Water Contamination Emergencies
Collective Responsibility

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PROCEDURES FOR THE DECONTAMINATION OF BUILDING PLUMBING SYSTEMS

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1 INTRODUCTION

Adequate supplies of clean, safe drinking water are a prerequisite for buildings and their occupants, including both commercial and residential structures and facilities. In the past, there have been occasional concerns regarding insufficient treatment of water supplies or undesirable migration of contaminants from plumbing system materials into water distribution systems, usually due to some change in environmental or operating conditions. More recently, another issue has arisen regarding the potential for accidental or intentional introduction of contaminants into water distribution systems, and the need for effective methods for dealing with such events. This paper describes recommended procedures for responding to building plumbing system contamination incidents and restoring the water system to safe operation. The recommendations are based on analysis of the results of a measurement and modelling research project investigated contamination and decontamination issues related to building plumbing systems.

The general classes of contaminants that are considered include chemicals such as fuels, solvents, pesticides and poisons, and biologicals, such as bacteria, spores and toxins.[1] Considering the wide range of plumbing system materials, including copper, PVC and iron pipe, solder, rubber gaskets and sealants, there are many potential combinations of contaminants and substrates that are of interest. The presence of chemical deposits and biofilms typically found on the interior of plumbing components present another consideration.[2] In addition, plumbing system designs can vary widely, and flow obstructions, water tanks and other water-using appliances can significantly complicate the analysis.[3]

2 BACKGROUND

In order to reach the objective outlined above, a combination of detailed static and dynami measurements was conducted, along with a computer simulation effort, aimed at identifying th tendency of various contaminants to accumulate in building plumbing systems, and enabling th determination of effective methods for eliminating or rendering innocuous any accumulate contaminants, thereby ensuring restoration of a safe water supply. The basic measuremen methodology involved exposing a particular plumbing material substrate, component or syster to a water/contaminant mixture followed by a flushing or other decontamination activity, whil periodically monitoring or collecting samples of the substrate and/or water to evaluate for the presence of the contaminant or any residual materials. The details of these measurements are beyond the scope of this paper, but are available elsewhere.[4,5,6]

In addition to the measurements of contaminant behaviour in building plumbing systems, the impact of plumbing system design and operation on decontamination strategies was investigated. Since building plumbing systems are typically composed of a complicated network of water supply piping, fittings, valves and fixtures, along with a sanitary drain system and water-using appliances, the potential for contaminant accumulation, and the associated strategies for removal, require careful consideration of real-world factors.

3 POTENTIAL CONTAMINATION SCENARIOS FOR BUILDING PLUMBING SYSTEMS

In general, contaminants may enter a building water supply anywhere upstream, as represented by the four locations shown in Figure 1.

1. Contaminants that are introduced far upstream from the building, either before or near the water treatment facility, and travel a significant distance through the water distribution system to reach the building service line
2. Contaminants that are introduced into a water main supplying multiple branch lines, including one that supplies the building
3. Contaminants that are introduced near to, but outside of, the building, via the building service line
4. Contaminants that are introduced to the building water supply from within the building

The reason that these scenarios are differentiated has to do with the fact that the methods and the amount of contaminant introduced would likely be different in the various cases. As a result, the duration and level of contaminant concentrations in the water supply system would vary, and the portions of the water distribution system, including the building plumbing system, that are affected would be different. Thus, the response to the contamination events, including methods to control the spread of the contaminant, and procedures used to remove the contaminant would differ depending on where the contaminate was introduced.

In scenario 1 above, the effects of dilution and water treatment will likely reduce, but not necessarily eliminate, the impact of most contaminants on downstream building plumbing systems. The closer the point of contaminant introduction is to the building, the higher the concentration and the greater the potential for contaminant accumulation. However, longer lengths of affected water supply lines will require longer flushing times.

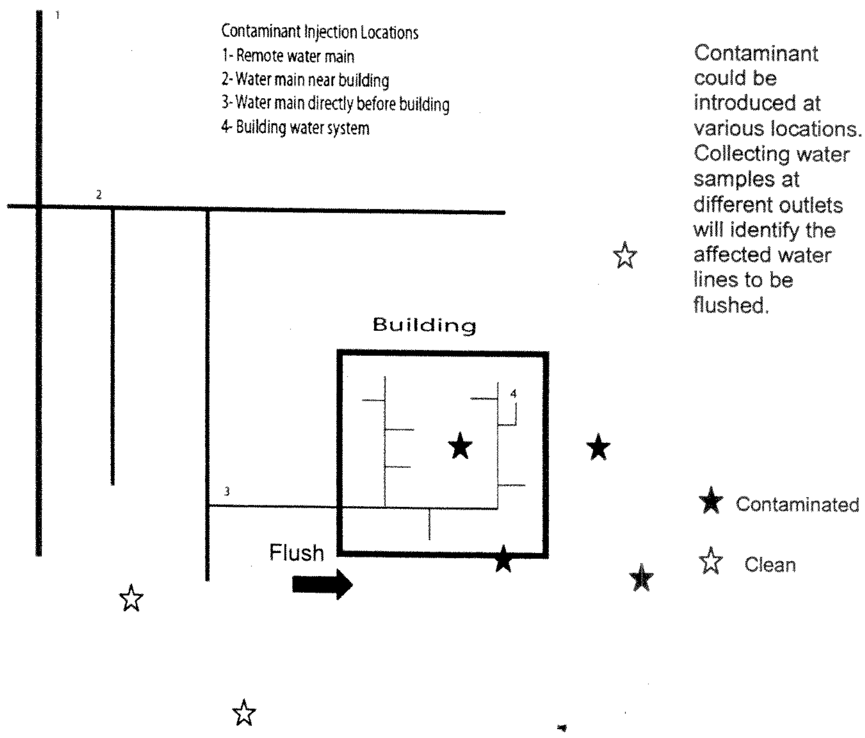

Figure 1 *Analyzing water samples from various locations will enable affected portions of the plumbing system to be identified*

Most contamination events will be recognized based on a consumer complaint (odor, color, taste), illness or reaction, a sensor reading (unlikely), or a verbal or written threat. The first step would be to determine if there is an actual contaminant present in the water supply, what the contaminant is, and the extent of the contamination. The point of contaminant introduction can be deduced by collecting water samples from a range of locations, and mapping the water lines that are found to be contaminated, working upstream until unaffected water lines are found, as shown in figure 1, where point 3 has been determined to be the point of contaminant injection. Once the affected water lines are identified, there remain a number of concerns, as follows:

- It will be difficult to precisely determine how long the contaminant has been in the water supply system, or how much of the contaminant was introduced
- Water samples can be collected/analyzed to identify the contaminant, but the sample contaminant concentration will likely be less than that at the point of injection
- Contaminant may have accumulated in the water supply system, so simply flushing out the contaminated water may not remove all of the contaminant
- Additional flushing or special procedures may be needed to restore a safe water supply
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Based on the above concerns, it is advisable to assume a worst case exposure condition, which would be a highly concentrated contaminant that has been introduced to the water supply system and had the chance to interact with substrates in contact with the water. Those contaminants that accumulate on plumbing system surfaces exposed to contaminated water will need to be eliminated before the system can be restored to safe operation and use. The accumulation may be due to the combined effects of a number of mechanisms, including different types of adsorption, chemical reactions and sedimentation on/with pipe materials and pipe scale. It may be possible to remove some small sections of piping or other components for laboratory analysis, but that is not always practical.

The magnitude and the location of contaminant accumulation will be a function of the characteristics of the contaminant/substrate interactions and the exposure conditions. For example, some substrates are more conducive to contaminant accumulation, and longer exposure times and higher concentrations are more likely to lead to greater accumulations. Contaminants may or may not be soluble in water, and may be more or less dense than water. Soluble contaminants will dissolve up to a point, and mix with the water so as to come into contact with most of the plumbing system surfaces. Insoluble contaminants will either float (specific gravity, SG<1) or sink (SG>1), thereby preferentially coming into contact with the upper or lower inside surfaces of pipes and tanks (see Figure 2). Contaminants with sedimentary characteristics, such as bacteria and spores, will sink due to gravity when water is not flowing, and may collect at the bottom of plumbing system components.

4 DECONTAMINATION PROCEDURES

The two basic steps in restoring a building plumbing system following a contamination scenario are to first safely purge the system of the contaminated water, and second, to flush or treat the system to eliminate any accumulated contaminant. The most effective methods for removing the accumulated contaminants will be a function of the contaminant, plumbing system materials and design. The preferred method, in terms of simplicity and cost is, of course, conventional flushing using water directly from the water distribution system. Other methods may be faster or more effective at cleaning, however. In general, the three choices that need to be made are:

1. *Which flushing fluid should be used?*
2. *How should the flushing fluid be introduced?*
3. *How should the system be flushed?*

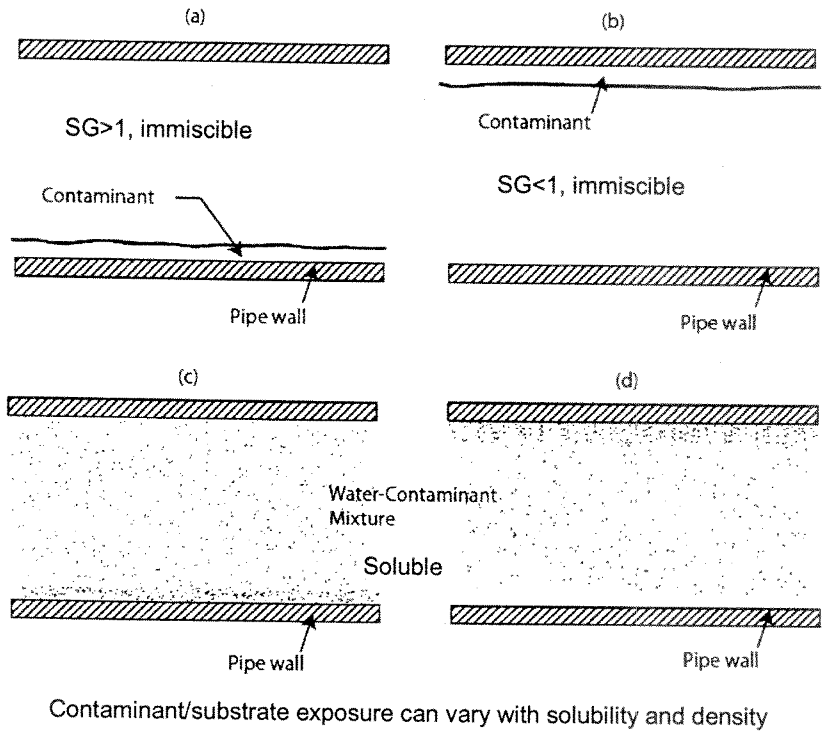

Figure 2 *The contact between the contaminant and plumbing system components will depend in part on the contaminant properties.*

The fluid could be:

- water as is available from the distribution system,
- water that has been treated with additional chlorine or other disinfectant,
- water that has been treated with surfactants or other chemicals to neutralize or react with the contaminant, or
- hot water or steam
- germinant solution to promote spore germination

The fluid source could be:

- from the distribution system,
- from a reservoir supplied by the distribution system, or
- from tanker truck.

The flushing method could be:

- conventional flushing, effuse down drain,
- conventional flushing, effuse collected for disposal,
- flood system and let stand, then drain effuse,
- flood system and let stand, then collect effuse for disposal,
- high velocity pumping,
- steam injection, or
- pulsating flow.

Generally, the most effective method for removing *chemical* contaminants is by continuous flushing, since accumulated contaminants tend to become entrained in the water due to turbulence, advection and diffusion; thus removal is primarily a function of the amount of clean water passing through the system. This approach works best for pipe sections, but is less efficacious for water tanks or reservoirs, especially those that have their outlet at the top. Flush water velocities are very low in tanks with large diameters relative to pipe diameters, which is usually the case, so the interaction of flush water with any contaminant that has accumulated on surfaces exposed to the water is slight. However, given enough time/water, water soluble contaminants will tend to be removed from the plumbing system. The amount of time/water required to reduce contaminant residuals to a safe level depends upon many factors, including the type and severity of the contamination, the design of the plumbing system and the residual levels considered to be safe, and is beyond the scope of this paper. Previous contamination events and measurements with immiscible organic substances suggest that flushing times on the order of days may be required in some cases.[7,8]

For contaminants that are immiscible, flushing with hot water will help dissolve the contaminant and thereby shorten required flushing times. Immiscible contaminants that float are best removed from water tanks by flushing out through the top, rather than draining from the bottom, since the latter procedure allows a high concentration of the contaminant to come into direct contact with the sediments that tend to accumulate at the bottom of the tank, making removal more difficult. In contrast, immiscible contaminants that sink should be drained from the bottom of the tank, and the sediments flushed out if possible.

In the case of bacterial contaminants, they are best attacked by flooding the plumbing system with disinfectant such as chlorine, and letting it stand to kill or otherwise disable the bacteria, followed by a short flushing to restore clean water.[9] For spores, the plumbing system should be flooded with germinant solution, such as an inosine or L-alanine solution, which will encourage the spores to germinate making them susceptible to killing by disinfection in the same manner as bacteria. In both cases, use of hot water enhances the decontamination effectiveness. Also, since the disinfection and growth media solutions only need to flood the system, as opposed to a continuous flushing, only a modest amount of solution is required.

Flushing with water from the water distribution system is the simplest method, but it is difficult to control water velocities, since they are dependent on water pressure, which will vary with location and as a function of the water demand. Sequential flushing of individual water lines will provide the highest water velocities, and therefore the greatest scrubbing. Flow control devices, such as faucet aerators and showerheads, should be removed before flushing and cleaned individually. It is important to ensure that the number of water lines being flushed simultaneously does not overwhelm the capacity of the building drainage system, since drainage lines are sized based on the expectation of some probabilistic usage pattern. It is possible that additional chlorine or other disinfectant or cleaner could be introduced into the flushing water, either directly from the distribution system, or from an auxiliary source closer to the contaminated water system. Care should be taken to ensure that the concentrations of disinfectant or cleaner will not damage the plumbing system materials.

Another concern is the possibility that a contaminant might become an inhalation hazard due to volatilization into the air after exiting a faucet or other fitting above a sink or tub. Where that is a consideration, avoiding this problem might require special flushing precautions, such as a direct connection between water supply outlets and drain lines. Following flushing, all sinks, tubs and other surfaces that have been exposed to the contaminated water should be thoroughly cleaned.

Water-using appliances present another set of challenges regarding decontamination, and the greatest concerns lie with those that involve water that may be consumed or come into contact with building occupants. Chief among these are water tanks, such as hot water heaters, that tend to accumulate sediments and deposits, and are difficult to flush due to their large volumes and corresponding low flow rates. Cleaning water tanks may require direct draining and filling with special cleaning solutions using one of the techniques described below. In some cases, it may not be possible to eliminate all of the accumulated contaminant, and water lines, fittings, fixtures or appliances may need to be replaced. Appliances that have no drain provision, such as residential ice makers, will not be able to be flushed so will need to be removed and cleaned or replaced. Appliances such as dishwashers and clothes washers cannot be flushed per se, but can be cleaned through operation, or disconnected to allow their supply lines to be flushed.

Figure 3 shows a schematic depiction of a possible configuration for flushing a building water supply system without using water directly from the distribution system, by connecting to an external water spigot or other similar connection point. It may be necessary to bypass or disable any back-flow prevention device to allow water to flow in the reverse direction. The flushing water can be pre-treated as is appropriate with disinfectant or cleaner before injection. If the valve at the water meter is closed, the flushing water will be forced under pressure through the water heater and both the cold and hot water supply lines to any fitting or fixture (e.g. faucet, shower, etc.) that is open. In this configuration, the flush water would be directed into the sanitary drains. It could also be collected and transported for disposal. The water supply line leading from the service connection would need to be flushed separately in the normal flow direction.

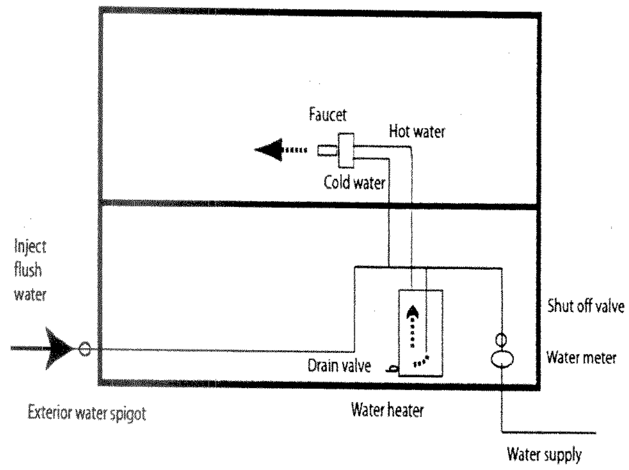

Figure 3 *Injecting flush water through an exterior water spigot or similar point will allow flushing of both hot and cold water lines, and water heaters*

Figure 4 shows a similar configuration for decontaminating a water heater tank, or for using the water heater an injection point for flushing the building water supply system. This operation would be similar to that described previously, although in this configuration, cleaning fluid could be both injected and extracted directly from the water heater via the drain valve. This could be repeated as many times as necessary.

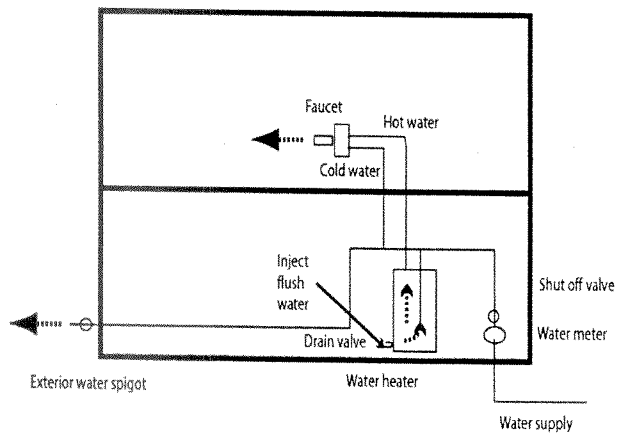

Figure 4 *Injecting flush water through the drain valve of a hot water heater can directly flush the tank and water lines.*

5 RECOMMENDED DECONTAMINATION PROCEDURES FOR BUILDING PLUMBING SYSTEMS

In general, lacking more specific information about a particular contaminant, the recommended decontamination procedures can be determined according to the type of contaminant, based on the following categories listed in table 1.

Table 1 *General Decontamination Procedures Based on Contaminant Type*

Contaminant Category	Example	Key Methods
Soluble chemicals	Strychnine, Cyanide	For pipes and tanks- Continuous flushing with water, water buffered with chlorine, or water mixed with cleaner
Immiscible chemicals with specific gravity less than one	Diesel fuel, Gasoline	For pipes- Continuous flushing with water, water buffered with chlorine, or water mixed with cleaner For tanks- Flush through drain valve at bottom of tank or water spigot
Immiscible chemicals with specific gravity greater than one	Phorate	Continuous flushing with water, water buffered with chlorine, or water mixed with cleaner For tanks- Drain through drain valve at bottom of tank, and fill with cleaning solution. Repeat as needed
Sediments or particles	-	For pipes- Continuous flushing with water, drain from cleanouts where available For tanks- Drain and flush from bottom
Bacteria	E. coli 0157:H7	For pipes and tanks- Flood system with water and disinfectant and let stand, followed by short flush. Repeat as needed
Spores	Bacillus Anthracis	For pipes and tanks- Flood system with germinant solution and let stand to allow spores to germinate, followed by short flush
Toxins	Ricin	For pipes and tanks- Continuous flushing with water, water buffered with chlorine, or water mixed with cleaner

The following is a summary of the recommended list of steps for dealing with a potential contamination scenario involving a building plumbing system following a complaint or other indication of a problem.

1. *Collect and analyze water samples to determine if the complaint is associated with the presence of a contaminant, and identify and measure the contaminant concentration*
2. *Determine the extent of the contamination*
3. *Isolate the contaminated water piping to prevent propagation to uncontaminated piping*
4. *Try to locate the source or point of introduction of the contaminant*
5. *Determine if the contaminated water can be flushed into the waste water system*
6. *Assess volatilization potential of contaminant if exposed to atmospheric pressure within a building*
7. *Determine maximum drainage water flow rate per building to prevent overloading the drainage system*
8. *Flush with water at the appropriate rate, if considered safe*
9. *Estimate contaminant accumulation within the plumbing system*
10. *Select appropriate decontamination procedure*
    a. *If water- continue flushing*
    b. *If cleaning agent or shock chlorine- select injection point, flush with solution*
11. *If waste water cannot be discharged into the drainage system*
    a. *Collect waste water*
    b. *Back flush where possible*
12. *Verify effectiveness of decontamination effort*
    a. *Analyze water samples*
    b. *Analyze pipe samples*
13. *Determine if remedial measures are needed to restore plumbing system components*
    a. *Clean/replace faucets, valves, aerators, tanks, hoses*
    b. *Possible surface restoration*
14. *Replace and dispose of any components that could not be decontaminated*

6 SUMMARY

This paper presents a discussion of methods for decontaminating building plumbing systems and restoring them to safe operation, based on generic contaminant characteristics. More specific recommendations are being developed that link decontamination procedures to particular contaminants or groups of contaminants with similar characteristics. It is hoped that these recommendation will prove useful as a starting point for a set of comprehensive guidelines that support general response plans for effective recover from water supply system contamination events.

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