Improving the decision base for nuclear and radiological emergency management by modeling external radiation exposure

In the recovery phase after a radioactive release incident, tools predicting the external radiation exposure based on existing knowledge are essential for justification and optimization of recovery countermeasure strategies for contaminated inhabited areas. To justify the application of the Monte Carlo code MCNP6 for this purpose, experimentally determined shielding factors for a common light construction dwelling type were obtained and compared to shielding factors based on theoretical calculations performed using the Monte Carlo code MCNP6. Therefore, sources of the gamma-emitting radionuclides 60Co and 137Cs were positioned around and on top of a modular building to represent homogeneous fallout. The modular building used was a standard prefabricated structure obtained from a commercial manufacturer. Four reference positions for the gamma radiation detectors were used inside the building. The results demonstrate the applicability of using MCNP6 for theoretical calculations of radioactive fallout scenarios. Subsequently, about 30 years old kerma conversion factors for one standard environment were re-calculated with MCNP6, showing significant differences compared to the old values.

As the number of data sets for different inhabited environments is limited, the estimation of external gamma irradiation from deposited activity in urban environments was improved by developing a model of a modern office or residential building with glass facades which was set up with eleven different building heights. Kerma conversion factors for the floors inside the building from contamination on different types of surfaces were determined by using MCNP6 for the primary gamma energies 0.3 MeV, 0.662 MeV and 3.0 MeV and for three different environmental scenarios. The kerma conversion factors were expressed as formulas for each possible deposition area for contaminants. The importance of the determined factors was shown by comparing them to previously generally used factors for multistory house blocks. In connection with the the kerma conversion factors knowledge on the environmental behavior of radiocountaminants is needed for predicting external radiation exposure. Therefore, one necessary requirement is to estimate the relative initial contaminant distribution on different types of surfaces in the environment and the resultant initial dose rates to humans staying in the environment. The latest parametric refinements for the use in the European emergency management decision support systems are reported, showing a considerable variation according to the physicochemical form of the contaminants. It was shown for a standard environment that contaminants deposited on the roof are of major concern in contributing dose to humans inside the building.

To also enable estimation of time-integrated external doses to persons staying in an environment that was radioactively contaminated, additional knowledge on the postdeposition migration of different types of contaminants on the various relevant types of environmental surface is needed. The migration process as it is modeled dynamically in the European decision support systems was described and the newest parametric datasets for these models reported. It is explained how the models can be used to estimate doses received over time by populations in radioactively contaminated inhabited areas in connection with the initial contaminant distribution. It was shown for a standard environment that additionally to the roof also contaminants deposited on a unpaved ground are of major concern in contributing dose to humans inside the building.

Focusing on the shielding effect of a building against radiation from various directions, further Monte Carlo simulations were applied that also give information on the dose contributions at various locations inside the building from specific areas outside. The concept of the isodose was developed to optimize decontamination activities, and was applied as isodose lines to define the smallest areas that lead to a certain dose reduction through decontamination of areas surrounding the building. The shape and position of the isodose lines depend on the geometry of the building, the wall thickness and material, and the observation point inside the building. Calculations have been made with a surface resolution of 1 m² for four observation points in a modular building, assuming depositions of 137Cs and 60Co on the ground surface. Geometry shielding was identified as main impact on the size of areas encompassed by the isodose lines and barrier shielding as main impact on the shape of the isodose lines. Moreover, the isodose concept was applied to typical Swedish residential houses. The influence of wood and brick as common building materials and the importance of the positions of doors and windows on the isodose lines were demonstrated for specific positions inside the houses as well as for the entire houses assuming people having a typical residential behavior. Decontamination of areas within isodose lines is demonstrated to provide an increased dose reducing effect compared to decontaminating an equal area of soil to a certain distance around the house. Furthermore, the impact of vertical contaminant migration in soil on the isodose lines was studied, showing how the zones that are encompassed by the isodose lines are getting smaller over time as the contaminants migrate deeper into soil. The resulting isodose lines and the degree of their transformation are dominated by the downward movement of the contamination in the topsoil layer. The impact of contamination variability on the final result was demonstrated with its dependence on building materials. Thus, the isodose concept shows promise for becoming a useful tool for the optimization of countermeasures in cases of radioactive fallout in populated environments.

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