ALANINE EPR DOSIMETRY OF THERAPEUTIC IRRADIATORS

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Abstract

The high-dose alanine EPR dosimetry is a very precise method in the dose range 1-100 kGy. The system is used generally as the standard high-dose transfer dosimetry in many laboratories. This is comparatively expensive technique so it is important to use it as a more universal dosimetry system also in the middle and low dose ranges. The problems of the middle-dose alanine dosimetry are discussed and the solution of several problems is proposed. The alanine EPR dosimetry has been applied to the dose measurements of medical irradiators in the Kiev City Oncology Center.

1. INTRODUCTION

In the Ukraine, the sources of ionizing radiation are widely used for the cancer radiotherapy in a number of hospitals. These medical irradiators were fabricated 20 to 30 years ago and need careful checking and calibration. Dosimetry devices are also very old and need calibration. Also, there is no standard transfer TLD dosimetry system for the checking of medical irradiators. Now, there are no means for purchasing of new dosimetry equipment and even for the regular calibration of the old devices.

In the laboratory of EPR dosimetry of the Institute of Semiconductor Physics, the standard high dose transfer alanine EPR dosimetry system based at the old Varian E12 spectrometer was developed. We have decided to develop the middle-dose transfer alanine EPR dosimetry system and use it for dose measurements of medical irradiators in Ukrainian hospitals.

The high-dose alanine EPR dosimetry is a very precise method and in the dose range 1-100 kGy the uncertainty of dose measurements can be as low as 2 %. Because of this in early 1980s it was selected as the standard transfer dosimetry system for the International Dose Assurance Service (IDAS) of the International Atomic Energy Agency (IAEA) [1].

In the middle and small dose range the uncertainty of the standard alanine EPR dosimetry can be much more than 2% due to many factors:

- background EPR spectra of the cavity, sample holder and alanine tablet;
- alanine tablet EPR anisotropy;
- intra-batch variability of tablets;
- sensitivity of the EPR response to the humidity level of the tablet during the storage and measurements;
- instability of the EPR spectrometer parameters due to instability of electronic units;
- instability of the EPR spectrometer output due to the variability of the room humidity and the temperature of microwave cavity;
- random noise of electronic circuits.

For the correct dosimetry of medical irradiators in the dose range 1-10 Gy it is desirable to decrease uncertainties of all components of the alanine EPR dosimetry system. We have proposed the technical solution of the above mentioned problems. Presently we are developing the middle-dose alanine EPR dosimetry system of high accuracy. Some components of the system have been manufactured, but others are not yet ready. The system is described and discussed in the next section.

For dose measurements of the medical irradiators in Kiev City Oncology Center the routine high-dose alanine EPR technique was used.

2. MIDDLE-DOSE ALANINE EPR DOSIMETRY SYSTEM

2.1. Alanine dosimeter technology

Alanine tablets produced by BRUKER Analytische Messtechnik GMBH and tablets produced in our laboratory were used for EPR dosimetry. Bruker tablets were EMS 914-1005 type. These have cylindrical form with 4.9 mm diameter and 5 mm height. They have been prepared from the mixture of the alanine powder(80%) and polyethylene(20%) as a binder. The weight of tablet is 87 mg ± 2%. But the variation of the alanine content may be more than 2% due to the heterogeneity of the mixture. Thus, the intra-batch variability for such tablets is due to (1) variation of the tablet mass and (2) variation of alanine content in the tablet.

We have developed the technology of tablet preparation using pure alanine without a binder. This technology allows to eliminate the uncertainty due to the alanine content variation and to measure precisely the alanine mass of each tablet. We have used the chromatographically pure L-α-alanine of "REANAL", Budapest. The "Sigma" L-α-alanine also was used. Our tablets are quite firm. The size is 4.9 mm diameter and 5 mm height, and the weight is 100 ± 3 mg. For the precise alanine EPR low-dose measurements the individual weight of each tablet must be measured. We have used electronic balance with uncertainty of 0.1mg. Alanine tablets are anisotropic. The EPR intensity of an irradiated tablet changes by about 0.5 % when the tablet is rotated in the microwave cavity.

2.2. EPR techniques

Varian E12 X-band spectrometer has been modernized for EPR dosimetry. Magnetic field sweep system and microwave cavity were improved. We have also found a significant drift of the Varian magnetic field modulation unit. The system for the stabilization of the magnetic field modulation has been manufactured. The optimized parameters used were: 9.3 GHz microwave frequency, 2 mW microwave power, 100 kHz magnetic field modulation frequency, 1 mT modulation amplitude, 2,5...10 mT scan width, 60 s time of one sweep, 16...64 number of sweeps, 4 ms time constant.

2.2.1. Magnetic field sweep system.

A digital control of the magnetic field sweep unit has been designed. Due to the digital control of the microwave frequency and a nuclear magnetic resonance magnetometer, the EPR spectrum is presented in units of g-factor. The new control unit allows changing the sweep speed in some sections of the sweep range. Critical sections of the EPR spectrum can be scanned with a slower speed for more effective averaging of the electronic noise or for correct registration of narrow EPR lines of a reference sample with Mn^{2+} impurity or Varian pitch. The system thus allows using the time of a sweep more effectively.

2.2.2. Microwave cavity.

We have used two cavities. Varian E-233 Cylindrical Rotating Cavity with the quality factor 20 000 has been used for low dose measurements. Reference sample MgO with $Mn(2^+)$ impurity was placed at the bottom of the cavity. Varian E-231/E-232 dual sample cavity with quality factor 7000 has been used for high dose measurements. In this case, the Varian 'Strong Pitch' can be used as a reference sample. All measurements of alanine EPR intensities were normalized to the intensity of the reference samples.

Cavity stabilization. The stability of the alanine EPR intensity depends on the variation of the cavity quality factor and the temperature of the cavity. The quality factor and tuning of a microwave bridge depend on the room humidity and the cavity temperature. The temperature of the microwave cavity changes due to the magnetic field modulation and the ambient variation during a day. Also, the humidity of air depends on the weather. We have manufactured a system for the humidity and temperature control of the cavity. The microwave cavity is isolated from the temperature variation in the room with foam plastic bandage. The volume of the cavity is filled with the flow of dry nitrogen gas with controlled temperature. The temperature of the cavity is maintained at 28 °C.

2.2.3. Sample rotation system.

An axial rotation of a sample was proposed to minimise the effect of anisotropy of the alanine samples [2] by scanning the samples through the angular range using a goniometer system [3,4]. The use of a goniometer allows also to subtract background spectra of empty cavity, sample tube and alanine tablet in a correct way. The shortcoming of the system proposed in Refs [3,4] is the necessity of precise manual adjustment of the system after each change of a sample. The change of the samples is a complicated procedure. We have designed an automatic system for sample rotation with a worm-gear. The large gear is placed at the sample tube, which is open and allows changing samples using an air lift. The system does not need manual adjustment after a sample changing. The step motor is used for the sample tube rotation. After each step of rotation the EPR spectrum is stored and normalized to the intensity of the reference EPR sample. The system allows averaging the EPR spectrum over the anisotropy of a sample.

2.2.4. Humidity control of alanine tablets

The humidity of the alanine tablets essentially influences the accuracy of alanine EPR dosimetry [5]. The humidity of the tablets changes along the cycle: tablet preparation - storage - irradiation - transportation - storage - measurements. To exclude the influence of the humidity variations, we propose to design a closed space system for tablet storage, processing and measurements. The base of the system is near the microwave cavity and the inner parts of electromagnet. This space is filled with dry nitrogen gas continually. After preparation, tablets are stored here. All stages of tablet processing would be performed in this space. For irradiation, the tablets will be placed in hermetic capsules inside this space. After irradiation, the tablets will be returned to the space and will be transferred from the capsule to the sample holder for the EPR measurements. Microwave cavity is constantly in this space. The system is not completed yet.

2.3. EPR spectrum processing

In the middle-dose range the important point of spectrum processing is a correct subtraction of a background spectrum. The best way is to obtain the correct (i.e. reproducible) individual background spectrum of each tablet. Due to the angular dependence the correct EPR background spectrum of a tablet and a sample holder is the average of number of spectra measured at different angles of the sample holder. The spectrum at each angle is normalized to the intensity of the reference sample. The goniometer system described in 2.2 was used for this process. The spectrum

of the irradiated tablet is also averaged over all the angles. For the dosimetry, the difference of these two averaged spectra was used.

2.4. Reference samples

As reference samples we have used:

(1) Bruker tablets, irradiated at the primary standard of the National Physical Laboratory, UK. We have 5 sets of tablets with absorbed doses 0.5, 1.0, 3.0, 10.0 and 30.0 kGy. For middle-dose EPR dosimetry, we have also used the set with an absorbed dose at 500 Gy and assumed the linear approximation.
(2) Set of 5 Bruker tablets irradiated at the primary standard of the National Institute of Standards and Technology, USA. The irradiation dose was 30 Gy.
(3) Set of 5 AWM (Albrecht Wieser Messtechnik) tablets irradiated at the primary standard of the National Institute of Standards and Technology, USA. The irradiation dose was 30 Gy.

3. DOSIMETRY OF THERAPEUTIC IRRADIATORS

The ASTM standard practice [8] was used for high-dose range (> 100 Gy). For middle-dose range (< 100 Gy), the amplitude of the observable random noise must also be taken into account. To obtain the correct EPR intensity, the short-term noise must be averaged using the computer code. The background spectra of the empty cavity, sample holder and alanine tablets before irradiation must also be taken into account as discussed in 2.3. All measurements were performed in the Kiev City Oncology Center.

3.1. Gamma irradiator

Gamma irradiator ROCUS-AM (manufactured in Russia) - The calibration in the center of the irradiation area and the estimation of the dose distribution over that irradiation area (10 x 10 cm^2) at the distance of 75 cm from the source has been made. For measurements the plexiglas matrix of 22 x 22cm^2 was manufactured. The matrix has 11x11 cells of 5 mm diameter for alanine tablets with steps of 1cm. In addition, 5 cells in each of N,S,E and W directions outside the main irradiation area, were provided. In total, 141 alanine tablets were used for dose mapping with the results: (a) pre-determined dose was 200 Gy; (b) the alanine EPR dose was 220 Gy in the center of the irradiation area, and (c) the total uncertainty was 5 %.

3.2. X-ray irradiators.

The alanine tablets were placed in the cells of the plexiglass plate at the distance of 40 cm from the tubus. Results are presented in Table I.

TABLE I. RESULTS OF ALANINE EPR DOSIMETRY OF X-RAY IRRADIATORS

Type of irradiator	Tube voltage, (kV)	X-ray energy, (keV)	Pre-determined dose, (Gy)	EPR dose, (Gy)
RUM 17	180	90	5.0	5.9 ± 0.3
RUM-17	230	110	5.0	6.2 ± 0.3
RUM-7	60	32	5.0	4.5 ± 0.4

3.3. Electron beam irradiator

Electron irradiator "MICROTRON-M" (manufactured in Russia) - Alanine tablets were placed in the cells of the plexiglass plate at the distance of 100 cm. The electron beam energy was 8

MeV. The pre-determined dose was 10 Gy. The alanine EPR dose was 9.6 Gy (1σ=5%). The dose distribution at a deeper plane inside the standard phantom was also measured for electron energy of 8 and 15 MeV.

3.4. Bremsstrahlung radiation of the "MICROTRON - M".

The energy of the bremsstrahlung radiation was 20 MeV. The distance to the dosimeters was 100 cm. Alanine tablets were placed in the cells of the plexiglass plate. Time of irradiation was 150 s. The pre-determined dose was 10 Gy. The alanine EPR dose was 5.7 Gy (1σ = 5%).

3.5. Uncertainties

The uncertainty of the EPR intensity measurement is:
- 1 % for large EPR signals ($I_{EPR} >> I_{NOISE}$, dose range> 100 Gy);
- 3 % for small EPR signals (I_{NOISE} is about 3 % of I_{EPR}, dose range about 10 Gy).

Total uncertainty of the alanine EPR dose measurements is:
- 3 % for dose> 100Gy; and
- 5 % for dose 10 Gy.

4. DISCUSSION

The principal concerns of the alanine EPR dosimetry which can significantly increase the total uncertainty of the dose measurements at high and middle doses are: the EPR spectropmeter stability, the intra-batch variability of the tablets, the tablet anisotropy, the background EPR spectrum, the long term stability and reproduceability of the EPR measurements, the random electronic noise of the spectrometer, and the tablet humidity variation during the work cycle.

Here we have proposed and discussed the solution for some of the problems. The problem of the total humidity control is not yet resolved. We hope to solve this problem soon. After this, the total uncertainty of the middle-dose alanine EPR dosimetry will decrease to the level that will allow the use of this system as the transfer dosimetry system in the middle-dose range.

The application of the alanine EPR dosimetry for the routine measurements at the medical therapeutic irradiators in the Kiev City Oncology Center has proved to be useful for the local dosimetry service.

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