DOSE INTERCOMPARISON STUDIES FOR STANDARDIZATION OF HIGH-DOSE DOSIMETRY IN VIET NAM

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Abstract

The Irradiation Center of the Vietnam Atomic Energy Commission (IC-VAEC) is planning to establish a traceability system for high-dose dosimetry and to provide high-dose standards as a secondary standard dosimetry laboratory (SSDL) level in Vietnam. For countries which do not have a standard dosimetry laboratory, the participation in the International Dose assurance Service(IDAS) operated by the International Atomic Energy Agency(IAEA) is the most common means to verify own dosimetry performance with a certain uncertainty. This is, however, only one-direction dose intercomparison with evaluation by IAEA including unknown parameter at participant laboratories. The SSDL level laboratory should have traceability as well as compatibility, ability to evaluate uncertainties of its own dosimetry performance by itself. In the present paper, we reviewed our dosimetry performance through two-way dose intercomparison studies and self-evaluation of uncertainty in our dosimetry procedure. The performance of silver dichromate dosimeter as reference transfer dosimeter in IC-VAEC was studied through two-way blind dose intercomparison experiments between the IC-VAEC and JAERI. As another channel of dose intercomparison with IAEA, alanine dosimeters issued by IDAS were simultaneously irradiated with the IC-VAEC dichromate dosimeters at IC-VAEC and analyzed by IAEA. Dose intercomparison between IC-VAEC and JAERI results into a good agreement (better than ±2.5%), and IDAS results also show similar agreement within ±3.0%. The uncertainty was self-estimated on the basis of the JAERI alanine dosimetry, and a preliminary value of about 1.86% at a 68% confidence level is established. The results from these intercomparisons and our estimation of the uncertainty are consistent. We hope that our experience is valuable to other countries which do not have dosimetry standard laboratories and/or are planning to establish them.

1. INTRODUCTION

A semi-commercial scale ^{60}Co gamma-ray irradiator, the first one in Vietnam, has been operated at IC-VAEC since 1991 for food irradiation and radiation sterilization of medical products. The facility is equipped with a plaque source (120 cm height × 60 cm width, 2.8×10^{15} Bq, 1997) and a hanger-type conveyor system. High-dose dosimetry techniques have been developed in IC-VAEC for the dose-rate profile measurements in the irradiation field and the product boxes, for optimization of processing parameters, and for validation and commissioning procedures. Since the national standards laboratory for high-dose is not yet established in Vietnam, the Fricke dosimetry was chosen as a tentative reference dosimetry on the basis of its G-value. The dichromate dosimetry was successively developed as a reference transfer system for high-dose[1,2], also see Refs [3,4,5]. Other routine dosimeters such as perspex dosimeters and ethanolchlorobenzene (ECB) dosimeter have also been tested.

IC-Vietnam is now expected to be a SSDL level laboratory in Vietnam in radiation processing and reliability check of dichromate dosimetry is required for high-dose dosimetry. The SSDL level laboratory should have traceability/compatibility not only one-way comparison through IDAS, but also through two-way comparison with a sort of SSDL level laboratories, besides demonstrating its ability to estimate uncertainty in dosimetry performance by itself.

For evaluation of the potentiality of IC-VAEC as a SSDL level laboratory, dose intercomparison studies were performed with JAERI involving JAERI alanine and IC-VAEC dichromate dosimeters, and with IDAS as yet another channel. Also, self-evaluation of the uncertainties for IC-VAEC dichromate reference transfer dosimetry system was carried out.

2. EXPERIMENTAL PROCEDURES

2.1. Dosimeter systems for dose intercomparison

The silver dichromate dosimeters prepared at IC-VAEC and commercially available alanine dosimeters were used for the present studies. Silver dichromate with two different initial concentration of Cr^{+6} ions according to useful dose range, Type(a) and Type(b), were prepared following the ASTM standard E1401-96 [5]:

Type(a) : dichromate dosimeter for dose range 1-12 kGy
0.5mM $Ag_2Cr_2O_7$ in 0.1M $HClO_4$
Type(b) : dichromate dosimeter for dose range 3-50 kGy
2.0mM $K_2Cr_2O_7$+0.5mM $Ag_2Cr_2O_7$ in 0.1M $HClO_4$.

Dosimeter bulk solution was oxygen-bubbled for one hour and irradiated with gamma rays up to a dose of 1 kGy before flame-sealing in 3 ml Pyrex glass ampoules.

The alanine-PS dosimeters (Aminogray, HITACHI Cable Ltd.) prepared with 70 wt% of DL-α-alanine and 30 wt% of polystyrene were provided by JAERI or IAEA for these dose intercomparison studies. The alanine dosimeter is a rod of 3 mm dia. and 30 mm length, which is put in a capped polystyrene capsule with 4-mm thick wall. The ESR-spectrometry analysis of irradiated alanine dosimeters were performed using a compact ESR reader at the JAERI [6,7] or a ESR spectrometer ESP-300 (Bruker) at IAEA.

2.2. ^{60}Co Gamma-ray irradiation

The irradiation of dosimeters was carried out using the above-described γ-ray irradiation facility at IC-VAEC under electron equilibrium condition. The dose rate at the calibration position was estimated by air-saturated Fricke dosimeters, which were prepared in 2.5 ml sealed glass ampoules (10 mm dia and 25 mm solution length). Fricke dosimeter at IC-VAEC is well-characterized and satisfies the requirements stated in the ASTM Standard Practice E1026-95 [8]. An absorbed dose (to water) rate at the calibration position was 34.54 Gy/min (February 1997), and transient dose was 0.023 kGy. The irradiation of dosimeters at JAERI was performed using a plaque ^{60}Co γ-ray source (3.8×10^{15} Bq, 37.4 cm in width and 45.0 cm in height). The dose rate at the irradiation point was estimated using the parallel-plate free-air ionization chamber periodically calibrated at the Electrotechnical Laboratory, the primary standard laboratory in Japan [9].

2.3. Traceability and its verification plan in Vietnam

There are different channels for traceability check with the national and/or international standard laboratory[4]. Traceability checks and calibration chain of different class dosimeters in Vietnam is under the planning stage as shown in Fig.1, involving two different dose intercomparisons. As one channel, dichromate as a tentative reference transfer dosimeter is used to compare with alanine transfer dosimeters calibrated by the ionization chamber which maintains traceability to the Japan national standard laboratory [9]. The dose rate at the calibration position in the in-house irradiation facility of the IC-VAEC was measured using Fricke dosimeter and then verified by JAERI alanine transfer dosimetry. In another rout to maintain traceability and performance check of local reference dosimeters, the intercomparison experiments have been performed with the IAEA through the IDAS [10,11].

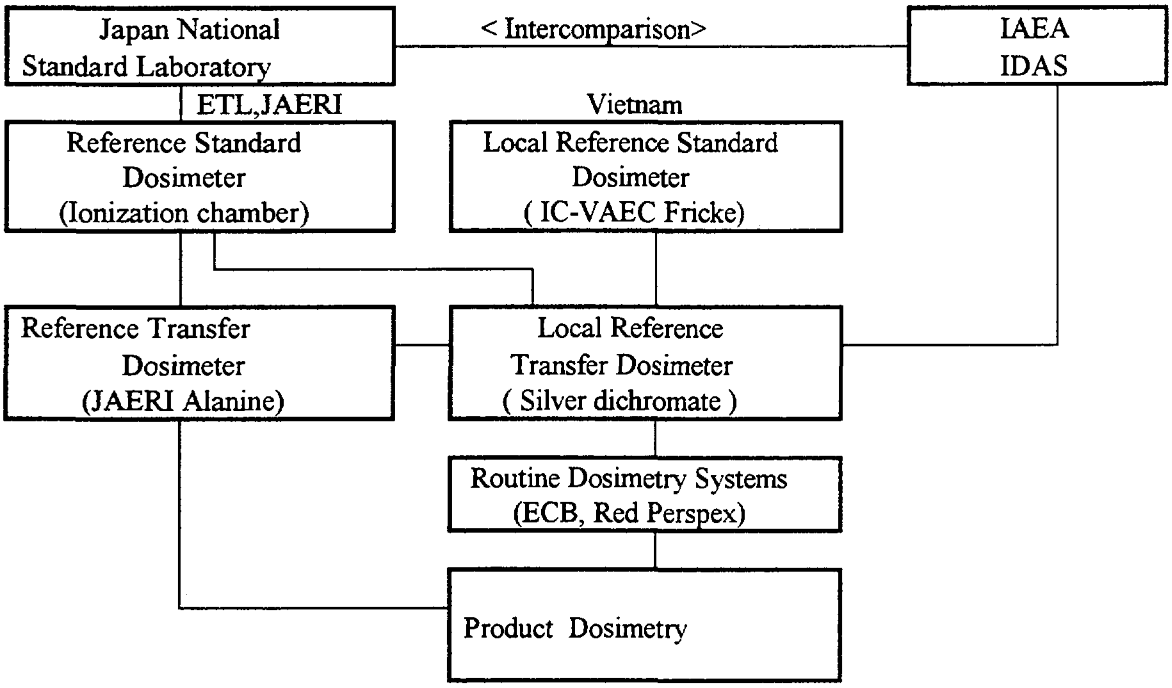

FIG. 1. The schematic diagram of traceability and international calibration chains of high-dose dosimetry at IC-VAEC under planning.

3. RESULTS AND DISCUSSION

3.1. Dose Intercomparison between IC-VAEC and JAERI

The gamma ray dose intercomparison experiments have been periodically carried out between IC-VAEC and JAERI since 1994 [2]. Dichromate dosimeters of the IC-VAEC were mailed to JAERI and then returned after irradiation for spectrophotometry analysis at IC-VAEC. While the JAERI alanine dosimeters were mailed to the in-house facility at the IC-VAEC and returned after irradiation to JAERI for ESR analysis.

The results of the dose intercomparison experiments carried out in March 1997 and May 1998 with JAERI alanine are listed in Table I. The relative deviations between the absorbed dose values quoted by IC-VAEC and those estimated at JAERI are within ± 2.5% in the dose range of 5-25 kGy. The results of the dose intercomparison experiments of March 1997 using IC-VAEC dichromate dosimeters are shown in Table II. The dose values estimated at the IC-VAEC are in agreement with dose values quoted by JAERI within ±2.3% for both types of dichromate dosimeters, type(a) and (b).

TABLE I. DOSE INTERCOMPARISON EMPLOYING JAERI ALANINE DOSIMETERS WHICH WERE IRRADIATED AT IC-VAERC

Irradiation Laboratory	Readout Laboratory	Quoted dose (kGy)	Estimated dose (kGy)	Relative deviation, %
IC-VAEC	JAERI	5.0	4.97	+0.6
		10.0	9.89	+1.1
		15.0	14.80	+1.3
		25.0	24.39	+2.4

TABLE II. DOSE INTERCOMPARISON EMPLOYING IC-VAEC DICHROMATE DOSIMETERS WHICH WERE IRRADIATED AT JAERI

Dosimeter	Irradiation laboratory	Readout laboratory	Quoted dose, kGy	Estimated dose, kGy	Relative deviation, %
Type (a)	JAERI	IC-VAEC	10.0	9.84	-1.6
Type (b)	JAERI	IC-VAEC	10.0	10.18	+1.8
			30.0	30.69	+2.3

3.2. Dose intercomparison through IAEA-IDAS

As another channel, IC-VAEC applied to IDAS for the verification of its dosimetry performance. The measurements were carried out in March 1997 and in May 1998. The two alanine dosimeter sets provided by the IDAS and three IC-VAEC dichromate dosimeters were irradiated with ^{60}Co gamma rays for 10 and 15 kGy in the IC-VAEC irradiation field at a dose rate of about 2 kGy/h. The IC-VAEC dichromate dosimeters were readout at IC-VAEC to quote absorbed doses given to IDAS alanine dosimeters, while the alanine dosimeters after irradiation were returned to the IAEA for analysis. The results of the IDAS measurements are summarized in Table III. The relative deviations between the dose values estimated by IDAS and that quoted by IC-VAEC were -2.9% and -2.78%. These deviations are within the acceptance limit of the IDAS, ±5%, although the values given by IC-VAEC dichromate system seems to have a tendency of a lower value than those given by IDAS.

TABLE III. DOSE INTERCOMPARISON STUDY THROUGH IDAS

Dosimeter	Irradiation laboratory	Readout laboratory	Date of study	Estimated dose, kGy	Relative deviation, %
IDAS alanine	IC-VAEC	IDAS	Mar.1997	11.02	-2.90
IC-VAEC dichromate	IC-VAEC	IC-VAEC	Mar.1997	10.70	
IDAS alanine	IC-VAEC	IDAS	May.1998	15.03	-2.78
IC-VAEC dichromate	IC-VAEC	IC-VAEC	May.1998	14.46	

3.3. Uncertainty estimation on performance of silver-dichromate dosimetry at IC-VAEC

To be recognised as a SSDL-level laboratory, IC-VAEC should have an ability to estimate the uncertainty of its dichromate reference transfer dosimetry. The following is the preliminary estimation of the uncertainties for each component of the IC-VAEC dosimetry procedure on the basis of the JAERI alanine transfer dosimetry. Each uncertainty component is classified as either "Type A" and "Type B", which are respectively defined as uncertainty estimated by experiments and that cited from published report or based on other information, according to the ASTM standard 1707-95 [12].

The dichromate dosimetry system at IC-VAEC has the major uncertainty components as follows:
- uncertainty arising from the characterization of the irradiation field and calibration point;
- uncertainty arising from the calibration procedure of the dosimetry system; and
- uncertainty arising from the dose estimation using the calibrated dosimetry system.

The dichromate dosimetry system consists of the dosimeter ampoules, the spectrophotometer and the calibration curve with mathematical fitting. The uncertainties in the absorbance measurement and wavelength setting of the spectrophotometer were determined by repeating measurements using a standard holmium filter. These uncertainty components are regarded as negligible. The uncertainty due to intra-batch absorbance variation of dichromate dosimeters was estimated from measured values for 30 dosimeters that were randomly picked from the same batch. The uncertainties associated with calibration of dosimeters and curve fittings were evaluated as per the ASTM standard guide E 1707-95. Table IV lists the uncertainty components in the calibration procedure of the dichromate dosimetry system, including that transferred from JAERI [13]. All components of uncertainty are expressed in percentage (%) at 1σ (approximating at a 68% confidence level), and combined to determine the overall uncertainty, which is the square root of the sum of their squares.

TABLE IV. UNCERTAINTY IN THE CALIBRATION OF DICHROMATE DOSIMETRY

	Component of uncertainty	Type A, %	Type B, %
4.1	Dose rate at IC-VAEC given by JAERI alanine	0.63	1.60
4.2	Source decay correction (every two days)	0.02	0.01
4.3	Irradiation timing(1sec)	0.03	
4.4	Positioning of dosimeters	0.19	
4.5	Averaging of response of three dosimeter replicates	0.23	
4.6	Temperature effect during irradiation ($\leq \pm 1°C$)	0.20	
4.7	Absorbance variation in one batch of dosimeter sol.	0.36	
4.8	Fitting goodness of calibration curve		0.47
4.9	Type A and Type B combined, separately	0.81	1.67
4.10	Overall uncertainty: combined A & B in quadrature	1.86	

The quoted uncertainty of the JAERI alanine transfer dosimetry was 1.72 % at 1σ. The variation of the irradiation timing was estimated to be 0.7 s, and its contribution is about 0.03 % in case of 1 kGy when the irradiation time is about 2,000 s. The precision of positioning of the JAERI alanine and the dichromate dosimeters at the same calibration point was estimated to be 0.19% according to the scattering of the center of the effective volume within ±2 mm. The uncertainty in averaging of dose response of three dosimeter replicates is 0.23 % including dose rate distribution in the effective volume. The variation of temperature during irradiation for calibration is $\leq \pm 1$ °C and results into uncertainty of 0.20 % in correction of temperature dependence of alanine and dichromate dosimeters, with the temperature coefficients of 0.2 % [7] and -0.2 % [3,14], respectively. Variation of the absorbance in the same batch of solution is 0.36 % including uncertainty of spectrophotometry. The uncertainty related to the calibration curve fitting with the first-order function is 0.47 %. From combination of these uncertainty components in quadrature, overall uncertainty in dichromate dosimetry at IC-VAEC is estimated to be 1.86 % at a 68 % confidence level. This preliminary estimate of the uncertainty value is, however, smaller than the difference in the dose intercomparison studies. It might be necessary to seek more uncertainty components in dichromate dosimetry with more careful reviewing of our dosimetry procedure.

4. SUMMARY

The dose intercomparison studies were carried out at IC-VAEC through two different channels. Relatively good agreement (within ±3%) was obtained for both dose intercomparison studies with JAERI and IDAS. The uncertainty in dichromate dosimetry as a local reference transfer dosimetry at IC-VAEC was estimated to be 1.86% by reviewing dosimetry procedures. The combination of the results of the dose intercomparison and the preliminary study of the uncertainties in dichromate dosimetry demonstrates a potentiality to establish a SSDL level laboratory at IC-VAEC which has also maintain compatibility with other SSDL level laboratories as well as metrological ability of self-evaluation of uncertainty in own dosimetry.

This kind of dose intercomparison study and self-evaluation study of uncertainty for own reference transfer dosimetry should contribute towards establishing the SSDL level laboratory in Vietnam, as well as other countries without domestic dosimetry standard laboratories.

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