ELSEVIER

Nuclear Instruments and Methods in Physics Research A 481 (2002) 749–755

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

A simple and versatile $^{222}Rn/^{220}Rn$ exposure chamber

K.N. Yu*, V.S.Y. Koo, Z.J. Guan

Department of Physics and Materials Science, City University of Hong Kong, Tat Chee Avenue, Kowloon Tong, Hong Kong

Received 11 April 2001; received in revised form 25 May 2001; accepted 19 June 2001

Abstract

A simple $^{222}Rn/^{220}Rn$ exposure chamber is described. The chamber is made of acrylic and has a volume of 0.41 m^3. The ^{222}Rn and ^{220}Rn sources can be operated independently or simultaneously. The concentrations of ^{222}Rn and ^{220}Rn were monitored by a continuous alpha spectrometer called RAD7. The capability of alpha spectrometry has removed the mutual interference between ^{220}Rn and ^{222}Rn, which is a major problem in measuring ^{220}Rn. Furthermore, the capability can also provide fast response to changes in the ^{222}Rn level and ^{220}Rn level in the exposure chamber, with temporal resolutions of about 20 and 2 min, respectively.

PACS: 29.40; 23.60

Keywords: Radon; Thoron; CR39 detector; LR115 detector; Detector sensitivity

1. Introduction

It is established that the tracheobronchial deposition of ^{222}Rn (radon) progeny in the human body can lead to lung cancers, and people have become more and more aware of the ^{222}Rn problem nowadays. There are various methods to measure concentrations of ^{222}Rn and its progeny, and the reliability of these methods invariably depends on the validity and accuracy of the calibrations involved. Exposure chambers are almost indispensable for calibration of instruments for measuring ^{222}Rn and its progeny. Besides, exposure chambers are often designed in such a way that other characteristics of ^{222}Rn progeny can also be studied, such as the potential alpha energy concentration (PAEC) of the progeny and the size distribution of the PAEC.

It has been proposed that the problem of ^{220}Rn (thoron) should not be overlooked [1]. In recent years, there is increasing attention to the problem. Research and survey on the behavior of ^{220}Rn and its progeny have been carried out [2–4] and have shown that the concentrations of ^{220}Rn and its progeny are not negligible compared to those of ^{222}Rn and its progeny. While calibrations using ^{222}Rn exposure chambers are rather well established, the construction of exposure chambers of ^{220}Rn or more importantly of mixed $^{222}Rn/^{220}Rn$, and the associated problems are less studied. Many factors can make accurate measurements of ^{220}Rn concentrations difficult. The first one is the presence of and interference from ^{222}Rn. The second is the short half-life of ^{220}Rn. As can be

*Corresponding author. Tel.: +852-2788-7812; fax: +852-2788-7830.

E-mail address: peter.yu@cityu.edu.hk (K.N. Yu)

0168-9002/02/$ - see front matter
PII: S0168-9002(01)01418-8

seen below, while the short half-life of ^{220}Rn has simplified some aspects of its measurement, the sampling method is a critical issue.

More recently, Monte Carlo simulations have shown that the sensitivities of CR39 and LR115 detectors, which are the two commonly used solid state nuclear track detectors (SSNTDs), to ^{220}Rn are at least comparable to those to ^{222}Rn. The errors introduced in measurements of ^{222}Rn concentrations by the presence of ^{220}Rn depend on a number of factors such as the ratio of ^{220}Rn/^{222}Rn concentrations and dimensions of the diffusion chamber [5,6]. Since SSNTD method is one of the most commonly employed to measure ^{222}Rn concentrations, it is essential to analyze and quantify the influence of ^{220}Rn through experimental studies. An exposure chamber of mixed ^{222}Rn/^{220}Rn is in need for this purpose. The current paper describes the construction of such an exposure chamber. Sample exposure conditions achieved by the exposure chamber will also be presented.

2. The ^{222}Rn/^{220}Rn exposure chamber

The exposure chamber was made of acrylic with a size of $1.1 \times 0.61 \times 0.61\,m^3$ ($=0.41\,m^3$). The size of the chamber is designed to be small to allow changes in the ^{222}Rn and/or ^{220}Rn levels inside the chamber on relatively small time scales. A block diagram of the chamber is shown in Fig. 1. The air flow pattern into and out of the exposure chamber is determined by different pumps and valve controls. The chamber is mainly operated in a recirculation mode, but operation in the flow-through mode is also possible. At the center of the front panel is a door with a size of $0.40 \times 0.36\,m^2$ ($=0.144\,m^2$) which can be opened for putting various equipment or detectors into the exposure chamber.

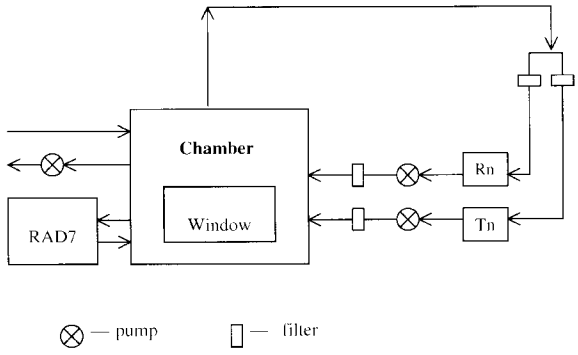

Fig. 1. Block diagram of the ^{222}Rn/^{220}Rn chamber.

2.1. ^{222}Rn and ^{220}Rn gas supply

The ^{222}Rn source is ^{226}Ra while the ^{220}Rn source is ^{228}Th (both purchased from Isotope Products Laboratories, California). Both sources had an activity of 10 μCi (370 kBq) as of 17 August 2000. The sources were formed as evaporated metallic salts in ceramic matrix which were affixed to the internal bottom of 10 ml vials. Air is passed through the vial but not through the source to avoid getting the radionuclides out of the ceramic matrix. The gas from each source is driven by an individual diaphragm pump (GAST® DOA-P101-BN, from Gast Manufacturing, Inc., MI) through a membrane filter (pore size of 0.45 μm) into the chamber. In the recirculation mode, the output air from the chamber is recirculated through the ^{222}Rn and/or ^{220}Rn sources. The free air flow rate of each diaphragm pump is $1.6\,m^3$/h. The ^{222}Rn and ^{220}Rn sources can be operated independently or simultaneously.

2.2. ^{222}Rn and ^{220}Rn monitor—RAD7

The instrument RAD7 (from Durridge Company Inc., MA) forms the basis of a comprehensive ^{222}Rn and ^{220}Rn monitor for our exposure chamber. Air from within the chamber is drawn to the RAD7 inlet first through a small drying tube filled with dessicant and then through a 0.45 μm filter, and the air from the outlet of RAD7 is then recirculated into the chamber. The filter prevents ^{222}Rn and ^{220}Rn progeny from getting into RAD7, so that RAD7 can measure the ^{222}Rn and ^{220}Rn gas concentrations alone. The pump of the RAD7 will start running when the preset program is executed. The pump is microprocessor controlled and the flow rate is around 650 ml/min.

There are different continuous $^{222}Rn/^{220}Rn$ monitors on the market, and most of these are based on detection of alpha particles. There are currently three types of alpha particle detectors being used as electronic $^{222}Rn/^{220}Rn$ monitors, namely, scintillation cells (or "Lucas" cells), ion chambers and solid state alpha detectors. RAD7 has an internal sample cell of a 0.7 l hemisphere, with a solid state ion-implanted planar silicon alpha detector at the center. The inside of the hemisphere is coated with an electrical conductor which is charged to a potential of 2–5 kV relative to the detector, so that positively charged progeny decayed from ^{222}Rn and ^{220}Rn are driven by the electric field towards the detector. When a progeny atom reaches the detector and subsequently decays and emits an alpha particle, the alpha particle has a 50% probability of being detected by the detector. As a result, an electrical signal is generated with the strength being proportional to the alpha energy. RAD7 will then amplify and sort the signals according to their energies [7].

The RAD7 spectrum is a scale of alpha energies from 0 to 10 MeV, which is divided into 200 channels each of 0.05 MeV width. The alpha energies associated with ^{222}Rn and ^{220}Rn are in the range of 6–9 MeV. These 200 channels are grouped into eight energy windows (labeled as A–H). Windows A–D are the functional ones.

Window A: records 6.00 MeV alpha particles from ^{218}Po, which has a half-life of 3 min, and is thus the window for ^{222}Rn sniff mode or "new" ^{222}Rn.

Window B: records 6.78 MeV alpha particles from ^{216}Po, which has a half-life of 0.15 s, and is thus the window for ^{220}Rn sniff mode or "new" ^{220}Rn.

Window C: records 7.69 MeV alpha particles from ^{214}Po, which has a half-life of nearly an hour, and is thus the window for "old" ^{222}Rn.

Window D: records 8.78 MeV alpha particles from ^{212}Po, which has a half-life of about 10 h, and is thus the window for "old" ^{220}Rn. For every 66 counts in window D, there should be 34 counts (6.05 and 6.09 MeV) in window A due to the two-way split from ^{212}Bi, so the counts in window A are automatically corrected for counts in window D by RAD7.

RAD7 adds windows E–H together to form window O (for "other"), which is mainly for diagnostic purposes.

RAD7 allows different modes of measurements, such as the normal mode and the sniff mode. For our purposes, the sniff mode is employed. In the sniff mode, RAD7 uses only ^{218}Po signals to determine the ^{222}Rn concentrations and ^{216}Po signals to determine the ^{220}Rn concentrations, ignoring subsequent and long-lived progeny.

Our RAD7 instrument was calibrated by the manufacturer on 20 February 2001. The ^{222}Rn sensitivity in the sniff mode is 0.233 CPM/(pCi/l), and the ^{220}Rn sensitivity in the sniff mode is 0.117 CPM/(pCi/l). The ^{220}Rn calculations is based on a standard setup calibrated by the manufacturer. A small drying tube (6 in.) filled with 30 g of Drierite dessicant, three feet of vinyl tubing with an inner diameter of $\frac{3}{6}$ in, and the male Luer type inlet filter (pore size of 0.4–1.0 μm) are all standardized.

2.3. RAD7 settings for monitoring ^{222}Rn and ^{220}Rn in the exposure chamber

For ^{222}Rn measurements, in the sniff mode, the RAD7 counts only ^{218}Po decays. Since ^{218}Po has a half-life of 3.05 min, the ^{218}Po atoms on the detector surface takes about five half-lives, or around 15 min, to reach equilibrium with the ^{222}Rn gas in the chamber. Cycle times of 10 min were adopted, which would provide a response time to variations in ^{222}Rn concentrations with a time scale of about 20 min.

For ^{220}Rn measurements, the main problem arises from the decay during its acquisition since ^{220}Rn itself has a half-life of less than a minute. The ^{216}Po, whose decays we count in the sniff mode, has a half-life of only 150 ms, so the response of RAD7 to ^{220}Rn, once the ^{220}Rn is in the chamber, is instantaneous. For most of our experiments, the RAD7 is also kept on 10-min cycles, and it will print out a ^{220}Rn value as well as a ^{222}Rn value at the end of every cycle.

2.4. Computer interface

The RAD7 has an RS232 serial port that can be used for transfer of data into a file on a personal computer. A computer software (Capture 1.2.0) is provided by the manufacturer for this purpose. Besides this, for $^{222}Rn/^{220}Rn$ concentrations which vary on small time scales, a small and simple program can be written to perform the time integration of $^{222}Rn/^{220}Rn$ concentrations to evaluate the exposure conditions (in units of Bq h m $^{-3}$), which is useful for calibration of detectors.

Furthermore, although not being employed at present for our exposure chamber, the $^{222}Rn/^{220}Rn$ concentrations in the exposure chamber can also be controlled by RAD7 with the optional RADLINK software and an external relay box. Two thresholds can be set for each of the two relays in the box. At the end of each measurement cycle, RAD7 will compare the measured $^{222}Rn/^{220}Rn$ concentrations with the values set for each of the thresholds and turn on or off the relays accordingly. In this case, no extra external controller is required.

3. Advantages of the present $^{222}Rn/^{220}Rn$ exposure chamber

The greatest advantage of RAD7 we exploit for monitoring ^{222}Rn and ^{220}Rn levels in our chamber is its capability of alpha spectrometry, i.e., the energy of each particle can be electrically determined. This gives detailed information on the ^{222}Rn or ^{220}Rn progeny being detected (e.g., ^{218}Po, ^{214}Po, etc.), from which the amount of new or old ^{222}Rn, or ^{220}Rn can be individually determined.

Therefore, one of the difficulties encountered in measuring ^{220}Rn levels, namely the interference from ^{222}Rn, can be comfortably removed by RAD7. RAD7 separates ^{222}Rn and ^{220}Rn signals and counts them at the same time with no interference between them.

Another great advantage associated with the capability of alpha spectrometry is the fast response to changes in the ^{222}Rn and ^{220}Rn level in the exposure chamber. When an instrument draws in air with ^{222}Rn and makes measurements, the ^{222}Rn will also decay within the instrument and there should be buildups of ^{222}Rn progeny. The relatively long-lived ^{222}Rn progeny, ^{214}Po, takes many hours to decay away. The RAD7 is capable of focussing at ^{218}Po alone and discarding information on ^{214}Po, and since ^{218}Po has a half-life of only 3 min, RAD7 has a response time of only 15 min to changes in ^{222}Rn levels. Regarding ^{220}Rn, on the contrary, ^{216}Po has a half-life of 150 ms, so RAD7 has an instantaneous response to changes in ^{220}Rn levels effectively. As mentioned earlier, we employed the sniff mode for monitoring our exposure chamber, for which RAD7 uses only ^{218}Po signals to determine the ^{222}Rn concentrations and ^{216}Po signals to determine the ^{220}Rn concentrations. In this way, RAD7 has a fast response to changes in the ^{222}Rn and ^{220}Rn levels.

4. Results and discussion

Sample exposure conditions achieved by the exposure chamber are presented in this section. In Figs. 2 and 3, the curves for buildup and clearance of ^{222}Rn alone and ^{220}Rn alone, respectively, in the $^{222}Rn/^{220}Rn$ chamber are shown. The ^{222}Rn gas or ^{220}Rn gas was pumped into the chamber in a recirculation mode for 60 min, and clearance was started at 60 min. Both the data for the ^{222}Rn or ^{220}Rn concentrations were reported at the end of every 10 min. The maximum achievable ^{222}Rn or ^{220}Rn concentrations are both around 140 kBqm $^{-3}$. From Figs. 2 and 3, owing to the fast response of RAD7, we can observe the variations of the ^{222}Rn or ^{220}Rn concentrations on a relatively small time scale. The capability of generating these fast variations of the ^{222}Rn or ^{220}Rn concentrations in the exposure chamber, together with the ability to quantify such changes, may be useful to test the response of some detectors, such as the characteristics of a diffusion barrier for the activated charcoal canister [8–10] and the optimization of the skim-off technique using the charcoal canister method [11,12]. Moreover, the fast response can also provide more accurate time integration of the ^{222}Rn and ^{220}Rn concentrations to evaluate the exposure conditions (in units of Bqhm $^{-3}$).

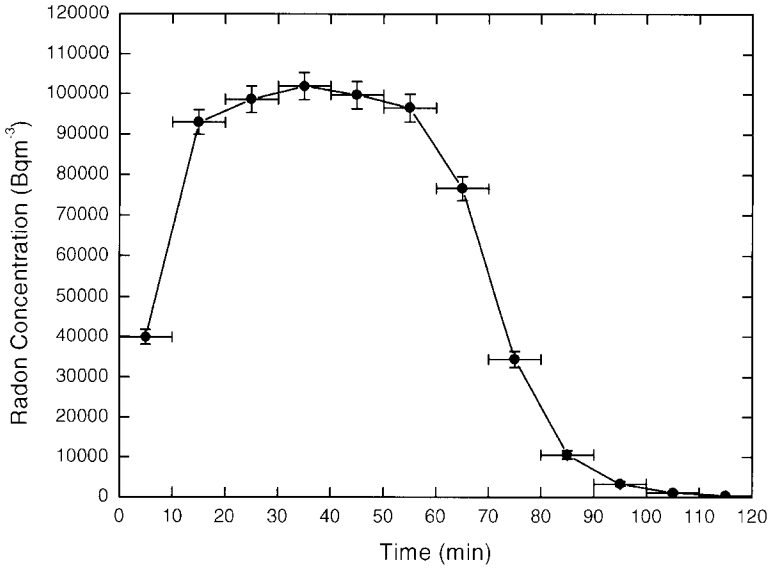

Fig. 2. The curve for buildup and clearance of ^{222}Rn alone in the ^{222}Rn/^{220}Rn chamber. ^{222}Rn was pumped into the chamber in a recirculation mode for 60 min, and clearance was started at 60 min. Data for the ^{222}Rn concentrations were reported at the end of every 10 min.

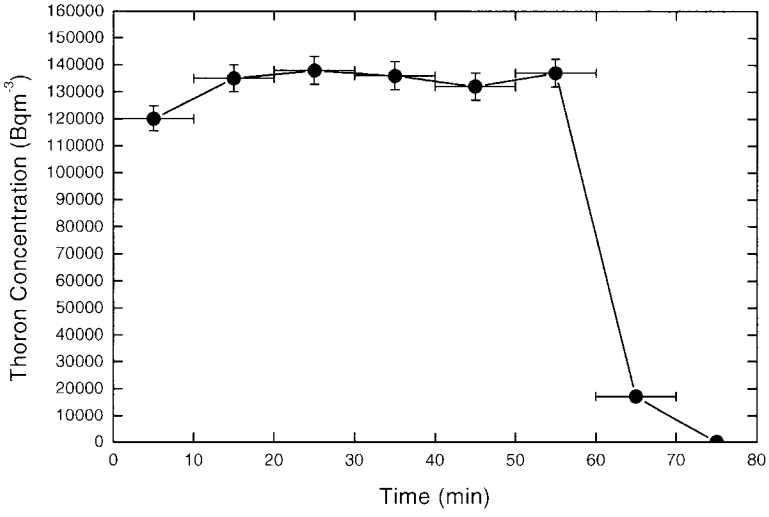

Fig. 3. The curve for buildup and clearance of ^{220}Rn alone in the ^{222}Rn/^{220}Rn chamber. ^{220}Rn was pumped into the chamber in a recirculation mode for 60 min, and clearance was started at 60 min. Data for the ^{220}Rn concentrations were reported at the end of every 10 min.

Fig. 4 shows the curves for buildup and clearance of ^{222}Rn and ^{220}Rn together in the ^{222}Rn/^{220}Rn chamber. Here, ^{222}Rn and ^{220}Rn were pumped into the chamber simultaneously in a recirculation mode for 60 min, and clearance was started at 60 min. The data for the ^{222}Rn and ^{220}Rn concentrations were again reported at the end of every 10 min. From this figure, it is obvious

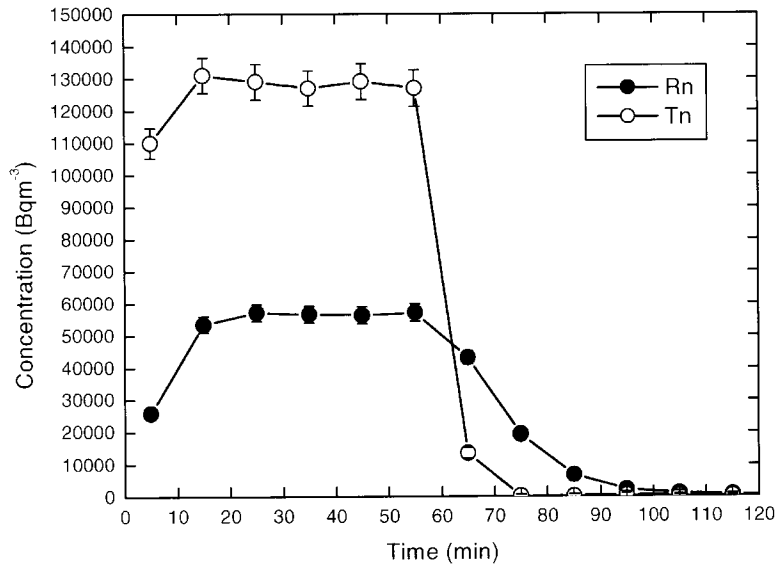

Fig. 4. The curves for buildup and clearance of ^{222}Rn and ^{220}Rn together in the ^{222}Rn/^{220}Rn chamber. ^{222}Rn and ^{220}Rn were pumped into the chamber simultaneously in a recirculation mode for 60 min, and clearance was started at 60 min. Data for the ^{222}Rn and ^{220}Rn concentrations were reported at the end of every 10 min.

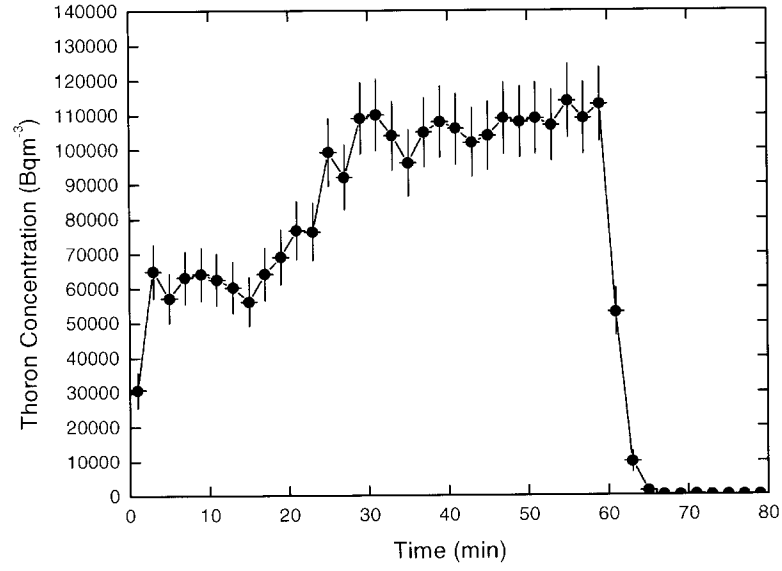

Fig. 5. The curve for buildup and clearance of ^{220}Rn alone in the ^{222}Rn/^{220}Rn chamber. ^{220}Rn was pumped into the chamber in a recirculation mode for 60 min, and clearance was started at 60 min. Data for the ^{220}Rn concentrations were reported at the end of every 2 min.

that the signals from ^{222}Rn and ^{220}Rn inside the exposure chamber are separated and counted at the same time with no mutual interference. This directly demonstrates the removal of the difficulty introduced by the interference from ^{222}Rn in measuring ^{220}Rn levels.

As mentioned before, RAD7 has an instantaneous response to changes in ^{220}Rn levels effectively, since ^{216}Po has a half-life of 150 ms. Therefore, if only exposure to ^{220}Rn is required, a much shorter cycle time of 2 min can be adopted. An example is shown in Fig. 5. Here, a curve for buildup and clearance of ^{220}Rn alone in the ^{222}Rn/^{220}Rn chamber is shown, where ^{220}Rn was pumped into the chamber in a recirculation mode for 60 min and clearance was started at 60 min. The data for the ^{220}Rn concentrations were reported at the end of every 2 min. It can be seen that variations in the ^{220}Rn concentrations with a much smaller time scale can be recorded. In this way, a far more accurate time integration of the ^{220}Rn concentrations can be performed to evaluate the exposure conditions (in units of Bqhm ^{3}).

In the above, we have presented the characteristics of a simple and versatile ^{222}Rn/^{220}Rn exposure chamber. Although the current exposure chamber is not designed for studies on the characteristics of ^{222}Rn and ^{220}Rn progeny such as the size distribution of the potential alpha energy concentration (PAEC), inclusions of these measurements only represent one further step on top of the current design. Note that the methodologies for determinations of the PAEC of ^{222}Rn and ^{220}Rn progeny and the size distribution of PAEC are more or less well established.

Acknowledgements

This research was supported by a strategic research grant 7001068 from City University of Hong Kong. The authors acknowledge very useful advice on RAD7 from Derek Lane-Smith of the Durridge Company.

References

[1] J. Bigu, Health Phys. 51 (1986) 534.
[2] F. Steinhäusler, W. Hofmann, H. Lettner, Radiat. Prot. Dosimetry 56 (1994) 127.
[3] K.N. Yu, T. Cheung, Z.J. Guan, E.C.M. Young, W.N. Mui, Y.Y. Wong, J. Environ. Radioactivity 45 (1999) 291.
[4] K.N. Yu, T. Cheung, Z.J. Guan, W.N. Mui, Y.T. Ng, J. Environ. Radioactivity 48 (2000) 211.
[5] D. Nikezic, K.N. Yu, Nucl. Instr. and Meth. A 419 (1998) 175.
[6] D. Nikezic, K.N. Yu, Health Phys. 78 (2000) 414.
[7] Durridge Company Inc., RAD7 Manual, V 6.0.1, 2000.
[8] H.M. Pichard, K. Marien, Health Phys. 48 (1985) 797.
[9] B.L. Cohen, R. Nason, Health Phys. 50 (1986) 457.
[10] K.N. Yu, E.C.M. Young, T.H. Wong, Appl. Radiat. Isot. 49 (1997) 49.
[11] B.L. Cohen, L.S. Cohen, Health Phys. 45 (1983) 501.
[12] V. Urošević, D. Nikezić, Appl. Radiat. Isot. 55 (2001) 121.