Uncertainties in Modelling Atmospheric Dispersion of Radioactive Contaminants

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Since the beginning of the peaceful use of nuclear energy, the assessment of the safety of nuclear installations has been a critical issue, including the evaluation of the environmental consequences of radioactive releases. Atmospheric dispersion models have been widely used to analyze the consequences of radioactive releases, to estimate the radiation conditions in the environment and the population doses for hypothetical scenarios and real emergencies.

Model and parameter uncertainties in atmospheric dispersion model calculations can significantly affect the calculated activity concentrations and the resulting doses. I investigated and quantified the effects of input data uncertainties and the usage of different numerical methods on the final results of deterministic safety analyses and calculations for nuclear emergency preparedness through the simulation of different hypothetical release scenarios.

The objective of deterministic nuclear safety analyses is to demonstrate that spread of radioactivity and the resulting exposure consequences for all reasonably possible occurrences comply with the regulatory requirements. There are different approaches and models utilized around the world for deterministic safety assessments of releases from a nuclear facility, increased transparency and harmonization of the methods would facilitate the comparison and independent evaluation of the safety of different installations to be on consistent basis. The atmospheric dispersion calculations applied in safety analyses are typically conducted in two ways: either by utilizing a meteorological case that describe a proposed worst case scenario to ensure conservativism in the calculations or by using the upper limit, e.g. the 95% of results (95th percentile), derived from multiple years of meteorological measurement data. A simplified and easy-to-use calculation methodology has been developed with the goal of harmonization, capable of demonstrating compliance with the atmospheric release criteria for nuclear facilities. One of the key benefits of this improved methodology is its ability to use site-specific meteorological data and input parameters that describe the habits of the population. I took part in the development of the models and their integration into the CARC (Calculating Atmospheric Release Criteria) software. I performed code-to-code validation of the methodology, demonstrating that the internal results of calculations obtained with the improved models show differences between 50%-150%, and thus agree adequately according to such comparisons with the results obtained with other conventional programs used in international practice. I verified the practical applicability of the improved method through a case study, demonstrating compliance with the criterion applied in deterministic nuclear safety analyses for a hypothetical release case. I investigated the impact of the use of different meteorological and habit data on the calculation results. I showed that variation in the breathing rate, the level of shielding and the time spent outdoors did not significantly affect the public dose, while consumption of certain contaminated foods significantly increased it. Using a meteorological database based on real measurements, I have confirmed that the application of the 95th percentile is appropriate as a final result, with the computed short-term dose being sufficiently robust due to different amount of missing data and compared to the results obtained with the proposed worst case meteorological data.

In nuclear emergency preparedness, decision support systems use atmospheric dispersion models to provide estimates of the environmental contamination levels in the event of a real or a hypothetical accident, based on which recommendations can be made regarding countermeasures aiming to reduce the received dose to ensure the protection of the public. Uncertainties in the model used for the simulation have an impact on the calculated results, the quantification and visualization of which is essential to making informed decisions. I investigated the numerical methods of the atmospheric dispersion model in the SINAC (Simulator Software for Interactive Modelling of Environmental Consequences of Nuclear Accidents) decision support system responsible for the propagation of the radioactive air parcels (puffs), identifying the most optimal in terms of computation time and precision. I quantified the impact that the uncertainty in meteorological input data (wind speed, wind direction, atmospheric stability, rainfall) has on the calculation of the activity concentrations by sensitivity analysis conducted with the SINAC software. I integrated a new module into the SINAC software for the use of ensemble meteorological data produced by running numerical weather prediction models several times with slightly different initial conditions or parametrizations, allowing the effect of meteorological uncertainties to be directly reflected in the results. I demonstrated the applicability of the ensemble module of SINAC with calculations carried out in the framework of an international project, showing the visualization of uncertainties by presenting the statistical characteristics of different results on maps. To facilitate the operational use of the ensemble method, I investigated and evaluated possible optimization methods to minimize run times of the simulations which are critical from the point of view of emergency decision-making.