POLICY BRIEF

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MAJOR OUTCOMES ON DISINFECTION AND DISINFECTION BY-PRODUCTS AND SOLUTIONS

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Context

Safe drinking water as a fundamental human right is well regulated by the EU Drinking Water Directive. As a major challenge, microbial risks and chemical risks interfere in disinfection that is utilized in many water supply areas (mandatorily for example in Spain): While chlorine-based disinfection is applied to control pathogens in the drinking water distribution network, reactions of harmless background water constituents with the disinfectants generate secondary substances, so-called disinfection by-products (DBP). Several DBP (trihalomethanes, haloacetic acids, chlorate, bromate and chlorite) are limited in the EU Drinking Water Directive with parametric values, and risks associated with residual disinfectants and DBP have to be assessed. However, the balance of safe disinfection and limited chemical risks remains challenging.

The EU project SafeCREW focusses on various aspects of drinking water disinfection. Major outcomes are summarized in the present policy brief.

SafeCREW Outcomes

- **Novel DBP are identified that deserve precautionary attention**
- **Haloacetonitriles form quickly, are unstable and may pose health risk**
- **Effect-based assays reveal potential toxicities from DBP and materials**
- **Optimized treatment reduces DBP formation**
- **Improved online monitoring enables early warning of elevated DBP levels**
- **Modelling of DBP formation enables proactive management**
- **AI-based soft sensors will form foundation for advanced early warning systems**
- **A new risk assessment approach combines chemical, microbial and toxicity data**

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Novel DBP are identified that deserve precautionary attention

In addition to the regulated DBP, the SafeCREW project identified a new class of sulfonated DBP present in all drinking water samples disinfected with chlorine or chlorine dioxide, regardless of water source or treatment processes. These compounds are highly water soluble and are therefore not captured by standard analytical methods. They may have been present in drinking water systems for many years without being routinely identified. The SafeCREW results indicate that these new DBP have distinct origins and formation pathways, meaning current control measures targeting regulated DBP unlikely reduce their presence. Although little is known about their health effects, their chemical similarity to other harmful DBP and widespread occurrence deserve precautionary attention.

To address these DBP, drinking water monitoring programs should expand surveillance beyond regulated DBP by incorporating modern analytical techniques such as high-resolution mass spectrometry and methods specifically designed to detect highly water-soluble substances, to better identify and prioritize emerging DBP.

More details are provided in the respective SafeCREW report.[1]

Haloacetonitriles form quickly, are unstable and may pose health risk

Another group of DBP, so-called haloacetonitriles, were also detected in one of the pilot sites. Laboratory studies and full-scale monitoring confirmed that they are quickly formed in contact with chlorine, but they are chemically unstable and react further within a few days. In drinking water networks with a residence time of less than one week, they might be harmful (cytotoxic and genotoxic). However, since they can transform to other DBP (such as haloacetamides), toxicity might persist or shift rather than diminish. The complexity challenges traditional regulatory approaches based on more stable DBP and underscores the need to consider time-resolved exposure and transformation pathways when assessing their health relevance in drinking water systems.

Effect-based assays reveal potential toxicities from DBP and materials

Non-animal methods for the evaluation of the toxicity of chemicals can cover harmful but unregulated or even unknown pollutants. SafeCREW applied several so-called effect-based methods to assess potential toxicity pathways (cytotoxicity, genotoxicity, oxidative stress, endocrine effects and others). Among 16 relevant DBP tested in detail, 11 showed potential health effects in at least one biological assay. Tests with chlorinated water in contact with 14 materials authorized for drinking water use, such as polymer pipes, seals, fittings, epoxy resins, and cement mortar, showed some biological effects. While reactions involving polypropylene or polyethylene pipes showed no significant toxicity in the applied biological assays, reaction products formed with polyvinylchloride (PVC) pipes and epoxy resin coatings exhibited substantial toxicity. Chlorinated drinking water from Milan/Italy and Tarragona/Spain were also evaluated using effect-based methods. While most tests showed no adverse effects (such as endocrine disrupting activities like estrogenicity-, inhibition androgenicity- and PFAS-like toxicities), some tests revealed results around values that the scientific community currently discusses as relevant (specifically early warning PXR and oxidative stress Nrf2-like activities).

More details are provided in respective SafeCREW reports.[2,3,4]

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[1] Deliverable D1.1 SafeCREW - Advanced analytical procedures for the characterization of disinfection by-products and methodology for remote sensing of natural organic matter

[2] D1.3 SafeCREW - Test protocol for effect-based in-vitro toxicity assessment of disinfection by products

[3] SafeCREW Policy Brief #1: Advancing NAM/EBM for the assessment of disinfection by-products and complex chemical mixtures in drinking water

[4] SafeCREW Analytical Protocol #3: Test protocol for effect-based in-vitro toxicity assessment of disinfection by-products

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Optimized treatment reduces DBP formation

The SafeCREW project demonstrates that optimizing or adding treatment stages effectively reduces organic matter, a key precursor of many harmful DBP. Targeted analysis of organic matter content enables tailored treatment improvements, minimizing DBP risks. Partially replacing chlorine with ozone as an oxidant lowers the formation of halogenated DBPs during treatment. Oxidizing organic matter and using activated carbon filters before the final chlorine disinfection decreases DBP generation. Selecting appropriate activated carbon based on the specific water matrix is critical for maximizing DBP reduction.

More details are provided in the respective SafeCREW report.[5]

Improved online monitoring enables early warning of elevated DBP levels

Recent advancements in continuous monitoring and differentiation of trihalomethanes (THM) have been an objective of SafeCREW. While online THM monitoring is not yet fully perfected, it enables early warning to prevent the delivery of drinking water with elevated DBP concentrations. Despite these improvements, laboratory analyses remain essential for accurate and comprehensive assessment.

More details are provided in the respective SafeCREW report.[6]

Modelling of DBP formation enables proactive management

Formation of DBP in distribution networks depends on the disinfectant dosage and contact time between the disinfectant and the water. Consequently, the disinfectant dosage and network topology play a critical role in the final DBP concentration. Modelling the formation of regulated DBP in the water distribution network enables water utilities to predict where and when DBP might form, supporting proactive management to protect public health. SafeCREW's modelling tools support optimized operational decisions, such as adjusting disinfectant dosage or residence time, to ensure regulatory compliance and maintain high-quality drinking water throughout the system.

Implementing and calibrating these models improves understanding of system dynamics and often uncovers opportunities for operational optimization. Reliable estimates of the DBP trihalomethanes and haloacetic acids depend on the knowledge of key operational parameters like residence time, temperature and residual chlorine at important points within the system. Similarly, accurate estimation of chlorate introduced into the network as a result of hypochlorite degradation in storage tanks is possible when storage conditions and chlorine dosing applied during the disinfection process are well characterized.
More details are provided in the respective SafeCREW report.[7]

[5] D2.3 SafeCREW - Application guideline about DBP precursor removal by different materials
[6] D1.6 SafeCREW - An online reagent-free trihalomethane analyser with trihalomethane differentiation based on contactless technology
[7] D3.2 SafeCREW - Disinfection by-product prediction models

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AI-based soft sensors will form foundation for advanced early warning systems

Drinking water utilities face increasingly dynamic water quality conditions caused by climate variability, aging infrastructure, and complex distribution networks. Traditional grab samples often fail to capture rapid changes. So-called soft sensors constitute an approach based on artificial intelligence that supports real-time early warning systems.

In the SafeCREW project, soft sensors were developed and tested to predict water quality parameters in different case studies. This approach will help in the prediction of anomalies in the water distribution networks, supports proactive management of drinking water supply systems and, following further validation, will represent the backbone of an early-warning system.

More details are provided in the respective SafeCREW report.[8]

A new risk assessment approach combines chemical, microbial and toxicity data

Chemical and microbiological risk assessments are essential for informed decision-making, leading to safer drinking water and more efficient resource use. The SafeCREW project developed a unified framework to support water utilities and control authorities in assessing risks under various conditions, depending on the treatment at the source (bank filtration) or in a dedicated treatment plant, with or without disinfection. Besides microbial and chemical risks, also in-vitro toxicity has been considered to support decision-makers in properly tuning disinfection. A user-friendly decision tree was developed and applied to some case studies to show its applications.

More details are provided in the respective SafeCREW report.[9]

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[8] D4.2 SafeCREW - Guidelines to develop and validate soft sensors for target contaminants, as backbone of an early-warning system

[9] D4.3 SafeCREW - An integrated modelling framework for risk management optimization, combining Effect-Based-Trigger, Quantitative Microbial Risk Assessment and Quantitative Chemical Risk Assessment

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