

Systematic Radioecological Experiments in the United Arab Emirates (UAE) for Nuclear Safety and Emergency-Preparedness

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Abstract—Nuclear power and other radioactivity-producing industries like oil and gas, desalination, etc. are rapidly maturing in the arid countries, most importantly in the United Arab Emirates (UAE). Thus, it becomes vital to study and model the transfers and impacts of radionuclides' release into the local environments. Baseline or predictive studies on this subject are extremely scarce for the UAE-like desert-marine ecosystems. In global literature, the retention and transfer mechanisms of natural and anthropogenic radionuclides in arid soils and plants are grossly underrepresented. We debrief the recent research activities in the UAE and nearby nations on background radioactivity measurements in soils and plants, as well as those estimating the radioecological transfer factors or concentration ratios. Soil to plant transfer is a key sought after data for arid region radioecology. We further outline some systematic field and laboratory experiments executed by Khalifa University of the UAE, which includes numerous field surveys, identifying radionuclides and crop categories of importance, sampling in representative localities in the Abu Dhabi emirate, developing protocols for sample management and processing, and radiometry using gamma-spectrometry and inductively coupled plasma mass-spectrometry.

Keywords —Radioecology, Soil, Uptake, Emirates, NORM.

I. INTRODUCTION

Robust radiological environmental impact assessments (REIA) are essential to establish and enhance the safety cases at different stages of a nuclear power program [1]. It is necessary for design and operational decisions throughout a nuclear plant's lifecycle, from reactor conceptualization to site selection, radioactivity effluent releases, all the way to plant dismantling and waste management. REIA, in simple words, quantifies the radiological and physicochemical characteristics of a region's environmental matrices, primely, the bedrocks, topsoil, groundwater, surface and marine waters, plants, crops, winds, rains, etc. It measures the susceptibility of the ecosystem to accumulate and/or transfer the radionuclides which are either operationally or accidentally released/deposited in the region. Through the various food chain routes, e.g., cows consuming contaminated grass crops followed by humans consuming

cows' milk, traces of the environmental radionuclides reach animals and humans. Radioecological experiments involve in-situ or controlled measurements of these transfer processes, defined using *transfer factors* (TF). As an example, a *plant-soil TF* is defined as the ratio of measured radioactivity of a selected radionuclide (e.g., ²²⁶Ra) in plant to that in soil [2]. The TFs then serve as input for biosphere-scale modeling and REIA.

Radioecological experiments are of utmost importance for the United Arab Emirates (UAE), as it is the first Arab country to set forth on long-term nuclear energy with now operational Barakah Nuclear Power Plants (BNPP) [3]. Radionuclides of natural and anthropogenic origins have historically impacted some habitat zones of the Middle East and North Africa (MENA) region, and the Arabian Peninsula [4]. But scientific knowledge remains very scarce and inconsistent for the radionuclides' dispersion, retention, and transport among the region-specific air, bedrocks, soil/sand, water, plants, animals, etc. Increasing risks with the upcoming nuclear sector has made this information critical. Interlinked industries, like oil and gas, modern agriculture (e.g., via fertilizers), seawater desalination, etc., also add radioactivity transmission channels under some conditions, which are poorly studied. International agencies like the International Atomic Energy Agency (IAEA) [5] and International Union of Radioecologists (IUR) [6] have thus recommended immediate research for a rigorous 'arid region radioecological (ARRE) database'. This research will advocate the safety and emergency-readiness of reactors in the UAE, as well as prepare us to deal with similar issues in the ever-increasing warmer and drier climates worldwide.

For the UAE's nuclear power program, the Emirates Nuclear Technology Centre (ENTC) of Khalifa University (KU) [7] based in Abu Dhabi (UAE) is the major academic stakeholder from the research and knowledge management points of view. It began facility and skill development in REIA since the last decade and took part in the IAEA MODARIA II [8], as well as is engaging in the ongoing IAEA CRP K41022 [9]. The center is conducting several field sampling and controlled plant growth experiments, to generate UAE-specific TFs for natural and main fallout nuclides, while also developing a knowledge base for dispersion of BNPP-origin radionuclides in the marine, atmosphere, and terrestrial domains.

In this paper, we present a concise overview of the status-quo

of environmental radiation measurements in the UAE. While negligible imprints are found of artificial isotopes like ^{137}Cs and ^{90}Sr , naturally occurring radioactive material (NORM) isotopes like ^{40}K , ^{238}U , ^{232}Th are frequently detectable in the UAE environs but below their respective global average values [10]. Such limited field-scale studies have been done on soils, rocks, farm products like dates, vegetables, and groundwaters. Baseline soil to plant TF studies on fruits and vegetables have been started in the ENTC since 2020. Laboratory studies are underway for more difficult measurements, like uptake of cesium and strontium in major crops like tomatoes under a hypothetical accidental scenario. For radiometry, gamma spectroscopy is being most employed, but techniques like gross alpha-beta, and sequential extraction of trace radionuclides are being developed. Plasma mass spectrometry is under use for isotopic analysis, albeit not for radioisotopes yet.

II. AVAILABLE DATA FOR ARID REGION RADIOACTIVITY

Located between the Persian Gulf and the Gulf of Oman, sharing borders with Saudi Arabia and Oman, ~80% of the UAE's land area is desert, which includes plains, sand sheets, sand dunes, sabkhas, rocky outcrops, and mountains [11]. However, seas and coasts, oases and mangroves also make important parts of the UAE's ecosystems. The major population density is near the coastlines in Dubai, Sharjah, and Abu Dhabi. In terms of activities causing radionuclide releases, a large portion of oil and gas exploration as well as nuclear power production is held in the Abu Dhabi emirate, with many industries localized in the western region (Al Dhafra). The UAE has low annual rainfalls, high temperatures and loose and infertile soil. The UAE soils are primarily sandy Aridisols and Entisols, with median sand component of 90 to 95% [11].

More than 90% of the daily produced/used water in the UAE is desalinated seawater, while a small fraction (~1% of total consumption) is groundwater for use in farming and forest sustenance. In terms of human food sources in the UAE, about 82% is imported, but a slowly increasing share of 18% is locally produced, including fresh vegetables and fruits, some meats, poultry, and dairy products. Most farming within the Abu Dhabi emirate happens in Al Ain, Liwa and Ghayathi. A major part of crop production is done in the northern emirates as well, most importantly in Ras al Khaimah. If one focuses on radionuclide migration within national boundaries, i.e., ignoring the transfers from imported goods, then soil to plant transfer for fodder crops (which then connects to the animal kingdom), fruits, vegetables, etc. are important. So are the water to soil to plant transfers.

In Table I, data from literature is reported to highlight frequently measured radionuclides in UAE's environment, based on the national radiological environmental monitoring program (REMP) report of the year 2015 [12]. Data is reported as range of measured *activity concentrations* (AC, in Bq kg^{-1}) and their averages in the brackets. In a previous review, we have collated a few other academic studies in the UAE on this subject [4]. For the soil data sources in this review, we get averages of radionuclide concentrations (in Bq kg^{-1}) as 13.6 to 15.5 for ^{238}U decay chain, 3.3 to 8.3 for ^{232}Th chain, and 98.2 to 349.7 for ^{40}K . Some instances of global fallout radionuclide from nuclear weapons' testing, most commonly ^{137}Cs , are also recorded.

Table I: Literature values for radioactivity (Bq kg^{-1}) in the UAE soil and the major farm products: date fruits and cucumbers. Source of data: [12] ; BDL means below detection limit.

	Soil	Date fruit	Cucumber
^{238}U chain	7.7-23.4 (15.4)	BDL-0.8 (0.66)	BDL
^{232}Th chain	2.8-12.7 (6.5)	BDL-0.23 (0.15)	BDL
^{40}K	133-364 (231.4)	191-362 (277)	42.4
^{137}Cs	0.03-0.93 (0.38)	BDL	BDL

Date palms are a categorically unique agricultural product from the UAE and Arab nations [13]. Radiological studies on date fruits and trees, especially their tendencies to transfer radionuclides from soil and water to food, are extremely rare in global literature. The REMP report (Table 1) suggests that they have a higher average of ^{40}K than the soil, with plant-soil TF~1.2 if calculated using estimated average values. Likewise, TF~0.04 for ^{238}U and TF~0.02 for ^{232}Th chains. Among the vegetables grown in the UAE, cucumbers have been measured in literature, mostly below gamma detection limits, but a TF (^{40}K)~0.18 could be estimated based on averages in Table I. Note that the plant samples are measured at fresh/wet weights.

Some more data on plant-soil TF in arid areas are found in literature from nearby countries as reviewed in [4], and extracted in Table II. These values range from extremely low uptakes, like TF~ $1.7\text{e-}4$ for fruits to possible bioconcentration (TF>1) regimes like TF~1.1 for non-leafy vegetables. Also, the standard deviations are very high for these averages, making us conclude that the data from these limited studies do not lead to a consensus and it is dangerous to apply literature values in REIA. This forms the fundamental motivation for the UAE-specific experiments developed at ENTC, as reported here.

Table II: Estimated plant-soil TF from literature of arid Arab countries for fruits and non-leafy vegetables (NLV). Source of data: [4]; Values are geometric means (GM) with geometric standard deviations (GSD) in brackets.

	^{238}U chain	^{232}Th chain	^{40}K	^{137}Cs
Fruits	$1.7\text{e-}4$ (1.5)	0.033 (2.2)	0.6 (2.8)	0.011 (1.6)
NLV	0.032 (2.5)	0.11 (3.6)	1.1 (5.4)	0.058 (3.5)

III. EXPERIMENTAL METHODS

We present the ENTC experiments designed to measure the baseline radioactivity in soils and plants of the UAE, and to quantify the soil to plant transfer process through *concentration ratios* (CR). We define the CR, a measure of TF, as the ratio of measured radioactivity (Bq kg^{-1} units) in plant parts (often measured for edible parts like fruits or leaves) to that in the soil.

Based on a detailed radioecological strategy formulated in 2020 [4], we decided to focus our studies on the Abu Dhabi emirate: as it constitutes 85% of the land area, 56% of the crop area, and 55% of the agricultural economic value generated in the UAE [11]. Within that, we conducted field work in Bahya (representing semi-urban farms), traditional farming and oases

areas in Al Ain and Liwa, both also known for large-scale farming and exports, and Ghayathi and Sila where farming is minor activity, but they are geographically closer to BNPP. Some of the sampling areas are denoted in Fig. 1 (top). Crops which make it to the markets in larger quantities were prioritized, consisting of 46% fodder (although no experiment on fodders have been concluded to be reported yet), 24% vegetables, 30% fruits, and native trees. Finally, the focus isotopes were gamma-emitters from the NORM chains [10]. We report four experiments as discussed in the following.

We conducted in-situ CR measurements for date fruits and leaves and for three top vegetable crops in Abu Dhabi. Dates are unique in the sense that they are economically and culturally important to the region, they can grow in harsh desert environments, and the data on their soil to plant transfer of radionuclides is largely unavailable in the literature. For this study, seven sampling spots were selected in the Sas al Nakhl area of Abu Dhabi near to ENTC campuses [13]. For each tree studied, large (~5-10 kg) portions of fruits, pedicels and leaves were sampled. Each of the plant samples were then processed through a protocol developed in-house (see Fig. 1 bottom [14]), ultimately leading to ~1 kg dried powders of fruits and leaves, packed in radon-tight plastic bottles/beakers.

For vegetables, three top grown crops were selected: cucumbers, tomatoes, and bell peppers. They were sampled in >10 kg sample sizes per spot from multiple commercial farms in Bahya, Liwa and Al Ain. In study of the vegetables fresh samples were packaged by grinding each of them to < 1mm grain size. To convert our sample masses from wet to dry weights, which is part of our adopted protocol [6], small aliquots of each sample were dried to obtain average wet to dry ratios. Like plants, rhizosphere soils were sampled for both the experiments. Typically, rooting depth varies depending on plant species and the nature of soil and irrigation. But for consistent comparison across regions, agencies like IUR recommend ~20 cm depth from topsoil [6]. In each field study, soils were Augered to a representative root depth of 20-22 cm.

Besides fruits and vegetables, a first of its kind NORM radioactivity estimation has been done for leaves of the Ghaf tree (*prosopis cineraria*) through sampling in Abu Dhabi, Al Ain-Dubai highway and Ghayathi. Ghaf is a native tree found all over the Arab region, and for its geographical prevalence, vitality in sustainability of the desert lands, and for being a crucial link to nomad camels, ghaf is an important non-food plant to study for REIA. Leaves were sampled from various heights, composited, and processed as in Figure 1 (bottom).

For date palm, vegetables, and ghaf leaves, all plant and soil samples were at first stored after radon-tightening for about 4-5 weeks to establish secular equilibrium. Then blank samples and calibration standards were measured to obtain efficiency calibration and minimum detectable activities (MDA). Then the samples were measured using high-resolution HPGe detectors, over counting times of 8 to 24 hours to obtain Bq Kg⁻¹ of progenies of ²³⁸U, ²³²Th and ⁴⁰K. Artificial radionuclides could not be quantified confidently in our measurements, but ^{137/137}Cs gamma peaks were occasionally observed.

For artificial radionuclides, a controlled potting experiment of tomatoes, cucumbers, and eggplants was conducted [15]. For this, surveys of productional farms were conducted in Abu

Dhabi, and representative soil mixture, chemical use and irrigation regimes were ascertained. The experiment, involving spiking of the soil using solutions of stable Sr and Cs, ran for 3-4 months. The obtained fruit, leaf, shoot, and root samples will be studied using ICP-MS techniques, for which they have been processed through multi-acid microwave digestion. Weekly sampling of the spiked soil was also done, which are under physicochemical and radiometric studies, employing leaching and sequential extraction methods.

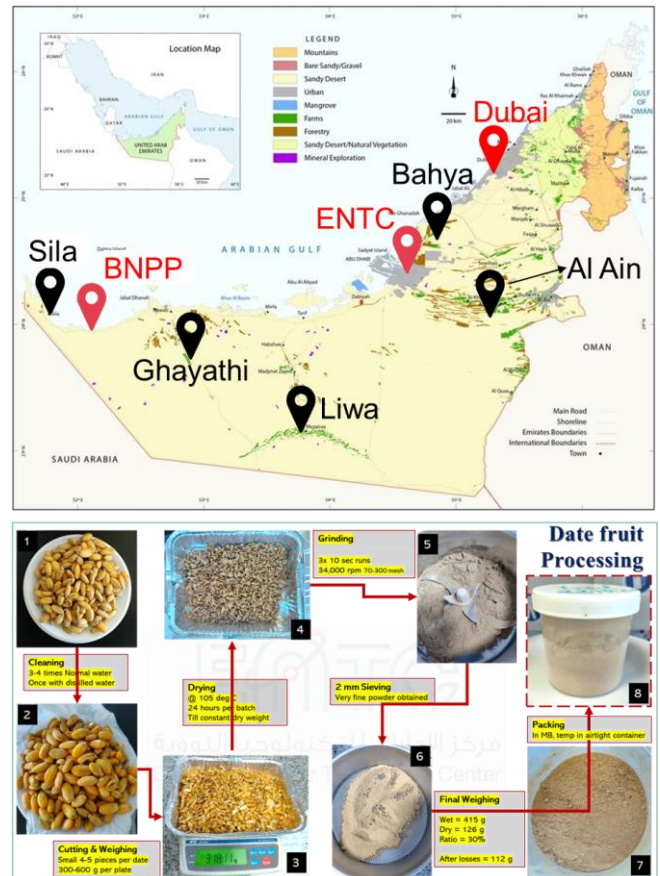


Fig. 1. (top) geographical map of the UAE with red markers showing locations of BNPP, ENTC and Dubai, and black markers showing areas of sampling. (Bottom) an example sample processing protocol developed at ENTC. Here it shows processing and packaging of date fruits in Marinelli (MB) or similar plastic bottles/beakers for gamma spectrometry.

IV. TENTATIVE RESULTS

The gamma spectrometry of all samples showed presence of all NORMs. Counting times were optimized for quantification of the three decay chains but many of them had large uncertainties. Most frequently measured progenies were ²¹⁴Pb or ²¹⁴Bi for ²³⁸U chain, and ²¹²Pb or ²¹²Bi or ²²⁸Ac for ²³²Th chain. A typical gamma spectrum with peak analyses and nuclide identification is reported in Fig. 2 (shown sample is of ghaf leaves collected at a spot between Al Ain and Dubai highway).

Drying procedures concluded that 90-96% of vegetables are moisture/water, while that for date fruits was 24-34%, for date leaves ~38%, for ghaf leaves 51-72%, and for the soil samples it is ~10%. For the measurements done with fresh samples (vegetables), each sample's AC data has been divided by its respective drying fraction to obtain its equivalent dry mass AC.

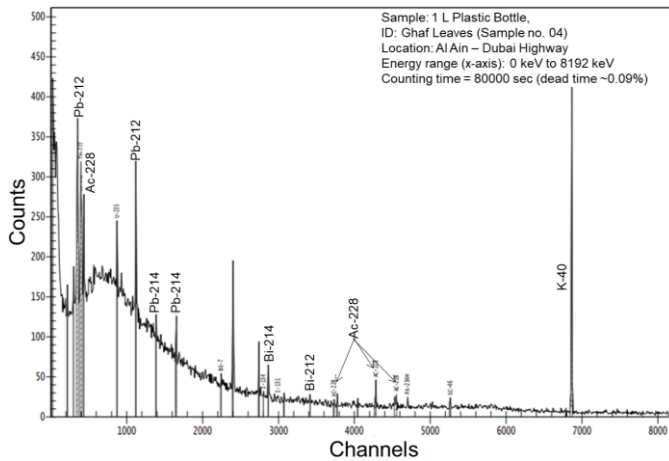


Fig. 2. Example of a measured and analyzed gamma spectrum as obtained in the reported study of ghaf leaves.

In the field sampling experiments, we collected and analyzed soil samples from more than 25 geographical spots, each being a homogenous composite of multiple sub-spots within a section of the farm or trees plantation. From date-palm studies, average ACs (in Bq kg^{-1}) of NORMs in the soil are around 15.5 for ^{238}U , 8.3 for ^{232}Th , and 278.9 for ^{40}K . Measurements from vegetable farms (tentative values, data is still under scrutiny) lead to similar average ACs (in Bq kg^{-1}): 13.0 for ^{238}U , 5.6 for ^{232}Th , and 296.3 for ^{40}K . Our soil measurements compare well with the literature values (see Table I) and follow the necessary rigid protocol of sampling for consistent comparison globally.

Detailed analyses of date fruits and leaves were reported in ref. [13]. For date fruits, indicative plant-soil CRs have been measured as 0.08 for ^{238}U , 0.17 for ^{232}Th , and 1.12 for ^{40}K . Respective CRs for palm leaves, another commodity, are 0.13, 0.36, and 0.77.

For the studies on vegetables and ghaf leaves, the data is under scrutiny and will be published elsewhere. However, tentative analyses of this data are presented here in Fig. 3 for a discussion, with the caveat that the final numerical values may alter after detailed analyses. The plotted data shows how the nuclide specific average CRs for different crops vary. In this estimation, GM of date fruits and leaves are used from ref. [13], while arithmetic average are taken for vegetables' CRs. For Ghaf leaves, the soil was not sampled. To suffice for CR estimation of the ghaf leaves, average soil ACs from the nearest regions were extracted from the national report in ref. [12].

Among the NORM chains, the CRs follow sequence $^{40}\text{K} > ^{232}\text{Th} > ^{238}\text{U}$. Higher uptake of potassium is frequently observed in arid lands due to higher ^{40}K in soil, as well as K being a macronutrient, and large application of NPK containing fertilizers. Absolute values of U- or Th-CRs are difficult to come by due to large uncertainties, and we expect more complex radiometric techniques will be required to establish these numbers with confidence. Tree samples, namely, date fruits, leaves and ghaf leaves have CRs smaller than vegetables. Comparing date fruits with vegetables, the latter have CRs larger by 2 to 27 times of the former. Mechanisms of uptake between smaller seasonal vegetable plants and desert evergreen trees like date palms need to be compared to elucidate this data.

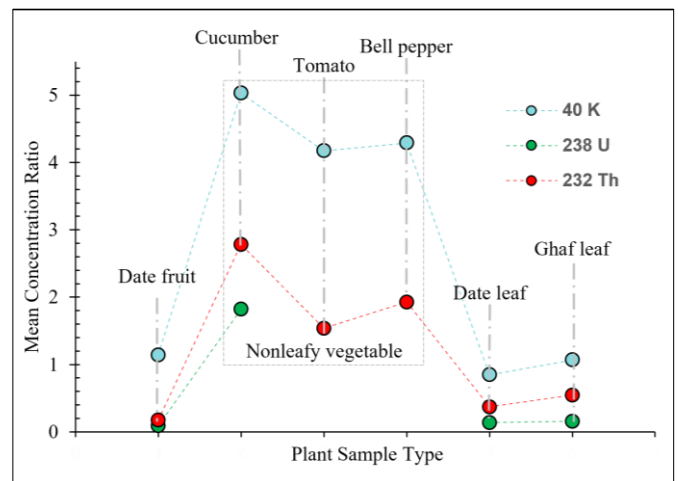


Fig. 3. Average CR values for various plant sample types and the three NORM chains, as measured or estimated through field experiments in this work and literature soil data. Dotted lines connecting the markers do not show a trend and are used for visual guidance only.

In-house potting experiments simulated contamination of the irrigation water, with ~ 1000 ppm of ^{133}Cs and 150 ppm of ^{89}Sr . Rough estimates of translocation factors have been obtained for tomatoes. Cesium is accumulated at 30% in leaves, 30% in fruit, 19% in stalk and 21% in roots. Likewise, strontium is absorbed 51% in leaf, 22% stalk, 25% in roots, and negligibly small $\sim 1\%$ in fruits. On tomatoes, this study with stable analogues of ^{137}Cs and ^{90}Sr have provided their rather high TFs as 12.1 and 2.1, respectively. Newer plantation experiments have been conceptualized based on this learning experience.

V. PROPOSED FUTURE EXPERIMENTS

For the missing gaps in ARRE and the UAE's local radioecology, several systematic experiments are necessary to be implemented. First, field experiments need to be extended to all kinds of crops, grasses, native trees etc., and to all regions of the UAE. The controlled potting experiment reported here served only for development of an experimental methodology. For measurement of CR for artificial radionuclides, further controlled planting in farm like setting needs to be conducted. Among other missing studies are the atmospheric dispersion measurements with UAE's wind patterns, and wet deposition dynamics for fogs which occur more often than rains in this region. Vertical and lateral migration speeds of radionuclides deposited on sand dunes/sheets need to be formally evaluated. There are some existing and underway studies on groundwaters and marine waters, but those need to be extended as well. Finally, completely amiss data for the UAE is on the transfer to animals. Among them, camels are an important subject of study. Such empirical data will find immense use in predicting radiation transmission pathways and impacts on biota and humans in the UAE.

VI. CONCLUSIONS

Arid region radioecological data, especially on radioactivity of soils and plants and plant-soil concentration ratios are vital for the radiological protection of the UAE's environs, animals, and humans. There is a major gap in this data worldwide, and

literature values of the CRs vary over several orders of magnitude. Therefore, at ENTC Abu Dhabi, several field-based sampling and controlled lab potting experiments are conducted. Stringent protocols are developed through experimentation for sample collection, transport, storage, cleaning, drying, processing, and packaging for gamma-spectrometry. Likewise, for ICP MS, sample leaching and acid digestion protocols are developed. Soil and plant radioactivity for NORM radionuclides and their respective plant-soil CRs are measured for date fruits and leaves, top vegetables and ghaf leaves. They are tentatively concluded to range 0.08-1.82 for ^{238}U , 0.17-4.66 for ^{232}Th , and 0.77- 5.26 for ^{40}K . Rough estimates of uptake CR and translocation for Cs and Sr isotopes in tomatoes have been obtained with controlled potting experiment. Finally, some crucial next steps are outlined to continue and enhance the discussed experiments.

ACKNOWLEDGMENT

The authors would like to thank the kind support received from Dr. Natalia Semioshkina and Dr. Gabriele Voigt of the erstwhile r.e.m. GbR (Munich, Germany) for the discussions and advice in building the protocols for the experiments presented in this manuscript. Many of these experiments have been conducted using instrumentation at the Environmental Laboratories of Nawah Energy Company in Ruwais (Abu Dhabi, UAE), Quality and Conformity Council (QCC) Laboratories (Abu Dhabi, UAE), and International Center for Biosaline Agriculture (ICBA Dubai, UAE). The authors would like to acknowledge the scientists from these labs, particularly Dr. M Millinor and Dr. A Maddison of Nawah Labs, Mr. Abdulla Yousuf Almarzooqi of QCC labs and Dr. Ahmed el-Naggar of ICBA's soil analysis lab.

DISCLAIMER

This work was carried out under theme-3 (radiation safety and environment) of the Emirates Nuclear Technology Center (ENTC) of Khalifa University Abu Dhabi (UAE). The expressed opinions and thoughts reflect only the authors' views, and do not represent the views of their affiliation institutions.

REFERENCES

- [1] D. Coplestone, C.-M. Larsson, P. Strand, and M. K. Sneve, "Protection of the environment in existing exposure situations," *Ann. ICRP*, vol. 45, no. 1_suppl, pp. 91–105, Jun. 2016, doi: 10.1177/0146645316630167.
- [2] N. Caplin and N. Willey, "Ionizing Radiation, Higher Plants, and Radioprotection: From Acute High Doses to Chronic Low Doses," *Front. Plant Sci.*, vol. 9, p. 847, Jun. 2018, doi: 10.3389/fpls.2018.00847.
- [3] ENEC, "Emirates Nuclear Energy Corporation," 2022. <https://www.enec.gov.ae/> (accessed May 25, 2022).
- [4] P. Raj *et al.*, "Conceptualization of arid region radioecology strategies for agricultural ecosystems of the United Arab Emirates (UAE)," *Sci. Total Environ.*, vol. 832, p. 154965, Aug. 2022, doi: 10.1016/j.scitotenv.2022.154965.
- [5] IAEA TECDOC 1979, *Soil-Plant Transfer of Radionuclides in Non-Temperate Environments*. in Technical Document, no. 1979. Vienna: International Atomic Energy Agency, 2021.
- [6] "IUR: International Union of Radioecology." <https://www.iur-uir.org/en/>
- [7] "Emirates Nuclear Technology Center, Khalifa University, Abu Dhabi (UAE)." <https://www.ku.ac.ae/entc>
- [8] J. Brown, D. Telleria, T. Yankovich, T. Cabianca, and C. Halsall, "Overview of the MODARIA programme (and comments on implications for future programmes of work) *," *J. Radiol. Prot.*, vol. 42, no. 2, p. 020505, Jun. 2022, doi: 10.1088/1361-6498/ac5bdd.
- [9] IAEA CRP K41022, "New CRP: Transfer of Radionuclides in Arid and Semi-Arid Environments for Radiological Environmental Impact Assessment (K41022)," Apr. 29, 2021. <https://www.iaea.org/newscenter/news/new-crp-transfer-of-radionuclides-in-arid-and-semi-arid-environments-for-radiological-environmental-impact-assessment-k41022> (accessed May 25, 2022).
- [10] J.-F. Lecomte *et al.*, "ICRP Publication 142: Radiological Protection from Naturally Occurring Radioactive Material (NORM) in Industrial Processes," *Ann. ICRP*, vol. 48, no. 4, pp. 5–67, Dec. 2019, doi: 10.1177/0146645319874589.
- [11] UAE MOCCA, "Open Data | UAE Ministry of Climate Change and Environment;," 2022. <https://www.moccae.gov.ae/en/open-data.aspx#page=1> (accessed May 25, 2022).
- [12] R. L. Conatser *et al.*, "Radiological Environmental Monitoring in the United Arab Emirates, First Report, January 1 - December 31, 2015; Federal Authority for Nuclear Regulations (FANR);," *Available Online Httpsbitly2DhwwVQ Accessed 25 August 2022*, [Online]. Available: <https://www.fanr.gov.ae/en/Lists/Publications/Attachments/12/FANR%20REMP%20English.pdf>
- [13] P. Raj *et al.*, "Transfer of Natural Radionuclides from Soil to Abu Dhabi Date Palms," *Sustainability*, vol. 14, no. 18, p. 11327, Sep. 2022, doi: 10.3390/su141811327.
- [14] Prasoon Raj *et al.*, "Baseline soil-to-plant transfer of NORM radionuclides in Abu Dhabi date-palms," presented at the 9th Intl. Conf. Radiation in Various Fields of Research (RAD 2021) 14–18.06.2021 | Montenegro, 2021. doi: <https://doi.org/10.21175/rad.abstr.book.2021.34.14>.
- [15] Nemeer Padiyath *et al.*, "Soil-to-plant transfer factors in arid regions using stable isotopes of caesium and strontium in local vegetables," presented at the 9th Intl. Conf. Radiation in Various Fields of Research (RAD 2021) 14–18.06.2021 | Montenegro, 2021. doi: <https://doi.org/10.21175/rad.abstr.book.2021.34.10>.