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Review Article

Environmental Modeling for Radiation Safety

Paweł Krajewsk* and Grażyna Krajewska

Central Laboratory for Radiological Protection, Warsaw, Poland

Abstract

The newly launched IAEA project MEREIA (MEthods for Radiological and Environmental Impact Assessment; 2021- 2025), MEREIA continues some activities of previous IAEA exercises in the field of radioecological modelling and focuses on areas where the probabilistic approach determines the predictive capability of environmental models. The program offered the opportunity to set up well-designed and verified scenarios to collect and compare exposures predicted by particular models based on this scenario and then perform a validation study of contributing models. It consists of the comparison of model prediction with observed data or in the case where there is a lack of measurement data to perform a comparison within model prognoses. The previous international works have brought significant improvement in environmental modeling in terms of better understanding and mathematical description of complex physical and chemical phenomena that occur in various environmental media and also have promoted new areas for experimental investigations. The new experimental results yielded updated handbooks of a large number of environmental parameters for less-known elements. Moreover, the principal objective of the activities in environmental modelling was an integrated risk assessment of the reference group of population and biota associated with radionuclides releases from various kinds of nuclear facilities as from different types and power nuclear reactors, radioactive waste disposal and more complex nuclear research facility. This reflects recent international recommendations to extend protection against radiation hazards of humans to wildlife flora and fauna. However, the statistics supported knowledge on some essential environmental parameters still remain small. Therefore, one could be aware of some limitations of the probabilistic approach that required advanced methods of probabilistic prognosis Monte Carlo.

More Information

***Address for correspondence:**
Paweł Krajewski, Central Laboratory for Radiological Protection, Warsaw, Poland, Email: krajewski@clor.waw.pl

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Introduction

The project MEthods for Radiological and Environmental Impact Assessment MEREIA

The project **ME**thods for **R**adiological and **E**nvironmental **I**mpact **A**ssessment MEREIA (2021- 2025), is the eighth consecutive program of the International Atomic Energy Agency (IAEA), to help countries and the environment further build their capacities in carrying out radiological environmental impact assessments. MEREIA offers an opportunity to exchange information with experts around the world on applying the most appropriate models and methods for REIA[1] [1]. The main objectives of the MEREIA program are:

- Collaboration between experts and professionals from different countries within an international Forum;
- A specific program to strengthen the development of young professionals through a series of workshops and opportunities to interact with senior specialists.
- A dissemination and outreach strategy to give visibility and recognition of MEREIA's output at the international level.

Recently, five working groups were established, comprising a number of topics including assessment context and environmental conditions, i.e.:

- A low-level radioactive waste disposal facility in operation;
- A clean-up situation in an urban area following the breach of a Cs-137 source;
- The historical marine dumping of low and intermediate-level radioactive waste;
- A former uranium mining and milling in a tropical climate and a fjord receiving radioactive; and
- Chemical discharges from hospitals and other industries (including the NORM industry) [2].

[1]*REIA is the assessment of the expected radiological impacts of facilities and activities on the environment for the purposes of protection of the public and protection of the environment against radiation risks.*

MEREIA will also enhance the professional means in countries, not only in terms of its modelling possibility but also through a tutorial approach to improve knowledge management. The MEREIA program is expected to be an exchange knowledge platform for professionals from regulatory bodies, operating organizations, technical support organizations, scientists, researchers, decision-makers, and others with responsibilities in carrying out radiological environmental impact assessments.

Story of IAEA coordinated research programs on model testing and validation

Almost 40 years story of these programs started just after the Chernobyl Accident (26 April 1986), when an urgent need appeared to assess doses, inhabitants of contaminated areas, where radioactive plumes passed through, that required relevant models and calculation tools. These programs, search for information on the environmental behavior of radionuclides which became available as a result of the monitoring efforts established in countries of the former Soviet Union and many European countries after April 1986. This information might be applied to test the reliability of assessment models used in assessing the radiological impact of all parts of the nuclear fuel cycle. There is a broad requirement to be able to quantify the hazards that arise from radionuclides present in the environment due to past human activities and to be capable of predicting the possible future risks associated with planned and unplanned (accidental) releases from nuclear facilities. Evaluating the impact of releases requires wide-ranging knowledge of the physicochemical processes and pathways of the transport of radionuclides from their release point to humans via air and water and through transfer in food chains by which radionuclides can reach humans. The issues of development and validation of new (real-time) computer codes adopted for emergency situations that could be used as decision-supporting tools, were published in the IAEA report as the recommendation of the International Nuclear Safety Advisory Group (INSAG) [3]. Moreover, it was reported that due to using the unperfected methodology, the overestimation of population doses might have occurred which could have resulted in controversial and harmful decisions of safety authorities on massive relocations from contaminated areas. For instance, the Chernobyl accident caused the immediate evacuation of about 116,000 people and the permanent relocation of about 220,000 people. The accident caused social and psychological disruption, but apart from the 1800 thyroid cancers that have been reported in individuals exposed in childhood, there is no evidence of a major public health impact attributable to radiation exposure [4].

In subsequent program editions, most efforts have been focused on current problems of dose predictions and assessment of environmental impact from ionizing radiation. These previous international exercises include VAMP: Validation of Model Predictions MAEA (1988 - 1996) [5,6], BIOMOVS: BIOspheric Model Validation Study (Swedish Radiation Authority), (1991 - 1996) [7], BIOMASS: BIOsphere Modelling and Assessment (1996 - 2001) [8], EMRAS I: Environmental Modeling for Radiation Safety (2003 - 2007) [9], EMRAS II: Environmental Modeling for Radiation Safety (2009 - 2011) [10], MODARIA I- MOdelling and DAta for Radiological Impact Assessments (2012 - 2015) [11], MODARIA II- MOdelling and DAta for Radiological Impact Assessments (2016 - 2020) [12].

In the course of the subsequent IAEA programs, the scope of validation tasks has been substantially extended, inter alia: models of routine releases in the normal operation of NPPs [10], developing and improving models for particular environments, that is, environmental impact from waste disposal facilities, uranium tailing or else NORM[2] and TENORM[3] topics [9] as well as modeling of radionuclides behavior in urban area due to contamination caused by malevolent activity [13]. Specific objectives of the programs were to establish modeling of very important and less common elements such as tritium ^{3}H and carbon ^{14}C [14]. The validation procedure consists of several stages, in the first, the special type scenario is prepared, which is regarded as a unique standard for each participant, therefore the scenario contains the same input parameters as isotopic composition and activity released to the environment, meteorological conditions, description of nuclear facility surrounding, including agricultural practices and habitat of neighboring population. Commonly, the scenario authors indicate "a priori" the reference group of the population (at highest risk). The scenario draft is previewed by participants and possibly improved (its preparation lasts about two years).

Toward progress of environmental modeling

Another issue undertaken toward improving modeling capacity focused on the recent recommendation of the International Commission on Radiological Protection ICRP [15,16] that established the framework for assessing radiation hazards for biota e.g. so called "Reference Animals and Plants (RAPs)". This prompted intense research conducted in the frame of the ERICA program [17] and the new experimental results yielded updated handbooks of a large number of new environmental parameters for less known elements [18,19]. This was implemented as an almost obligatory approach for environmental modeling of radiation impact from NPP discharges [20]. Furthermore, the latest published IAEA Standards [21-25] have been transposed to the Directive of the European Commission and since 2018 have been strongly recommended for European Union members. According to the mentioned publications, the conservative approach, that is, *deriving a prognosis based on the highest available parameters' values in order to ensure the safety threshold of*

[2]*Normally Occurring Radioactive Materials*
[3]*Technically Enhanced Normally Occurring Radioactive Materials*

predicted doses is no longer valid, instead the uncertainty doses assessment methodology became standard for evaluating the environmental impact of a nuclear facility and would be required by a regulatory body. This methodology brings certain advantages, as it shows explicate unlikelihood of high doses at normal operation of NPP (Figure 1), however, the statistics supported knowledge on some essential environmental parameters is still not enough numerous [18,19] and an accurate statistical description of parameters characterizing the behavior of elements in the environment remain unperfect. Therefore, one could be aware of some limitations of the probabilistic approach that required advanced methods of probabilistic prognosis Monte Carlo. Furthermore, available measurement data of radionuclides transfer in different environmental components do not allow for the application of AI, as it last has occurred for instance in medical diagnostic imaging. The main reason for that appears that nuclear facility accidents are rare and data for machine learning are seldom. Moreover, the monitoring data from surrounding nuclear facilities during normal operation are in majority under the limit of detection and do not bring in valuable information.

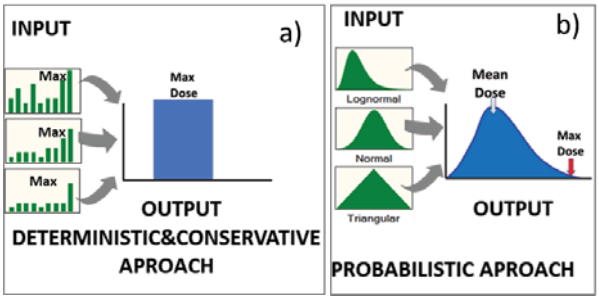

Figure 1: Schematic illustration of "old" conservative and "new" probabilistic approach to assess exposure levels of the public and in the environment.

Conclusion

The IAEA MERIEA program will further the development of the environmental assessment models and methodologies initiated by previous IAEA programs and aims to build international consensus on good practice in this area, under the umbrella of the IAEA Safety Standards. MODARIA has given opportunity to such developments, that were very important and MEREIA is looking forward to continue. It took almost 40 years and a lot of cooperative work to develop the conceptual and methodological approach to assess explicitly the level of radiological protection of the environment. MEREIA Program and related achievements of previous programs contributed to gaining confidence in such an approach. Still, there are more aspects to scrutinize and develop, including research, conceptual, and methodological improvements, particularly for less generic scenarios, higher levels of exposure, or other peculiarities are considered. IAEA needed to further develop such an approach to incorporate in the Safety Standards.

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