ENVIRONMENTAL PROTECTION IN NATURAL GAS INDUSTRY
Comparison of Different Spatio-Temporal Radiological Risk Assessment Scenarios

by

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The paper analyses results of spatio-temporal radiological risk assessment scenarios based on existing in-situ long-term monitoring data from a natural gas processing plant to analyse the effect of different input data on the assessment outcome. The ERICA Assessment Tool was used to estimate the dose rates to biota and potential impacts due to the exposure to ionising radiation. The input data for radiological risk assessment scenarios included annual data on activity concentration of radionuclides in soil from *in-situ* measurements performed from 1994 to 2016 and laboratory gamma-spectrometric data related to the period from 2014 to 2019. Predicted total dose rate to biota was generally below the ERICA Tool's screening dose rate of 10 μGyh^{-1} or slightly above, with the highest total dose rate estimated for lichen and bryophytes. Total dose rates to lichen and bryophytes in the studied period show certain temporal variation, but a specific trend was not detected. Estimated total dose rates to biota from different assessment scenarios were below internationally proposed reference levels for which no detrimental effects are expected. The overall potential radiological risk to terrestrial biota from the operation of the natural gas processing plant was found to be negligible.

Key words: NORM, natural gas, radiological risk assessment, environmental protection, Erica tool

INTRODUCTION

Natural gas is being used worldwide as a primary energy source, with global data showing it constitutes as more than a quarter in the global energy mix [1] and similarly in the energy mix of the EU [2]. Natural gas also has an important role in the global energy security [3-5]. Consequently, the natural gas industry has a significant impact on the quality of the overall environment.

Naturally occurring radioactive material (NORM) results from different industrial processes as an industrial by-product where radionuclides accumulate in different types of waste. Industrial activities that may lead to the enhanced levels of radioactivity have been gaining attention in the last decades. The European Council 2013/59/Euratom recognizes possible risks arising from natural radioactivity, *i. e.*, NORM, while possible environmental contamination risks associated with NORM-related industries were documented in detail by international community as well [6-10]. Different aspects of NORM generation in industries, its emissions, and possible effects on health and the environment have been studied in the last two decades [11, 12]. Since industrial NORM releases can be associated with detrimental effects on populations and environment, radiation protection in the context of industries related to NORM aims to mitigate adverse effect by using radiation protection principles of justification, and optimization in occupational exposure [13-16].

The importance of oil and gas industries as NORM-related industries in establishing standards and ensuring adequate protection of both populations and the environment has been researched in several specific studies. Koppel *et al*. [17] stress the potential role of oil and gas facilities that are to be decommissioned, risks associated with decommissioning options, and possible ecological impacts. In their paper Cowie *et al*. [18] present a practical industrial experience in developing a NORM management strategy in oil and gas industry. Jodlowski *et al*. [19] studied waste from gas exploration

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and production including drill cuttings, drilling muds, fracking fluids, return, fracking fluids, and waste proppants, while Gafvert *et al*. [20] sampled produced water from offshore platforms in Norway. Al-Masri and Haddad [21] used fly and bottom ash samples from a natural gas power plant to study NORM emissions. Several studies were conducted on soil and sludge samples, Xhixha *et al*. [22] conducted an extensive study using soil and sludge samples in order to identify areas for strategical plan of future radiological assessments in Albania, where Barros *et al*. [23] sampled scale in industrial pipelines in Venezuela. Garner *et al*. [24] explored oil and gas producing region in the United Kingdom, Attallah *et al*. [25] studied scale samples from petroleum industry in Egypt, and study from Taheri *et al*. [26] used samples of soil and sludge from a gas field in Iran. There are also studies that include characterization of waste arising from oil and natural gas production [27] and geochemical signature of NORM waste from oil industry [28]. The study from Husain and Sakhnini [29] focused on radiological impacts of NORM from oil and gas industry in Bahrein. All these studies demonstrate the importance of robust environmental monitoring and proper attention paid to NORM waste and assessments of its potential radiological risks to the environment in all production phases. Lazarus *et al*. [30] investigated presence of mercury, and other stable metalloids and radionuclides in biota as a part of the extensive monitoring of soil, earthworms, moss, livestock and wildlife animals at the natural gas treatment plant.

The main goal of environmental monitoring is the quantification of radioactive substances or ionising radiation that arise from human activities and natural sources in different environmental media [31]. Regarding the practical context of environmental monitoring programmes, Article 35 of the Euratom Treaty implies implementation of comprehensive national programmes of monitoring the environmental radioactivity. These programmes aim at monitoring main pathways of potential exposure of population and include sampling and analyses of the environmental media [32]. These programmes might not include particular industrial sites related to NORM, but environmental monitoring of NORM-related industrial locations aligns with the overarching goals of national environmental radioactivity programmes. Environmental radioactivity monitoring also has a role in effective risk preparedness and prevention [33]. Study from Riberio *et al*. [34] presents an example of extensive environmental monitoring programme implementation. Sun *et al*. [35] focused on optimization of long-term monitoring of radiation air-dose rates, while including the goals of long term environmental monitoring *i.e*., detecting possible changes of contaminant mobility and validating the reduction of hazard levels. Michalik [12] emphasizes the importance of environmental radioactivity monitoring including non-human species representatives, and possible radiation dose and effects on biota. Soil radioactivity was also studied to establish baseline data for future radiation impact assessments [36], to estimate possible pollution with industry as a source of radionuclides and heavy metals [37], and to estimate possible use of organisms as biomonitors [38].

The assessment of potential impacts arising from exposure of non-human biota to ionising radiation can be performed using different approaches and models [39, 40]. The ERICA Integrated Approach and ERICA Tool were developed through EU co-funded 6th Framework Program EURATOM project Environmental Risk from Ionising Contaminants Assessment and Management (ERICA). The key characteristics of the ERICA Tool is the assessment-based risk quantification through use of data on environmental transfer and dosimetry, resulting in the measure of exposure that is further compared to exposure levels associated with known detrimental effects of radiation [41-44]. The use of ERICA Tool can be used for planned, emergency or existing exposure situation, where NORM-related activities are regarded as planned exposure situations [45, 46].

This paper compares different spatio-temporal radiological risk assessment scenarios based on existing in-situ long-term monitoring data from a natural gas processing plant to analyse the effect of different input data on the assessment outcome. Additionally, a risk assessment using laboratory gamma-spectrometric data from the same site was conducted, and results from both studies were compared. The results of these comparisons could provide valuable feedback for design of future radiological risk assessments in NORM-related industries and general insight in justifiability of conducting long-term radioactivity monitoring and using the resulting data to perform radiological risk assessments, as opposed to using more concise environmental radioactivity data sets.

MATERIALS AND METHODS

Assessment site

The research area included the natural gas processing plant site Molve, located in Croatia, Europe. The site is part of Podravina reservoir and presents one of the largest natural gas and gas condensate reserves in the Republic of Croatia that accounts for the majority of the national natural gas production [47]. After initial research in 1974, as a part of the project *Podravina* the production at the natural gas field Molve first started in 1981 with two gas wells and was later further developed in several phases [47, 48]. The ongoing production of natural gas and gas condensate for the last 40 years makes this the most complex energy project related to hydrocarbon exploration and production in Croatia, as well as an example of a project implementation that effectively combined energy-related goals and environmental protection principles [49]. The ongoing activities at the site include the production and purification of gas and gas condensate for transport.

Assessment data

In-situ gamma-ray spectrometry measurements were performed by Radiation Protection Unit of the Institute for Medical Research and Occupational Health in the period from 1994 to 2016 on three locations at the plant site which included the location of the central gas station (CPS) and locations of two gas wells, station M-9 and station M-10, fig. 1.

In-situ gamma-spectrometric measurements were carried out to determine the sources of basic radiation, both cosmic and terrestrial, by direct measurements in the field using a semiconductor detector ORTEC HPGe, a multi-channel analyser (with 16000 channels) and the associated electronic circuit with a computer. The characteristics of the HPGe detector included resolution of 1.75 keV at 1.33 MeV ^{60}Co and relative efficiency of 21 % at 1.33 MeV ^{60}Co. All *in-situ* measurements were conducted during 1000 seconds and ORTEC Gamma Vision software was used to analyse the resulting spectra. The activity concentrations of natural radionuclides in the soil were calculated assuming their uniform distribution in the soil.

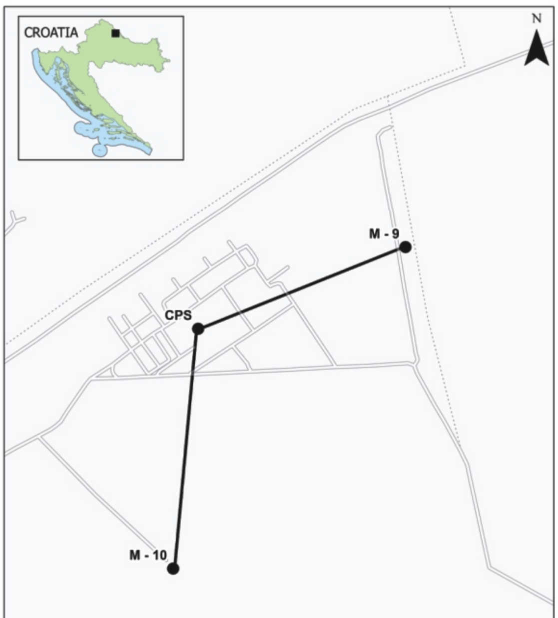

Figure 1. Assessment site and sampling locations (CPS, M-9, and M-10) layout

In the period from 2014 to 2019, samples of soil (0-10 cm) were taken from the location of central gas station CPS, station M-9, and station M-10. All the samples were prepared in the laboratory and analysed using gamma-ray spectrometry. The sample preparation included sample sieving, drying of samples at 105 °C, and then ashing at 450 °C in a muffle furnace. The samples prepared in this manner were then packed in sealed containers of 200 ml volume. The samples were measured in a gamma-spectrometric laboratory after 66 days to ensure the secular equilibrium within the uranium and thorium decay chains. Determining radioactivity in soil samples was performed using high-resolution gamma-spectrometry with a method accredited according to HRN EN ISO/IEC 17025. HP GMX ORTEC detector system was used with the following characteristics: resolution of 2.2 keV at 1.33 MeV ^{60}Co and a relative efficiency of 74.3 % at 1.33 MeV ^{60}Co. Efficiency calibration was carried out by the standards from the Czech Metrological Institute covering the energy range from 40 to 2000 keV. Data on ^{238}U, ^{226}Ra, and ^{232}Th activities were determined from those of their decay products. Activity of ^{226}Ra was determined from that of ^{214}Bi (photopeaks at 609 keV, 1120 keV, and 1764 keV), activity of ^{232}Th from that of 228Ac (photopeaks at 338 keV, 911 keV, and 968 keV), and activity of ^{238}U from those of ^{234}Th (photopeak at 63 keV). The measured activity in all the samples was above the detection limit. The quality assurance of radionuclide determination was performed through systematic participation in comparative measurements organized by the International Atomic Energy Agency (IAEA), the World Health Organization (WHO), as well as the EU's Joint Research Centre (JRC) [50].

Use of the ERICA tool

The ERICA Assessment Tool (version 2.0) was used to calculate dose rates to terrestrial biota from exposure to radionuclides. The assessment can be performed by selecting different default ecosystems: terrestrial, marine and freshwater. The ERICA Tool uses activity concentrations in environmental media *i.e.*, sediment, soil, water and air as input data for the assessment. The estimation of radionuclide transfer to the environment is performed using the concentration ratio (CR) values [41, 43, 45]. The ERICA Tool assesses potential effects arising from both internal and external exposure by interpreting activity concentration data in environmental media and biota which is done through the use of internal and external dose conversion coefficients (DCC_{int} and DCC_{ext}) [44, 45]. The Tool also uses weighting factors to address different components of radiation, 10 for alpha, 3 for beta and 1 for gamma radiation [43]. The default list of radionuclides in the ERICA Tool in line with the environmental protection framework of the International Commission on Radiological Protection, as well as the use of reference organisms as generalised ecosystem representations [43]. For reference organisms, the occupancy factors define the fraction of time that the organism spends in a certain environmental media, and these values can be modified by the user if necessary [44, 45].

The ERICA Assessment Tool allows users to run assessment in different assessment contexts, *i.e.*, different tiers. Tier 1 presents the basic highly conservative assessment that requires minimal user data input. The Tier 2 assessment context allows users to input site-specific media concentrations and to use single point or more complex temporal and spatial data series. Tier 2 also offers users to perform a less conservative assessment and comparison of results against tables of radiological effects and exposure due to naturally occurring radionuclides [45]. The default screening dose rate proposed by the ERICA Tool is 10 μGyh^{-1}, and suggested uncertainty factors (UF) are 3 and 5 that enable the assessment for 5 %, and 1 % probability of exceeding the dose rate screening value, respectively [43-45].

All risk assessment scenarios using the *in-situ* gamma-spectrometric measurements from the long- term monitoring data were run at Tier 2 of the ERICA Tool for a terrestrial ecosystem. The reason for this is that only Tier 2 allows users to input multiple series data and specific combination of spatial and temporal series of data.

The input data included annual activity concentration of radionuclides in soil (in Bqkg^{-1}) from samples collected at three sampling locations, at a natural gas processing plant, in the period from 1994 to 2016. Table 1 summarizes activity concentrations in the soil samples for the studied period.

The assessments included all ERICA Tool's default terrestrial reference organisms, and the default occupancy factors, assuming that the selected organisms spend 100 % of their time at the site, which could be regarded as a conservative approach. The selected screening dose rate for all the assessment scenarios was the ERICA Tool's default value of 10 μGyh^{-1}. Other default parameters included UF of 3, percentage of dry weight of media of 100 %, and the default weighting factors for alpha, high energy betta/gamma and low energy beta radiation of 10, 1, and 3, respectively. The CR values used in the assessments were default values provided by the assessment Tool, as site-specific CR values were not available. The use of site-specific CR values by the ERICA Tool in a NORM-related assessment context was researched in detail by other authors and generally, the results show lower dose rate estimations as opposed to assessments that use ERICA Tool's default CR values [51-53]. Table 2 summarizes parameters used in the risk assessments: list of radionuclides and reference organisms.

The study performed multiple radiological risk assessment scenarios using the *in-situ* gamma-spectrometric measurements. The first risk assessment scenario used the complete long-term data set on annual activity concentrations per sampling location (CPS, M-9, and M-10) from 1994 to 2016. For the same data set separate risk assessment were performed using an annual average radionuclide concentration from all three sampling locations. Additional assessment used the maximum measured activity concentrations from all the sampling locations in the studied period. In order to assess the potential cumulative effects, a separate assessment scenario used tripled maximum measured activity concentrations from the sampling locations.

A second radiological risk assessment scenario using the data from the laboratory gamma-spectroscopic measurements, for the period from 2014 to 2019, was also performed using the Tier 2 assessment context with data on activity concentration of radionuclides in soil (in Bqkg^{-1}) from three sampling locations at the Molve site. This assessment also included the ERICA Tool default reference organisms and default parameters of the screening dose rate, occupancy factors, UF of 3, the percentage of dry weight of media of 100 %, and the default weighting factors for an alpha, high energy betta/gamma, and low energy beta radiation. Again, Tool's default CR values were used. Table 3 summarizes all assessment input data, and tab. 4 lists activity concentrations of soil samples used in the assessment scenario.

Table 1. Activity concentrations (Bqkg^{-1} dry mass) in soil the samples from in-situ gamma spectrometric measurements in the period 1994-2016, (N-number of measurements, the range is given in parenthesis)

Activity concentrations SD [Bqkg^{-1}]			
Sampling location	N	^{232}Th	^{226}Ra
CPS	18	40 15 (11-61)	44 19 (26-97)
M-10	16	30 20 (11-90)	36 12 (23-77)
M-9	18	34 32 (5-128)	38 14 (20-69)

Table 2. Assessment parameters in terrestrial assessments using *in-situ* gamma-spectrometric data

Radionuclides	Reference organisms
^{232}Th ^{226}Ra	Grasses and Herbs
	Shrub
	Tree
	Amphibian
	Annelid
	Arthropod – detritivorous
	Bird
	Flying insects
	Lichen & Bryophytes
	Mammal – large
	Mammal – small burrowing
	Mollusc – Gastropod
	Reptile

RESULTS AND DISCUSSION

Risk quotient (RQ), a unitless value calculated by the Tool, using the data on selected screening dose rate and the total estimated whole body absorbed dose rate for each individual organism [45], did not exceed 1 in risk assessment scenario related to the *in-situ* gamma spectrometric temporal data set. The risk assessment scenario that used laboratory gamma-spectrometric data detected a RQ slightly above 1 and resulting in lichen and bryophytes as the most affected reference organisms. These results could be explained by the laboratory gamma-spectrometric data including more radionuclide data which then increases the estimated dose rates and consequently the estimated RQ.

In assessment scenarios using the *in-situ* gamma spectrometric data and laboratory gamma spectrometric data, Tool's output data on external and internal dose rate was analysed to determine the dominant exposure route and key contributors to the dose rate. The assessments based on the *in-situ* gamma spectrometric data resulted in external dose with ^{226}Ra as the main contributor, with amphibian, annelid, arthropod, small burrowing mammals and reptile as the most affected organisms. The internal dose rate was also primarily associated with exposure to ^{226}Ra, with the highest internal dose rate to lichen and bryophytes and shrub.

Table 3. Assessment parameters in terrestrial assessments using laboratory gamma-spectrometric data

Radionuclides	Reference organisms
^{238}U ^{232}Th ^{226}Ra ^{210}Pb	Grasses and Herbs
	Shrub
	Tree
	Amphibian
	Annelid
	Arthropod – detritivorous
	Bird
	Flying insects
	Lichen and Bryophytes
	Mammal – large
	Mammal – small burrowing
	Mollusc – Gastropod
	Reptile

Table 4. Activity concentrations (Bqkg^{-1} dry mass) in soil samples from laboratory gamma-spectrometric measurements in the period 2014-2019, (N-number of measurements, the range is given in parenthesis)

Sampling location	N	Activity concentrations SD [Bqkg^{-1}]			
		^{238}U	^{232}Th	^{226}Ra	^{210}Pb
CPS	5	38 5 (33-45)	44 17 (31-74)	45 10 (35-60)	53 21 (28-76)
M-10	5	44 12 (28-57)	52 19 (31-83)	49 15 (31-73)	49 21 (28-77)
M-9	5	48 16 (30-67)	54 23 (14-70)	33 22 (5-57)	38 28 (11-84)

Again, the internal dose rate was the parameter that affected the estimated total dose rate the most irrespective of the temporal aspect of the input data or if the maximum activity concentrations was used in the assessment. The calculation of dose rate in assessment scenarios using laboratory gamma-spectrometric data showed that the main contributor to the external dose rate for all reference organisms was ^{226}Ra, with the highest contribution to following reference organisms: amphibian, annelid, arthropod, mammals (small -burrowing), mollusc, and reptile. The data on the internal dose rate showed that ^{226}Ra contributes the most to the internal dose rate, primarily observed in reference to lichen and bryophytes and shrub. The total dose rate estimation can almost entirely be attributed to internal dose rate. The contribution of different radionuclides, specifically ^{226}Ra, to the total dose rate from our study is in accordance with results from previous studies related to exposure to naturally occurring radionuclides from other authors [51, 54-57]. Additionally, the presence of ^{226}Ra and importance of its activity concentration for the assessment results is related to the fact that ^{226}Ra is a prevalent radionuclide in scales and deposits found in equipment of the oil and gas industry and discharges, and as such, is a major source of radiation exposure [13, 20, 24].

Individual temporal assessments that relied on the annual *in-situ* data from 1994 to 2016 resulted in estimated dose rates between the lowest of 0.1 μGyh^{-1} to the tree as a reference organism and the highest total dose rate of 10.13 μGyh^{-1} to lichen and bryophytes. The same data set, that was temporally averaged before calculation, resulted in an estimated total dose between 0.1 μGyh^{-1} for tree and 4.39 μGyh^{-1} for lichen and bryophytes.

Results from assessment scenario that used laboratory gamma-spectrometric data from 2013 to 2019 showed that the total dose rate to biota ranges from 0.05 μGyh^{-1} for tree to 15.20 μGyh^{-1} to lichen and bryophytes. Figure 2 shows the comparison of the average values of the estimated total dose rate in the studied period for two most affected reference organisms (lichen and bryophytes and shrub) from individual assessment scenario using in-situ and laboratory gamma spectrometric data from 1994 to 2016.

Additional assessment scenario, performed using the maximum soil activity concentrations from the period 1994 to 2016, estimated the total dose rate from 0.26 μGyh^{-1} for tree and 10.87 μGyh^{-1} to lichen and bryophytes. In order to conduct an assessment considering the highest input values, maximum measured activity concentrations from all the sampling locations were used. A comparison of estimated total dose rates to all reference organism from assessment scenarios that used temporal average and maximum activity concentrations from *in-situ* gamma-spectrometric measurements is presented in fig. 3. To estimate the potential cumulative radionuclide concentration effect, the maximum mea-

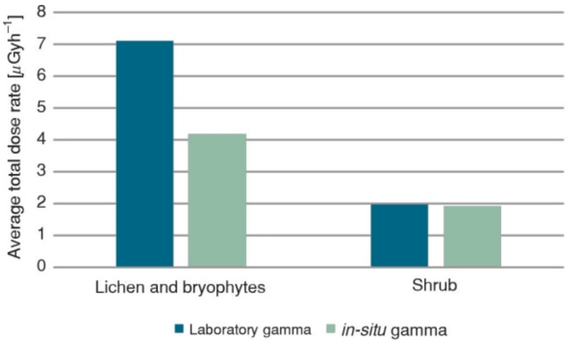

Figure 2. Comparison of average total dose rates to most affected reference organisms from assessments based on *in-situ* and laboratory gamma-spectrometric data sets

sured activity concentrations per radionuclide from all three sampling locations were tripled and another assessment scenario was run with these parameters. In this case, the predicted total dose rate to lichen and bryophytes was 32.5 μGyh^{-1}, which exceeded the ERICA Tool's default screening value, but was below the reference values of 400 μGyh^{-1} for terrestrial plants [57]. These results would imply that even in the case of cumulative contamination the predicted effects to the biota in the proximity of the facility would be below internationally recognized reference levels.

Since lichen and bryophytes were found to be the most affected reference organisms in all the assessment scenarios, and given they are often used as biomonitors of potential environmental contamination [58-60]. Figure 4 presents the estimated total dose rate to lichen and bryophytes based on the in-situ gamma spectrometric data from 1994 to 2016. Total dose rates to lichen and bryophytes in the studied period show certain temporal variation, but our analysis did not detect a specific trend.

Estimated total dose rate value in the studied period was below the selected screening dose rate of 10 μGyh^{-1}, which together with the assessments results, based on the maximum input activity concentrations, implies that the potential radiological risk to terrestrial biota arising from the operation of the natural gas processing plant is not significant. The overall results from various temporal assessments, including in-situ and laboratory data, are in accordance with the results from previous studies. Study by Ćujić and Dragović [55] assessed NORM-related total dose rate to lichen and of 14.4 μGyh^{-1}. Lazarus *et al*. [30] reported estimated dose rates to terrestrial biota up to 3.7 μGyh^{-1} to mosses and lichen. Study by MacIntosh *et al*. [61] on radiological risk assessment to marine biota from exposure to NORM related to decommissioning offshore oil and gas pipeline, estimated a potential dose rate from external exposure up to 33 μGyh^{-1}.

Presented results from risk assessment scenarios need to be observed keeping in mind certain uncertainties associated with performed assessments. One of the possible contributors to the uncertainty is a minimal data gap in available in-situ gamma spectrometric data, *i.e.*, missing data points for a specific radionuclide in a

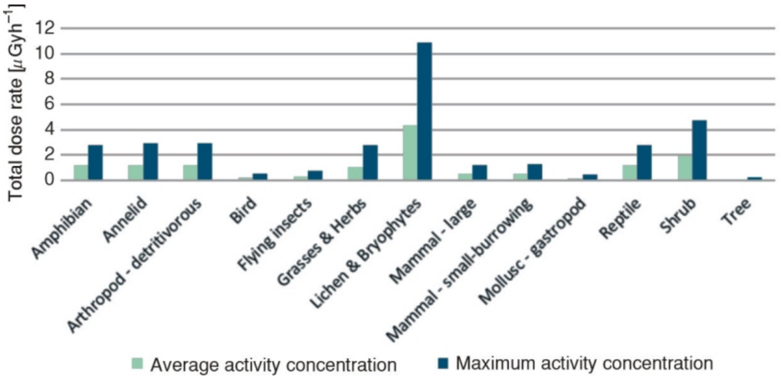

Figure 3. Comparison of total dose rates [μGyh^{-1}] to reference organisms estimated by different input data on activity concentrations (average or maximum values)

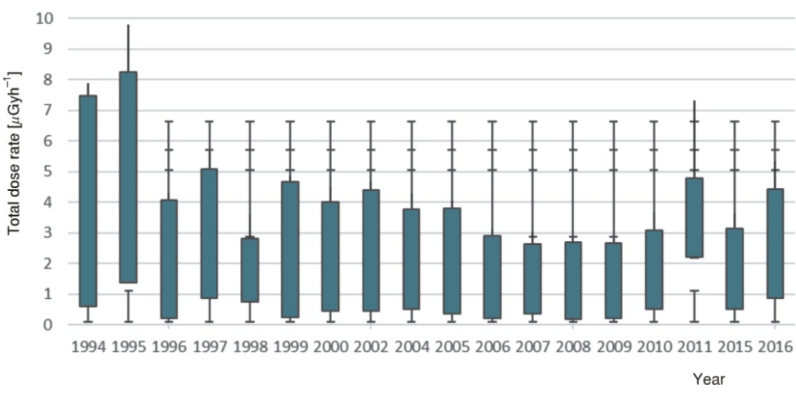

Figure 4. Estimated total dose rate to lichen and bryophytes based on the *in-situ* gamma-spectrometric data from the period 1994 to 2016

certain year, but given the observed temporal variations of the available data, extreme activity concentrations of the missing data are unlikely. Other uncertainties are associated with the lack of experimental data on site-specific transfer values. The ERICA Tool uses a conservative approach to assessments, especially when Tool's default CR values are used, as was the case in all risk assessment scenarios conducted in this study. Hence, the chance of assessment results underestimating the radiological effects and risks should be minimal, but an overestimation of the total dose rates due to the use of Tool's default CR values is possible.

CONCLUSIONS

The assessment results from temporal assessments using *in-situ* gamma spectrometric data showed that the same reference organisms, lichen and bryophytes, were the most affected for in all performed assessment scenarios, irrespective of the time period selected, with the highest estimated total dose rate of 10.13 μGyh^{-1}. The effect of using average activity concentrations in temporal assessments resulted in total dose rates generally below the assessment screening dose rate of 10 μGyh^{-1}. Assessments that relied on maximum activity concentrations as input resulted in total dose rate only slightly exceeding the default screening dose rate for lichen and bryophytes. The assessment scenario that used gamma-spectrometric laboratory data from soil samples from the same location, resulted in the highest total dose rate to lichen and bryophytes of 15.20 μGyh^{-1}. In this context, the results correlate with the previous studies related to NORM-related exposure scenarios, recognizing the lichen and bryophytes as organisms most sensitive to potential radiological hazards. Given the Tool's inherent conservativism and the effect of using the Tool's default CR values, which are known to lead to overestimation of the potential dose rates, the overall radiological risk in all assessment scenarios can be considered negligible. Nonetheless, the continuation of environmental monitoring is encouraged. The conclusions of this study should be observed in a particular research context, where the assessment results identifying the exposure situation as posing no significant risk to the environment could also be attributed to the gas industry in question setting and implementing robust standards of both radiological and environmental protection that are continuously being confirmed through monitoring and assessment.

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AUTHORS' CONTRIBUTIONS

Conceptualization of the paper was done by A. Getaldić and methodology by A. Getaldić and B. Skoko. B. Skoko conducted the formal analysis. B. Petrinec and T. Bituh provided the resources and data curation. Original draft was prepared by A. Getaldić, and review and editing was carried out by A. Getaldić, M. Surić Mihić, B. Skoko, B. Petrinec and T. Bituh. Supervision was performed by M. Surić Mihić and Ž. Veinović.

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ЗАШТИТА ОКОЛИНЕ У ИНДУСТРИЈИ ПРИРОДНОГ ГАСА – УПОРЕЂЕЊЕ РАЗЛИЧИТИХ ПРОЦЕНА ПРОСТОРНО-ВРЕМЕНСКИХ РАДИОЛОШКИХ РИЗИКА

Рад анализира резултате просторно-временских сценарија процене радиолошког ризика на темељу постојећих *in-situ* података дуготрајног мониторинга на локацији постројења за прераду природног гаса, да би се одредио учинак различитих улазних података на исход процене. ERICA Assessment Tool коришћен је за процену доза на биоту и потенцијалних утицаја због изложености јонизујућем зрачењу. Улазни подаци за сценарије процене радиолошког ризика укључивали су годишње податке о концентрацији активности радионуклида у тлу из *in-situ* мерења обављених од 1994. до 2016. године, те лабораторијске гамаспектрометријске податке који се односе на период од 2014. до 2019. године. Предвиђена укупна јачина дозе на биоту генерално је била испод јачине дозе алата ERICA од 10 μGyh^{-1} или незнатно повишена, с највећом укупном јачином дозе процењеном за лишајеве и бриофите. Укупне јачине доза на лишајеве и бриофите у посматраном раздобљу показују одређене временске варијације, али у раду није уочен одређени тренд. Процењене укупне јачине дозе за биоту из различитих сценарија процене биле су испод међународно предложених референтних нивоа за које се не очекују никакви штетни учинци. Утврђено је да је укупни потенцијални радиолошки ризик за копнену биоту због рада постројења за прераду природног гаса занемарив.

Кључне речи: NORM, природни гас, процена радиолошког ризика, заштита околине, алат Erica