Ranking of nuclear facilities by assessing potential radiation impact on the environment

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1. Background and Goal of the present work

Ensuring NPP safety entails comprehensive radioecological evaluations. While operational safety is maintained through adherence to radiation limits, the potential for radioactive releases during emergencies remains. Robustly justifying environmental safety involves meticulous assessment of hypothetical accident impacts on both public and environment.

This paper proposes a method to assess and compare nuclear reactor units and other facilities in regard to their potential environmental impact in case of accidental releases.

2. Methodological aspects

2.1. Emergency scenarios and assessment terms

The emergency scenarios for the following reactors were considered: VVER-1000, VVER-1200, PWR-890, BWR-1412, EPR-1600.

The assessments were performed for the 1st year after the hypothetical accident.

2.2. Reference natural object

Pine stand was used as a reference natural ecosystem for assessing acute radiation exposure on biota because:

- pine tree is on the list of the ICRP's list of RAPs;
- pine canopies effectively capture a significant portion of radionuclides in atmosphere;
- the tree layer is preferable for use than mammals that move through radioactive areas;
- damage to the trees disrupts the ecosystem's overall structure and functioning;
- there is available data to parameterize migration-dosimetric models gathered from extensive studies in forest radioecology after the Kyshtym and Chernobyl accidents.

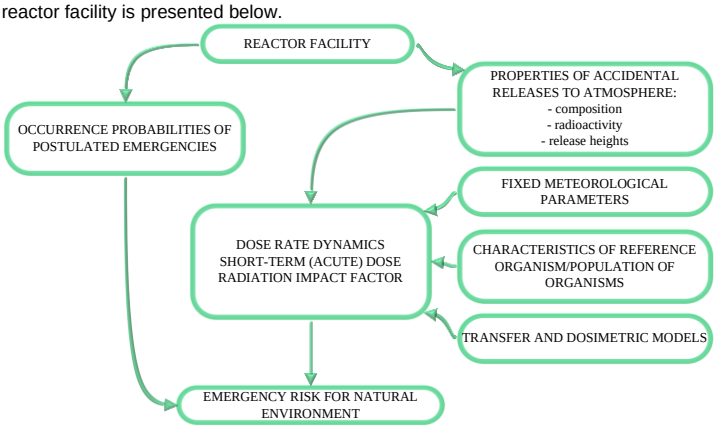
2.3. An approach to the evaluating the radioecological emergency risk

The IAEA glossary defines risk as follows:

$$R = \sum_i p_i \cdot C_i$$

where p_i is the probability of occurrence of scenario or event sequence i and C_i is a measure of the consequence of that scenario or event sequence.

For a screening comparative assessment of nuclear energy facilities as potential sources of radiation impact on biota, a conservative approach was adopted. The consequence characteristic of an accident scenario (C) in this case was the Radiation Impact Factor (RIF). The RIF represents the ratio between the maximum dose experienced by the reference natural community and the dose limit. The overall scheme of the approach for assessing radiological accident risk for a reactor facility is presented below.



Scheme for a conservative accident risk assessment of the impact of a reactor facility on the environment

2.4. Dose criterion

Pine trees can be fatally affected by intense radiation during nuclear accidents. Therefore, it was decided to consider the lethal dose of 100 Gy as the threshold limit.

3. Calculation tools and input data

3.1. Models and parameters

Doses on pine trees were evaluated using a combination of migration and dosimetric models. The transport of radionuclides in the atmosphere was calculated using a Gaussian model. Meteorological parameters included atmospheric stability category (F) and wind speed (0.5 m/s).

Modelling radionuclide redistribution in the forest ecosystem considered primary retention by tree canopies (retention factor - 0.9), ecological decay (ecological decay constant - 7.7×10^{-3} day^{-1}), and radioactive decay.

3.2. Parameters of the emergency scenarios

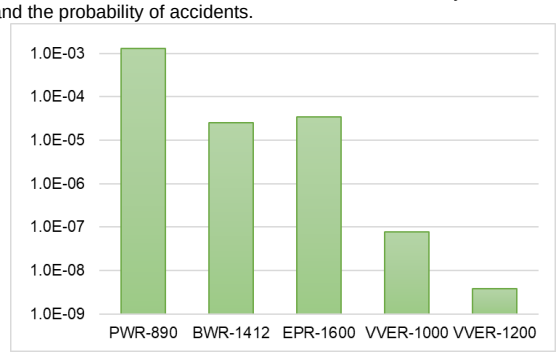
The main characteristics of the most severe emergency scenarios (total activity, release height and accident probability):

Reactor	Total activity, TBq	Release height, m	Probability, year^{-1}
PWR-890	$7{,}51 \cdot 10^{6}$	8,4	$1{,}0 \cdot 10^{-5} – 2{,}0 \cdot 10^{-5}$
BWR-1412	$2{,}38 \cdot 10^{7}$	39,6	$3{,}0 \cdot 10^{-7}$
EPR-1600	$1{,}04 \cdot 10^{8}$	10	$3{,}83 \cdot 10^{-9}$
VVER-1200	$1{,}49 \cdot 10^{4}$	30	$1{,}0 \cdot 10^{-7}$
VVER-1000	$4{,}50 \cdot 10^{5}$	25	$1{,}0 \cdot 10^{-7}$

4. Radioecological ranking of reactor facilities

RIFs were calculated using a conservative approach for various reactor accident scenarios. Each reactor has its own set of RIF values. For the PWR-890 reactor, RIFs span from 22 to 57; the BWR-1412 reactor has values ranging from 5 to 23, and the EPR-1600 reactor ranges from 0.001 to 8300. The majority of accidents involving PWR-890, BWR-1412, and EPR-1600 reactors yield RIFs exceeding 1, indicating radiation doses to forest vegetation surpassing the lethal threshold. Conversely, RIFs for VVER-1000 and VVER-1200 reactors remain below 1, with minimum values of 0.0005 and 0.0001, and maximum values of 0.77 and 0.037, respectively.

Based on the calculation results, it can be concluded that a comparative radiological assessment of reactor installations based on individual accident scenarios is not comprehensive. Ranking reactors for radioecological impact on the environment requires considering all postulated accidents due to variability in scenario characteristics. So, the emergency risks were calculated. The risk evaluation was based on data that describes the activity of released radionuclides and the probability of accidents.



Emergency risks of the impact of reactor facilities on the environment

According to the conservative risk assessment, the PWR-890 reactor is identified as potentially posing the greatest risk to biota. The calculations for this reactor employ the highest values within the range of accident scenario probabilities. Although the EPR-1600 reactor has the most severe scenario, its contribution to the overall risk value is minimized due to its low occurrence probability.

The radiological risks related to VVER-1000 and VVER-1200 reactors are low, mainly due to the relatively low levels of radionuclide activities in their compositions. Notably, the risk value for the advanced-generation VVER-1200 reactor is twenty times lower than that for the VVER-1000 reactor.

5. Conclusions and Acknowledgements

- With the continuous progress of nuclear energy and the creation of innovative reactor facilities and fuel cycles, there is an urgent requirement for radioecological assessments. These assessments are essential in order to compare reactors and determine their potential impact on the environment. A proposed approach facilitates such a comparison by assessing radiation impact risks on a representative natural habitat – the canopy of pine forests. This methodology utilizes information on accident scenario attributes developed for reactor installations. This comprehensive strategy is not only applicable to assessing individual nuclear power plant units but also extends to other facets of the nuclear fuel cycle, thus serving as a comprehensive tool for gauging potential radiation hazards. Integrating such assessments during the preparatory phase of nuclear energy facilities and systems aligns with sustainability objectives and forms an integral part of their environmental validation.