Iodine Disinfection in the Use of Individual Water Purification Devices

Technical Information Paper #-31-005-0211

PURPOSE

This information paper provides an in-depth review of iodine as a disinfectant in potable water supplies. This paper is intended to assist the reader in evaluating the disinfection capabilities of Individual Water Purification Devices (IWPDs) using iodine to kill or inactivate disease-causing bacteria, viruses, and protozoan cysts.

REFERENCES

Appendix A contains a list of references.

INTRODUCTION

Background

Understanding the disinfection capabilities of iodine to kill or inactivate disease-causing microorganisms is important in protecting Soldiers, who are considering using this technology, from acute health threats posed by these microorganisms. Soldiers deployed beyond traditional field drinking water supplies must have access to microbiologically safe water. Using IWPDs is one way to provide microbiologically safe water in these situations. These IWPDs must protect the Soldier from acute microbial health threats. The U.S. Environmental Protection Agency (USEPA) Guide Standard and Protocol for Testing Microbiological Water Purifiers (reference 1) provides performance standards by which an IWPD using iodine can be evaluated. The performance standards are a minimum 6-log reduction/inactivation of bacteria, 4-log reduction/inactivation of viruses, and 3-log reduction/inactivation of protozoan cysts (typically *Giardia* or *Cryptosporidium*). Iodine-using IWPDs meeting these standards are considered effective against disease causing bacteria, viruses, and protozoan cysts. Some IWPD manufacturers test their devices using this protocol. This is the best way to evaluate the IWPDs disinfection capabilities. In the absence of that testing data, this information paper can be used to gain an understanding of iodine disinfection capabilities and help determine if an IWPD using iodine could successfully meet the EPA Guide's minimum performance standards.

General

Iodine (I_2) has long been recognized for its anti-microbial properties. It has been used extensively in the health care industry as an antiseptic and disinfectant (references 2 and 3). The U.S. Army also realized the benefits of iodine as a drinking water disinfectant, issuing iodine- based tablets (Globaline™) to American Soldiers in 1952 (references 4 and 5). The Army continues to provide iodine-based tablets in addition to other emergency field drinking water products (i.e., Chlor-Floc™) (reference 6). Today, there are several Commercial-Off-The-Shelf (COTS) IWPD products that use iodine for disinfection. (Globaline™ is a trademark of Wisconsin Pharmacal Co.; Chlor-Floc™ is a trademark of Control Chemical Co., D/B/A Deatrick and Associates, Inc.)

USAPHC
U.S. ARMY PUBLIC HEALTH COMMAND (Provisional)

Use of trademarked products does not imply endorsement by the U.S. Army but is intended only in identification of a specific product.

Types of Iodine-based Disinfectants

Iodine-based disinfection products available today can be divided into two categories; iodine solutions and iodine resins. Iodine solutions are made by adding iodine (e.g., tincture of iodine, a 2 percent iodine solution), or by adding a tablet containing iodine along with carrier and stabilizing agents to enhance dissolvability (e.g., Globaline, composed of tetraglycine hydroperiodide, sodium acid pyrophosphate and talc, reference 4). Iodine resins are solid-phase iodine disinfectants. Iodine resins are used by passing water through the iodine resin where disinfection occurs through direct contact of the microorganism and the iodine sorbed onto the resin. Iodine resins are generally considered demand-release disinfectants (reference 7). Demand-release iodine resins release iodine to the microorganism after coming into contact with the resin and generally produce a dilute iodine residual (reference 7).

IODINE CHEMISTRY

Chemistry of Iodine in Water

When iodine is added to water, it may remain unchanged or it may hydrolyze into five different species depending on pH and the initial iodine concentration (references 4 and 8). In general, the following reaction occurs when iodine is added to water (reference 9):

Equation $I_2 + H_2O \leftrightarrow HOI + I^- + H^+$ $K_{eq} = 3 \times 10^{-12}$ at 25 deg Celcius

In addition to the formation of hypoiodous acid (HOI) and iodide ion (I^-), hypoiodite ion (OI-), triiodide ion (I3-), and iodate (HIO3) may be formed. However, under typical concentrations used in drinking water disinfection, and at typical pH ranges for natural water sources, hypoiodite ion, triiodide ion, and iodate are not considered to be formed at any appreciable concentrations (reference 12). The small equilibrium constant indicates a higher concentration of reactants (iodine) compared to the products (hypoiodous acid and iodide ion) present at equilibrium. In other words, this equation suggests that in natural waters with typical pH ranges from 5 -8, iodine is present and can be present in significant amounts depending on initial iodine concentration (reference 10). The figure shows the distribution of iodine species at various pH levels and initial iodine concentrations at 25 degrees (º) Celsius (adapted from references 9 and 11).

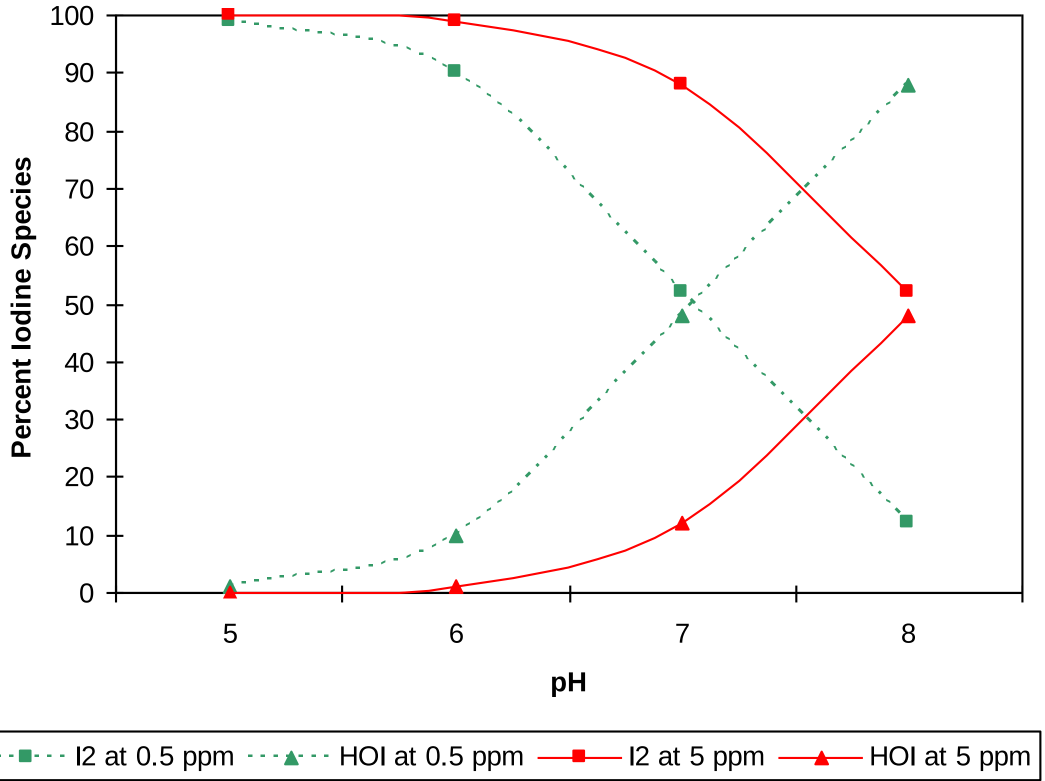

Figure. Distribution Diagram of Iodine Species at 25 Degrees Celsius

From the figure, we can see that at near neutral to alkaline pH levels (~7+), depending on initial iodine concentration there can be significant concentrations of both iodine and hypoiodous acid present. Lower initial iodine doses result in significant concentrations of both iodine and hypoiodous acid at near neutral pH levels. At higher pH levels above 8, hypoiodous acid dissociates by the following reaction (reference 9):

$$HOI \leftrightarrow H^{+} + OI^{-} \quad pK_a = 12.3 \text{ at 20 deg. Celsius}$$

The production of hypoiodite ion (OI^-) is considered negligible since it would only be present in significant concentrations at pH levels not typically seen in natural waters (i.e., above pH 10) (reference 10). Further limiting production of hypoiodite ion is the fact that hypoiodous acid is unstable at pH levels above 8 and decomposes to iodate and iodide according to the following reaction (reference 10):

$$3HOI + 2(OH^{-}) \leftrightarrow HIO_3 + 2H_2O + 2I^{-}$$

Iodine Resin Preparation

Preparation of iodine resins involves binding polyiodide ions to a strong-base anion resin. This creates a positively charged resin. Most microorganisms are negatively charged at typical pH levels (i.e., 5 – 8) encountered in natural waters (references 13 and 14). These opposite charges produce an electrostatic attraction that helps bring the microorganism into direct contact with the iodine resin (reference 15). There are generally two types of iodine resins produced for drinking water treatment, a triiodide (I_3^-) and a pentaiodide (I_5^-) resin.

DISINFECTION CAPABILITIES

General

Iodine Solutions

Iodine is an effective disinfectant for viruses, bacteria, and many cysts at IWPD manufacturer-recommended iodine dosages and contact times. In general, iodine is most effective against bacteria, followed by viruses. Iodine is least effective against cysts. Iodine is not an effective disinfectant against *Cryptosporidium parvum* oocysts (references 2, 3, 15 and16). Most manufacturers of iodine solution IWPDs recommend dosages between 4 and 16 milligrams per liter (mg/L) with contact times ranging from 20 – 35 minutes (min), resulting in CTs of 80 – 560 mg-min/L. CT is the product of disinfectant concentration (C in mg/L) and contact time (T in min). The CT product is a useful way for comparing alternative disinfectants and the resistance of various pathogens (reference 26). Because cysts are most resistant, dosages and contact times will be based on inactivation of cysts and CTs will be in the high-end of the 80 – 560 mg-min/L CT range. Compared to other disinfectants such as chlorine and chloramines, iodine reacts less with organic compounds, is less soluble, is least hydrolyzed in water, and is effective over the pH range likely encountered in natural water sources likely to be treated with an IWPD (references 2, 3 and 17). Together, these characteristics mean that low iodine residuals will persist longer, be more stable, and exert less of a demand in the presence of organic matter compared to chlorine and chloramines (reference 12). It has been established that only iodine and hypoiodous acid are capable of biocidal activity. The other iodine species are not effective biocides (references 3, 11, 12 and 16). For these reasons only iodine and hypoiodous acid are the iodine species considered in this paper.

Iodine Resins

Like iodine solutions, iodine resins are effective disinfectants against bacteria, viruses, and many cysts. However, the resins have not been proven effective against *Cryptosporidium* oocysts (references 3, 15, 18, 19 and 20). Iodine resins used in IWPDs are generally combined with other treatment processes such as filtration and are not usually used as stand-alone IWPDs. Iodine resin disinfection operates on the theory that iodine binds to the microbe, penetrating and inactivating it. Contact between the microbe and the resin is necessary and is assisted by electrostatic forces (reference 3). Microbes are exposed to high iodine concentrations when passing through the resins, which allow for reduced contact time compared with iodine solutions (reference 16). Iodine resins typically produce a residual of 0.02 - 2 mg/L in water passed through the resin (reference 15). However, the iodine residual is not considered to provide additional disinfection. In most cases, bacteria and viruses are immediately killed or inactivated after coming into direct contact with the iodine sorbed to the resin. For cysts, additional contact time is sometimes necessary after passing through the resin to allow sufficient time for the iodine picked up from the resin to penetrate the cysts and kill or inactivate it. In theory, the iodine residual produced by the resin is not used for disinfection. However, the iodine residual may provide a measure of microbial protection when storing water to prevent microbial growth in the storage container, similar to the maintenance of a disinfectant residual in a distribution system. Of the two types of resins used in drinking water, pentaiodide resin has been shown to have better biocidal capabilities than triiodide resin (reference 7).

Environmental Effects on Disinfection Capability

Effect of pH on Disinfection Capability

In general, the pH of most natural water sources is neutral to mildly acidic, which is within the effective range for chemical disinfectants used for drinking water, including iodine solutions (reference 3). Iodine and hypoiodous acid have varying degrees of biocidal effectiveness against various pathogens. Iodine is up to three times more cysticidal and six times more sporocidal than hypoiodous acid (reference 3). Hypoiodous acid, on the other hand, is 40 times more virucidal and up to 4 times more bactericidal than iodine (reference 3). Because the concentration of these iodine species is dependent upon pH and initial iodine dose (see Figure), the following generalizations can be made. Iodine solutions are more effective cysticides and poorer virucides and bactericides at mildly acidic pH levels (< pH 7). Iodine solutions are more effective virucides and bactericides and poorer cysticides at alkaline pH levels (> pH 7). And, because it generally takes much longer to inactivate cysts than bacteria and viruses, iodine solutions used as IWPDs would be most effective at near neutral to mildly alkaline pH levels. However, at pH levels above 8, biocidal capability may drop sharply because HOI becomes unstable and decomposes to iodate and iodide, which are not effective biocides (see iodine chemistry above). To use iodine most effectively as a disinfectant, the pH should be near neutral to mildly alkaline to allow adequate levels of both iodine and hypoiodous acid (reference 4). Resins do not appear to be significantly affected by pH levels typically encountered in natural waters. One study using both triiodide and pentaiodide resins showed less than 4-log virus inactivation at extremely low pH levels (pH 2.5 and 3.0) (reference 15). At these low pH levels, it was believed that the viruses lost their negative charge, becoming neutral or positively charged, effectively reducing the electrostatic attraction and subsequently preventing direct contact with the iodine on the positively charged resins. Greater than 4-log virus inactivation was achieved at all higher pH levels
(pH 4.0 – 7.0).

Effect of Temperature on Disinfection Capability

In general, colder water temperatures reduce the disinfection capability of iodine solutions and other chemical disinfectants (references 9, 17 and 21). Cold water temperatures slow disinfection and must be compensated for by longer contact time or higher concentration to achieve comparable disinfection at warmer water temperatures (reference 3). A 2 to 3-fold increase in inactivation rates per 10 degrees Celsius (°C) water temperature increase seems a generally accepted rule (reference 3). Studies have shown a significant impact on iodine disinfection capability by temperature. One study showed CT's to provide 2-log inactivation of the *E. Coli* bacteria were 2-9 times higher in colder waters (2-5 °C) than in warmer waters of 20-25 °C (references 9 and 22). Another study showed a CT 3 times higher was necessary at a 3 °C water temperature (CT = 200 mg-min/L) compared to 23 °C water temperature (CT = 65 mg-min/L) for a 2-log inactivation of *E. histolytica* cysts (references 9 and 10). Another study using *Giardia* cysts showed CT's up to 3 times higher in 3 °C water resulted in only a 1.5-log inactivation compared to CT's at 20 °C which resulted in > 2.7-log inactivation (references 7 and 21). These studies show temperature has a significant effect on iodine disinfection capability. Longer contact times and/or higher iodine doses (i.e., increased CT's) are necessary in colder waters. Using a 2-fold CT increase for every 10 °C decrease in water temperature is a good estimate to use when determining CT requirements for iodine disinfection capability.

There is limited information on the effect of water temperature on the disinfection capability of iodine resins. Water temperatures do not appear to affect bacteria and virus inactivation when using iodine resins. However, cysts may require additional contact time after passing through a resin to ensure inactivation. One study evaluated water temperature's effect on *Giardia* cyst inactivation by pentaiodide resin (references 7 and 23). The data suggested that additional contact time was necessary to provide a 3-log inactivation after passing through the resin (reference 23). Three minutes additional contact time was necessary at 25° Celsius while more than 40 minutes additional contact time was necessary at 4 °C. Although an iodine residual was present in the water after passing through the column, the inactivation of the *Giardia* cysts is likely due to the iodine bound to the cysts after coming into contact with the resin (reference 23). Additional contact time of water passed through an iodine resin is recommended to ensure adequate *Giardia* cyst inactivation (3-log).

Effect of Turbidity on Disinfection Capability

In general, disinfection capability of iodine solutions is reduced since microorganisms can be protected from the iodine by adsorption to or enmeshment in solid particles in water (references 16 and 24). There is limited information discussing the effects of turbidity on the disinfection capability of iodine. Most iodine disinfection studies involving varying turbidities also include other variables that affect iodine disinfection (e.g., pH and temperature). However, some limited information can be extracted. One study indicated turbidity from clays measuring 50-500 mg/L total suspended solids had no measurable effect on iodine disinfection capability, but high concentrations of fine loess (165 – 245 mg/L) interfered with bactericidal capability of iodine (reference 25). This study would indicate that turbidity does have an effect on iodine disinfection capability but not as significant compared to temperature.

Available information on fouling of iodine resins focuses more on the impact of dissolved organic matter and not on turbidity (i.e., solid or particulate matter). Resins will act as filter media and can physically remove particulate matter from water (reference 26). The particulate matter could interfere with the disinfecting capability of the iodine resin by preventing direct contact between the organism and the resin. Dissolved organic matter can have a large impact on iodine resin disinfection. One study indicated dissolved organic matter (measured as total organic carbon) at concentrations of 6 mg/milliliter (mL) (6,000 mg/L) reduced the disinfection capability of a triiodide (I_3) resin against viruses. The organic matter competed for sites on the resin beads and prevented direct contact between the resin and the virus (reference 20). However, a 10-fold reduction in dissolved organic matter (600 mg/L) did not appear to adversely affect the triiodide's disinfection capability of viruses. Heavy organic matter loading could reduce the disinfection capability of an iodine resin. A pretreatment process to remove/reduce organic matter (particulate and dissolved) will provide better resin disinfection capability in highly turbid waters.

Bactericidal Capability

Iodine Solutions

Numerous studies indicate iodine is an effective bactericide over the range of temperature and pH expected in natural water sources (references 9, 10, 22 and 27). Very low CT levels, ranging from 0.4 – 2.4 mg-min/L are required to inactivate 2-logs of *E. Coli* over a wide pH range (6 – 9) and temperature range (2 – 37 °C) (reference 9). CT's of less than 10 mg-min/L resulted in a 4-log inactivation of *E. Coli* at a near neutral pH (6 – 7) and extreme temperatures (~ 0 – 37 °C) (references 9 and 27). These low CT's translate into low iodine residuals and/or short contact times. For example, assuming a contact time of 20 minutes, a 0.5 mg/L iodine residual would be necessary to provide 4-log inactivation of *E. Coli* at near neutral pH at any temperature encountered in natural waters (20 min x 0.5 mg/L = 10 mg-min/L). When iodine solutions are used at typical doses for emergency drinking water disinfection (4 – 16 mg/L) and typical recommended contact times (20 – 35 minutes), the resulting CT's of 80 – 560 mg-min/L would likely ensure a 6-log inactivation of bacteria.

Iodine Resins

Data indicate iodine resins may achieve a 6-log inactivation of bacteria. One study showed at least a 4-log inactivation of *Staphylococcus aureus* over a wide pH range of 2.5 – 7.0 using triiodide (I3) and pentaiodide (I5) resins (reference 15). Other studies showed 4 – 9-log removal/inactivation for various pathogenic bacteria including *E. Coli* and *Salmonella typhimurium* using a triiodide resin (references 15 and 19). No significant removal of bacteria by filtration was reported. The effectiveness of resins against bacteria is due to its disinfecting ability and not for the ability to filter, or physically remove bacteria (reference 19). Iodine resins will likely provide a 6-log inactivation of bacteria under most situations.

Virucidal Capability

Iodine Solutions

Several studies also show that iodine solutions are effective virucides (references 9, 10, and 27). Viruses are more resistant to iodine disinfection than bacteria, typically requiring higher CT's than bacteria and in some cases much higher CT's at low pH levels (e.g., 4 – 5), where hypoiodous acid (HOI) is not present, and at cold water temperatures (e.g., 5 °C) (reference 9). Most studies evaluated the virucidal efficacy of iodine solutions against f_2 virus and Poliovirus. Data indicate 2-log inactivation at near neutral to alkaline pH levels (6 – 10) and various water temperatures (5 – 30 °C) occurred at CT's of 15 – 75 mg-min/L with the higher CTs occurring at lower pH levels and colder water temperatures. One study showed a CT of less than 10 mg-min/L resulted in a 4-log inactivation of f_2 virus at a pH of 7 and a very warm water temperature of 37 °C (reference 9). Iodine solutions will likely provide a 4-log inactivation of viruses under most natural water conditions expected. Because IWPD dosages and contact times will be based on cyst inactivation, and resulting CTs will be large (80 – 560 mg-min/L), it is likely an IWPD will achieve 4-log virus inactivation under most water quality conditions.

Iodine Resins

Data reviewed indicates iodine resins can likely achieve 4-log virus inactivation levels. Several studies show at least 4-log inactivation of various viruses at pH levels above 3.0 with low turbidity water for both triiodide (I3) and pentaiodide (I5) resins (references 15 and 20). One study showed a reduced virucidal capability of a triiodide resin when water containing significant amounts of organic matter (6 mg/ml or 6,000 mg/L organic matter) was tested (reference 20). However, a 10-fold reduction in organic matter (0.6 mg/ml or 600 mg/L) did not appear to affect the triiodide resin's disinfection capability (reference 20). Triiodide and pentaiodide resins will likely provide a 4-log virus inactivation under most natural water quality conditions.

Cysticidal Capability

Iodine Solutions

Most cysts, in particular *Giardia* cysts and *Cryptosporidium* oocysts, appear to be more resistant to iodine disinfection than bacteria or viruses. Achieving adequate cyst inactivation should ensure adequate bacteria and virus inactivation.

There are several studies evaluating the iodine disinfection capability against *Giardia* cysts (references 6, 8, 21 and 28). Overall, the data from these studies indicate that iodine is capable of providing a 3-log *Giardia* cyst inactivation, but additional contact time or higher doses (i.e., higher CT's) are necessary at colder water temperatures and more turbid waters (references 6, 8 and 28). Warmer waters (> 20 °C), both clear and cloudy, with pH levels ranging from 6 – 9, resulted in > 2.7 log (~3 log) *Giardia* cyst inactivation with CT's ranging from 45 – 241 mg-min/L. As water temperatures decreased (< 20 °C) CT values for > 2.7 log *Giardia* cyst inactivation increased, ranging from 123 – 600 mg-min/L (clear and cloudy waters, pH ranged from 6 – 9). One study recommended CT's ranging from 240 – 720 mg-min/L for colder waters (5 – 15 °C) to ensure a 100 percent inactivation of *Giardia* cysts (reference 17). At colder water temperatures (clear and turbid) achieving a 3-log inactivation of *Giardia* cysts is not likely when using iodine according to recommended instructions (CT's ranging from 80 – 560 mg-min/L). Additional contact time and/or higher iodine dosages, beyond those recommended by IWPD manufacturers, are likely necessary to ensure 3-log *Giardia* cyst inactivation.

There is limited data on *Cryptosporidium* oocyst inactivation by iodine (references 8 and 29). These data indicate iodine solutions are ineffective at inactivating *Cryptosporidium* oocysts. One study indicated a CT of 1,015 mg-min/L is required to achieve a 2-log *Cryptosporidium* oocyst inactivation (reference 29). This CT is far beyond IWPD CT's resulting from using iodine solutions according to manufacturer recommended instructions (CT's ranging from 80 – 560 mg-min/L). This indicates iodine would not be an effective disinfectant against *Cryptosporidium* due to the extremely high iodine dose and long contact times necessary to provide a 3-log inactivation.

Iodine Resins

Pentaiodide resins are much more effective at inactivating *Giardia* cysts than triiodide resins (reference 23). A pentaiodide resin achieved a 3-log *Giardia* cyst inactivation compared to 0.2 – 0.4-log inactivation achieved by triiodide resin under identical experimental conditions (temperatures of 4 and 25 °C) (reference 23). Additional contact time after passing through the pentaiodide resin column was necessary to achieve the 3-log inactivation. The 3-log inactivation was achieved within 3 minutes of passing through the column at 25 °C (reference 23). More than 40 minutes of additional contact time was necessary at 4 °C water temperature to achieve similar inactivation rates (reference 23). Other literature indicates that for adequate cyst inactivation (with the exception of *Cryptosporidium* oocysts) that additional contact time is necessary after passing through the resin (references 3, 7, 15, 16 and 28). Although an iodine residual was present in the water after passing through the column, the inactivation of the *Giardia* cysts is likely due to the iodine bound to the cysts after coming into contact with the resin and not due to the iodine residual (reference 23). The additional contact time indicates *Giardia* cysts are more resistant to iodine resin inactivation compared to bacteria and viruses. There is evidence that *Giardia* cysts can be filtered by the resin. Approximately 65 percent of *Giardia* cysts passing through a pentaiodide column temporarily adhered to the resin bead surface (reference 23). However, these cysts were subsequently washed off the resin beads after continued use and passed through the pentaiodide resin column. These cysts were inactivated (reference 23). A 3-log inactivation of *Giardia* cysts can be achieved if a pentaiodide resin bed is used and additional contact time is provided after passing through the resin bed. In colder waters, longer contact time is necessary to ensure *Giardia* cyst inactivation. Ensuring adequate *Giardia* cyst inactivation (3-log) will ensure adequate bacteria (6-log) and virus (4-log) inactivation.

Iodine resins are not effective at inactivating *Cryptosporidium* oocysts. One study showed no inactivation of *Cryptosporidium* oocysts that passed through a pentaiodide resin (reference 18). Similar to *Giardia* cysts, there is evidence that *Cryptosporidium* oocysts are filtered by the resin bed (reference 18). This is likely due to electrostatic interactions. Therefore, resins could provide a measure of physical removal of *Cryptosporidium* oocysts. However, like *Giardia* cysts, subsequent use of resins might cause the release or washing off of oocysts from the resin and the oocysts could remain viable. Iodine resins cannot be considered effective for inactivating *Cryptosporidium* oocysts. Additional treatment such as filtration would be necessary to control *Cryptosporidium*.

IODINE TOXICITY

Iodine is not widely used as a disinfectant in typical municipal drinking water systems due to potential adverse health effects caused from excessive iodine intake (reference 30). It's been suggested that chronic (long term) intake of 2 mg/day should be regarded as excessive and potentially harmful (reference 30). When ingested, iodine is converted to iodide and efficiently absorbed into the body. Most iodide resides in the thyroid gland (reference 30). Excessive amounts of iodine can cause an enlarged thyroid, a condition known as goiter (reference 30). For healthy individuals without pre-existing thyroid conditions or sensitivity to iodine, ingesting iodine concentrations associated with using IWPDs for short periods of time (i.e., 3 months or less) are not likely to experience adverse health effects (reference 31). It is recommended that pregnant women, people with known hypersensitivity to iodine, people with a history (or family history) of thyroid disease, and people from countries or localities with chronic iodine deficiency should not use iodine as a means of water treatment (reference 31).

CONCLUSIONS

Iodine Solutions

Iodine solutions are effective disinfectants against bacteria, viruses, and *Giardia* cysts. They are not effective against *Cryptosporidium* oocysts. Temperature appears to have the greatest effect on iodine disinfection capability. *Giardia* cysts are more resistant to iodine disinfection than bacteria or viruses. Achieving adequate *Giardia* cyst inactivation should ensure adequate bacteria and virus inactivation. At colder water temperatures (both clear and turbid), and turbid water at any temperature, additional contact time and/or higher iodine dosages than recommended by IWPD manufacturers are likely necessary to achieve a 3-log inactivation of *Giardia* cysts (and 6-log bacteria and 4-log virus inactivation). CT's up to 720 mg-min/L are recommended for cold waters (5 °C) to ensure *Giardia* cyst inactivation. Using iodine solutions to inactivate *Cryptosporidium* oocysts is not practical.

Iodine Resins

Pentaiodide resins are effective disinfectants against bacteria, viruses, and *Giardia* cysts. Triiodide resins are less effective than pentaiodide resins. Both resins are not effective for inactivating or removing *Cryptosporidium* oocysts. Turbidity and organic matter can reduce the disinfection capability of iodine resins. Similar to iodine solutions, *Giardia* cysts appear to be more resistant to inactivation by iodine resins than bacteria and viruses. Achieving adequate *Giardia* cyst (3-log) inactivation should ensure adequate bacteria (6-log) and virus (4-log) inactivation. Additional contact time is necessary after passing through a pentaiodide resin to ensure *Giardia* cyst inactivation. Provide at least 3 minutes additional contact time for warmer waters (> 20 °C). Provide at least 40 minutes additional contact time for colder waters (< 5 °C). The table provides a summary of the disinfection capability of iodine resins and solutions.

Table. Summary of Disinfection Capabilities of Iodine Solutions and Resins

Parameter	Iodine Solutions	Iodine Resins
General	Cysts most resistant. Achieving *Giardia* cyst inactivation will ensure adequate bacteria and virus inactivation.	Cysts most resistant. Achieving *Giardia* cyst inactivation will ensure adequate bacteria and virus inactivation
Bacteria	Effective	Effective
Viruses	Effective	Effective
Giardia Cysts	Provide additional contact time beyond IWPD manufacturer recommended CTs.	Pentaiodide resin effective. Triiodide resin not effective. Provide additional contact time after passing through resin.
Cryptosporidium Oocysts	Not effective.	Not effective.
Effect of Temperature	Major effect. Increase contact time and/or dose at colder temperatures. CT's up to 720 mg-min/L recommended for *Giardia* cyst inactivation in colder waters.	Major effect. Increase contact time after passing through pentaiodide resin at colder temperatures. Allow up to 40 minutes additional contact time for *Giardia* cysts inactivation in colder waters (< 5 °C)
Effect of pH	Minor effect. Generally effective over typical pH levels for natural waters	Minor effect. Generally effective over pH range typical for natural waters
Effect of Turbidity	Affects disinfection capability. Provide additional contact time and/or increase iodine dose in more turbid waters.	Affects disinfection capability. Heavy organic matter loading can significantly reduce disinfection capability.

PREPARED BY: Steven H. Clarke, Environmental Engineer

DATED: March 2006, updated January 2011

APPENDIX A
REFERENCES

1. U.S. Environmental Protection Agency (USEPA), Registration Division Office of Pesticide Program, Criteria and Standards Division Office of Drinking Water, 1987. *Guide Standard and Protocol for Testing Microbiological Water Purifiers*. Washington, D.C.

2. Lawrence, C. A., & Block, S. S., 1968. Disinfection, Sterilization, and Preservation. Lea & Febiger, Philadelphia, PA.

3. Auerbach, P.S., 1995. Wilderness Medicine Management of Wilderness and Environmental Emergencies, 3rd ed. Mosby-Year Book, Inc., St. Louis, MO.

4. U.S. Army Natick Research, Development and Engineering Center, 1991. *Inactivation of Giardia Cysts by Iodine with Special Reference to Globaline: A Review*. (U.S. Army Natick Technical Report NATICK/TR-91/022). Natick, MA. Prepared by E.M Powers.

5. Rogers, M. R., & Vitaliano, J.J., 1977. Military Individual and Small Group Water Disinfecting Systems: An Assessment. *Military Medicine*, 142(4), 268 – 277.

6. U.S. Army Natick Research, Development, and Engineering Center, 1993. *Efficacy of Flocculating and Other Emergency Water Purification Tablets*. (U.S. Army Natick Technical Report NATICK/TR-93/033). Prepared by Powers, E.M.

7. Jarroll, E.L., 1988. Effect of Disinfectants on *Giardia* Cysts. *CRC Critical Reviews in Environmental Control,* 18(1), 1 – 28.

8. Gerba, C. P., Johnson, D. C., & Hasan, M. A., 1997. Efficacy of Iodine Water Purification Tablets Against *Cryptosporidium* Oocysts and *Giardia* Cysts. *Wilderness and Environmental Medicine*, 8, 96 – 100.

9. National Academy of Sciences, 1980. *Drinking Water and Health Vol. 2.* National Academy Press, Washington D.C.

10. Chang, S. L., & Morris, J. C., 1953. Elemental Iodine as a Disinfectant for Drinking Water. *Industrial and Engineering Chemistry*, 45, 1009 – 1012.

11. Chang, S.L., 1958. The Use of Active Iodine as a Water Disinfectant. *Journal of the American Pharmaceutical Association*, 47(6), 417-423.

12. Black, A.P, et al., 1965. Use of Iodine for Disinfection. *Journal of the American Water Works Association (AWWA),* 57(11), 1401-1421.

13. Harden, V.P., & Harris, J.O., 1953. The Isoelectric Point of Bacterial Cells. *Journal of Bacteriology*, 65(2), 198-202.

14. Gerba, C.P., 1984. Applied and Theoretical Aspects of Virus Adsorption to Surfaces. *Advances in Applied Microbiology*, 30, 133-168.

15. Marchin, G. L., Fina, L. R., 1989. Contact and Demand-Release Disinfectants. *CRC Critical Reviews in Environmental Control,* 19(4), 277 – 290.

16. Backer, H., 2002. Water Disinfection for International and Wilderness Travelers. *Travel Medicine,* 34, 355 – 364.

17. Fraker, L. D., 1992. *Giardia* Cyst Inactivation by Iodine. *Journal of Wilderness Medicine,* 3, 351 – 357.

18. Upton, S.J., Tilley, M.E., Marchin, G.L., & Fina, L.R., 1988. Efficacy of a Pentaiodide Resin Disinfectant on *Cryptosporidium parvum* (Apicomplexa: Cryptosporidiidae) Oocysts *In Vitro*. *Journal of Parasitology*, 74(4), 719 – 721.

19. Taylor, S., Fina, L.R., & Lambert, J.P., 1970. New Water Disinfectant: An Insoluble Quaternary Ammonium Resin-triiodide Combination that Releases Bactericide on Demand. *Applied Microbiology*, 20, 720 – 722.

20. Fina, L.R., et al., 1982. Viricidal Capability of Resin-Triiodide Demand-Type Disinfectant. *Applied and Environmental Microbiology*, 44(6), 1370-1373.

21. Jarroll, E. L., Bingham, A.K., & Meyer, E. A., 1980. *Giardia* Cyst Destruction: Effectiveness of Six Small-Quantity Water Disinfection Methods. *American Journal of Tropical Medicine and Hygiene,* 29(1), 8 – 11.

22. Chambers, C.W., Kabler P.W., Malaney, G., & Bryant A., 1952. Iodine as a Bactericide. *Soap and Sanitary Chemicals*, 28(10), 149 – 151.

23. Marchin, G.L., Fina, L.R., Lambert, J.L., Fina, G.T., 1983. Effect of Resin Disinfectants-I_3 and –I_5 on *Giardia muris* and *Giardia lamblia. Applied and Environmental Microbiology*, 46(5), 965-969.

24. AWWA, 1999. Water Quality & Treatment A Handbook of Community Water Supplies, Fifth Edition. McGraw-Hill, Inc. New York, NY.
25. EPA Office of Drinking Water, 1984. *Drinking Water Microbiology NATO/CCMS Drinking Water Pilot Project Series CCMS 128*. (EPA 570/9-84-006). Washington, D.C.

26. Crittenden, J.C. et al., 2005. Water Treatment: Principles and Design Second Edition. John Wiley & Sons, Inc. Hoboken, NJ.

27. U.S. Army Medical Research and Development Command (USAMRDC), 1969. *Mode of Action of Halogens on Bacteria and Viruses and Protozoa in Water Systems*. (USAMRDC Contract No. DA-49-193-MD-2314). Prepared by Kruse, C.W.

28. Ongerth, J.E., et al., 1989. Backcountry Water Treatment to Prevent *Giardiasis*. *American Journal of Public Health*, 79(12), 1633 – 1637.

29. Butkus, M.A., et al., 2005. Do Iodine Water Purification Tablets Provide an Effective Barrier against *Cryptosporidium parvum*? *Military Medicine*, 170(1), 83 – 86.

30. National Academy of Sciences, 1980. *Drinking Water and Health Vol. 3.* National Academy Press, Washington D.C.

31. Backer, H., & Hollowell, J., 2000. Use of Iodine for Water Disinfection: Iodine Toxicity and Maximum Recommended Dose. *Environmental Health Perspectives*, 108(8), 679 – 684.

32. Clark, R.M., Sivaganesan, M., Rice, E.W., & Chen, J., 2003. Development of a CT Equation for the Inactivation of *Cryptosporidium* Oocysts with Chlorine Dioxide. *Water Research*, 37, 2773-2783.