototype.

8. References

Agarwal, B., "Diffusion of Rural Innovations: Some Analytical Issues and the Case of Wood-Burning Stoves." World Development, 1983. 11(4): 359-376.

Battigelli, D. A., M. D. Sobsey and D. C. Lobe (1993). "The Inactivation of Hepatitis A Virus and Other Model Viruses by UV Irradiation." Water Science and Technology **27**(3-4): 339-342.

CEH Wallingford (for the UK Department for International Development.) (2002) Using the Water Poverty Index to Monitor Progress in the Water Sector.

Koller, L. R. (1952). Ultraviolet Radiation. New York, John Wiley & Sons, Inc.

Malley, J. P. (2000). Sydney, Australia, WaterTECH Conference.

Qin, S. M. and C. P. Gerba (1996). "Comparative inactivation of enteric adenoviruses, poliovirus and coliphages by ultraviolet irradiation." Water Research **30**(11): 2665-2668.

Purdey, A.F., et al., "Participatory Health and Development in Rural Nepal: Clarifying the Process of Community Empowerment" Health Education Quarterly, 1994. 21(3):329-343.

Shin, G.-A., K. G. Linden, M. J. Arrowood and M. D. Sobsey (2001). "Low-Pressure UV Inactivation and DNA Repair Potential of Cryptosporidium parvum Oocysts." Appl. Environ. Microbiol. **67**(7): 3029-3032.

Triangular Wave Technologies Inc (1997). UV inactivation chart, Wyckomar Inc. **2001**.

Wolfe, R. L. (1990). "Ultraviolet disinfection of potable water." Environmental Science and Technology **24**(6): 768-773.

World Health Organization (WHO). (2002). "The World Health Report 2002." [on-line] www.who.int/whr/2002/en.

Appendix A: Assumptions for Energy Calculations

			Daily Energy Use Joules	Energy/Liter kiloJoules/Liter
General				
Neighborhood size:	100	people		
Drinking water per person:	2	liters/day		
Water treated per day for drinking:	200	liters		
Commercial UV				
Commercial UV system:	30	Watts		
Hours of operation per day:	5	hours		
Daily energy use, commercial UV system:	150	Watt-hours	540000	3
UV-Tube				
Medium UV-Tube power:	30	Watts		
Hours of operation per day:	5	hours		
Daily energy use, UV-Tube	150	Watt-hours	540000	3
Boiling				
Starting temp:	20	^{o}C		
Stove efficiency:	60%			
Specific heat of water (cp)	4.19E+03	J/kg ^{o}C		
Mass of water heated:	200	kg		
energy used per day:	111626667	J	111626667	558
Bottled Water				
Trucking energy	2000	Btu/ton-mile	(Delucci, 1997)	
Trucking energy	2325	J/kg-mile		
Distance shipped:	30	miles		
Mass shipped:	200	kg		
energy used in shipping:	13950791	J	13950791	70

Appendix B:

Example Operation and Maintenance Procedures:

Operation:

1. Turn on the UV-Tube.
2. Use the window to make sure the light is on.
3. Wait two minutes for the lamp to warm up.
4. Open the valve or pour water into the UV-Tube at a rate less than the specified flow rate.
5. Collect the water that exits from the unit in a clean container.
6. When finished taking water, tip the UV-Tube slowly to drain out the water.
7. Turn off the light.

Maintanance:

- Empty the UV-Tube and let it dry when not in use.
- Monthly, remove the top and fill the trough with bleach solution. Let it stand for at least 20 minutes. Drain the bleach water and allow system to dry.
- Change the bulb annually, even if it is still lit.
- The electical systems will also have maintenance procedures.

Tools and Supplies

Supplies:
Germicidal bulb
florescent ballast
starter
bulb holders
wire
wire nuts
fuses
wire mesh
mortar mix
copper pipe
copper elbows
PVC pipe with end caps
sheet metal
a three pronged plug
3cm x 3cm piece of glass
nuts and bolts

Tools:
hack saw
needle nose pliers with wire cutter
safety glasses
electric drill with bits
box cutter
round metal file
electrical tape
measuring tape
trowel
screw drivers
silicon sealant