

RAILWAY ACCIDENT WITH BENZENE RELEASE INTO THE ENVIRONMENT IN 2025: ESTIMATION OF HEALTH RISKS FROM AVAILABLE DATA

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SUMMARY

Objectives: The aim of the study was to assess potential health risks associated with a large-scale environmental release of benzene following a railway accident in Moravia, Czech Republic, in 2025, with emphasis on differences between population and occupational exposure.

Methods: An assessment of potential health risks associated with exposure was performed using available environmental monitoring data. Conservative exposure scenarios were defined for the general population and for remediation workers. Non-carcinogenic risk was expressed as the hazard quotient (HQ), and carcinogenic risk as excess lifetime cancer risk (ELCR).

Results: Short-term peaks in ambient air benzene concentrations were observed in the period immediately following the accident and during remediation activities, with occasional hourly values reaching the order of tens of $\mu\text{g}\cdot\text{m}^{-3}$. During the accident and its immediate aftermath, benzene concentrations at the accident site ranged from $< \text{LOQ}$ – $32.3 \text{ mg}\cdot\text{m}^{-3}$ (LOQ – limit of quantification) in soil gas (March–April 2025), 0.0004 – $2.43 \text{ g}\cdot\text{l}^{-1}$ in groundwater (March–May 2025), $< \text{LOQ}$ – $19.9 \text{ }\mu\text{g}\cdot\text{l}^{-1}$ in surface water (March–June 2025), and $< \text{LOQ}$ – $849.7 \text{ mg}\cdot\text{kg}^{-1}$ in soils (March–April 2025). Extreme values were confined to the immediate accident zone and represented the dominant exposure for workers rather than residents. For the general population, HQ values remained below 1 and ELCR ranged from 10^{-6} to 10^{-5} . In contrast, remediation workers exhibited substantially higher risks, with HQ values reaching 10^4 – 10^5 and ELCR up to 10^{-3} , particularly for inhalation exposure.

Conclusion: While population exposure remained within acceptable limits, occupational exposure during remediation represented the dominant health risk. Two workers involved in remediation activities were excluded from further work based on the results of biological monitoring of benzene exposure. The results highlight the need for strict exposure control and health surveillance of exposed workers.

Key words: benzene, railway accident, health risk assessment, occupational exposure, biomonitoring

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INTRODUCTION

Benzene (C_6H_6) is a volatile aromatic hydrocarbon with well-established haematotoxic and carcinogenic effects. Excessive exposure has long been associated with bone marrow suppression and an increased risk of leukaemia, particularly acute myeloid leukaemia. Consequently, benzene is classified by the International Agency for Research on Cancer (IARC) as carcinogenic to humans (Group 1) (1). As a genotoxic carcinogen, benzene is considered to have no safe exposure threshold, which is of particular relevance in accidental release scenarios (2, 3).

Large-scale releases of benzene into the environment may generate complex exposure profiles, involving acute high-level exposure shortly after the incident as well as longer-term lower-level exposure during remediation. In such situations, remediation workers are often subject to substantially higher exposure than the general population. This short communication summarises hazard identification and quantitative health risk assessment (HRA) following a major railway accident with benzene release in Moravia, Czech Republic, in 2025 (4–6).

The mechanism of benzene toxicity is linked to its metabolic activation into reactive metabolites (including phenols and qui-

nones), which contribute to oxidative stress, DNA damage and dysregulation of haematopoiesis. From a practical perspective, both chronic exposure to low concentrations and short-term exposure to high concentrations during accidental releases are relevant.

In the Czech Republic, protection of health against the adverse effects of benzene was historically based on hygienic regulations issued by the Ministry of Health in 1962 and amended in 1974 (7, 8). Current practice relies on a combination of preventive measures, occupational hygiene limits, biological monitoring (biological exposure indices) and health risk assessment, particularly in the context of major incidents (9).

MATERIALS AND METHODS

Accident Overview

On 28 February 2025, a freight train transporting benzene derailed in Moravia, Czech Republic. Seventeen tank wagons were damaged, and a subsequent fire led to extensive release of benzene into soils, groundwater and surface water. Available

technical documentation indicated approximately 12 tonnes of benzene in contaminated soils and about 260 tonnes present as a free phase on the groundwater table, with locally dissolved benzene concentrations reaching up to 1.8 g.l^{-1} (4). Emergency response measures included restriction of access to affected areas, recovery of free-phase benzene and long-term environmental monitoring (4, 6).

Health Risk Assessment Framework

Risk assessment focused on human health was conducted according to standard risk assessment methodology, comprising hazard identification, dose-response assessment, exposure assessment and risk characterization (10). Quantitative health risk assessment (QHRA) was applied using internationally accepted toxicological reference values for benzene (2).

Artificial intelligence-based tools were used in a supportive manner to assist with structuring and synthesis of heterogeneous environmental monitoring data, toxicological information and exposure scenarios; all methodological decisions and interpretations were based on established health risk assessment principles.

Receptor Groups and Exposure Pathways

Two receptor groups were evaluated: the general population and remediation workers. For the general population, inhalation of benzene vapours, dermal contact and incidental ingestion during outdoor activities were considered. For remediation workers, inhalation of vapours from soil air, contact with contaminated groundwater and dermal exposure during handling of contaminated materials were evaluated.

Exposure Scenarios and Risk Metrics

Conservative exposure scenarios were defined separately for population and occupational settings. Non-carcinogenic risk was expressed as hazard quotient (HQ), while carcinogenic risk was expressed as excess lifetime cancer risk (ELCR). Results were interpreted according to commonly applied regulatory criteria.

Exposure Dose Calculation and Risk Characterisation

Exposure estimates were derived from measured or representative concentrations of benzene in environmental media (ambient air, soil air, groundwater and surface water) combined with standard exposure parameters. For non-carcinogenic effects, average daily dose or chronic daily intake (ADD/CDI) was estimated for ingestion and dermal contact pathways, while time-weighted exposure concentration (EC) was used for inhalation scenarios. Exposure parameters included exposure frequency and duration, daily exposure time, intake or inhalation rates, body weight and averaging time; parameter values reflected typical population behaviour and work-shift characteristics for remediation workers.

Non-carcinogenic risk was characterised using the hazard quotient, defined as the ratio of estimated exposure (ADD/CDI or EC) to the corresponding reference value – reference dose (RfD) or reference concentration (RfC).

Interpretation was based on the following criteria:

HQ < 1: the risk is generally considered acceptable (adverse effects are not expected).

HQ > 1: adverse effects cannot be excluded; the risk is considered unacceptable and requires risk management.

Where multiple exposure pathways were relevant, hazard quotients were summed to derive the hazard index (HI), assuming additivity of non-carcinogenic effects.

Carcinogenic risk was expressed as excess lifetime cancer risk, calculated by combining lifetime-averaged exposure estimates with benzene cancer potency values (slope factor for ingestion or dermal exposure, or inhalation unit risk for inhalation exposure). ELCR values represent the estimated increase in lifetime cancer risk associated with the assessed exposure scenario. The result represents an increased lifetime risk of cancer development (e.g., a value of 1×10^{-5} corresponds to one additional cancer case per 100,000 exposed individuals over a lifetime at the given exposure level). Risk estimates were evaluated against acceptability ranges commonly used in regulatory practice.

RESULTS

Short-term peaks in ambient air benzene concentrations were observed in the period immediately following the accident and during remediation activities, with occasional hourly values reaching the order of tens of $\mu\text{g.m}^{-3}$ (6).

During the accident and its immediate aftermath, benzene concentrations at the accident site ranged from < LOQ–32.3 mg.m^{-3} (LOQ – limit of quantification) in soil gas (March–April 2025), < LOQ–2.43 g.l^{-1} in groundwater (March–May 2025), < LOQ–19.9 $\mu\text{g.l}^{-1}$ in surface water (March–June 2025), and < LOQ–849.7 mg.kg^{-1} in soils (March–April 2025), with extreme values confined to the immediate accident zone and representing the dominant exposure for workers rather than residents (4) (Table 1).

For the general population, HQ values remained below 1 for all evaluated exposure pathways, indicating acceptable non-carcinogenic risk. Estimated ELCR values ranged from 10^{-6} to 10^{-5} .

In contrast, remediation workers exhibited substantially elevated risks. Inhalation exposure scenarios resulted in HQ values up to 10^4 – 10^5 and ELCR values up to 10^{-3} . Accidental ingestion of contaminated groundwater also led to HQ values in the range of 10^2 – 10^3 and ELCR up to 10^{-3} . These results identify occupational exposure during remediation as the dominant health risk associated with the accident (4) (Table 2).

Exposure scenarios and health risk assessment are described in Table 1 and 2.

A graphical presentation of the results is provided in Figure 1. The bar chart plotted on a logarithmic scale presents HQ and ELCR values for the main exposure scenarios. While risk estimates for residents remain well below commonly accepted threshold values, remediation workers exhibit several orders of magnitude higher risk levels, particularly for soil air inhalation and contact with contaminated groundwater. The figure clearly demonstrates that the dominant health risk associated with the entire accident is linked to occupational exposure during remediation activities.

Table 1. Summary of measured benzene concentrations in major environmental compartments following the railway accident (2025)

Environmental compartment	Typical location/samples	Sampling period	Concentration range	Arithmetic mean	Reference value/limit	Brief interpretation
Soil gas	Probes at the accident site (20 samples)	March–April 2025 (repeated sampling)	< LOQ–32.3 mg.m ⁻³	3.1 mg.m ⁻³	MoE guideline indicator: 1.6 mg.m ⁻³	Extreme contamination, dominant source of inhalation exposure for workers
Groundwater	Monitoring within and around the accident area (50 samples)	March–May 2025 (continuous monitoring)	424.00–2,432,149.00 µg.l ⁻¹	526,419.00 µg.l ⁻¹	MoE guideline indicator: 0.39 µg.l ⁻¹	Massive contamination, locally presence of free-phase benzene
Surface water	Lake No. 6 (northern shore) (14 surface and depth samples)	March–June 2025	< LOQ–19.9 µg.l ⁻¹	1.8 µg.l ⁻¹	EQS-AA: 10.0 µg.l ⁻¹	Local impact without widespread exceedance of limits
Soils	Soils at and around the accident site (60 samples)	March–April 2025	< LOQ–849.7 mg.kg ⁻¹	30.3 mg.kg ⁻¹	MoE guideline indicator: 5.4 mg.kg ⁻¹	Significant contamination in the immediate accident zone

LOQ – limit of quantification; n.a. – not available in the source documentation; MoE – Ministry of the Environment of the Czech Republic; EQS-AA – environmental quality standard (annual average)
Source: Nedbal et al. (4)

Table 2. Health risk assessment of benzene exposure for different population groups

Group	Exposure scenario	Main exposure route	HQ	ELCR	Risk evaluation
Residents	Presence in the area	Air inhalation	< 1	< 1 × 10 ⁻⁵	Acceptable
Residents	Recreational use of the area	Water/soil contact	< 1	< 1 × 10 ⁻⁵	Acceptable
Remediation workers	Soil air inhalation	Inhalation	Up to 9.3 × 10 ⁴	Up to 2.4 × 10 ⁻³	Unacceptable
Remediation workers	Accidental ingestion of groundwater	Oral	Up to 8.3 × 10 ²	Up to 2.6 × 10 ⁻³	Unacceptable
Remediation workers	Contact with contaminated soil	Dermal + oral	> 1	~ 10 ⁻⁶	Unacceptable (non-carcinogenic)

Source: Nedbal et al. (4)

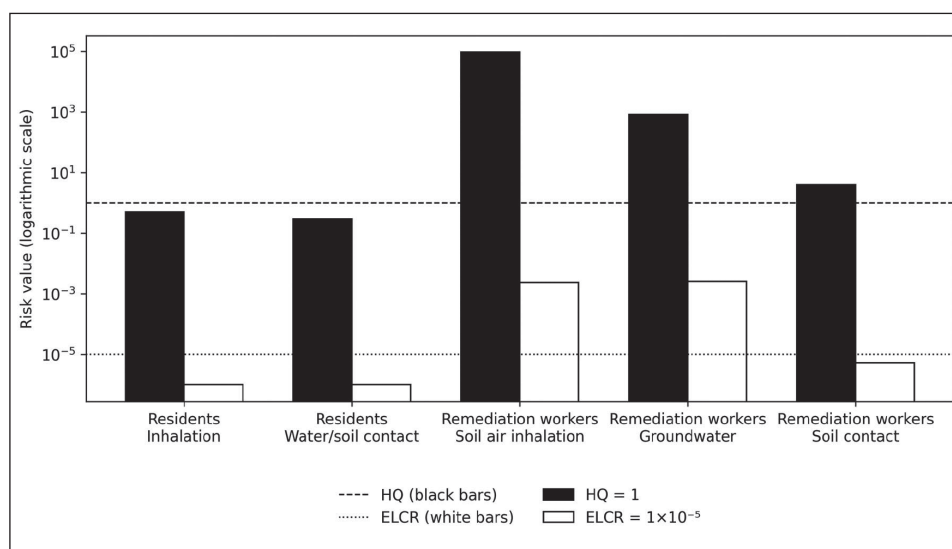


Fig. 1. Comparison of non-carcinogenic (HQ) and carcinogenic (ELCR) benzene risks for residents and remediation workers.

Black bars represent the hazard quotient (HQ) for non-carcinogenic effects. White bars represent excess lifetime cancer risk (ELCR). The dashed horizontal line indicates the non-carcinogenic acceptability threshold (HQ = 1). The dotted horizontal line indicates the commonly used acceptability level for carcinogenic risk (ELCR = 1 × 10⁻⁵). Risk values are displayed on a logarithmic scale.

DISCUSSION

In the Czech Republic, risk assessment of contaminated sites is commonly performed according to the methodological guidance of the Ministry of the Environment (10). While this approach includes a component of human health risk assessment, it is primarily designed for environmental management purposes. Public health authorities have therefore pointed out that the methodology may not always fully capture the complexity of health risks associated with exposure.

The conducted health risk assessment indicates that an accident involving a massive release of benzene into environmental compartments may result in markedly different health impacts depending on the nature of exposure and the type of exposed population. The results of this study confirm that, based on the available data, exposure of residents in the affected area did not represent unacceptable health risks, whereas occupational exposure during emergency response and remediation activities was identified as the dominant source of significant health risk.

This difference can be explained by a combination of extremely high local concentrations, direct contact with the contaminated environment, and the duration of exposure among workers. In contrast, exposure of residents was limited spatially and temporally and further reduced by organisational and preventive measures (restricted access to the most contaminated zones, control of water use, and other regime measures). From a public health perspective, this provides a practical demonstration that, in accident situations, the rapid identification of exposure pathways and timely implementation of control measures may be more decisive than the absolute amount of the released substance alone.

No data on firefighter exposure related to the accident were identified, and the assessment of occupational exposure therefore relied on indirect indicators, particularly environmental concentrations within the immediate accident zone and the nature of the activities performed.

The assessment demonstrates a clear contrast between population and occupational exposure following a large-scale benzene release. Population exposure remained within acceptable risk limits, most likely due to rapid implementation of access restrictions and mitigation measures. In contrast, remediation workers faced high exposure levels due to direct contact with contaminated media and prolonged presence in affected areas. Personal protective equipment (PPE) (not only respirators but also protective clothing) of workers involved in benzene spill remediation is also essential because combustion of benzene produces mainly carbon dioxide, carbon monoxide, water, soot and particulate matter, as well as unburned aromatic hydrocarbons, polycyclic aromatic hydrocarbons (e.g., naphthalene, benzo[a]pyrene) and oxidized organic compounds including aldehydes (e.g., formaldehyde and acrolein).

This pattern is consistent with international experience from major benzene-related incidents, such as the Songhua River spill in China in 2005, where rapid public health interventions limited population exposure while occupational exposure represented the primary health concern (11, 12). Toxicological syntheses similarly emphasise that worker protection is a critical element of risk management following large-scale releases of volatile hydrocarbons (2, 3).

The findings underline the importance of integrating quantitative health risk assessment with environmental monitoring and occupational health measures. Biomonitoring of remediation workers using established biomarkers of benzene exposure can provide additional assurance of effective exposure control (9). Based on the results of hazard identification and risk assessment, targeted biomonitoring is recommended for exposed persons, particularly remediation workers and, where relevant, individuals spending prolonged time near the remediated area. For benzene, the following exposure biomarkers are internationally recommended:

- S-phenylmercapturic acid (SPMA) in urine – a specific and sensitive marker of low-level benzene exposure;
- trans,trans-muconic acid (t,t-MA) in urine – useful mainly at higher exposure levels;
- haematological indicators in blood (e.g., complete blood count) as potential early effect markers of haematopoietic toxicity.

Biomonitoring should be targeted, periodic and aligned with the nature and duration of exposure; results should support evaluation of control measures and early identification of potential health effects.

Biological exposure indices in urine according to Decree No. 432/2003 Coll. (9) are presented in Table 3.

During biological monitoring of individuals entering the controlled zone and directly involved in remediation activities, 648 urine samples from 115 persons were collected between 28 March 2025 and 19 February 2026 for the determination of a benzene metabolite in urine (SPMA). Based on the results of biological monitoring of benzene exposure, two remediation workers were excluded from further work due to exceeding the limit value of this metabolite.

CONCLUSIONS

The railway accident with benzene release in Moravia in 2025 did not result in unacceptable health risks for the general population based on available data. However, occupational exposure during remediation constituted a substantial health risk. Risk management following such events should prioritise worker protection, long-term environmental monitoring and targeted biomonitoring as part of an integrated public health response.

Table 3. *Biological exposure indices in urine*

Substance	Indicator	Limit	Conversion	Sampling time
Benzene	S-phenylmercapturic acid (SPMA)	0.05 mg/g creatinine	0.024 µmol/mmol creatinine	End of shift
Benzene	trans,trans-muconic acid (t,t-MA)	1.5 mg/g creatinine	1.2 µmol/mmol creatinine	End of shift

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Conflicts of Interest

None declared

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author used ChatGPT in order to identify data sources. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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