Foreword

After a first book dealing with applied physics of external radiation exposure, the authors review the state-of-the-art in terms of dosimetric and radiation protection calculations through exercises related to practical applications in the covered fields.

For each problem, the book provides resolutions by means of analytical and semi-empirical formulas derived from nuclear physics theory and the latest research contributions. For some applications (cavity theory, absorbed dose calculation for protons, quantities and dimensioning calculations in the surroundings of X-ray generators…) the most recent data and calculation methods are among the tools used.

Moreover, in most of the applications/problems discussed, an inter-comparison with the numerical results obtained with a Monte-Carlo code is presented. Indeed, computational codes based on this approach are widely used in the radiation exposure field, given the reliability of the physical and dosimetric quantities' estimation they offer. Furthermore, the recent increase in performance and the democratization of computing means allow a practical use of these codes requiring significant computing resources. The MCNP code developed by the Los Alamos National Laboratory (LANL) has been considered for several years, as a reference in the field of numerical calculations for nuclear physics. It has been chosen in this book to provide "actual" values in order to test the accuracy of analytical or semi-empirical results. For each case study, the input file is fully provided, and their structure is detailed. Some of the complex geometries involved in the modeled radiological scenes are described, as well as the features used to generate, transport and track particles. On another note, emphasis is placed on the raw MCNP result normalization and on variance reduction techniques used to improve or allow the convergence of statistical estimators toward the end result. Although the aim of this book is not to replace the MCNP user's manual, it provides the necessary elements for the modeling, the simulation and the calculation of the desired quantities within the topics discussed. All MCNP simulations were performed by means of the

DOI: 10.1051/978-2-7598-2461-8.c901

MCNP6 version 1.0. Note that the input files shown in this book are generally compatible with previous release of the MCNPX and MCNP5 code. The MCNP code is distributed by the RSICC (Radiation Safety Information Computational Center) and its use requires a personal license distributed by this center.

The interest of a dual resolution, analytical or semi-empirical and numerical, is diverse and meets the rigorousness required to carry out physical calculations. Firstly, the theoretical knowledge and the analytical approach which result from it allow to corroborate the numerical results obtained during the simulation. They can avoid using the calculation code as a "black box", *i.e.*, without any real control over the physics options implemented. They also prevent the user from obtaining the desired result without having a tangible element to compare it to. Even if the analytical or semi-empirical result only provides, in some cases, a rough estimate of the quantities, it is still a gauge of the numerical value obtained or, at the very least, provides the orders of magnitude necessary to validate the chosen numerical method. In contrast, in the context of the radiological dimensioning of facilities, for example, the numerical simulation can make a contribution by refining the thicknesses of biological protection previously calculated with an analytical or semi-empirical model. It should also be added that, depending on the objective of the dosimetric or radiation protection calculation, and the accuracy of the result sought, the choice of an analytical or semi-empirical method may turn out to be sufficient. As a result, the subsequent cost of the engineering study will be limited compared with the study involving numerical simulations. Finally, it should be mentioned that in some cases, only one of the two approaches can be successful: the evaluation of the build-up factor is a relevant illustration of this case since it can only be achieved rigorously with a numerical simulation.

Three main topics, grouped in three chapters, are discussed in this book:

- Chapter 1: Calculation of radiometric and dosimetric quantities (fluence, kerma, dose and ambient dose equivalent).
- Chapter 2: Detection principles, detector response to reference physical quantities and operational dosimetric quantities.
- Chapter 3: Shielding and activation calculations for several types of facilities or devices (radioactive sources, X-ray generators, accelerators…).

An introduction to MCNP introduces basic notions and concepts to model a radiological scene with the MCNP (Monte-Carlo N-Particle) transport code. The block structure of a typical input file are discussed.

The first chapter starts with fluence calculations for simple and more complex geometries. Then, elementary dose equivalent calculations are carried out. These appear as simple applications of the MCNP code and enable the reader to become familiar with usual and classic functionalities of the code. The calculations of in-depth absorbed dose for β particles and protons are also proposed with a double resolution. Similarly, a study of dose and kerma profiles is undertaken for successive materials exposed to a photon field. Finally, a first collision kerma calculation for a neutron field is developed using both approaches, and a microdosimetric spectrum is drawn from the numerical simulation of a tissue-equivalent proportional counter.

The second chapter deals with detection principles, detector responses and calibration for applications related to radiation protection and ionizing radiation metrology. The detection and measurement of physical and dosimetric quantities for photons, neutrons, electrons, β particles and protons are addressed. The study of different types of reference detectors and absolute dosimeters are the subject of the applications discussed: ionization chamber, proportional counter, thermoluminescent dosimeters (LiF), extrapolation chamber, proton recoil telescope, time-of-flight measurement device, Bonner spheres spectrometer and calorimeter. In this chapter, special attention is paid to the evaluation of correction factors, which are of particular importance in the field of metrological measurements (*e.g.*, attenuation and scattering in a detector wall).

The last chapter is devoted to radiological shielding and activation. Different radiation source facilities (photons, neutrons or X-ray generators) are studied. In addition to analytical calculations, the convergence issues of the Monte-Carlo code, typical of radiation protection problems, are addressed and solved with variance reduction techniques. Finally, a complete application dedicated to an electron accelerator facility is proposed. It depicts the successive steps leading to the evaluation of the source term (Bremsstrahlung, photonuclear reactions), the shielding calculation process (primary and secondary barrier, skyshine), the air activation and accordingly the ozone concentration.

The book is intended to be didactic and each problem is treated independently. The reader can therefore study the applications of interest in the desired order. Nevertheless, it is recommended that the introduction and the first chapter be studied first, in order to understand and assimilate methods and techniques used for analytical and Monte-Carlo calculations of physical and dosimetric quantities.