Review

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IAEA technical reports 465 and 468 – a review

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During the last decade, the number of nuclear-medicine-oriented cyclotrons, installed in many parts of the world, has increased rapidly. Since a few years, the need of a modern, comprehensive manual for the personnel of such facilities has been recognized by the IAEA, and the two recently published technical reports[1] are the result of the IAEA initiative.

The first part of the set, TRS-465, begins with a review of numerous, not only medical, applications of radionuclides. Its following chapter describes several types of accelerators (linacs, cyclotrons, tandem cascade and Van de Graaff accelerators) and discusses the criteria for a proper choice of the accelerator for a particular task. Later, the theory of radioisotope production is outlined in terms of nuclear reaction models and energy relationships. The further part of the book is dedicated to the design of gas, liquid and solid targets for irradiations with the internal or extracted cyclotron beams, and then to preparation, activation and processing of particular targets, along with the recovery of expensive, isotopically enriched materials. Targetry problems are presented from three main viewpoints: (a) physical interactions of the accelerated particles with the target material; (b) chemical reactions within the activated target and their influence on activation yields and composition of nuclear reaction products; (c) target engineering, with particular emphasis on the calculation of heat transfer and on the problems of mechanical and thermal resistance of target construction elements. The targetry part includes practical advice related to the operation with intense cyclotron beams. A detailed discussion, illustrated with informative photographs and schemes, is devoted to representative examples of cyclotron-produced isotopes: a highly specific SPECT tracer – Tl-201 – produced in an indirect way with medium-energy protons from the electroplated metallic target, and the most versatile PET labels – C-11 and F-18 – produced in a direct way with low-energy protons from the nitrogen gas and liquid water targets, respectively. This part is followed by examples of chemical syntheses involving these positron emitters and by characteristics of commercial synthesizers for the most common PET radiopharmaceuticals. The volume ends with two appendices giving detailed characteristics of the currently produced cyclotrons, grouped as PET (up to 18 MeV protons) and 'high-energy' (up to 70 MeV protons) machines. Full algorithms for calculating beam heating effects on thallium target and for optimization of production yield, radionuclidic purity and hotcell shielding of Ga-67 are attached to the book as two annexes on a CD. The third annex is the Excel file with the results of optimization for Ga-67.

The second publication of the reviewed set, TRS-468, can be read either as an independent monograph or as a complement to the previous one. Its first chapter provides the basic information about cyclotrons, targets and nuclear reaction theory. It also outlines the principles for the design of radioisotope production facilities and the regulations for isotope transportation. The second chapter lists the physical characteristics of 49 cyclotron-produced nuclides, most of which are known as tracers for emission tomography (SPECT and PET), and a few others are the alpha emitters used in or aimed at targeted radiotherapy. The tabulated data compile the nuclear decay characteristics and the data relevant for the choice of production routes. Apart from these 'standard' tables, technical details related to production as well as information about clinical applications are given for the following radioisotopes: At-211, C-11, Co-57, Cu-64, Cu-67, F-18, Ga-67, Ge-68, In-111, I-123, I-124, Kr-81, N-13, O-15, Pd-103, Na-22, Sr-82, Tl-201, Y-86.

The main advantage of these two publications is their close connection with everyday practice of isotope production and applications. Among the numerous virtues of the reports, one of those most valuable is the professional advice given in TRS-465 on decision-making at the stage of purchasing a cyclotron (supported by the tables attached in the annex), the discussion of the operating costs and the schemes of cyclotron maintenance tasks. The theoretical part of TRS-465 provides useful examples of the limitations of different physical models in stopping power calculations. The other parts of both publications are equally important except, maybe, Sections 2.6 and 2.7 of TRS-465, where the information on industrial, environmental, biological and agricultural applications of radioisotopes, although interesting, does not seem relevant in view of the specific subject of the book.

Another virtue of the two reports is the fact that they were prepared in a short time, which minimizes their lag with respect to original papers published in specialist journals. However, the side effect of this speed is excessive simplification or poor quality of some figures.[2] Another shortcoming, probably also due to the haste, is the inconsistent notation of the energy ranges for nuclear reactions tabulated in TRS-465 and of

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positron decay energies tabulated in TRS-468. As no comment about the adopted notation is given in the text, this may be misleading to less experienced readers. It seems also a pity that the theoretical part has not been extended by some references to numerical codes available for calculation of the nuclear reaction excitation curves.

Sometimes, the reader must exercise caution with respect to detailed information, which is occasionally incomplete or incorrect. For instance, the only application of I-123 listed in Table 2.7 of TRS-465 is that of diagnosing the thyroid function, while the crucial role of I-123-labelled radiopharmaceuticals in non-thyroid cancer diagnosis is disregarded. In the same table, a long list of *reactor-produced* radionuclides (Am-241, Cs-137, Ca-47, Cf-252, C-14, Co-60, Cm-244, I-129, I-131, Ir-192, Ni-63, P-32, Pu-238, Pm-147, Sr-90, Tl-204, Th-229, Th-230, H-3, Xe-133), plus *natural* U-235 and U-238, does not seem justified by the title of the book. As to Table 8.1, the presence of the alpha-emitting At-211 among positron emitters contradicts the title of the table. A few errors of similar nature can be found also in TRS-468.[3] Finally, it should be pointed out that credit for a method of Tl-201 separation was erroneously attributed to the Institute of Nuclear Physics in Krakow.[4]

Nevertheless, at the time when this review is being written, the two reports are the most complete and the most up-to-date collection of the technical information necessary for cyclotron production and applications of 'medical' radioisotopes. Usually, such information is dispersed in the literature and requires much time to become ready at hand. Owing to professional work done by the contributors, the TRS-465 and TRS-468 are a very good starting point for further reading and for individual practice. Therefore, I strongly recommend both publications as manuals to all people starting or planning their careers in isotope production and related disciplines.

References

[1] *TRS-465*: *Cyclotron Produced Radionuclides*: *Principles and Practice*, IAEA, Vienna, **2009**. Available from: http://www-pub.iaea.org/MTCD/publications/PubDetails.asp?pubId = 7849. *TRS-468*: *Cyclotron Produced Radionuclides*: *Physical Characteristics and Production Methods*, IAEA, Vienna, **2009**. Available from: http://www-pub.iaea.org/MTCD/publications/PubDetails.asp?pubId = 7892.

[2] The former refers to Figures 3.4, 3.7 and 5.1of TRS-465 and the latter to Figure 1.2 of TRS-468. In Figure 3.4 the hills and valleys at the side view of the cyclotron are described in reversed order, and in Figure 3.7 the shape of the beam trajectory behind the stripping foil is wrong. In Figure 2.1.2 of TRS-468, the word EMPIRE appears in the legend to the excitation curve, but there is no reference in the text to this calculation code.

[3] The 100%EC decay mode assigned to Co-55 on p. 76 contradicts the information from the beginning of Chapter 2.13 (23% EC+77% beta plus). On p. 78, the product of the Mn-55(He-3,3n) reaction should be Co-55, not Fe-52.

[4] TRS-465, Tables 7.6 and 7.7.