THE NIM ALANINE–EPR DOSIMETRY SYSTEM: ITS APPLICATION IN NDAS PROGRAMME AND OTHERS

Jun-Cheng GAO
Ionizing Radiation Division,
National Institute of Metrology,
Beijing, China

Abstract

In 1983, National Institute of Metrology (NIM) began to study alanine–EPR dosimetry system. From 1988 on, the system has been used as a transfer standard to launch into the National Dose Assurance Service (NDAS) programme for cobalt-60 facilities in China. In this paper, the eleven years implementation of NDAS programme are presented by statistics. In 1991, under an IAEA coordinated research programme, NIM had studied to extend the range of the system to therapy level. In recent years, the NIM in cooperation with other institutes has been developing film–alanine dosimeter for electron beam dosimetry.

1. INTRODUCTION

In order to suit the rapid development in radiation processing in China, NIM initiated a research project, having the name of "to establish metrological standards for dosimetry of ^{60}Co gamma-rays used in medicine, industrial irradiation and agriculture" in 1983. The key section of the project is to develop primary, secondary and transfer standards at processing level. At that time, the standardization on dosimetry of industrial radiation processing made the first step in China. When the research was fulfilled in 1988, several new primary and secondary dosimetric standards had been established in China. These standards are water calorimetry system, Fricke system, alanine-EPR system, potassium (silver) dichromate system, silver dichromate system and ceric-cerous sulfate system. Together with the old standards, graphite calorimetry and ionization chamber systems, there is a more complete group of metrology systems for high-dose dosimetry at NIM.

The idea that the alanine-EPR system had been placed on the project at that time, was affected by the IAEA report[1] and Regulla's work[2].

2. NIM ALANINE -EPR DOSIMETRY SYSTEM

The NIM alanine-EPR dosimetry system under the research project had been developed independently by ourselves. The comprehensive study on the system was summarized in a NIM final research report in 1987[3].

The system consists of alanine dosimeters, an EPR spectrometer, a precision balance, a fused quartz tube with high quality, a dose calibration curve and a national documentary standard.

The cylindrical alanine samples, having the size of ø3mm×8mm and the mass of about 68mg, are prepared with mixture of DL-α-alanine powder and paraffin in the weight ratio of 4 to 1. A sartoris electronic analytical balance with 0.1mg resolution is used for weighing the samples. Three samples are placed into a Perspex capsule to form an alanine dosimeter. There is fixed number on one end of the capsule, however, another end is sealed with a Perspex screw and paraffin to protect the samples from moisture. The outer size of the capsule is the same as that of NIM Fricke ampoule to make the calibration of alanine dosimeters convenient. Its wall thickness can meet secondary electron equilibrium for ^{60}Co gamma-rays.

The EPR instrument at NIM is a JES-FE1XG ESR spectrometer. EPR spectra of alanine samples are recorded under x-band at room temperature. The parameter of modulation width is selected as 0.63 mT to obtain higher spectrum amplitude in spite of its distortion, as the system belongs to relative measurement method. The ESR amplitude of the central peak for irradiated alanine sample is proportional to the absorbed dose.

Among the NIM primary standards, the Fricke system is chosen to make dose calibration for NIM alanine dosimeters. The calibration is carried out within a water phantom placed in a ^{60}Co irradiation field with substitution method. Since the NIM does not have its own standardization gamma-ray field, the calibration has to be performed in a user's field. Therefore, it is important to keep the same scattering condition and the same position for both Fricke and alanine dosimeters in the irradiation field throughout the calibration.

After the calibration of the field, a set of alanine dosimeters which had received accurate doses ranging from 1 to 10kGy, is applied to establish a dose calibration curve. In this dose range, the relationship between dose D and its response h, the peak amplitude of ESR spectrum of the calibrated alanine dosimeter, shows a good logarithmic linearity with a linear correlation coefficient of more than 0.9999 generally.

$$ln h = a + b ln D \quad (1)$$

The calibration of the dosimetry system should be made once a year.

A China national documentary standard with the name of "Alanine-EPR dosimetry system for radiation processing" was drafted by NIM and put into effect in June 1. 1997[4]. The standard is refereed to ASTM E1607-94 "Standard practice for use of the alanine-EPR dosimetry system" and made some appropriate changes. One of them is that the section of "Precision and bias" has been replaced with "uncertainty in measurement" which is refereed to the ISO Guide.

3. THE NDAS PROGRAMME FOR ^{60}CO FACILITIES

There is no doubt that the idea of the NDAS programme was inspired by the IDAS programme and had come true in 1988 in China. The procedure of the NDAS is similar to that of IDAS [5,6].

Each participant in NDAS gets a set of two alanine transfer dosimeters from the NIM every half an year. The NIM dosimeters and the participant dosimeters are bunched up together. Then the bundle of dosimeters is put in between irradiated articles for irradiation. The nominal dose D_1 of NIM dosimeters determined by the participant is based on the dose measurements of its own dosimeters.

The irradiated alanine dosimeters are returned to NIM to measure the response value h_0. According to the formation (1), the NIM evaluated dose D_0 can be obtained,

$$D_0 = \exp[(ln h_0 - a) / b] \quad (2)$$

The expanded uncertainty of D_0 is not more than 4% (2σ, or k=2). The percent deviation δ given in the NIM certificate is calculated as follows:

$$\delta = (D_1 - D_0) / D_0 \quad (3)$$

In 1990, a China national metrological norm, Monitoring method of dose assurance for radiation processing with gamma rays, had been put into force[7]. The norm explains the purpose, the significance, the method, the procedure and the result evaluation of NDAS programme. The norm established the role and the position of NDAS programme in dissemination of absorbed dose at processing levels in China.

The NDAS programme, with a scale of sixty participants now, has performed for more than ten years. By the end of August 1998, all together 798 dose checks had been carried out under the frame of NDAS.

Table I lists the distribution of the dose check results in different deviation ranges. It can be seen from the Table that 526 checks are within ±5%, accounting for 65.9% of the total number. However 161 (20.2%) and 111(13.9%) checks on the ranges between 5% and 10% and more than 10%, respectively. That is to say, the deviations for 86.1% dose checks are less than 10%.

TABLE I. THE DISTRIBUTION OF THE DEVIATIONS FOR NDAS DOSE CHECKS (1988–1998)

Deviation range (%)	< -20	-20 to -15	-15 to -10	-10 to -5	-5 to 0
Number of dose checks	21	16	26	110	305
Percentage (%)	2.6	2.0	3.3	13.8	38.2

Deviation range (%)	0 to +5	+5 to +10	+10 to +15	+15 to +20	>+20
Number of dose checks	221	51	14	7	27
Percentage (%)	27.7	6.4	1.7	0.9	3.4

Table II lists the number of dose checks, the corresponding averages of the percentage deviations and the standard deviations of the averages in chronological order. The result of last five years (1994–1998) in a general way, is better than that of the first six years (1988–1993) from the statistics in Table II. The mean value of all deviations for 798 checks is -0.88%. In other words, the mean ratio of users nominal doses to NIM evaluated doses is 0.9912.

TABLE II. THE ANNUAL MEAN VALUES AND CORRESPONDING STANDARD DEVIATIONS OF THE THE DEVIATIONS δ FOR ALL 798 DOSE CHECKS BY THE END OF AUGUST 1998

Year	1988	1989	1990	1991	1992	1993
Number of dose checks	7	64	64	52	90	53
Mean value of δ (%)	+1.85	-0.99	+7.30	-3.57	-4.58	+1.19
Standard deviation (%)	3.8	1.7	3.3	1.5	1.6	1.9

Year	1994	1995	1996	1997	1998
Number of dose checks	89	127	89	95	68
Mean value of δ (%)	+0.74	-1.75	-1.19	-1.56	-2.56
Standard deviation (%)	1.0	0.62	0.87	0.74	0.87

4. *RESEARCHES IN RADIOTHERAPY DOSIMETRY*

In 1991, NIM had participated in the IAEA coordinated research programme of therapy level dosimetry with the alanine-ESR system[8]. The main task of the research is to study the metrological properties of NIM alanine-EPR system in dose range of 1 to 100Gy, especially bellow 10Gy to enable the system to suit radiotherapy dosimetry.

The contribution of each component and their combination of the system to the background signal has been studied. They are: empty resonance cavity, cavity plus quartz tube, raw material of pure alanine powder, mixture of alanine and paraffin powders and shaped sample made of the mixture. Some parameters of the system has been changed or adjusted in order to increase its detective sensitivity, reduce the dose equivalent of noise and finally increase the signal–to–noise ratio. The main changes are as

follows: the outer size of alanine sample has been enlarged from ⌀3.0mm×8mm to ⌀4.5mm×10mm; the microwave power and the modulation width adjusted to 5mW and 1.25mT, respectively. In addition, the batch homogeneity of samples, the angular dependence of readout, the measurement repeatability and the influence of storage humidity have also been studied.

The dose comparisons between IAEA and NIM have been carried out by using NIM alanine dosimeters as the transfer elements. The mean dose ratio for 28 dosimeters in the range of 2.5 to 100 Gy is 0.974, which is within the uncertainty of NIM exposure standard.

The conclusion of the research is that the NIM alanine-EPR system can be used for therapy dosimetry for more than 5 Gy dose at present. We wish it could have a chance to try the system on a hospital ^{60}Co therapy unit.

5. RESEARCHES IN ELECTRON BEAM DOSIMETRY

In recent years, NIM has developed film-alanine dosimeter for electron beam (EB) dosimetry, in cooperation with Beijing Normal University and China Institute of Atomic Energy respectively[9,10]. The research is related to preparation technology of film samples, batch homogeneity of samples, angular dependence of readout, measurement repeatability, short-term and long-term stability, dose response curve, influence of irradiation temperature, influence of storage humidity and so on. Part of the research had been accomplished in 1996 and a preliminary plan for dissemination of absorbed dose value in EB dosimetry is drawing up. Since there would be a high degree of difficulty in realizing this dissemination, it is impossible to start the desired NDAS programme for EB dosimetry in a couple of years.

6. OTHER RELATED WORKS

The NIM alanine dosimeters were used to determine the technological irradiation dose ranges in drawing up China national hygienic standards of irradiated foodstuffs. In this application, two alanine samples are sealed in a plastic tube with a thickness of 1mm to become a dosimeter, which can be placed in any position of the foodstuffs. In this situation, there is no need to consider the electron equilibrium.

The dosimeters were also applied to check and accept the irradiation field of a new ^{60}Co facility according to the norm JJG591-89 "gamma ray irradiation source for radiation processing"[11]. In the meantime, several NIM alanine dosimeters were matched with GSF ones one by one by the user to be irradiated in the field while NIM know nothing about it. Then the NIM and the GSF dosimeters were sent to the institutes they belong to separately and measured by the institutes individually. The results evaluated by NIM are within 3% with those by GSF for more than ten pairs of dosimeters.

7. CONCLUSION AND DISCUSSION

NIM started to develop alanine-EPR dosimetry system in 1983 independently and initiated the NDAS programme by mailing alanine dosimeters in 1988. NIM is one of the institutes which have developed and applied the system earlier.

Up to now, there has been a dose dissemination and comparison network centered in the NIM under the frame of NDAS programme for high-dose dosimetry in China. The network possesses a scale of 60 participants and has the national regulations to support its validity.

The NDAS programme has been implemented for eleven years in China and 798 dose checks in all have been performed by the end of August 1998. Most checks, 526(65.9%), have a deviation less than 5%. The total mean value of all deviations is -0.88%.

The statistics in Table I do not obey normal distribution. For one thing 48 deviations are more than ±20%, making up 8%, and it shows that the ability in dosimetry has yet to be improved for a few

participants. For another thing, of the deviations less than ±10%(687), the negative ones are near to 60%(415). the reasons of unsymetrical distribution should be sought from both participants and NIM.

NIM possesses several kinds of dosimetry systems, however does not have its own standardization irradiation field at processing level.

For conducting dissemination of dose value in EB dosimetry, more difficult works have to be done for us.

We hope it is possible to make cooperations and intercomparisons between the NIM, the organization and the institute in the range of high-dose dosimetry.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, High-dose Measurement in Industrial Radiation Processing, IAEA Technical Reports Series, No. 205, Vienna(1981).

[2] REGULLA, D., DEFFENER, U., Dosimetry by ESR Spectroscopy of Alanine, Int. J. Appl. Radiat. Isot. 33(1982)1101.

[3] GAO JUN-CHENG, et al., Alanine/ESR Dosimeter—The Transfer Standard for ^{60}Co Rays at Radiation Processing level, NIM Final Research Report(1987) (in Chinese).

[4] CHINA STATE BUREAU OF TECHNICAL SUPERVISION, Alanine-EPR Dosimetry System for Radiation Processing, China National Documentary standard, GB/T 16639-1996, China Standard Publishing House, Beijing(1996).

[5] NAM, J., REGULLA, D., The Significance of the International Dose Assurance Service for Radiation Processing, Appl. Radiat. Isot. 40(1989) 953.

[6] MEHTA. K., GIRZIKOWSKY, R., IAEA Activities on High–Dose Measurements, SSDL Newsllett. 31(1992)31.

[7] CHINA STATE BUREAU OF TECHNICAL SUPERVISION, Monitoring Method of Dose Assurance for Radiation Processing with Gamma Rays, China National Metrology Norm, JJG1020-90, China Metrology Publishing House, Beijing(1990).

[8] GAO JUN-CHENG, WANG ZAIYONG, The Extension of the Range of NIM Alanine/ESR Dosimetric System to Therapy Level, Appl. Radiat. Isot. 47(1996)1193-1196.

[9] GAO JUN-CHENG, et al., Alanine/ESR Dosimetry System for Radiation Processing with Electron Beams, NIM Final Research Report (1996) (in Chinese).

[10] LIN M., et al., A Set of Dosimetry Systems for Electron Beam Irradiation, These Proceedings.

[11] CHINA STATE BUREAU OF TECHNICAL SUPERVISION, Gamma Ray Irradiation Source for Radiation Processing, China National Metrology Norm, JJG591–89,China Metrology Publishing House, Beijing (1989).