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Decontamination procedures of water distribution systems

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Introduction, page 10 : more explanation that with aerosolisation the risk should be very low according to the dose;

Chapter 3, paragraph 3.1, pages 21 to 23: improvement of the last paragraph and addition of Table 2;

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References added and corrected.

Summary

After a deliberate pollution of drinking water distribution networks with Chemical, Biological, Radiological or Nuclear (CBRN) agents, a crucial step, among other activities (e.g. information of population, shifting to alternative water supply, isolation of contaminated areas), is safe and effective decontamination procedure. This includes the removal of contamination water and deposits/biofilm from the networks, neutralization and safe disposal of wastes. The knowledge about effectiveness of methods which are routinely used for cleaning (e.g. disinfection, flushing, descaling) of the networks for decontamination after deliberate pollution is limited. Therefore, the aims of this report are (i) to provide an overview on commonly used cleaning procedures; (ii) to evaluate challenges of their applicability in case of deliberate contamination with CBRN and (iii) to identify the needs for developing of safe and effective decontamination techniques.

The current legislation regarding procedure of how to act in a case of terrorist attack on drinking water supply systems in several European Countries (France, United Kingdom, Germany, Finland and Latvia) is described. The authors have reviewed literature and technical reports about conventional cleaning methods of drinking water networks. To gain more insight in practical issues related to decontamination, the experience from waterborne outbreaks is also shortly reported. Based on scientific articles and practical experience from water companies their effectiveness in decontamination after deliberate contamination is analyzed. The approaches which are used in other industrial sectors or are in the developing stage but appear to be potentially effective, cheaper (*e.g*. less time consuming) and environmentally safer (less water consuming, higher safety) are also presented. The challenges related to removing CBRN from the networks and discussion on how to handle them are presented.

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Abbreviations

ANPC - National Authority of Civil Protection (Portuguese acronym)
AOP - advanced oxidation processes
BASR spores - anaerobic bacteria sulfito reducing (in French)
CBRN - chemical, biological, radiological or nuclear
CFU – colony forming units
COMAH - Control of Major Accident Hazards
DGS - General Health Directorate
DTPA - Pentetic acid or Diethylene triamine pentaacetic acid
DVGW - Deutsche Vereinigung des Gas- und Wasserfaches e.V. / German Technical and Scientific Association for Gas and Water
DWI - Drinking Water Inspectorate
EDTA - ethylenediaminetetraacetic acid
EPA – Environmental Protection Agency
ICRP - The International Commission on Radiological Protection
IRAR - Regulatory Institute of Water and Wastes
ISO - International Organization for Standardization
LD50 – the median lethal dose required to kill half the members of a tested population after a specified test duration
NRA - National Rivers Authority
NSF - National Sanitation Foundation (International, The Public Health and Safety Company™, a not-for-profit, non-governmental organization)
PVC - polyvinylchloride
PE - polyethylene
REPPIR - Radiation Emergency Preparedness and Public Information Regulations
SEPA - Scottish Environmental Protection Agency
UV - ultraviolet
WHO - World Health Organization
WICS - Water Industry Commission for Scotland

1 Introduction

Terrorism destroys our feeling of safety and normality, and introduces substantial stress and uncertainty in individuals and communities [Ursano et al., 2003]. Water resources and drinking supply systems are attractive targets because contaminants can rapidly spread (though water distribution networks) creating casualties and obscurity within a short period of time. The typical scenario for a terrorist attack on domestic water supplies involves introducing a chemical or biological agent into local water supplies or using conventional explosives to damage basic infrastructure such as pipelines, dams and treatment plant units [Gleick, 2006]. Water distribution systems are the primary target of attack, because they are relatively easily accessible for intruders (*e.g.* though firefighting hydrants, clean water reservoirs). Most of chemical, biological, radiological or nuclear (CBRN) agents are effectively removed during conventional drinking water treatment and disinfection, thus attack on raw water sources is not a primary concern. Biological agents are most likely to be introduced in water supply system because some of the microbes cause diseases and death even at low concentrations [Ursano et al., 2003]. Besides some of them are very resistant towards chlorination and remain in water supply system for long time causing long term risks of contamination (Table 1).

Table 1. Pathogens considered being a threat through drinking water [Gleick, 2006]

(B – bacteria; R – rickettsia; V – virus)

Pathogen	Type	Weaponized	Stable in water	Chlorine tolerance
Anthrax	B	Yes	2 years spores	Spores resistant
Brucellosis	B	Yes	20–72 days	Unknown
C. perfringens	B	Probable	Common in sewage	Resistant
Tularemia	B	Yes	<90 days	Inactivated, 1 ppm, 5 min
Shigellosis	B	Unknown	2–3 days	Inactivated, 0.05 ppm, 10 min
Cholera	B	Unknown	Yes	"Easily killed"
Plague	B	Probable	16 days	Unknown
Q Fever	R	Yes	Unknown	Unknown
Hepatitis A	V	Unknown	Unknown	Inactivated, 0.4 ppm, 30 min

Chemical contaminants are not very effective due to the volume of chemical required and the relative toxicity of most chemicals [Gray, 2008b]. On other hand chemicals are more easily commercially available and can be obtained by terrorists in large amounts. Of particular concern are pesticides and related chemicals which are applied to kill insects, rodents and plants. These include organophosphate pesticides and chlorinated pesticides. Several inorganic chemicals are also widely available and potential threats to water systems, including various forms of arsenic and cyanide. Both are soluble in water and can be lethal. Contamination of water supply system with radionuclides is also likely because of their strong sorption to the pipe walls, which may paralyze water supply of the city because of need to replace pipes of water supply.

Although CBRN agents have been studied due to their importance in other applications (*e.g.* remediation of polluted groundwater with pesticides, radioactive waste disposal), yet little is known about their fate in drinking water distribution networks. Even less information is available about methods which can be used to effectively remove and neutralize them. After terrorist attack in September 11, 2001 in the United States of America several research projects were started which have resulted in amendment of legislation: Homeland Security Presidential Directives and the Public Health Security and Bioterrorism Preparedness and Responses Act was enforced. In European Union the development of such legislation is underway.

Although there are some emergency plans how to organize people in case of attack, there is still need for more reliable and safe decontamination methods. Water companies over many years of operating the distribution networks have gained extensive experience of dealing with discoloration events. There is literature available on this topic including a book [Ainsworth, 2003] and reports of an EU research project [1] from application of these methods by water companies. Some of the lessons can also be learned from past experiences in dealing with unintentional pollution. However,

[1] http://www.techneau.org

there are several substantial differences between terrorist attack and unintentional contamination, which makes the formal one to be handled with higher level of precaution. The contaminants used by terrorists most likely will be more resistant [Krisshan and Piao, 2008] and will be difficult to remove with commonly used decontamination methods such as chlorination (Table 1). Moreover, it is highly probable that CBRN agents will be even more dangerous than contamination in sewerage. Thus, consequences from inefficient decontamination will be more severe, which may result in long-term loss of confidence in water supplier by the consumers. In comparison with flushing which is used in case of discoloration, the removal of contaminants is more difficult to accomplish because some of the agents, for example bacterial spores, can be aerosolized and spread in the air during the flushing in form as small water droplets. Firstly the LD50 for example of *Bacillus anthracis* spores varies widely with species and route of exposure (Watson and Keir, 1994; Haas, 2002). *B.anthracis* critical dose for human via inhalation route is 600 – 2150 spores (Watson and Keir, 1994).

The clinical forms of anthhrax are inhalational, cutaneous and gastrointestinal. The comparison between the infection route with *B. anthracis* spores leads to conclusion that inhalational anthrax is the most dangerous forma as case-fatality estimates are extremely high, even with all possible supportive care including appropriate antibiotics (bulletin by Department of Health and Human Services). The health risk linked to directly or indirectly contaminated drinking water system will likely be posed by showering or bathing as the aerosolation of the Bacillus spores will be great. A worst-case critical dose via the inhalation route is estimated as 600 spores, corresponding to a drinking water concentration of 100 spores/L for consumption (getting in contact with 6 L). In worst case scenario (the average water use 200 L/person/day) a person may get in contact with 20000 (if there is 100 spores/L) spores, which will be a big risk.

Moreover the staff which is involved in decontamination might be exposed to high doses of CBRN, for example, during flushing of water with high level of radionuclides. Thus, preferably the contaminants shall be neutralized *in situ* (inside the pipe or

reservoir) and than safely removed (e.g. by flushing, pigging) and disposed. This is also more viable approach as the amount of water to be disposed can be very large. This is because the time between the contamination and detection can be long (few days or weeks) allowing contamination to spread in large parts of the network. Neutralization can be also carried out outside the pipes but for this the water which is used in flushing should be treated, for example using cyclones, and than recycled. When CBRN agents are introduced in water supply system they not only contaminate bulk water but also accumulate on the surfaces of the pipes by penetrating corrosion layer or being trapped in biofilm or loose deposits which are usually present in the water supply systems. The removal of such contamination is very difficult, for example killing of bacterial spores with chlorine [Szabo et al., 2007] or removing radionuclides (e.g polonium) with chemical methods. Thus one of the major challenges is to make sure that contaminants are released from these surfaces or, in contrary, immobilized and than removed as sludge. As in many cases the exact substance or biological agent will not be known, the efficiency of methods should be sufficient to deal with the worse case scenario. Finally, after cleaning the cleaning procedure shall be simple enough so that water companies can perform it themselves. In addition, to avoid microbial outbreaks due to limited access to water and sanitation services, the cleaning should not take longer then few days, otherwise the hygienic problems due to lack of sanitation may arise.

There is a limited experience in decontaminating water supply networks after terrorist attack, thus more detailed analyses of existing practical experiences and research are required. This report aims to identify the gaps of knowledge which shall be addressed in Secureau project. The specific tasks of this report are (i) to provide an overview legislation addressing decontaminate actions in Europe and present commonly used cleaning procedures today; (ii) evaluate challenges and effectiveness of their applicability in case of deliberate contamination with CBRN and (iii) to identify the needs for developing of safe and effective decontamination techniques.

2 Legislation on actions to be taken after a contamination

2.1 International and EU guidelines

The EU sets legislation on drinking water quality in addition to factors such as how, where and when water can be extracted from the environment. The primary piece of legislation governing drinking water is *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*, known as the Water Framework Directive. Each member state is responsible for establishing the required policing measures to ensure that the legislation is implemented. In 2007 The Green Paper was issued by EC which intended to stimulate a general debate and launch a process of consultation at European level on how to reduce biological risks, and to enhance preparedness and response ("bio-preparedness") which may lead to concrete actions within the Community's and Union's competence [2]. It was concluded that the said actions have to be presented and developed separately in specific areas of work following the applicable decision-making procedures and in order to improve the ability of the EU to prevent, respond to and recover from a deliberate criminal activity, the coherence of actions in different policy sectors requires that all the relevant stakeholders in Member States and at EU level be consulted. The feedback from stakeholders to the policy options and deliverables outlined in the document was deemed essential by the Commission to evaluate the mechanisms and frameworks which are already in place and how they are implemented, identify possible shortcomings and subsequently propose specific actions where needed and in accordance with the principle of subsidiarity as set out in art 5 of the EC Treaty. Regarding the biocontamination via drinking water there is no particular pan-European regulation requiring or defining the disinfection protocols of drinking water distribution

[2] http://www.europarl.europa.eu/meetdocs/2004_2009/documents/com/com_com(2007)0399_/com_com(2007)0399_en.pdf is a document issued by EC and emphasizes the principle of subsidiarity set in the art 5 of the EC Treaty

systems after a terrorist attack. The member state countries have different guidelines on actions to be taken under the terrorist attack. In the following chapter a review of present laws and guidelines in several EU countries is given, with an emphasis on the strategies used for drinking water decontamination. More information about guidelines used by the different countries is given in the Appendix 1 and 2.

Disruption of drinking water supplies can have grave consequences and result from both man-made and natural causes, ranging from terrorist attack to industrial pollution of rivers to hurricanes. Water supply organizations of all sizes and types have become increasingly aware of the need to achieve and demonstrate proactive security performance related to their physical facilities, services, activities, products, supply chains, and operational continuity. They do so within the context of increasing security risks and threats, more stringent legislation and regulation, heightened awareness of the need for adequate emergency response and remediation planning, concerns of interested and affected parties, and the need to assure operational continuity. While the management of drinking water utilities under crisis needs to meet national or regional requirements of relevant authorities, the development of international standards can provide further assistance.

With the security of drinking water a major concern worldwide [ISO, 2008] published new guidelines on managing drinking water supplies during crises, entitled the International Workshop Agreement on Water Security (IWA 6)[3]. Water security standardization can be very useful to help water companies face these challenges. The IWA 6 guidelines constitute the first stage of a comprehensive suite of standards for water security that will serve society. IWA 6 provides a framework for the management of water crises and proposes tools and means for ensuring drinking water security, and models for water distribution systems security. The main topics covered are:

[3] An International Workshop Agreement (IWA) is an ISO document produced through an international workshop rather than through the full ISO technical committee process. Market players and other stakeholders directly participate in developing an IWA and do not have to go through a national delegation. An IWA can be developed swiftly (published in less than 12 months) to address a rapidly emerging market need or public policy requirement. IWA 6 was the first document of its type backed by international consensus.

- Water security products and means, including water contamination detection and identification technologies, physical and electronic protection and hardening of water contamination containment.
- Optimized modes, including for prediction of and dealing with dissemination of contamination in water system, designing the most effective and efficient ways for positioning monitors and means of containment in water supply systems, and best practice for decontamination
- Technologies and processes for managing a water security event that includes risk management, security and continuity management, communications, interoperability, training and competence.
- The authorities through regulations and laws conduct crisis management in water disaster.

The responsibility for supplying water to the consumers falls on the water utility. IWA 6 focuses on water utilities since these entities are the ones that need the guidance, best practices and tools to meet and coordinate expectations with their consumers as well as demonstrate best practice in relation to the authorities.

It gives water utilities an approach for securing for themselves and for providing their stakeholders assurance about their security and continuity preparedness, emergency, contingency plans and performance. The guidelines also provide a framework for meeting legal and policy requirements in these areas. In addition, the management methodology proposed is based on the Plan-Do-Check-Act model, to facilitate continual improvement.

2.2 Action undertaken if a deliberate drinking water contamination has occurred

2.2.1 France

Guidelines about procedure for cleaning, flushing and disinfection of reservoirs and pipes and disposing of wastewater in sewage system are available from Ministry of

Health (March 15, 1962). However, there are no recommendations on strategy to be used after deliberate decontamination.

2.2.2 Latvia

The Republic of Latvia has issued a Law [Epidemiological Safety Law, 1999] regarding the procedures of the evacuation and the isolation of the patients however Latvian legislation does not impose every water supply company to have a plan in a case of a terrorist attack. If there would be such a case, the company would try to solve this problem using their own means. Should that prove to be impossible they are obliged to inform the authorities (see Appendix 1, Table 3). If during routine analyses a company identifies a contamination it has to decide the preventive action to be taken. All the water supply companies must have an Action Plan for emergency situation in case of a limited water supply. No specific guidelines of technical measures to be taken for drinking water supply system decontamination exist.

2.2.3 Finland

The regulations concerning general principles of drinking water safety in Finland are included in the Health Protection Act 763/1994. Drinking water quality regulations follow the Council Directive 98/83/EC. The regulations set in the Directive are included in the Decrees of the Ministry of Social Affairs and Health 461/2000 and 401/2001. By virtue of the Health Protection Act 763/1994, municipal health protection authorities can give instructions on the treatment of drinking water and are obliged to report all suspected waterborne outbreaks to the National Institute for Health and Welfare (THL), which then gives expert help when needed in solving the outbreak. There are no specific guidelines defining the cleaning protocols of drinking water distribution systems. In the case of a distribution network contamination, the decision making body is the municipal health authority.

2.2.4 Germany

The Federal Ministry of Health is responsible for management and control of supervision of health protection and subsequent rules and regulations based on it. Due to the

federal structure of Germany each of the 16 federal states have their own authority responsible for quality surveillance of drinking water protection within their region. There is no specific law or other legal regulation requiring or defining the cleaning of drinking water distribution systems. In the case of distribution network contamination, the decision making body is the municipal health authority. The judgment of the cleaning protocols depends on the estimated severity of the contamination. The selection of the cleaning protocols is made in local level in co-operation with municipal health authority and water works.

In the presence of a public health hazard, the responsible health offices of the federal states are entitled to conduct investigations on the basis of the Infectious Diseases Control Act (*Infektions-schutzgesetz*) and the Drinking Water Ordinance, and issue directives to avert the danger.

Generally flushing water through the pipe section at a minimum velocity of 0.8 m/s to remove particles is advisable [Buelow et aI., 1976]. Bacteriological tests for stressed coliforms [McFeters et al., 1986] and the HPC (Heterotrophic Plate Count) should then be performed. Chlorine levels should not decrease below 25 mg/L during the 24-h holding period before the line is flushed and bacteriological testing is repeated. In pipes free of extraneous debris, free available chlorine (1 to 2 mg/L), potassium permanganate (2.5 to 4.0 mg/L), or copper sulfate (5.0 mg/L) have been used to meet coliform requirements [Harold, 1934; Hamilton, 1974; Martin et al., 1982;].

2.2.5 The UK

Water supply companies in the UK have a duty under primary UK legislation to notify the Drinking Water Inspectorate (DWI) of events affecting or potentially affecting the quality of drinking-water supplies [Gray, 2008a]. Legislation in the UK is controlled through various Acts of Parliament relating to the three main UK regions, as follows:

England and Wales

The law relating to water companies in England and Wales is contained principally in the Water Industry Acts 1991 and 1999 and the Water Act 2003. Also relevant are the Water

Resources Act 1991 as amended and other national and European environmental legislation, particularly the Water Framework Directive 2000/60/EC.

The Water Industry Act 1991 was amended by the Water Industry Act 1999 and the Water Act 2003, among other things, providing for the regulation by the Environment Agency of:

- water resource management, abstraction and impounding; and
- water quality standards and pollution control.

Scotland

The Environment Act 1995 created the Scottish Environmental Protection Agency (SEPA). Under the Water Environment and Water Services (Scotland) Act 2003, SEPA exercises similar powers to those of the Environment Agency in England and Wales.

Northern Ireland

In Northern Ireland, water supply and sewerage services were also originally provided by local authorities. However, as a result of the troubles, responsibility for such services was transferred to central government. For some years water and sewerage services were then provided by the NI Department for Regional Development under the name of Northern Ireland Water Services. On 1 April 2007, under the Water and Sewerage Services (Northern Ireland) Order 2006, responsibility for water supply and sewerage services was transferred to a government-owned company called Northern Ireland Water. Based on the English Water Industry Act 1991, the 2006 Order includes provisions on the following:

- The establishment of the Northern Ireland Authority for Utility Regulation, responsible for the economic regulation of utilities;
- The establishment of the NI General Consumer Council;
- Power for the NI Department of Regional Development and/or the Authority to appoint water and sewerage undertakers; and
- The powers and duties of water and sewerage undertakers.

Environmental regulation is in the hands of the NI Department of the Environment, which operates through its Environment and Heritage Service. Its responsibilities are similar to those of the Environment Agency in England and Wales.

Additional UK legislation

Other UK legislation which can apply to the safety and contamination of drinking water supplies include:

- Civil Contingencies Act (2004);
- Civil Contingencies Act 2004 (Contingency Planning) (Scotland) Regulations 2005;
- Control of Major Accident Hazards Regulations 1999 (COMAH);
- Control of Major Accident Hazards (Amendment) Regulations 2005;
- Environment Act 1995;
- Pipelines Safety Regulations 1996;
- Radiation (Emergency Preparedness and Public Information) Regulations 2001 (REPPIR);
- Transport Act (2000);
- Water Resources Act 1991.

2.2.6 Portugal

With the enactment of the Law 27/2006, of 3rd July, which approved the Basic Law for Civil Protection, the national system for Civil Protection was redefined, and the National Authority of Civil Protection (Portuguese acronym ANPC) assumed a primary role in the scope of planning, coordination and implementation of the Civil Protection policy.

The services and institutions dedicated to technical and scientific research, either public or private, with specific competences in the domains of interest in the pursuit of the Civil Protection objectives, cooperate with the management, planning and coordination agencies which integrate the national system for Civil Protection.

3 Cleaning methods of drinking water distribution systems

Conventionally to prevent the pollution caused by the drinking water supply system flushing of distribution network with water and shock chlorination are applied. The well established flushing techniques are the conventional flushing, unidirectional flushing and air scouring. Applicability of these methods is described in examples of outbreak cases (Appendix 3 and 4). Other methods are more seldom applied and some of them are for special cases *e.g.* pigging. New cleaning methods based on different mechanisms as well as combination of cleaning methods are under development *e.g.* ultrasound (more detailed description in Appendix 5).

The challenges which shall be taken in to account are as follows:

- Attachment of CBRN agents to the biofilm deposits which may be integrated (attached) with corrosion and scale deposits. This problem was displayed in Nokia (Finland) outbreak case where *Giardia* sp. was detected in biofilm sample several days after outbreak (Appendix 4).
- Large part of networks is polluted, must be handled and the material disposed of as exposure time of CBRN agent can be several days. As an example Divonne-Les-Bains (France) outbreak (Appendix 3) is described where exposure time of *Cryptosporidium*, *Escherichia coli* and *Streptococci* took 15 days and additional 15 days were necessary to eliminate contamination.
- The existing treatment methods are ineffective. Further in the Chapter 3 several lab and pilot tests are described together with effectiveness of existing methods (flushing, shock chlorination etc.) to decrease concentration of CBRN in water and biofilm (adherent) phase.

3.1 Conventional pipeline cleaning methods

The conventional flushing known since 1970ties [Mays, 2000] is a simple approach of opening of one or more fire hydrants for indefinite time. The method can be

accomplished by low-skilled 1-2 person team and useful to raise the disinfectant residual. The disadvantages of the technique are the quite large amount of water used, low velocities and uncertain flow direction in looped pipes.

Since 1990ties a more effective cleaning method called “unidirectional flushing” has been proposed [Antoun et al., 1999; Vreeburg, 2007]. This technique requires planning and skilled executors (at least 3 people per team). The valves are closed and hydrants opened in a systematic fashion and pipes of network are cleaned with a “clear water front”. When the valves are closed, water travels towards the hydrant in a single direction thus high velocities are produced in the pipe (0.8 to 1.5 m/s depending on inner diameter), which makes the cleaning more effective and uses less water than conventional flushing. The method is effective to remove loose deposits and soft layer only for the pipes with a diameter 100-200 mm. To flush pipes with a diameter of 300-400 mm an operation using more than one open hydrant is needed. The effectiveness of the unidirectional flushing method decreases with the increase in number of bends, length and reduction in diameter of connected over ground pipe or hose to the operating hydrant.

During air water flushing (so-called air scouring) controlled injection of filtered and compressed air into the pipes usually via hydrant is performed. This technique is more effective regarding the removal of loose sediments, soft scales and biofilm from pipes with a diameter larger than 200 mm or in distribution systems with low pressure and flow rate (less than 30 m^3/h) at treatment plant. The method requires a compressor and a team consisting of at least 4 people to execute the work. Frequently the executors of air scouring mistakenly assume that method requires less water than unidirectional flushing however often after air scouring air slugs can remain in the highest points of pipelines which reduce the carrying capacity of the pipe [Ainsworth, 2003]. The effectiveness of air water flushing during this project will be determined by partners from IWW.

The cleaning of pipes with any kind of pigs (brushes, soft ball, swabbing disk) is an effective method used when removal of tuberculation or other scaling is needed. The technique is the same in both cases but the tools used in each case are different. In swabbing, the tool is a slightly oversized foam cylinder made of polyurethane whereas in the case of pigging the tool is a little more sophisticated. To perform any of these cleaning techniques special openings in network should be made or a section of the pipe should be removed. This method require special skills, notable human resources and usage of special equipment (e.g. hydrostatical machines) to get necessary pressure (60 mH_20) and flow (180 m^3/h) to clean a pipe of 200 mm.

To improve pipeline cleaning the flushing often is combined with usage of chemicals. The most frequently used disinfectants in drinking water treatment are disinfecting agents contain either chlorine dissolved in water or in liquid solution as sodium hypochlorite or solid form as calcium hypochlorite which decreases risk of bacterial growth in network. Effectiveness of chlorination depends on applied concentration and contact time. In the case of microbiological contamination in distribution network shock chlorination combined with pipe flushing is the most often applied method.

The partners from RTU will test free available chlorine and sodium hydroxide (NaOH) as potential chemicals to inactivate and desorb *Bacillus* spores from pipe walls. Variations in time, temperature, concentration and water pH may affect sporicidal and bactericidal properties of various chemical agents. Time of treatment, concentration of chemicals and water pH may be relatively easily controlled in opposite to water temperature. Thus the temperature within the distribution system in case of contamination may be used as a predictive parameter for evaluation of effect of chemical treatment or for calculation of time necessary to inactivate microbiological agents. Table (2) shows Ct values necessary to inactivate selected microbiological agents in 5°C and 20-25°C temperatures with free chlorine.

Table (2) Free chlorine inactivation of selected microbiological agents

Organism	Initial inoculum	Temp (°C); pH	Disinfection	Dose, mg/L	Ct value, mg min/L	Log kill	Author
Bacillus anthracis Ames	4.9-log10 CFU/ml	5°C, pH=7	Free available chlorine	0.80 2.80	220 for 2-$\log_{10}$ 339 for 3-$\log_{10}$		Rose et al., 2005
Bacillus anthracis Ames	4.9-log10 CFU/ml	25°C, pH=7	Free available chlorine	0.80 2.80	79 for 2-$\log_{10}$ 102 for 3-$\log_{10}$		Rose et al., 2005
Bacillus anthracis Sterne	4.1-log10 CFU/ml	5°C, pH=7	Free available chlorine	0.88 1.98 2.94	190 for 2-$\log_{10}$ 271 for 3-$\log_{10}$		Rose et al., 2005
Bacillus anthracis Sterne	4.1-log10 CFU/ml	25°C, pH=7	Free available chlorine	1.02 1.96	60 for 2-$\log_{10}$ 86 for 3-$\log_{10}$		Rose et al., 2005
Bacillus anthracis Sterne	4-log10 CFU/ml	5°C; pH=7	Free available chlorine	2.0	140 for 2-$\log_{10}$ 210 for 3-$\log_{10}$		Rice et al., 2005
Bacillus anthracis Sterne	4-log10 CFU/ml	23°C; pH=7	Free available chlorine	2.0	45 for 2-$\log_{10}$ 68 for 3-$\log_{10}$		Rice et al., 2005
Burkholderia mallei M-9	5.8-log10 CFU/ml	5°C, pH=7	Free available chlorine	0.14 0.39	0.2 for 2-$\log_{10}$ 0.3 for 3-$\log_{10}$		Rose et al., 2005
Burkholderia mallei M-9	6-log10 CFU/ml	25°C, pH=7	Free available chlorine	0.15 0.46	0.1 for 2-$\log_{10}$ 0.2 for 3-$\log_{10}$		Rose et al., 2005
Brucella melitensis ATCC 23456	6.6-log10 CFU/ml	5°C, pH=7	Free available chlorine	0.16 0.50	0.3 for 2-$\log_{10}$ 0.5 for 3-$\log_{10}$		Rose et al., 2005
Brucella melitensis ATCC 23456	6.9-log10 CFU/ml	25°C, pH=7	Free available chlorine	0.04 0.23	0.1 for 2-$\log_{10}$ 0.2 for 3-$\log_{10}$		Rose et al., 2005
Francisella tularensis NY98	6.5-log10 CFU/ml	5°C, pH=7	Free available chlorine	0.20 0.54	7.8 for 2-$\log_{10}$ 10.3 for 3-$\log_{10}$		Rose et al., 2005
Francisella tularensis NY98	6.6-log10 CFU/ml	25°C, pH=7	Free available chlorine	0.30 0.72	2.0 for 2-$\log_{10}$ 3.9 for 3-$\log_{10}$		Rose et al., 2005
Yersinia pestis A1122	6.1-log10 CFU/ml	5°C, pH=7	Free available chlorine	0.42 0.98	0.5 for 2-$\log_{10}$ 0.7 for 3-$\log_{10}$		Rose et al., 2005
Yersinia pestis A1122	6.4-log10 CFU/ml	25°C, pH=7	Free available chlorine	0.37 0.76	0.4 for 2-$\log_{10}$ 0.6 for 3-$\log_{10}$		Rose et al., 2005

Whitehouse and Clegg (1963) studied efficiency of sodium hydroxide on inactivation of *Bacillus subtilis* spores. They found that the overall effect can be expressed as:

$$t = \frac{2.6 \cdot 10^8}{C^{1.66} \cdot \theta^{3.79}}$$

where:

t – time in h for the 99% destruction of *Bacillus subtilis* spores,

C – concentration of NaOH (%, w/v),

θ – temperature, °F

From studies described above it can be stated that temperature has great effect on disinfection efficiency. But as it is hard to control temperature within the distribution systems this parameter may be used only to predict the bactericidal effect of selected chemical.

Traditionally, chemical cleaning of water tanks and pipelines involves three steps - an initial wash, followed by a purification using chemical treatment and final wash to eliminate added chemicals which can be discharged freely in the surrounding environment. The chemical cleaning should include sufficient wetting time of filled pipe to dissolute deposit layer/tubercles and to neutralize CBRN agent. In Appendix 6 the advantages and disadvantages of used flushing methods of distribution networks are summarized.

3.2 Ultrasound and hydrodynamic cavitation

In the last years the usage of ultrasound has been applied to control algae and scale in open water systems, marines and heat exchangers and cooling towers[4]. This noninertial cavitation is the process in which small bubbles in a liquid are forced to oscillate in the presence of an acoustic field, when the intensity of the acoustic field is insufficient to cause total bubble collapse.

[4] http://www.envirosonic.eu

The more significant erosions cause inertial cavitation where one of the known forms in industry is hydrodynamic cavitation. The phenomena of hydrodynamic cavitation in a flowing liquid is associated with the formation, growth and the collapse of microbubbles, leads to local generation of very high energy densities, resulting in very high temperatures and pressures at the surface of the bubbles for a very short time. The momentum balance equation predicts that when a fluid is passed through a constriction the static pressure downstream drops due to an increase in velocity. If the pressure falls below a critical value, usually below the vapor pressure of the medium of operating temperature, then small bubbles or vapor cavities are formed in the fluid. An increase in the velocity will result in a further drop in pressure and an increase in the cavitation intensity. The term cavitation threshold is used to describe the minimum conditions necessary to initiate the cavitation. It has been estimated that sound pressures of 1–8 bars are required to reach the cavitation threshold for water depending on the temperature. The probability of cavitation occurring in a flow regime is predicted by calculation of the ratio of forces collapsing cavities to those initiating their formation. This ratio is called cavitation number (σ) and is defined as $\sigma = \frac{P_r - P_v}{1/2\rho V^2}$ where P_r is the recovery pressure, P_v the vapor pressure of the liquid at the operating temperature, and ρ, V the liquid density and the liquid velocity at the orifice constriction, respectively. In pipe systems, cavitation typically occurs either as the result of an increase in the kinetic energy (through an area constriction) or an increase in the pipe elevation. The hydrodynamic cavitation is effective in disturbing deposit or corrosion layer in pipes, rendering their effective removal by flushing.

3.3 Application of Biofilm Release Agents

A major problem for decontamination and remediation of water supply networks is the tenacious attachment of CBRN agents to the biofilm deposits which may be integrated with corrosion and scale deposits on the pipe walls. If physical release methods are not completely effective then other means must be investigated to release CBRN agents, or

the biofilm deposits themselves from the pipe surfaces. Recent advances in biofilm formation and physiology indicate that it may be possible to trick attached microorganisms displaying a 'biofilm phenotype' into adopting a 'planktonic phenotype' where they are more susceptible to disinfectants and may also physically detach from the pipe surfaces. In laboratory studies using the model biofilm organism, *P. aeruginosa*, low, non-toxic concentrations of the nitric oxide (NO), was identified as an important factor in mediating biofilm dispersal by inducing a transition from the sessile biofilm mode of growth to the motile planktonic phenotype [Darling and Evans, 2003; Barraud et al., 2006; Van Alst et al., 2007]. Nitric oxide-mediated dispersal in *P. aeruginosa* biofilms involves cyclic di-GMP, a conserved secondary messenger level of which is regulated by diguanylate cyclases and phosphodiesterases [Ryan et al., 2006]. Gene expression studies have indicated global responses to NO in *P. aeruginosa* biofilms, including the upregulation of genes involved in motility and energy metabolism and the downregulation of adhesins and virulence factors [Barraud et al., 2009a]. Site-directed mutagenesis of candidate genes and physiological characterization of the corresponding mutant strains uncovered that the chemotaxis transducer BdlA is involved in the biofilm dispersal response induced by NO [Morgan et al., 2006].

Genes encoding for diguanylate cyclases and phosphodiesterases are widely distributed among bacteria and are often associated with redox sensors, capable of sensing NO [Delgado-Nixon, 2000; Römling et al., 2005]. This suggests that NO-mediated dispersal is not restricted to *P. aeruginosa* but may occur among various bacterial species [Barraud et al., 2009b]. Various NO donors, at concentrations estimated to generate low concentrations of NO have been tested on single-species biofilm of relevant microorganisms (Appendix 7) and on multi-species biofilms from water distribution and treatment systems. Nitric oxide-induced dispersal was observed in all biofilms assessed, and the average reduction of total biofilm surface was 63%. The efficacy of conventional chlorine treatments at removing multi-species biofilms from water systems was increased by 20-fold in biofilms treated with NO compared with untreated biofilms. These data suggest that the combined treatments with NO may allow for novel and

improved strategies to control biofilms and have widespread applications in many environmental, industrial and clinical settings, including remediation of contaminated mains distribution drinking water supplies.

3.4 Removal of radionuclides

As decontamination waste amount is large, there is a need to concentrate radionuclides to smaller volumes. There is currently no high affinity rapid detoxification system that can absorb radionuclides. In nature, sulphate-reducing bacteria produce strongly magnetic iron sulphide, whose surface disorder produces an efficient and effective adsorbent for heavy metals, including radionuclides, and halogenated carbon compounds. The material can be continually produced by growing the bacteria in a chemostat and by feeding back a proportion of the strongly magnetic material. Contaminant uptake is rapid and the loading of the adsorbent is high due in part to the high surface area of the adsorbent and the fact that many of the ions investigated are chemisorbed [Watson et al., 2001]. The structural properties have been examined using high-resolution imaging and electron diffraction, transmission electron microscopy (TEM), the dependence of the magnetisation on magnetic field and temperature, extended X-ray absorption fine-structure (EXAFS) spectroscopy, X-ray absorption near edge structure (XANES) spectroscopy and neutron diffraction. For example, using EXAFS, pertechnetate ion, $TcO4-$, was shown to be chemically reduced on the adsorbent surface to $TcO2$ where it remained chemisorbed.

Following the success of the biologically-generated FeS, attempts were made to produce a similar but less-expensive FeS by chemical precipitation. The development of such material having a large surface area and good adsorbent properties for cationic heavy metals has been previously achieved [Lidzey, 1995] comparable in performance to the biologically generated material [Hooper, 2000]. However, the performance of the material with anions was greatly inferior to the biological material and it appeared to have no chemically reductive capacity. It was discovered that the biologically produced

material was a mixture of mackinawite $Fe_{1+x}S$ and greigite Fe_3S_4 whereas electron diffraction studies revealed that the non-biological precipitate is a tochilinite related compound perhaps partially composed of mackinawite. SOTON, one of SecurEau partners has previous knowledge into the biotechnology production of FeS from sulphate reducing bacteria (SRB) and applicability of this method for decontamination of water distribution networks from radionuclides will be further tested in the project.

4 Effectiveness of commonly used methods

4.1 Flushing

Routinely flushing is used to remove loose deposits or combined with air scouring to remove inner corrosion layer form the pipes (see Chapter 3.1). When only turbidity from the corrosion of iron pipes is of concern (e.g. not removal of pathogens after disinfection or removing) the flushing is preferable, because more aggressive methods (e.g. air scouring and pigging) can remove protective layer and expose pipe to more rapid corrosion. In case of a terrorist attack corrosion after cleaning is of secondary importance, and flushing technique should be as effective as possible thus decreasing the risk of post-contamination.

The flow velocity is one of variables affecting effectiveness of the flushing. The flow velocities used in decontamination tests in lab-scale experiments in EPA [Krisshan and Piao, 2008] during flushing reached only 0.762 m/s which correspond to conventional flushing technique (Chapter 3.1). The tests showed that efficiency on *Bacillus subtilis*, arsenic, mercury and diesel fuel concentration reduction in adherent phase was insufficient since only 29%, 51%, 57% and 74% respectively of the initial adherent concentration was reduced.

Some pilot-scale experiments [Feliers et al., 2007] have been performed with flow velocity of 1 m/s which corresponds to requirements of unidirectional flushing technique. The pilot system was decontaminated after pollution with wastewater. The results showed that even if the concentrations of fecal indicators (*E.coli, Enteroccoci*) were reduced from 3 to 5 log, they were still present at the end of the decontamination in both water and biofilm (1 or 2 log, respectively) thus the removal efficiency can be evaluated as insufficient. Unidirectional flushing technique was shown to be efficient since it provided a good removal of *Giardia* cysts and *Cryptosporidium* oocysts [Feliers et al., 2007] .

It can be concluded that flushing must be used in combination with another technique to decontaminate drinking watre distribution system polluted with CBRN. The principles of unidirectional flushing can be effective to remove loose deposits only in case of smooth pipes (PE, PVC, cement lined ductile iron) while decontamination of heavily corroded cast iron pipes is insufficient.

4.2 Chlorination and chemical cleaning

Chlorination of the pipes after contamination or replacement of pipes is the most frequently used method. Vegetative bacterial bioterrorist agents (gram-negative) have been shown to be more susceptible to disinfectants than spores in the planktonic phase in lab-scale experiments. The removal of *Bacillus* species in water phase by 2-3 log was achieved using shock chlorination [Rose et al., 2005; Rice et al., 2005].

The tests in annular reactor with corroded iron coupons showed that shock chlorination is only effective for removal of *Bacillus atrophaeus* subsp. *globigii* spores in distribution systems where disinfection was not used before. The concentration of spores could be decreased by 2 log with initial concentration 10^6 CFU/cm^2. The rough surface of corroded iron water pipe also provided areas that free chlorine could not reach. It appears that this type of surface provides safe areas where spores, and possibly other disinfection resistant organisms such as oocysts, can reside for long periods of time unless removed by phenomena such as sloughing or hydraulic shear or physical removal such as pigging [Szabo et al., 2007].

The pilot-scale tests about shock chlorination efficiency on adherent *Bacillus subtilis* have also been performed [Krisshan and Piao, 2008]. Shock chlorination was performed at a free chlorine level of 200 mg/L with a contact time of two hours to reach the target contact time (CT) value of 30, 000 m/L-min. The chlorine demand from the pipe surfaces was not very significant since the cement-lined ductile iron pipe

was used in this study. The test results indicated that the decontamination efficiency of shock chlorination for *Bacillus subtilis* ranged from 94 to 96 % (i.e., 1.2 to 1.4 log removals).

The pilot-scale experiments performed by Veolia [Féliers et al., 2007] showed that the concentrations of faecal indicators and BASR spores were above the analytical detection level, with 2 or 3 log elimination after 5 h treatment with concentration of chlorine 1 and 2 mg/L. The results obtained by Veolia indicate that the shock chlorination approach would make it possible to remove the *Cryptosporidium* oocysts from biofilm in water phase [Feliers et al., 2007].

Review about removal effectiveness of *Bacilus* spores using chlorine and other agents is given in Appendix 8. Several lab scale experiments have shown that *Bacilus* spores 10^5–10^9 CFU/mL can be eliminated up to 99% in water phase using calcium or sodium hypochlorite.

Decontamination tests in pilot with arsenic, mercury, chlordane diesel fuel and *Bacillus subtilis* done by EPA are listed in Appendix 9. Experiments were carried out to clarify the effectiveness of several methods for decontamination of mentioned agents adherent on pipe surface. PVC and cement-lined ductile iron pipe samples were used in the experiment which can be described as smooth materials. To increase the solubility of adherent agents hydrochloric acid and phosphate buffer solution were applied. Acidified potassium permanganate solution was used as a strong oxidant. Results showed that effectiveness of applied decontamination methods is insufficient.

No data on chemical decontamination methods for removal of radionuclides from water pipe surfaces could be found in the literature. Therefore an approach using non-toxic chemicals that are known to form stable and soluble complexes with the radionuclides will be investigated in the Project. Both DTPA and EDTA form stable

complexes with americium [Rizkalla et al., 1989]. DTPA is clinically accepted for chelation therapy for people exposed to actinides [Durbin, 2003]. Also EDTA has been used in chelation therapy as it complexes with calcium (arteries) and lead (lead poisoning) [Chisolm, 1992]. EDTA is widely used in various industries and is therefore widely available and not expensive material. Strontium exhibits tendency to form complexes with citrate, oxalate, and acetate ions. Also, EDTA-SR -complex is very stable and soluble. Based on this knowledge it can be concluded that the most viable (available, non-toxic, inexpensive) chemical decontamination agents could be EDTA, citrate, oxalate, and acetate.

The accumulation of radionuclides in water distribution network has been investigated [Hämäläinen *et al.*, 2004] and it was concluded that about 26% of radium was adsorbed on water pipes probably precipitating with limestone or adsorbing onto biofilms. Behavior of polonium varied but around 30% of polonium in water was retained in the pipes. Polonium has previously been recorded to adsorb onto the walls of ground water storage container [Lehto et al., 1999, Vaaramaa et al., 2003].

In general decontamination applying shock chlorination which is most often used method can be effective for removal of bacteriological agents in water phase. To decontaminate adhered spores on heavily corroded metal pipes thus it is likely that physical treatments (ultrasound, cavitation) or application of release agents are needed to facilitate detachment of the spores. Other chemicals (phosphate buffer, hydrochloric acid, acidified potassium permanganate solutions, DTPA and EDTA) do not correspond to reliable materials for removal of bacteriological agents but could, instead be used for radionuclide removal.

4.3 Ultrasound and hydrodynamic cavitation

Several lab-scale and pilot-scale studies are performed to determine effectiveness of ultrasound and hydrodynamic cavitation on elimination of bacteria concentration in water phase. The results indicated that most important factors which influence

effectiveness of methods is flow rate or water volume, electrical power and initial concentration of bacteria [Jyoti and Pandit, 2001; Joyce et al., 2003; Hulsmans et al., 2009]. The initial concentration of *Bacillus subtilis* in a water volume of 25 L was reduced with 2 log-units (99%) after 120 min of treatment however the reduction efficiency decreased with the volume used to 97% and no significant change in 50 L and 100 L, respectively [Joyce et al., 2003]. Higher water flow rate during continuous circulation in the pilot scale water disinfection system resulted in a higher disinfection rate however in a single-pass experiment lower water flow rates resulted in a higher disinfection efficacy. After 180 min, treatment with maximal electrical power achieved a 2 log CFU/mL bacterial reduction (>99%), while set at 70% of the maximum power the reduction achieved was only 1 log (90%) [Hulsmans et al., 2009].

The degree of disinfection efficiency increases with increase of pressure [Jyoti and Pandit, 2001] since it took 2 h to decrease the count by 41% at 1.72 bars whereas 44% reduction was achieved within 1 h when the system was operated at 5.17 bars discharge pressure of the pump. Increasing of the treatment intensity also leads to increase in bacterial reduction which has been shown using *P. aeruginosa, B. subtilis* and *S. aureus* cells and intensities from 1 to 3 W/cm^2 after 15 min of treatment [Hulsmans et al., 2009].

Ultrasound and hydrodynamic cavitation have been applied for disinfection of microbiological agents in water phase. Both methods, applied separately, showed insufficient effectiveness since they do not have not lasting effect on microbiological agents and are usually described as expensive. These methods could however be used for removal of CBRN agents from pipe surfaces which in some cases can be tuberculated in combination with shock chlorination and unidirectional flushing to decontaminate drinking water distribution systems.

5 Handling of decontamination sludge

After a deliberate contamination of water distribution network both sludge and water from sludge dewatering is generated. The sludge can be either neutralized *in situ* or conveyed to the waste water treatment plants. There is limited literature regarding handling of sludge from water supply system contaminated with CBRN agents. Removal of radionuclide from the sludge posses the highest concern, therefore in this section the focus is on removal of this CBRN agent.

Most of the literature available deals with radiological accidents during which raw water sources (lakes, reservoirs, rivers) are contaminated and radiological hazards take place at drinking water treatment plants. Removal of various artificial radionuclides using different water treatment processes [Alexander et al., 1988; Lowry and Lowry, 1988, Hämäläinen et al., 2004, Gäfvert *et al.* 2002] are summarized on Table 6 (Appendix 10). A review on the effect of treatment methods for the removal of radionuclides can be found in EURANOS handbook [Brown et al., 2007]. Brown and Hammond [2009] modified this handbook to be used in the UK and included an assessment of radionuclide concentrations in sludge produced during drinking water treatment. Brown *et al.* [2008] also evaluated doses to the workers at drinking water treatment works.

In case of a malevolent contamination of water distribution networks, the contamination point may be after drinking water treatment and hence it is important to recognize that protection of workers must be implemented also at waste water treatment plants right after an incident. Experience of handling sludge from wastewater treatment plants which is contaminated with radionuclides is available from the Chernobyl accident. It has been shown that relatively high concentrations of ^{137}Cs were found in the sludge [Puhakainen and Rahola, 1991]. About 39% of ^{137}Cs and 48% of ^{90}Sr in waste water were retained in the sludge after biological treatment [İpek *et al.,* 2004]. Since little is still known on the adsorption of various radionuclides onto pipe and reservoir surfaces within the network, it is possible that clean-up work of water mains and reservoirs at pump stations must also be commenced after an incident. Principles of

assessment of external doses received by clean-up workers are presented in Appendix 10.

5.1 Advanced Oxidation Processes

Recent progress in water/wastewater treatment has led to the development of advanced oxidation processes (AOPs), which have proved to be promising and attractive for the destruction of a large number of hazardous and organic pollutants. These processes are particularly suitable for the effective degradation of pesticides [Chiron et al., 2000; Malato et al., 2002; Maldonado et al., 2007].

Among the several AOPs, the Fenton and photo-Fenton reaction-based methods are efficient and economical. Oxidation with Fenton's reagent is based on the ferrous ion catalyst and hydrogen peroxide, and exploits the very high reactivity of the hydroxyl radical (HO•) produced in acidic solution by the catalytic decomposition of H_2O_2. The photo-Fenton reaction is known to improve the efficiency of the Fenton's reagent by means of the interaction of radiation with Fenton's reagents. A key feature of these (and other) processes is the possibility of oxidizing organic compounds under mild conditions of temperature and pressure (room temperature and atmospheric pressure).

6 Main conclusions

The report was aimed at providing the overview of commonly used methods and evaluates the potential of their application in cases of deliberate contamination, as well as to identify the knowledge gaps and challenges that are restraining from offering to water companies safe and efficient decontamination procedures. The following specific conclusions are drawn from this study:

- Experience from accidents in drinking water distribution system contamination showed that the procedure of decontamination is cumbersome and requires long time before sufficient levels of safety is established;
- The state-of-art cleaning methods such as shock chlorination and flushing are not efficient enough to provide high margin on safety for removal of resistant bacterial agents such as spores, whereas the loose deposits which are occurring in water distribution networks decrease the efficacy even more;
- Acidified potassium permanganate followed by flushing can be used as effective decontamination method for the removal of arsenic and mercury from cement-lined ductile iron pipe surfaces;
- The shock chlorination of spores (*Bacillus subtilis*) showed an average level of effectiveness for their removal from surfaces, but on the other hand is an effective method to remove of spores from bulk water;
- Application of release agents (*e.g*. FeS) is a very promising approach, however, more studies are need to test their applicability in full-scale;
- Alternative decontamination methods like ultrasound and cavitation have so far shown different results in bacteria decontamination from water phase in various studies however these methods have a potential to be used in combination with chemical treatment like shock chlorination to achieve better results;

- In the potential occasion where an industrial type of a sealed radiation source is used in an attack, great challenges are encountered in the protection of workers at water works and waste water plants as well as during the clean-up work;
- Protective measures are case-specific and must comply with generally accepted principles of radiation protection. Treatment and disposal of radioactive wastes must be integrated into the preparedness agenda;
- Decontaminated waste should be preferably neutralized in-situ before the disposal;
- To flush tuberculated pipes the principles of unidirectional flushing must be applied. Air scouring could be an efficient addition for the removal of CBRN agents in tuberculated pipes.

There are number of challenges which should be solved to optimize the efficacy of decontamination methods including the persistence of contaminant in the pipes and deposits, recycling of contaminated water and the exposure of emergency team to contaminants. However at the moment, the acquired knowledge enables to propose the following general protocol of decontamination actions:

1. Isolate the contaminated parts of the networks. The area is isolated to prevent a further spreading of the pollutant. Pollutant might accumulate in biofilm on the pathway from the contaminated site or in loose deposits. This shall be investigated.

2. Neutralize or remove the contaminants from surfaces. The CNBR agents can be neutralized *in situ* by pumping disinfection or release agents (e.g EDTA, NO) into the polluted pipes The application of mechanical devices such as ultrasound probe can be used to enhance the removal of sediments and corrosion layer. However the applicability of latter is limited to cleaning of the large diameter pipes with low number of bends and connections. The replaced water is neutralized or recycled (e.g. hydrocyclone) to increase the exposure of the contaminated pipes to the chemicals.

Neutralization is accomplished preferably *in situ*, because in this case sludge treatment is not necessary before discharging it to sewer or storm water system. Not all CNBR agents will always be identified before the start of decontamination, thus the release agents shall be effective to deal with the worst case scenario. As the contaminating material is not always known the methods shall be adequate for the worst case scenario.

3. Sludge and supernatant treatment. If the treatment *in situ* is not efficient, the pollutant is removed the network with flushing or pigging and handled outsides. Since polluted water cannot be discarded directly to sewer and to minimize the staff exposure to CNBR agents, the technology to collect large volumes of water shall be developed. The application of AOP both for oxidation of organic pollutants and disinfection can be applied. Hydrodynamic cavitation can potentially be used to remove biological agents from loose deposits in the sludge, thus improving the disinfection efficacy.

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8 Appendices

Appendix 1 Legislation

France

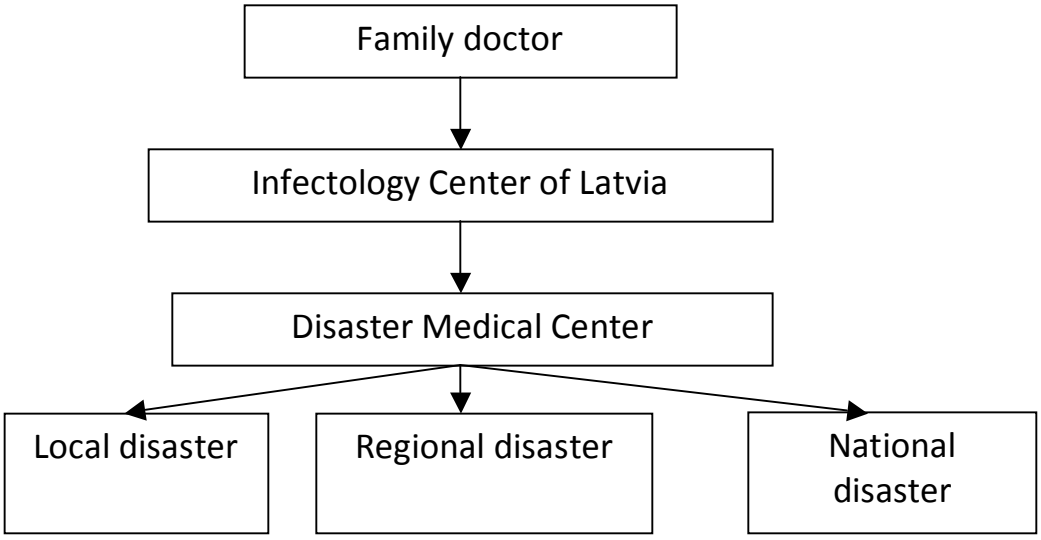
Guidelines about procedure for cleaning, flushing and disinfection of reservoirs and pipes and disposing of wastewater in sewage system are available from Ministry of Health (March 15, 1962). However, there are no recommendations on strategy to be used after deliberate decontamination.

Latvia

According to the Epidemiological Safety Law (Procedures for Registration of Infectious Diseases) [Epidemiological Safety Law, 1999] of Latvia, on the occasion of diagnosing smallpox, botulism, tularemia, plague or anthrax in a person, the hospital is required to inform the Infectology Center (IC) of Latvia and isolate the patient until IC specialists take over the case. If more infected persons are identified the Centre of Emergency and Disaster Medicine (CEDM) should be informed. CEDM is responsible for assessing the level of threat to public (local, regional or national) and to take the necessary action.

The Civil Protection Law applies to public protection for the disaster management, and the provision of the legal and organizational support for the protection of public, property and the environment in the cases of a disaster. The main tasks of the system are as follows: (i) to carry out disaster management; (ii) to provide aid to victims of disasters; (iii) to reduce the possible damage to property and the environment caused by the disasters; and (iv) if a military invasion or war has begun – to support the National Armed Forces with resources.

National Security Plan (NSP) regulates the responsibility of involved authorities in carrying out the disaster management. The State Cabinet of Ministers is responsible for risk management and remediation of the consequences after terrorist attacks



Latvian legislation does not impose every water supply company to have a plan in a case of terrorist attacks. If there would be such a case, the company would try to solve this problem using their own means. Should that prove to be impossible they are obliged to inform the National or State Security Council which consists of representatives of the Latvian Government and the President and the head of NSC is the Prime Minister. In practice if during routine analyses a company identifies a contamination it has to decide the preventive action to be taken (e.g. closing a part of distribution system to prevent further contamination). All the water supply companies must have an Action Plan for emergency situation in case of a limited water supply. If the company cannot provide the necessary amount of drinking water to the customers from water supply system they must provide it in containers. The company's public relation specialist should inform the public about such situation with the drinking water supply. An emergency technical council meeting then is convened for identification of the reasons of the emergency situation and fast involvement of the appropriate services to solve the accident and the consequences.

No specific guidelines of technical measures to be taken for drinking water supply system decontamination exist.

Table 3. The authorities responsible of consequences due to disaster in Latvia

No	Action	Reaction time	Responsible authority	Executors of the action
1	Information obtaining, processing, informing the government	10 min	Ministry of Interior	Rescue service
2	The involvement of special services	20 min	Ministry of Interior	Security police
3	Information of Foreign Office	20 min	Ministry of Interior	Security police
4	Information and involvement of other	20 min	Ministry of Interior	Rescue Service

	relevant services			
5	Arrival of the special services and emergency on the place of accident	40 min	Ministry of Interior	Security police, state police, rescue service
			Ministry of Health	Centre of Emergency and Disaster Medicine
6	Limiting the location	30 min	Ministry of Interior, Ministry of Regional Development and Municipality Affairs, Ministry of Defence	State police, municipalities, national armed forces
7	Terrorism suppression operation management	constantly	Ministry of Interior	Security police
8	Preparation for delivery of special medical equipment to the site of accident	as needed	Ministry of Health	Centre of Emergency and Disaster Medicine
9	Rescue works	constantly	Ministry of Interior, Ministry of Defence	Rescue service, national armed forces
10	Elimination of the consequences of the terrorists attacks	constantly	Ministry of Interior Ministry of Environment, Ministry of Regional Development and Municipality Affairs, Ministry of Transport	Rescue service, subordinate authorities of Ministry of Environment, municipalities, State Joint Stock Company "Latvian railway"
11	Preservation of evidences for criminal expertise	constantly	Ministry of Interior	Security police

According to National security law the Cabinet of Ministers is responsible for risk management and its aftermath. In case of country threat the crisis management council coordinates the civilian-military cooperation, and government institutions operational risk management measures.

Finland

Ministry of Social Affairs and Health is responsible for the management and control of supervision of health protection and subsequent rules and regulations based on it. National Supervisory Authority for Welfare and Health (Valvira) directs the implementation and supervision of legislation of health protection including legislation related to the drinking water. Municipal health protection authorities promote and supervise health protection within their region. In the field of water service, municipal authorities are responsible for taking care of quality surveillance of drinking water. Municipal authorities are entitled to order further treatments for drinking water e.g. disinfection in order to eliminate the health hazards.
The regulations concerning general principles of drinking water safety in Finland are included in the Health Protection Act 763/1994. Drinking water quality regulations follow the Council Directive 98/83/EC. The regulations set in the Directive are included in the Decrees of the Ministry of Social Affairs and Health 461/2000 and 401/2001. By virtue of the Health Protection Act 763/1994, municipal health protection authorities can give instructions on the treatment and use of drinking water to prevent harmful health effects. Since 1997, municipal health protection authorities are obliged to report all suspected waterborne outbreaks to the National Institute for Health and Welfare (THL), which then gives expert help when needed in solving the outbreak. There are no specific guidelines defining the cleaning protocols of drinking water distribution systems. The general idea is that good drinking water quality is maintained. In practice, some (mainly large) water works do have maintenance programmes including regular cleaning protocols (flushing, air-water scouring, pigging). Many (smaller) water works do not have any maintenance programmes for the pipelines. In case of distribution network contamination, the decision making body is the municipal health authority. The judgment of the cleaning protocols depends on the estimated severity of the contamination. The selection of the cleaning protocols is made in a local level in co-operation with municipal health authority and water works.

Germany

The Federal Ministry of Health is responsible for management and control of supervision of health protection and subsequent rules and regulations based on it. By this it is also responsible for the legislation related to drinking water. Due to the federalistic structure of Germany each of the 16 federal states has its own authority responsible for quality surveillance of drinking water protection within their region. At least the final responsibility for the supervision of the local water works and distribution systems is by the municipal health protection authorities, taking care of quality surveillance of drinking water. Municipal authorities are entitled to order further treatments for drinking water e.g. disinfection in order to eliminate health hazards and so on.
German drinking water quality regulations are specified in the “Trinkwasserverordnung” following the Council Directive 98/83/EC. By this, municipal health protection authorities can give instructions on the treatment, quality control and use of drinking water to the water works.
There is no specific law or other legal regulation requiring or defining the cleaning of drinking water distribution systems. In case of distribution network contamination, the

decision making body is the municipal health authority. There is no special legislation which includes regulations on cleaning processes. The judgment of the cleaning protocols depends on the estimated severity of the contamination. The selection of the cleaning protocols is made in local level in co-operation with municipal health authority and water works.

Technical rules

The German DVGW (Deutsche Vereinigung des Gas- und Wasserfaches e.V. / German Technical and Scientific Association for Gas and Water) has delivered several Technical Rules regarding safety of water supply systems. The most relevant in the context are the following:

- Code of Practice W 1000, November 2005: Requirements on the qualification and organization of drinking water suppliers;
- Guideline W 1001, August 2008: Safe and secure drinking water supply – risk management under normal operating conditions;
- Guideline W 1002, August 2008: Safe and Secure Drinking Water Supply – organization and management in the Event of a Crisis.

Code of Practice W 1000, November 2005: Requirements on the qualification and organization of drinking water suppliers

In this document the qualifications of the water supplier are outlined. The drinking water supplier has to ensure by means of suitable communication facilities and an appropriate organization that important information and messages can be received at any time and forwarded to the relevant authorities for processing. Vehicles with the necessary work appliances and implements have to be kept available for use to immediately ward off dangers in case of failures. Specification of the number of vehicles follows the size and structure of the supply area. The drinking water supplier has to devise his organizational structure such that all tasks, activities and processes can be reliably planned, executed and monitored. When devising the organization, the range of services, the enterprise size and the activities to be rendered by own employees or service providers have to be taken into account. The persons in charge of management and supervision have to verify the implementation and effectiveness of all regulations made at adequate intervals. If deficiencies are detected in the structural and process organization and in the documented provisions, modifications have to be initiated without delay. The drinking water supplier has to work out instructions guaranteeing the immediate elimination of disruptions and restoration of normal operations. The drinking water supplier has to document disruptions of normal operations. The documentation has to be evaluated and the reason for the disruption has to be established, correctional or preventive action has to be specified and checks regarding the effectiveness of correctional or preventive action have to be carried out.

Guideline W 1001, August 2008: Safe and secure drinking water supply – risk management under normal operating conditions

The DVGW Technical Rules addresses most questions regarding the general suitability of technical procedures or the definition of measures to control identified risks. It also describes how to apply and implement technical procedures as well as operational and water supply processes and recommends risk minimization measures; moreover, it offers information about nominal conditions, measurements and measurement intervals. In other words, all technical measures discussed in the DVGW Technical Rules can generally be considered proven and having general validity. If these measures are employed, it will suffice for the water supplier to properly implement all risk control measures and monitor their efficiency in accordance with the Technical Rules that apply to the supply system concerned. If the water supplier selects a risk control method not listed in the Technical Rules, the suitability of that measure requires a separate validation procedure.

In general, the following mutually complementary steps are eligible for risk control measure validation in a drinking water supply context:

Efficiency tests based on the determination of the water quality and/or general operation parameters measured before and after the technical measure to be validated has been taken (e.g. in the supply and outlet pipe of a water treatment stage). If necessary, check whether or not to conduct more comprehensive measurements (i.e., shorter monitoring intervals, for instance) for validation purposes to monitor the operational effectiveness of such a measure for a limited period of time. Evaluation of data or recordings collected under normal operating conditions after the measure has been implemented. Evaluation of critical operating conditions (e.g. by simulating hazard scenarios, testing various load cases, checking the robustness of measures) should be done. Theoretical approaches and computations regarding e.g. the elimination performance of individual treatment stages will support on-site validation. The effective implementation of measures shall be monitored, requiring the selection of procedures suitable for operational monitoring and the definition of verifiable nominal conditions. All established procedures shall ensure that deviations from nominal conditions are identified early enough to initiate corrective action. The procedures employed need not necessarily be metrological measures; visual inspection may also be considered, for instance. The type and number of the nominal conditions as well as the corresponding interference limits shall be defined as required to ensure expert monitoring of measures. Nominal conditions include, for instance, measurements or measurement ranges relating to specific parameters (e.g. pH value, turbidity, and throughput) and conditions that can be inspected (e.g. intact fencing around protection area). The selected parameters should be easy to measure; read-outs should be available immediately, if possible. Alternatively, meaningful indicators or secondary parameters may be used to monitor nominal conditions. Measurement intervals shall follow the principle that monitoring intervals must become shorter - up to continuous online measurement - as the significance and importance of a risk control measure increases. All procedures employed to monitor risk control measures shall be documented in writing. Such documentation shall contain data on nominal conditions, interference limits, types of measurement, measurement intervals, the necessary calibration of measurement types and devices; it shall also comprise the read-outs and their analysis.

Corrective action shall be taken as soon as the operational monitoring of risk control measures indicates a deviation from pre-set nominal conditions. Corrective actions should be defined in advance, if possible; any corrective-action measures taken should be recorded in writing.
Verification serves to prove that the defined risk control measures enable the water supplier to ensure the safety of supply. In order to verify compliance with health and aesthetic objectives, the final product, i.e. the drinking water, shall be analyzed at least on the basis of the provisions set forth in the Drinking Water Ordinance (Trinkwasserverordnung) with regard to the draw-off point, the sampling frequencies and the scope of parameters as well as regarding the mandatory limits that apply to individual parameters. The Drinking Water Ordinance specifies all analysis process requirements with regard to process characteristics and analytical quality assurance. It is necessary to appoint individuals responsible for analyzing results, keeping recordings on file, and deciding on need for action, if necessary. In order to verify that supply-related targets have been reached, in-house records and customer complaints, if applicable, shall be evaluated. The scope of verification may also comprise audits to check whether the measures installed to ensure the safety of supply as specified in Section 5.4 are implemented efficiently.

Guideline W 1002, August 2008: Safe and Secure Drinking Water Supply – organization and management in the Event of a Crisis
Drinking water suppliers must have at their disposal high-performance equipment, sufficiently qualified staff and well-functioning quality assurance measures or, alternatively, subcontract qualified experts and monitor the execution of the relevant services. Furthermore, they must be organized in such a way as to ensure their safe, reliable, environmentally friendly and economical operation [DVGW W 1000 (A)]. A risk management system designed to meet all these requirements that is focused on the individual water supply processes (protection of resources, water catchment, water conditioning, water storage, water transport and distribution) leads to success [cf. DVGW W 1001-1 (H)]. This risk-based approach complements the statutory final product inspection of drinking water stipulated by the Drinking Water Ordinance; it is described in the 2004 World Health Organization (WHO) Guidelines on Drinking Water Quality as a "Water Safety Plan". Beyond that, certain situations may arise that occur extremely rarely, are difficult to forecast and, therefore, impossible to make provisions. As drinking water suppliers may not be able to control such situations without any third-party assistance, the involvement of the local authority may become necessary. It is therefore impossible in such cases to act on the basis of pre-defined instructions for action as such situations require that appropriate decisions be taken that consider all general conditions relevant for operation in a crisis. The crises management tool at hand, which has been especially adapted by the DVGW in the form of this Guideline W 1002 on the supply of drinking water, has been designed for exactly that purpose. This Guideline describes the principles for corporate drinking water supply management in the event of a crisis, including preparatory and follow-up measures.
Legal basis in the event of crises.

In the event of a crisis, the operation of water supply systems must generally comply with the legal requirements that also apply in normal circumstances. In the presence of a public health hazard, the responsible health offices of the federal states are entitled to conduct investigations on the basis of the Infectious Diseases Control Act (Infektions-schutzgesetz) and the Drinking Water Ordinance, and issue directives to avert the danger. If speedy action is of the essence, the police and the general public order authorities may also exercise their rights to intervene on the basis of the Police and Order Laws of the federal states in order to avert danger. Beyond that, specific acts stipulating additional requirements and empowering the state to intervene apply in the event of war and disaster.

Practical handling of a contamination. Generally it is recommended, from handling of a bacterial contamination, which can be also advisable for other contaminants:

Upon completion of a new pipeline or after emergency repairs are made to a line break, flushing water through the pipe section at a minimum velocity of 80 cm/s to remove particles is advisable [Buelow et aI., 1976). In lines with diameters of 4.0 cm or more, this velocity may not be attainable or may be ineffective, requiring polypig or foam swab applications to be considered. Following flushing, cleaning water or disinfectant should be introduced into the new sections and the water held for 24 to 48 h to optimize line sanitation. Bacteriological tests for stressed coliforms [McFeters et al., 1986] and the HPC (Heterotrophic Plate Count) should then be performed. If the results of these tests are satisfactory (<1 coliform/100 mL; <500 HPC/mL), the line may be placed in service. If not, the line should again be flushed and refilled with distributed water dosed with 50 mg/L free available chlorine (chlorine gas). Chlorine levels should not decrease below 25 mg/L during the 24-h holding period before the line is flushed and bacteriological testing is repeated. In pipes free of extraneous debris, free available chlorine (1 to 2 mg/L), potassium permanganate (2.5 to 4.0 mg/L), or copper sulfate (5.0 mg/L) have been used to meet coliform requirements [Martin et al., 1982] [Harold, 1934] [Hamilton, 1974]. Only free available chlorine, however, was found to eliminate large numbers of cultivable heterotrophic bacteria [Geldreich and LeChevallier, 1999].

The UK

The EU sets legislation on drinking water quality in addition to factors such as how, where and when water can be extracted from the environment. The primary piece of legislation governing drinking water is *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*, known as the **Water Framework Directive**. Each member state is responsible for establishing the required policing measures to ensure that the legislation is implemented. For example, in the UK the Drinking Water Inspectorate polices the water companies.

Water supply companies in the UK have a duty under primary UK legislation to notify the Drinking Water Inspectorate (DWI) of events affecting or potentially affecting the quality of drinking-water supplies [Gray, 2008a]. Under the same legislation, DWI has a duty to investigate each event. After assessing all of the information available, including companies' reports, DWI advises on the way in which the event was handled and

whether any statutory requirements were contravened. If appropriate, a prosecution of the water company may be initiated. Copies of the assessment are sent to the water company, relevant local and health authorities, Ofwat (the economic regulator), the regional Consumer Council for Water and any other interested parties, including consumers who request it. Generic guidance may be issued to the industry on matters of wider concern. The importance of well-established contacts between the various interested parties involved in protecting public health is well recognised.
Legislation in the UK is controlled through various Acts of Parliament relating to the three main UK regions, as follows:

England and Wales
The law relating to water companies in England and Wales is contained principally in the Water Industry Acts 1991 and 1999 and the Water Act 2003. Also relevant are the Water Resources Act 1991 as amended and other national and European environmental legislation, particularly the Water Framework Directive 2000/60/EC. Legislation for water in England and Wales dates from Victorian times, when Acts of Parliament were passed to give local authorities, statutory boards and companies the powers they needed to provide water and sewerage services to expanding centres of population. The scope of this legislation was increased and consolidated through both world wars but without fundamental change. Then, in 1963, the Water Resources Act was passed. For the first time the abstraction and impounding of water resources became regulated on a regional basis. The 1963 Act created 'River Authorities' with responsibility for enforcing the law relating to water resources, river pollution, land drainage, fisheries and water space recreation. This was the beginning of river basin management. The administration of water law remained local until the Water Act 1973, which created ten regional water authorities whose areas were defined by river basins. These authorities had overall responsibility for water supply, sewage disposal and river basin management. They were, however, also required to work to some extent through the statutory water companies and the local authorities.
Privatisation of the ten water authorities' water supply and sewerage functions came with the Water Act 1989 and with it transfer of the river functions to a newly created National Rivers Authority (NRA). The NRA was later to be subsumed within the Environment Agency (Environment Act 1995). Still, however, much of the substantive law remained unchanged. Since 1989 water law in England and Wales has been consolidated and to some extent updated by the following Acts of Parliament:
The Water Industry Act 1991 as principally amended by the Water Industry Act 1999 and the Water Act 2003.
This deals with such matters as:
• the appointment and economic regulation of water and sewerage companies, and licensed water suppliers, by the Water Services Regulation Authority (Ofwat);
• water supply and sewage disposal powers, and duties of the companies and suppliers;
• drinking water quality obligations of water companies and licensed water suppliers, and the enforcement of those obligations by Defra and the Drinking Water Inspectorate;
• charging powers of water companies and the control of charges by Ofwat;

• protection of customers and consumers by Ofwat and the Consumer Council for Water; and
• retail and common carriage competition.

The Water Resources Act 1991 as principally amended by the Water Act 2003.
Among other things, this provides for the regulation by the Environment Agency of:
• water resource management, abstraction and impounding; and
• water quality standards and pollution control.

Water and sewerage companies have to take into account other national legislation and EC environmental directives as they relate to regulation by the Environment Agency of waste, land contamination, protected areas, air quality, flood defense, fisheries and water space amenity. The companies now also have regard to the qualitative and quantitative water standards imposed via 'River Basin Management Plans' under the Water Framework Directive 2000/60/EC.

Scotland

Scotland also went through the process of moving from locally administered legislation to regionalisation. However, with the Scotland Act 1998 legal responsibility for water supply and sewage disposal passed from the government and parliament in London to the Scottish Executive and the Scottish Parliament in Edinburgh.
The Scottish Parliament enacted the Water Industry (Scotland) Act 2002. This established:
• Scottish Water as the water supply and sewerage authority for the whole of Scotland. Its obligations were defined by the Water (Scotland) Act 1980 and the Sewage (Scotland) Act 1968 as amended;
• the Water Industry Commissioner, responsible to the Scottish Executive for the economic regulation of Scottish Water;
• the Drinking Water Quality Regulator for Scotland; and
• 'Water Customer Panels'.

The Water Services (Scotland) Act 2005 then:
• replaced the Water Industry Commissioner with the Water Industry Commission for Scotland (WICS); and
• provided for the separation of Scottish Water's operational and retail functions in order to open up to competition the retailing of water supply and sewage disposal services for businesses.

The Environment Act 1995 also created the Scottish Environmental Protection Agency (SEPA). Under the Water Environment and Water Services (Scotland) Act 2003, SEPA exercises similar powers to those of the Environment Agency in England and Wales.

Northern Ireland

In Northern Ireland, water supply and sewerage services were also originally provided by local authorities. However, as a result of the troubles, responsibility for such services was transferred to central government. For some years water and sewerage services were then provided by the NI Department for Regional Development under the name of Northern Ireland Water Services.

On 1 April 2007, under the Water and Sewerage Services (Northern Ireland) Order 2006, responsibility for water supply and sewerage services was transferred to a government-owned company called Northern Ireland Water.
Based on the English Water Industry Act 1991, the 2006 Order includes provisions on the following:
• the establishment of the Northern Ireland Authority for Utility Regulation, responsible for the economic regulation of utilities;
• the establishment of the NI General Consumer Council;
• power for the NI Department of Regional Development and/or the Authority to appoint water and sewerage undertakers; and
• the powers and duties of water and sewerage undertakers.
Environmental regulation is in the hands of the NI Department of the Environment, which operates through its Environment and Heritage Service. Its responsibilities are similar to those of the Environment Agency in England and Wales.

Additional UK legislation
Other UK legislation which can apply to the safety and contamination of drinking water supplies include:
- Civil Contingencies Act (2004);
- Civil Contingencies Act 2004 (Contingency Planning) (Scotland) Regulations 2005;
- Control of Major Accident Hazards Regulations 1999 (COMAH);
- Control of Major Accident Hazards (Amendment) Regulations 2005;
- Environment Act 1995;
- Pipelines Safety Regulations 1996;
- Radiation (Emergency Preparedness and Public Information) Regulations 2001 (REPPIR);
- Transport Act (2000);
- Water Resources Act 1991.

Portugal
Concerning the directives against cleaning water pipes and tanks, in Portugal, there is no specific law that requires the periodic cleaning of drinking water reservoirs. However, the two institutional bodies on that matter - IRAR (Regulatory Institute of Water and Wastes) and DGS (General Health Directorate) – have published a manual of good practices for water quality, recommending cleaning of the water tanks for drinking water at regular intervals, at least annually[5].
On the other hand, water reservoirs have to be inspected and cleaned/disinfected whenever any water quality parameter is not in compliance with the law (Portuguese Decree 236/98, recently substituted by Decree 306/2007).

[5] http://www.redecor.pt

As regards water distribution networks, the same applies. There is no legislation, but there are recommendations. For instance, some companies recommend cleaning every 5 or 10 years, depending on the water characteristics[6].

Concerning the general civil protection legislation, with the enactment of the Law 27/2006, of 3rd July, which approved the Basic Law for Civil Protection, the national system for Civil Protection was redefined, and the National Authority of Civil Protection (Portuguese acronym ANPC) assumed a primary role in the scope of planning, coordination and implementation of the Civil Protection policy.

The services and institutions dedicated to technical and scientific research, either public or private, with specific competences in the domains of interest in the pursuit of the Civil Protection objectives, cooperate with the management, planning and coordination agencies which integrate the national system for Civil Protection.

Issues related to water quality in distribution systems are dealt within two of the main fields of cooperation:

- Survey, forecast, evaluation and prevention of collective risks of a natural, technological or human nature and vulnerability analysis of populations and the environmental systems to which they are exposed;
- Study of adequate forms of protection of natural resources.

[6] http://www.manusystems.pt/infotecnica.jsp

Appendix 2 Permitted concentrations of radionuclides in drinking water and removal effectiveness water treatment process

The maximum concentrations in food—including liquid foods wherein tap water is also categorized—after a radiological emergency have been laid down by the Council of the European Communities [Council regulation (EURATOM) No 3954/87, 1987]. Also IAEA (2002) provides general action levels for foods including drinking water. These are presented on Table 4.

Table 4. European Council food intervention levels (CFIL) and IAEA generic action levels (GAL) and corresponding radionuclides studied in SecurEau - project

Radionuclide	CIFL (Bq/l)	GAL (Bq/l)	SecurEau, radionuclides of interest
Isotopes of strontium	120	100	^{90}Sr
Isotopes of iodine	500	100	^{131}I
Alpha-emitting isotopes of plutonium and transplutonium elements	20	1	^{241}Am, ^{252}Cf
All other radionuclides of half-life greater than 10 days	1,000	1,000	^{60}Co, ^{137}Cs, ^{192}Ir, ^{210}Po, ^{226}Ra,

The concentrations are permitted only after a radiological emergency and only as short a period as possible, maximum three months. The Commission summons a group of experts that coordinates transfer of data among the member states.
By using the concentrations listed on Table 4, we can assess doses to the end-users (Table 5). In a case of a deliberate contamination, the duration of exposure is most probably short. An average person ingests two liters of water per day. The highest effective doses would be received from polonium-210 and radium-226. In case of contamination with radium-226 and especially polonium-210, the protective strategies of end-users should be planned with special care (no adsorption data is yet available).

Table 5. Effective doses in millisieverts received from exposure to reference levels by CEC and IAEA.

Nuclide	Dose (in mSv) in 1 day		Dose (in mSv) in 3 days	
	CEC	IAEA	CEC	IAEA
Co-60	0.01	0.01	0.02	0.02
Sr-90	0.01	0.01	0.02	0.02
I-131	0.02	0.00	0.07	0.01
Cs-137	0.03	0.03	0.08	0.08
Ir-192	0.00	0.00	0.01	0.01
Po-210	2.4	2.4	7.2	7.2
Ra-226	0.56	0.56	1.7	1.7
Am-241	0.01	0.00	0.02	0.00
Cf-252	0.00	0.00	0.01	0.00

Table 6. The removal efficiencies for selected radionuclides by several water treatment methods.
Legends - 1: flocculation/coagulation, 2: sand filtration (rapid&slow), 3: activated carbon filtration, 4: lime-soda softening, 5: natural zeolites, 6: ion exchange, 7: reverse osmosis

Radio-nuclide	1	2	3	4	5	6			7
						cation	anion	mixed ion	
^{54}Mn									>99
Co	40-70	10-40	10-40	<10%	10-40%			40-70%	>70%
^{58}Co									>99
^{60}Co	8-23							90-99	>99
Sr	10-40	10-40	<10	>70	40-70			40-70	>70
^{89}Sr	0-58, 0-51	1-13		75-99		99	5-7	99	
^{89,90}Sr	2-5							99	
^{90}Sr-^{,90}Y	10-61							90	
^{90}Sr	0-70	17-23		20-80				99	99
^{95}Nb	2-99, 95-99	91-96		90		58-75	96-99	99	>99
^{103}Ru	43-96								99
^{131}I	0-10, 0-75	0-53		98			99,9	96-98	
^{131}I-^{135}I									96
Cs	10-40	10-40	<10	10-40	40-70			40-70	>70
^{134}Cs									98
^{137}Cs	0-6	50		0-20				99	
^{131}I	0-44	50-99	90	0-10			95	0	
^{140}Ba-^{140}La	1-84, 28-84	40		90		98-99	36-42	99	
^{144}Ce	85-96							90	>99
^{144}Ce	80-94	99							
Ra	30, 10-40	39–54, 40-70	10-40	>70	10-40			>70	>70
Ir	40-70	10-40	10-40	<10	10-40			40-70	>70
Am	>70%	10-40	40-70	<10	40-70			>70	>70
Po		14–90, 50–90							

Fission products	61-84								
particle bound	85-90								

Appendix 3 Waterborne outbreak and mitigation actions in France

The crisis concerned the contamination of distribution system with clarified water from sewage treatment plant in Divonne-Les- Bains (France). People were contaminated by *Cryptosporidium*, *Escherichia coli* and Streptococci. The length of exposure was estimated at 15 days, from August 20th to September 3rd [InVS, 2003].

Various actions were taken to manage the crisis, before and after the identification of the contamination source:

- restoration of distributed water quality,
- treatment of resource,
- elimination of contamination in the private network,
- information to the population.

Before the identification of contamination source the following actions were made:

1) Restoration of distributed water quality.

The contaminated area was flushed for 8 days (from August 26th to September 2nd) at a flow rate of 80 m^3/h. Disinfection was intensified with 0.95 mg/L chlorine which was supplied for 4 days, at the beginning of flushing (from August 26th to August 30th)

2) The following information was disseminated to the population of Divonne-Les-Bains: on August 29th an official statement by Veolia to inform of a recent anomaly in the distribution system but the water was described as drinkable and consumable.

After the identification of contamination source, the 2nd of September, other actions were made:

1) Restoration of distributed water quality.

Flushing activities were performed during the night of September 2nd. Disinfection with 1.60 mg/L chlorine was performed starting from the treatment plant till the end of the distribution system with all the valves closed to respect a contact time in the system. Shock chlorination was made in the tank as well.

After disinfection, flushing was progressively performed along the distribution system, from September 3rd to September 5th and also from September 8th to September 11th.

2) Treatment of resource.

Analyses of parasites from September 3rd showed the presence of *Cryptosporidium* and sometimes of *Giardia* in the source water and at the exit of the treatment plant. As a consequence, sanitary authorities asked to complete the treatment rapidly and the following modification in treatment process was made:

- - the coagulant injection that exists before decantation was moved between decantation and filtration;
- - the flow was optimized at the entry of filtration;
- - a follow-up of turbidity uninterrupted for raw water and treated water was set up with an objective for treated water ranging between 0.2 and 0.3 NFU;

- - the installation, on September 16, of a unit of disinfection with the UV with average pressure lamp.
-

3) Elimination of contamination in private network.

In a note of September 12th to the Managing Director of Health (DGS in France), the French Public Health Agency (AFSSA in France) made recommendation for the decontamination of domestic facilities:

- - regeneration of the ion exchange resins,
- - regeneration of the filters of the softeners,
- - change of the cartridges of filter,
- - drain of warm water boilers.

Between the 10th and the 16th of September Veolia realized with the inhabitants of the contaminated area, the flushes of the private network and the individual process of treatment.

4) Information to the population.

The following information was given to the population of Divonne-Les-Bains:

- on September 3 : the population of the contaminated zone was informed of pollution and it was recommended to not to use tap water for drink and cook. A distribution of bottled water was organized and a special phone number set up,
- on September 6 : restriction of use for tap water extended to the whole city and distribution of bottled water,
- on September 10 : maintaining of restriction and information concerning cleaning procedures for private network and installations
- on September 17 : after all the cleaning procedure and the improvement of water quality, the restriction were raised.

Appendix 4 Registered waterborne outbreaks and mitigation actions in Finland

In Finland, the compulsory monitoring and reporting system for waterborne outbreaks that even smallest waterborne outbreaks can be detected. In 1998 - 2007 59 outbreaks have resulted 26,900 illness cases. Outbreaks have typically been associated with the use of un-disinfected ground water in small communities serving less than 500 consumers. Noroviruses and *Campylobacter jejuni* have been the most common causative agents in the outbreaks [Miettinen *et al*., 2009]. In study collecting information concerning the DW outbreaks in Finland (1998-2005), it was found that in most outbreaks the first indication of an outbreak was an increase of gastroenteritis cases among consumers. Surprisingly but complaints from customers about bad smell and taste of drinking water or routine water quality analyses by companies were quite seldom the first sign of an outbreak [Miettinen *et al*., 2007].

The experience among the waterborne outbreaks during last ten years has shown that the boiling advice of drinking water is the most common and very effective mitigation action to control the outbreaks caused by waterborne pathogens. In many contamination cases (25), the use of contaminated water supplies was stopped and an alternative water source was taken into use. Once the microbes were removed/inactivated from raw water source the restriction of water use was removed. The simplest chemical treatment to inactivate microbes has been to use chlorination. In 27 contamination cases chlorination (1-2 mg Cl_2/l) combined with flushing was used as a main mitigation action to inactivated microbes harboring the network. The simplest action to clean network is to use flushing. Normally flushing has been a technique which is combined with other treatments like chlorination. Only in five cases it was the only technique used to clean the network. In two of these cases the network was contaminated with overdosing of NaOH in the water works. Shock chlorination (5-10 mg Cl_2/l, minimum 8 hours) was applied in 11 outbreaks due to a severe contamination. The local health authorities assess in these cases that the high health risks require efficient and rapid cleaning process which can be achieved by using shock chlorination. The most efficient action to remove loose deposits is to apply pipeline internal gauging (pigging) or air-water pulse cleaning techniques. Pigging/air-water pulse treatments have been used only three outbreaks. These techniques are usually considered too expensive and labor demanding cleaning methods. Furthermore, these methods do not clean the connection pipelines and indoor pipeline installations. Only in 2 outbreaks no mitigation actions were used despite the suspected contamination of distribution networks [I.Miettinen, personal communication, 2009)

The Nokia outbreak

In Nokia city drinking water distribution network faced a massive contamination in the end of November 2007 due a cross-connection between cleaned waste water (chemical precipitation + active sludge treatment) system and tap water pipeline. This occurred at the local waste water treatment plant which is located in the center of the Nokia city (30,000 inhabitants). The connection was open for two days resulting in intrusion of 450 m^3 of cleaned waste water in the drinking water distribution line.

The first signals of the contamination were the customer complaints beginning on 28th November about abnormal drinking water quality: odd color, taste, smell, and foam formation. The staff of waterworks received several hundred complaints during the first few days of the situation. The personnel of the waterworks supposed that the abnormal changes in the water quality originated from loosen deposits due to changes in water flow direction in the distribution network. The first cases of illness appeared in 30th November in local health care center. Symptoms included nausea, vomiting, diarrhea and fever. The illness cases finally resulted that the outbreak was finally recognized. This finding initiated immediate mitigation actions. In the first tap water samples very high counts of indicator bacteria, *E. coli* and intestinal enterococci were identified. Later also Campylobactersp., noroviruses , Salmonella enteritidis, and rotaviruses were detected both from water and human faecal samples. In addition, entero-, astro- , rota- and adenoviruses were also detected from water samples. Later on also Giardia sp. was identified as a cause of human infections and cysts were also detected from one biofilm/deposit sample taken from the drinking water distribution network in the beginning of December 2007.

Mitigation actions in Nokia case

The personnel of the waterworks were able to locate the source of contamination within the same day as the contamination was confirmed. The connection between the wastewater line and tap water line was immediately cut and flushing of the network with clean water was started. Based on analytical measurements and hydraulic information it was possible to define the contaminated area so that decontamination actions could be addressed on the contaminated area with 9,195 inhabitants. The distributed drinking water in Nokia city is normally disinfected with chlorine (approx. 0.5 mg/l). Among first mitigation actions chlorine concentration was first lifted up to 1.5 mg/l. Later it was raised up to 5 mg/l. Due to severe contamination of distribution network pipeline internal gauging (pigging) and air/water pulsed flushing were used to clean the main pipelines. Additionally, shock chlorination (10 mg/l, 24 h) was used to enhance cleaning of especially the connection lines and the indoor pipeline installations. Alternative drinking water service points (water tanks and distribution of bottled water) were also opened (18) in the contaminated city area.

A boiling water advisory (5 min) of drinking water was ordered immediately after the outbreak was recognized. Information on the contaminated water and boiling water advisory was spread using the local radio channels, Internet, TV and newspapers. Leaflets and loudspeaker cars were used to inform public. Also, the centers like schools, food factories and hospitals were informed on the drinking water contamination. Boiling water advisory continued for almost three months. It was cancelled gradually in February 2008 after contaminated pipelines were cleaned and no pathogens or indicator bacteria were found in the water samples taken after the cleaning.

Outcome of the case

A population survey conducted in Nokia and neighboring town showed total of 8,451 cases of gastroenteritis during the outbreak. 1000 persons sought care at the municipal health centre; nearly 200 were treated in hospital. Total 5,000,000 liters of tank water and 700,000 liters of bottled water were served as alternative drinking water to the inhabitants of Nokia city during the outbreak. Total costs of the outbreak including the mitigation actions ended at least 3.7 million euros.

The largest waterborne outbreak for at least 50 years shook strongly the Finnish water services. This outbreak underlined the significance of the public communication. Earlier recognition of the outbreak could have limited substantially the extent and the consequences of the outbreak. As a result of the outbreak, a national survey was launched in spring 2008 to check and remove similar waste water/clean water connections, which enabled the Nokia outbreak [Miettinen *et al.*, 2009].

Appendix 5 List of cleaning methods based on different principles and their effect on removing deposits

Legends: SD = sediments; BF = biofilm; CL = covering top layer; IL = inner top layer; IC = incrustation, x = possible, ? = no experience

#	Cleaning methods	Principles	Forces	Removal of deposit				
				SD	BF	CL	IL	IC
1	conventional water flushing	flow velocity	shear stress	X	?			-
2	unidirectional water flushing	higher flow velocity	shear stress	X	X			-
3	suction water flushing	higher flow velocity	shear stress	X	?			-
4	Air water flushing	higher flow velocity	shear stress	X	?			-
5	air water impulse flushing	higher flow velocity	shear stress	X	?			-
6	solid matter flushing (particles)	friction, abrasion	frictional	X	?			X
7	solid matter flushing (iced particles)	friction, pressing	frictional	X	?			X
8	pipeline cleaning pig (brushes)	friction, abrasion	frictional	X		X	X	X
9	pipeline cleaning pig (soft ball)	squeezing, pressing	shear force	X	X			
10	pipeline cleaning pig (swabbing disk)	squeezing, pressing	shear force	X	X	X	X	
11	sand blasting	friction, abrasion	frictional	X	X	X	X	X
12	water blasting	friction, abrasion	frictional	X	X	X	X	X
13	manual, per hand	scrape off	frictional	X	X	X	X	X
14	chemical cleaning (all chemicals)	resolve, transforming	chemical bond		X	X	X	
15	thermic cleaning	heating, acidification	shrinkages		X	X	X	X
16	ultra sonic cleaning (thixotrophic sediments)	thixotrophy	shear force	X	X		X	X

Appendix 6 Overview of flushing methods [Roscher, 2008]

advantages	conventional water flushing	unidirectional water flushing	suction water flushing	air water flushing	air water impulse flushing	solid matter flushing
low effort	x	x				
efficient and sustainable		x	x	x	x	(x)
shortened flushing duration			x			
flushing of several hydrants possible		x				
adequate cleaning effect at hydraulic bottleneck		(x)		(x)	x	x
adequate flushing complexity		x				
disadvantages						
possible damages of the protecting top layer in grey cast pipelines				x	x	x
lower flow velocity	x					
risk of red water in wide areas	x		(x)			
preliminaries necessary		x	x	x	x	x
refinishes necessary				x	x	x
analyses program necessary		(x)				
higher effort for traffic safety activities possible		x	x	x	x	
hydraulic tests necessary			x			
risk of germs cause by damaged biofilms	(x)	(x)	(x)	x	x	x
long flushing/cleaning duration	x			x	x	
Fields of application						
water exchange in case of bad water quality	x	x				
removing of sediments		x	x	x	x	x
removing of incrustations						(x)
pipelines up to DN 300		(x)	x	x	x	x
pipe lines up to DN 800					x	

Appendix 7 Release agents

The addition of various antimicrobial compounds was found to almost completely remove remaining *P. aeruginosa* biofilms that were exposed to NO, suggesting a general effect of NO on *P. aeruginosa* physiology [Barraud et al., 2006]. Further the data on other biofilm forming microorganisms is presented.

Table 7. Effects of low concentrations of NO donors on various biofilm-forming microorganisms

Biofilm-forming microorganism	**Optimum NO donor[a] concentrations**		**Maximum percentage removal (SE)[b]**
Gram-negative			
Serratia marcescens	SNP	25–500 nM	60.0% (±4.1%)
	SNAP	100 nM	37.8% (±10.5%)
Vibrio cholerae	SNP	25–500 nM	72.5% (±1.9%)
	SNAP	1 μM	28.6% (±3.6%)
	GSNO	1 μM	33.6% (±7.4%)
Escherichia coli	SNP	500 nM	38.1% (±8.7%)
Fusobacterium nucleatum	SNP	1–10 μM	55.6% (±5.6%)
Gram-positive			
Bacillus licheniformis	SNP	100–500 nM	93.2% (±2.0%)
Staphylococcus epidermidis	SNP	10 μM	58.6% (±2.8%)
Yeast			
Candida albicans	SNP	25–100 nM	61.4% (±6.7%)

a. NO donors used: SNP, sodium nitroprusside; SNAP, S-nitroso-N-acetylpenicillamine; and GSNO, S-nitroso-L-glutathione.

b. Percentage removal indicates the percentage of total biofilm surface that was removed after exposure to NO relative to control biofilms that were not exposed to NO. SE, standard error ($n \geq 3$).

FeS materials exhibit different states of disorder as a highly efficient absorbent with a high surface area (500 m2 g-1) capable of use in different environments such as soil and water [Watson et al., 2001 and 2002]. The material does not rely on diffusion through the material, just to the surface. Recent work suggests that this is 10 times faster than previously thought. The FeS material provides the capability to clean up a CBRN attack; indeed, FeS production from SRB can be described as one of Nature's important detoxification systems for soils and sediments, and mammalian GI tracts. The high capacity FeS sorption approach will be utilised during the project to clean up radionuclides in drinking water or released back into the water from the biofilm deposits.

Appendix 8 Removal effectiveness of Bacillus spores with several methods

In this table is summarized literature regarding removal effectiveness of *Bacillus* spores with several agent from studies since 1930 to 2002 [Spotts-Whitney et al., 2003].

Method	Concentration	Inoculum size	Time	Efficiency
Chemical sterilization				
Calcium hypochlorite	20 mg/L available; Cl_2, pH 8.0, 20ºC	3 x 10^5–4 x 10^5 spores of *Bacillus subtilis* in 5.0 mL sterile distilled H_2O	4.8 min	99% killed
	25 mg/L available; Cl_2, pH 6.0, 20ºC	2 x 10^7 spores/mL of *B. metiens* in 10 mL of sterile distilled H_2O	2.5 min	0.061 (log of average % survivors) 99% killed
Free available Chlorine	2.4–2.3 mg/L available; CL_2, pH 7.2, 22ºC	1.1 x 10^5 spore suspension of *B. anthracis*	1 h	>99.99% killed (1 spore/mL survived)
Sodium hypochlorite (NaOCl)	0.05%, pH 7.0, 20°C	Spore suspension of *B. subtilis globigii,* representing 1.6–2.2 x 10^9 CFU/mL		99.99% killed
	0.05%, pH 11.0, 20°C		30 min	50% spores survived

Boiling water for more than 10 minutes can reduce *Bacillus anthracis* spore counts by at least 10E6 . [Spotts-Whitney et al., 2003].

Appendix 9 Effectiveness of several methods applied for CBRN decontamination by EPA

The effectiveness of using conventional methods for removal of CNBR (arsenic, mercury, chlordane diesel fuel and *Bacillus subtilis*) agents has been studied in pilot scale by EPA [Krisshan and Piao, 2008] and results represented in table. The principle of conventional flushing when water was circulated with velocity 0.762 m/s was used as a control for removal of all agents (in table mentioned as water flushing). To improve effectiveness of removal of mentioned CBRN agents additionally were used flushing (velocity 0.21 m/s for 4 hour long and 0.762 m/s for 10min) with (i) hydrochloric acid, (ii) 1 mM phosphate buffer solution (50:50 KH2PO4:K2HPO4), (iii) acidified potassium permanganate (1% sulfuric acid/0.4% potassium permanganate) solution and (iv) several decontamination reagents available in the market i.e., NW-310/NW-400 (manufactured by Johnson Screens, Inc.), Floran Biogrowth Remover/Catalyst, and Floran Top Ultra/Catalyst (manufactured by Floran Technologies, Inc.), (v) surfactants — Surfonic TDA-6 (Huntsman Petrochemical Corporation).

The decontamination of arsenic can be possible by low-pH conditions (i.e., pH 4) due to increase of the solubility of metals in water (Ellison, 2003) and phosphate buffer due to experience in effective extraction of arsenic from sediment and/or soil samples [Bruce and Martens, 1997; Gonzalez et al, 2003]. Arsenic (V) anions (H_2AsO_4- and $HAsO_{42}$ –) form strong surface complexes at the mineral-water interfaces and undergo ligand exchange with H_2PO_4- and HPO_{42} -anions.

For removal of mercury and arsenic is used solution of acidified potassium permanganate which known as very strong oxidant that is widely used in the metal sample digestion. It can significantly increase the solubility of metals. Also, acidified potassium permanganate can destroy biofilm in the drinking water distribution system. Bench-scale drinking water pipe decontamination studies confirmed the high removal efficiency of acidified potassium permanganate flushing for mercury from various types of drinking water pipe surfaces (Chattopadhyay and Fox, 2006).

Several environmentally friendly products (NSF Product and Service Listing, 2006) were applied as representative decontamination reagents for arsenic. These pipe-cleaning aid products are being used in commercial applications for cleaning of drinking water pipes and/or wells.

The surfactant, Surfonic TDA-6, was identified based on AwwaRF's laboratory-scale test conducted on chlordane (Welter et al., 2006). The AwwaRF study indicated that Surfonic TDA-6 is a very effective surfactant for removing chlordane from the drinking water pipe surfaces. Therefore, Surfonic TDA-6 was applied during the current pilot-scale decontamination of diesel fuel and chlordane from the drinking water pipe surface.

Decontamination tests results [Krisshan and Piao, 2008].

Contaminants	Decontamination method	Decontamination efficiency for cement-lined ductile iron pipe	Qualitative performance rating[1]
	Water flushing	-7 – 51%	Average
	Low-pH	6 – 36%	Average
	Phosphate buffer	-24 – -16%	Poor

Arsenic	Acidified potassium permanganate	54 – 61%	Good
	NW-310/NW-400	46 – 65%	Good
	Floran Biogrowth Remover/Catalyst	63 – 67%	Good
	Floran Top Ultra/Catalyst	23 – 68%	Average
Mercury	Water flushing	19 – 46%	Average
	Low pH	21 – 23%	Average
	Acidified potassium permanganate	72 – 96%	Excellent
Bacillus subtilis	Water flushing	-29 – -11%	Poor
	Shock chlorination	94 – 96% (1.2 – 1.4 log removal)	Average
Diesel fuel	Water flushing	36 – 38%	Average
	Water flushing	74% for clear PVC pipe	Good
	Surfonic TDA-6	>91%	Excellent
	Surfonic TDA-6	78% for clear PVC pipe	Good
Chlordane	Surfonic TDA-6	89 – 91%	Excellent
	Surfonic TDA-6	99% for clear PVC pipe	Excellent

[1] The qualitative performance ratings are defined in terms of percent/log removal as shown below:

For Chemical Contaminants	
< 20%	Poor
20–50%	Average
50–80%	Good
> 80%	Excellent

For Biological Contaminants	
< 1 log removal	Poor
1–2 log removal	Average
2–3 log removal	Good
> 3 log removal	Excellent

Appendix 10 Staff exposure

2.2.1 Principles of protection of people in contamination of distribution networks with radiological agents

In case of a deliberate attack on water distribution system using radiological agents, protection of the public as well as protection of the clean-up workers and employees of waterworks must be considered. Internationally, radiological protection is based on recommendations by ICRP—The International Commission on Radiological Protection. The basic principals concerning protection of people in such cases are [ICRP, 2009] :

1. Principle of justification and optimization. The countermeasures should be planned and executed in order to maximize the benefits over harm following from the procedures. The doses following the countermeasures should be restricted both by individual dose levels and overall doses.
2. Any planned protective strategies should aim to reduce exposures below reference levels, which should be typically set between 20 mSv and 100 mSv effective doses. If the projected exposures are low, reference level below 20 mSv are justified. In events where the projected exposure is very high (e.g. malicious events), the reference levels may not be applicable and therefore plans should be developed beforehand to mitigate the health effects and measures should be taken to minimize the risks of such events.
3. The Commission recommends that all exposure pathways and all relevant protection options be considered when deciding on the optimal countermeasures. This approach increases the complexity of operation but provides more flexibility in planning the optimum countermeasures. This operational strategy takes also into consideration how different countermeasures affect each other.
4. It is important to recognize the dominant exposure pathways, the timescale of the event and the effectiveness of various countermeasures in during a given incident. In this way resource can be allocated in best possible countermeasure, which supports the optimization principle.
5. Every countermeasure should be planned and executed in such manner that the occurrence of severe deterministic injuries due to high exposure (radiation sickness, death) is avoided. Nevertheless, some individuals may be exposed to such high levels. These individuals should be identified and receive immediate medical care.

Detailed data on how to start countermeasures for protecting the public is presented in TMT-handbook [Rojas-Palma et al., 2009]. Also, instructions on personal protective equipment for monitoring staff are explained. The same level of protection should be used in monitoring and clean-up work if the contamination took place in water distribution system.

2.2.2 Dose assessments for the clean-up workers

The site of the clean-up work depends on the site of contamination. If the contamination takes place in the raw water reservoir (e.g. tank, pool), the following factors must be known: adsorption onto reservoir walls, adsorption on water pipe surfaces and adsorption during water treatment process. If only little adsorption takes place contaminated water is conveyed into water distribution system and

eventually to waste water treatment plant. If the contamination takes place within the distribution system, water mains and pipes may be contaminated, the public exposed following ingestion (and external radiation) and waste water treatment facilities may also be contaminated.

These are thus several scenarios where the clean-up work may take place. Only a few of them can be assessed here. First, we consider what sort of sources are available and how great activity they hold. Second, a review of adsorption of radionuclides during water treatment processes is made. The experiments studying adsorption of radionuclides onto inner surfaces of water pipes is under way, thus these assessments will not be made due to the lacking data. Then, we analyse assessment of external doses for the following scenarios: (i) Clean-up work of reservoir walls; (ii) Transport of contaminated filter sands (water treatment plant).

2.2.3 Available sealed sources

A stray/stolen industrial source may be used in a benevolent act. Activity data on the industrial sources used in Finland are presented on Table 8. Cesium is mostly in form of soluble CsCl, the chemical form of other radiunuclides have to be found out. Nevertheless, if we consider contamination of e.g. a 150 m^3-reservoir, the reference levels on Table 5 will be amply exceeded and criteria for a radiological emergency are met.

Table 8. Radioactive sources used in industry in Finland [Rantanen, 2009].

Other than high-activity sealed sources			
Radionuclide	N	Activity total (GBq)	Mean activity (GBq)
Co-60	1388	1139	0.8
Sr-90	51	28	0.5
Cs-137	4023	9052	2.3
Am-241 (gamma)	349	1704	4.9
Am-241 (neutron)	119	486	4.1
High-activity sealed sources			
Radionuclide	N	Activity total (GBq)	Mean activity (GBq)
Co-60	17	98111	5771
Sr-90	5	167	33
Cs-137	54	229496	4250
Ir-192	13	1036	80
Am-241 (gamma)	9	1036	115
Am-241 (neutron)	4	591	148

2.2.4 Gamma dose rates for the clean-up workers

There are several potential targets within the water distribution system where deliberate contamination could be pointed. In the following, two different scenarios are dealt with as an aim to have an idea of the scope of the problem arising from external radiation for the clean-up workers. Calculation of external doses is time-consuming especially in complex geometrical environments. In our assessments, we used WinMat computer code to calculate the air kermas [Turtiainen *et al*., 2008].

The photon mass-attenuation and energy-absorption coefficients were taken from Hubbell (1981). Effective dose per unit air kerma free-in-air conversion coefficients are from ICRU report 57 (ICRU 1998)

2.2.5 External doses during monitoring/clean-up work of reservoirs

The volume of a typical reservoir within the water distribution network is 100–10,000 m^3. We can calculate air kermas (absorbed dose rates in air) resulting from radionuclide contamination in the vicinity of an example tank (1000 m^3) with dimensions (w×l×h) 25×10×4 m. From this data we can assess the effective dose rates for clean-up workers/personnel of the water company.

We assume that the reservoir is full of water. The following (gamma-active) radionuclides are considered: Co-60, Cs-137 and Am-241. Based on the data in Table 9 we use the following contaminant activities in the assessments: 5000, 4000 and 150 GBq for Co-60, Cs-137 and Am-241, respectively. In case of full dissolution and no sedimentation/adsorption onto the walls, the respective activity concentrations in water of the reservoir are 5 MBq/L, 4 MBq/L and 150 kBq/L (Table 9).

Table 9. Effective dose rates in the vicinity a water reservoir (1000 m^3) contaminated with a typical Co-60, Cs-137 and Am-241 high-activity industrial source.

Source	Source activity	Concentration in water	In the middle, at 1-m height	2.5-m from the sides of tank
Co-60	5000 GBq	5 MBq/L	2100 µSv/h	280–750 µSv/h
Cs-137	4000 GBq	4 MBq/L	370 µSv/h	50–130 µSv/h
Am-241	150 GBq	150 kBq/L	0.2 µSv/h	0.03–0.08 µSv/h

The weak gamma-energy (59.5 keV) with low intensity of Am-241 is effectively attenuated by the water mass and increases the dose rates only slightly (normal background dose rates are 0.05–0.3 µSv/h) and hence clean-up work can be executed with protective clothing and respirator mask. The case is different for Cs-137 and especially Co-60. The highly intensive gamma rays with high energies (Cs-137: 662 keV; Co-60: 1173 and 1332 keV) are not absorbed by the water mass and high dose rates occur near the reservoir. Special care must be taken when planning the clean-up work. The water volume can be pumped from the reservoir and treated with e.g. inorganic ion-exchange units, such as CsTreat/CsFloc or CoTreat/CoFloc to remove the radioactivity [Harjula et al., 2004]. In this case, the ion-exchange unit must be shielded and placed far from workers in order to minimize doses to the clean-up workers.

It is, however, possible that part of the radionuclides is attached to the walls of the reservoir. The reservoirs are normally cleaned manually inside the tank by using scrubbing brushes. We can calculate the effective dose rates inside the reservoir walls similarly to the case of the full reservoir (Table 10).

Table 10. Effective dose rates at 1m-height inside the reservoir (1000 m^3) contaminated with Co-60, Cs-137 and Am-241. Adsorption (50% and 1%) onto the walls is assumed.

Source	Source activity	50% adsorption	1% adsorption
Co-60	5000 GBq	18–24 mSv/h	350–480 µSv/h
Cs-137	4000 GBq	3.3–4.5 mSv/h	70–90 µSv/h

Am-241	150 GBq	4.5–6.1 µSv/h	0.09–0.12 µSv/h

Again, the cobalt may be a problem if lot of adsorption occurs. The 20 mSv limit can be exceeded in less than an hour.

2.2.6 Doses during handling and transport of contaminated filtration sands at water works

Slow sand filtration is a common water purification process to produce drinking water. If the deliberate contamination takes place before the water works, we can assume that 10–40% of Co-60, Cs-137 and Am-241 are adsorbed onto the *schmutzdecke* of the filtration sand [Brown et al., 2007]. Here we assess a case where the filtration units has a surface area of 4×5 m, the *schmutzdecke* thickness is 20 cm and water layer on top is 50 cm. We assume 25% adsorption efficiency for all three radionuclides and same source activities as in reservoir cleaning. The increase in effective dose rate at 1-m height above the pool is highest for Co-60, 1–4 mSv/h. Cs-137 adsorbed onto the *schmutzdecke* will increase the effective dose rates 100–600 µSv/h whereas the increase caused by Am-241 are negligible.

Normally, the *schmutzdecke* is manually removed and the workers would thus be exposed to radiation. Without the 50 cm attenuating layer of water, the dose rates are much higher. At 1-m height above the *schmutzdecke*, the effective dose rates are 20–60 mSv/h for Co-60. In case of Cs-137, the effective dose rates are 4–12 mSv/h. The low gamma energies and intensities of Am-241 do not significantly elevate the external dose rates even without the attenuating layer of water. The effective dose rate is only 3–10 µSv/h.

These two samples clearly demonstrate that in case of contamination with a typical high activity source of Co-60 and—to lesser extent—Cs-137, safe planning of the clean-up work is extremely challenging. The effective dose rate can be up to 60 mSv/h, which means that 20–100 mSv limit for the clean-up workers can be exceeded in a short period of time. By employing a large number of workers for only short periods of exposure is also problematic: If dose of one sievert is received by one person (adult worker), his/her risk of getting cancer increases by 4.1 percentage points (ICRP 2007). If the same dose is divided between 10 workers (each 100 mSv), the risk of one of them getting cancer is still increased by 4.1 percentage points. The individual risk, however, increases only by 0.41 percentage points [ICRP, 2007]. From the radiation protection viewpoint the sum effect is thus the same.