Restoration of drinking water distribution systems following a deliberate contamination by radionuclides

TURTIAINEN T., HAKALA S., HIETA J-P., EKBERG J., VESTERBACKA P. & MUIKKU M.
STUK—Radiation and Nuclear Safety Authority, P.O. Box 14, Helsinki, Finland

Abstract. Vulnerability of drinking water distribution systems to malevolent attacks has been recognized. Such an attack would have major public health, economic and psychosocial consequences. SecurEau is a collaborative project carried out in the seventh Framework Programme. The project focuses on CBRN (chemical, biological, radiological and nuclear) threats and aims at launching an appropriate response for rapidly restoring the use of the drinking water network after an attack. STUK has investigated radiological impacts and decontamination methods. In the following, a brief overview of our work will be given.

KEYWORDS: contamination, decontamination, drinking water, malevolent, security

INTRODUCTION

Emergency preparedness authorities have identified drinking water distribution networks as a conceivable target of a deliberate, malevolent attack. In any event, disruptions in water distribution associated with damages in network structures incur discomfort and expenses (Young *et al.*, 2007). In the worst case, CBRN (Chemical, Biological, Radiological and Nuclear) agents that are hazardous to health are used for contaminating water, which would lead to increased morbidity and mortality rates among the consumers.

According to the public's perception nuclear power is generally considered as the most severe risk. Therefore, even small accidents at nuclear facilities "will be highly publicized and may produce large ripple effects" (Slovic, 1987). Conception of uncontrolled release of radioactive materials is always associated with nuclear accidents. Therefore, intentional and malevolent release of radioactive substances in water distribution networks would cause large-scale confusion and fear among the public and create great challenges to the radiation protection and rescue authorities, health care system and water distribution companies.

SecurEau[1] consortium brings together the expertise on drinking water distribution systems and consists of twelve partner institutes or organizations from six EU Member States. The project studies the security of drinking water systems by focusing on CBRN threats posed on water distribution networks. The main objective of SecurEau is to launch an appropriate response for rapidly restoring the use of the drinking water network after a deliberate contamination, specifically by:

- designing methods for identifying potential contaminants,
- modelling distribution of the contaminants inside the network,
- adapting and integrating various sensors in a surveillance system in an optimal configuration, and
- developing methods for decontaminating polluted drinking water networks and installations including neutralization of contaminated water and residues.

[1] http://www.secureau.eu

In this paper, we will present an overview of the investigations carried out at STUK. Our experiments are, however, only a part of the extensive work carried during the past two years. Therefore, we wish to invite all parties concerned with CBRN security issues to join the SecurEau workshop that will be held in Mülheim-an-der-Ruhr, Germany during the WCEC5 conference (19^{th}–21^{st} November 2012)[2].

REACTIONS OF RADIONUCLIDES INSIDE WATER PIPES

Radioactive sources are used for diverse beneficial purposes in industry, medicine, agriculture, research and education. If a radioactive source is stolen and dispersed into the environment, persons could be exposed to radiation at dangerous levels (IAEA 2003). Radioactive sources exhibiting highest activities are generally different types of irradiators (containing typically ^{60}Co or ^{137}Cs). These gamma emitting sources are concealed in large and heavy shielding devices and hence their transport and dissolution in water distribution systems are unlikely to occur. A malevolent act may not, however, aim to cause the highest possible doses to the public which would result in deterministic or even significant stochastic effects. Even by releasing radionuclides in concentrations that are projected to have little stochastic effects among the public, the anxiety and confusion after such an event would be detrimental to the society at all levels.

In the SecurEau project, seven conceivable radionuclides are studied in respect to their behaviour inside real water pipes with an aim to predict their transport within water distribution system and design early warning systems. The radionuclides investigated at STUK are ^{241}Am, ^{210}Po and ^{90}Sr. By understanding the reactions inside water pipes appropriate decontamination methods can also be utilized. Until now, there has been little information available on this.

The chemical environment inside water pipes is always complex. The pH-value, total hardness, dissolved inorganic and organic species are different in each water network. Drinking water also contains small amounts of colloids, pseudo-colloids and particles which may interact with radionuclides. All water pipe surfaces are covered with biofilms and various amounts of inorganic deposits (Fig. 1 and 2). Microorganisms found inside the water pipes facilitate several chemical reactions such as oxidation-reduction of metals, changes in pH and Eh, solubilisation and leaching of matter by microbial metabolites, immobilization leading to formation of stable minerals, immobilization by cells and biopolymers and release of biosorbed metals due to remineralisation (Francis, 1990).

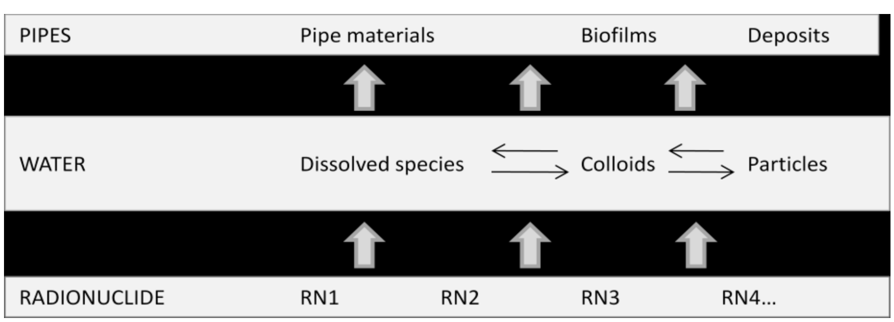

Fig. 1 Chemical reactions inside water pipes.

[2] http://www.wcec5.eu

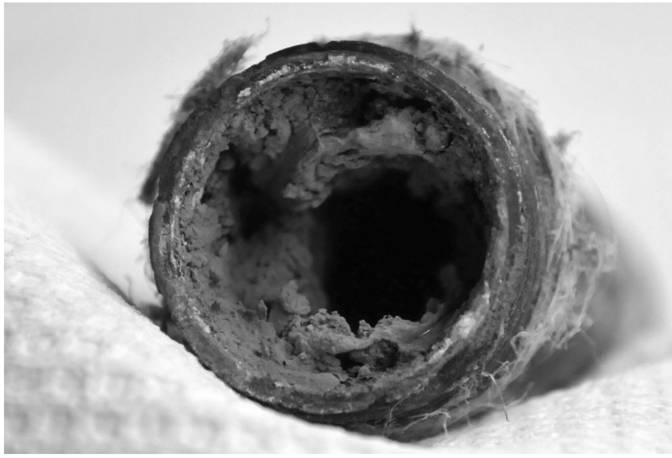

Fig. 2 A photo of a household drinking water pipe after a few years' usage showing ample amount of deposits on the inner walls.

EXPERIMENTS

Experiments investigating adsorption of waterborne radionuclides have been carried out in non-flow batch reactors and flow-through reactors. In the batch experiments, clean pipe materials, biofilms and deposits collected from real water pipes have been studied. In the flow-through reactors, pipe materials containing biofilms and deposits were investigated.

In the experiments studying radionuclide adsorption onto clean pipe materials (HDPE, PP, PVC, stainless steel) the materials were brought into contact with contaminated water. Several water samples were taken during the contact period and kinetic parameters were calculated by fitting the results using pseudo-second-order kinetics (Ho, 2006). Gravimetric deposition of formed colloids was also taken into account as well as parameters affecting water chemistry (pH, total harness, Fe, etc.). In the experiments carried out with biofilms, the biofilms were grown on plastic coupons in a separate reactor for more than one month. During this period of time, the biofilms are thought to reach their steady-state (Manuel et al., 2007). After the contact periods, the biofilms were leached from the coupons and the adsorbed activity was measured for calculating the kinetic parameters. Deposits containing several minerals and biofilms that were removed from real water pipes were also studied in batch experiments.

The flow-through reactors were modular systems built of commercial water pipes, joints, Teflon hoses and a peristaltic pump by which the water flow could be adjusted to the desired rates. Biofilms and deposits were let form naturally during one month of tap water flow through the reactors (Fig. 3). After this, radionuclide containing water was introduced into the reactor and the water was let flow trough the system once. The activity concentration was measured from the effluent for one day after the spiking. After this, the deposits and biofilms were removed and their activity measured. Microbiological analyses were also carried out for the biofilms.

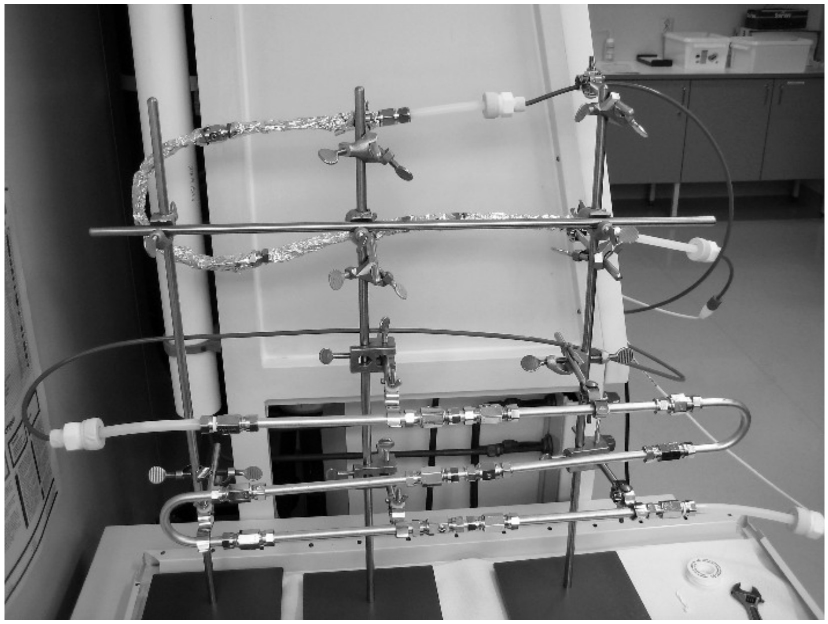

Fig. 3 A photo of a flow-through biofilms reactor.

After the adsorption experiments, five different chemicals ($Ca(OAc)_2$, EDTA, $NaHCO_3$, Na_3-citrate, NaClO) were studied for their ability to decontaminate the studied materials. The chemicals were considered non-corrosive, enough harmless for health (if any residual amounts would stay in the network after extensive flushing) and cheap enough for them to be used in large scale.

STUK also studied a novel analytical technique for rapid analysis of alpha emitting radionuclides in water. The method includes fast preparation of an alpha counting planchette, alpha spectrometry and computerized deconvolution of alpha spectra (Toivonen *et al.*, 2009).

RESULTS

We were able to obtain efficient decontamination of plastic pipe materials with $NaHCO_3$, Na_3-citrate. The decontamination rates were higher than 99%. Steel pipes were best decontaminated with EDTA-solution although sufficient decontamination rate may be achieved with subsequent decontamination steps by $NaHCO_3$ and Na_3-citrate solutions (Hakala, 2011).

During the project, we have gained a much better understanding of the adsorption of the radionuclides onto water pipes, biofilms and deposits. Due to the security aspects of the project the adsorption results and not discussed here. These results will be presented during the SecurEau workshop held in Mülheim-an-der-Ruhr, Germany on 19th–21st November 2012. Appropriate security clearance is required for attendance (instruction can be found on the web site http://www.wcec5.eu).

ACKNOWLEDGEMENT

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2011) under grant agreement n° 217976. The ^{241}Am solution used in the experiments was kindly donated by the Radioactivity Group at the National Institute of Standards and Technology (NIST).

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