9. Dosimetry

9.1 *Dosimetry Systems for Radiation Processing in Japan

N. Tamura

Takasaki Establishment, Radiation Application Developmemt Association
1233 Watanuki-machi, Takasaki, Gunma-ken, 370-12 Japan

Abstract The present situation of dosimetry systems for radiation processing industry in Japan is reviewed. For gamma-rays irradiation the parallel-plate ionization chamber in TRCRE, JAERI has been placed as a reference standard dosimeter for processing-level dose. Various solid and liquid chemical dosimeters are used as routine dosimeters for gamma processing industries. Alanine dosimeters is used for the irradiation purpose which needs precise dosimetry. For electron-beam irradiation the electron current density meter and the total absorption calorimeter of TRCRE are used for the calibration of routine dosimeters. Plastic film dosimeters, such as cellulose triacetate and radiochromic dye are used as routine dosimeters for electron processing industries. When the official traceability systems for processing-level dosimetry now under investigation is completed, the ionization chamber of TRCRE is expected to have a role of the primary standard dosimeter and the specified alanine dosimeter will be nominated for the secondary or reference standard dosimeter.

INTRODUCTION

Reliabale methods of evaluating the radiation dose are required in the radiation processing industries. Various dosimeters have been developed so far in Takasaki Radiation Chemistry Research Establishment (TRCRE), JAERI and other research institutions for the validation of gamma-rays and electron-beam irradiations mainly in the industries of product sterilization, food irradiation, and polymer processing and the radiation resistance tests of materials used in nuclear facilities and space environments.
Through the experiences and investigations on the use of dosimeters at many irradiation facilities in Japan, the characteristics and role of each dosimeter have been clarified. The local intercomparisons of dose measurement between TRCRE and other research institutions or industries in Japan, and also the international or bilateral intercomparisons carried out by IAEA and TRCRE have contributed greatly to the reliability of dose measurement at the industrial irradiation facilities in Japan.
This paper will show the present situation of dosimetry systems for radiation processing industry in Japan. The official traceability system for processing-level dosimetry now under investigation will be also presented.

STANDARD DOSIMETERS AND CALIBRATION LABORATORY FOR RADIATION PROCESSING

Radiation dosimeters can be classified according to their characteristics and position in the dose traceability system: primary standard dosimeter, reference standard dosimeter, routine dosimeter and transfer dosimeter. The transfer dosimeter is selected usually from reference standard dosimeters which are

intended for transport between different locations used as an intermediary to compare absorbed dose measurements.

Primary Standard Dosimeter

In Japan the Electro Technical Laboratory (ETL) responsible for the standard on radiation dosimetry has the primary standard on exposure with ionization chambers (National standard instrument). In the processing-level dosimetry the parallel-plate ionization chamber in TRCRE was developed in cooperation with ETL (Tanaka et al. 1985). This ionizaton chamber is used virtually as a standard dosimeter instead of the ETL's ionization chamber, although it is classified still as a reference dosimeter at present. Concerning the electron-beam dosimetry the ETL dose not provide a standard dosimetry system. Under such circumstances the electron current density meter (Tanaka et al. 1980) and the total absorption calorimeter (Tanaka and Sunaga, 1985) in TRCRE are often used for the calibration of dosimeters.

Reference Standard Dosimeter

Although the position and the role of reference standard dosimeter have not been strictly defined so far in Japan, the chemical dosimetry systems whose response to radiation and other environmental factors is reproducible and elucidated will occupy such position. Table 1 shows the reference dosimeters which have been used so far in Japan.

The Fricke dosimeter has been used as both reference and also routine dosimeters at gamma irradiation facilities for sprout inhibition of potatoes in Shihoro, Hokkaido, since the dosage necessary for the sprout inhibition is rather low, less than 150Gy, and in this dose range the Fricke dosimeter is the most reliable and well characterized. The inspection using Fricke dosimeter is carried out by the local public health center under the direction of Ministry of Health and Welfare (MHW).

For the sterilization of medical appliances both physical and chemical dosimeters are used in industrial gamma irradiation facilities as a reference dosimeter. In some irradiation facilities the physical dosimeters such as ionization chambers and N/P type silicon solar cells (Tanaka et al. 1976) have been used. The ceric/cerous dosimeters have been partly used in Nordion-type commercial irradiation facilities. The reliability of the dosimetry in the irradiation facilities as well as the result of routine dose measurement is inspected by MHW through a documentary examination.

Electron-beam irradiation has been applied mainly for the processing of polymeric materials so far and is now expanding to the sterilization of medical supplies. In this application field the electron current density meter and the total absorption calorimeter in TRCRE are used as a reference dosimeter as already mentioned.

The alanine/ESR dosimetry system has been recognized as the precision-grade dosimeter in Japan, which is measurable in a wide dose range from 1 to 10^5Gy (Kojima et al. 1986; Kojima and Tanaka, 1989). The alanine dosimeter is made by molding with polystyrene (PS) binders. Now this PS-alanine/ESR dosimeter system is under discussion as a role of the reference dosimeter and will be nominated as a new reference standard dosimeter. Internationally it has been already recognized as reference standard dosimeter (ASTM, 1994).

A High-Dose Radiation Dosimetry Calibration Laboratory

Although the ETL provides a ^{60}Co gamma dosimetry calibration laboratory, a

radiation field with a dose-rate appropriate to radiation processing is not available. Recently a high-dose gamma radiation calilbration laboratory has been installed at the Irradiation Room No.5 in TRCRE, which is calibrated by the pararell-plate ionization chamber. Figure 1 shows the plan view of the Irradiation Room No.5, where a plaque source consisting of ^{60}Co pencils is lifted up to the irradiation position in the room from the source storage pool. The parallel-plate cavity ionization chamber previously described is installed on an automatic positioning stand within an accuracy of ±0.2 mm and covers a wide dose-rate range from 0.1 to 10kGy/h. The dosimeters to be calibrated are irradiated in a movable sample chamber where the temperature and relative humidity are controlled (Tachibana et al. 1989).
The electron accelerators for the dosimetry calibration is not provided in the ETL. At present the calibration of routine dosimeters for electron beam is carried out by use of the electron current density meter and the total absorption calorimeter of TRCRE.

ROUTINE DOSIMETRY FOR INDUSTRIAL IRRADIATION FACILITIES

Many different routine dosimeters have been developed and tested so far at national and public research institutions for processing-level dosimetry. Table 2 shows the routine dosimeters, including the imported dosimeters, widely used at the industrial irradiation facilities in Japan.

Routine Dosimeters for Gamma Irradiation

In the gamma irradiation facilities for the sterilization of medical supplies dyed and undyed polymethylmethacrylate (PMMA) are mostly used, since these dosimeters were developed specially for the routine use in sterilization dosimetry. At present Red Perspex 4034, a dyed PMMA dosimeter, and Radix RN15, an undyed PMMA dosimeter, are mainly used in the sterilization industries.
For the radiation resistance test which needs more precise dose estimation the PS-alanine dosimeter known as Aminogray is frequently used for gamma irradition. The alanine dosimeter is applicable to the higer dose range than PMMA dosimeter.

Routine Dosimeters for Electron Beam Irradiation

For EB irradiation plastic film dosimeters are used as a routine dosimeter, since thin films are suitable for the measurement of depth profiles in the irradiated materials. Cellulose triacetate (CTA FTR-125) is the most widely used in EB processing industries in Japan and radiochromic dye dosimeter (FWT-60) is used mainly for low energy EB processing.
The CTA dosimeter has been developed in JAERI in collaboration with CEA, France and manufactured by Fuji Photofilm Co. (Tamura et al. 1981, Tanaka et al. 1984). The CTA film for dosimeter contains 15% triphenyl phosphate with no other additives. The absorbed dose is determined from the optical density change at 280nm before and after irradiation. The mechanism of the radiation-induced coloration of the CTA dosimeter was clarified (Matsuda and Nagai, 1991). A compact and precise readout system for CTA using the manganese hollow-cathode lamp as a monochromatic light source was developed and manufactured.

HIGH-DOSE INTERCOMPARISON BETWEEN THE IRRADIATION FACILITIES

The first high-dose intercomparison between the irradiation facilities in Japan was carried out in 1975 sponsored by the Radiation Application Development Association (RADA) after three industrial irradiation facilities had started: two are for sterilization of medical appliances and one is Shihoro potato irradiation facilities, where the irradiation process is assured by dosimetry. The aim of intercomparison was to improve the reliability of the irradiation process in industries and at the same time to harmonize the dosimetric measurement systems mutually between the irradiation facilities in the research institutions in Japan. Thirteen irradiation facilities, seven from national or public research institutes, two from universities and four from industries, participated in the intecomparison test. The Fricke dosimeter was used as a transfer dosimeter. Assuming the ETL value is a standard, the deviations from the ETL value were compared. The results show that the values of ten out of thirteen facilities agree with the standard value within ±5 % (Kawashima et al. 1978).

The second high-dose intercomparison was carried out by RADA in 1985 to harmonize and standardize the methods of dosimetry specially for low-enegy electron irradiations (Tanaka et al. 1989). The CTA (FTR-125) and radiochromic dye (FWT-60) dosimeters were used as transfer dosimeters. Ten irradiation facilities from research institutes, accelerator makers, and irradiation plants participated in this intercomparison. It was found that the transfer dosimetry by use of the thin film dosimeters, CTA and radiochromic dye, was useful and reliable for low energy electron-beam when care is taken for the environment such as humidity of the dosimeter films.

The dose intercomparison by using the PS-alanine/ESR dosimeter system was carried out with ten gamma irradiation facilities including the commercial plants. The main aim is to testify that the newly developed alanine dosimeter is appropriate for a reliable transfer dosimeter. The result of the intercomparison shows that the nominal doses agree with the estimated ones within ±5 % for most facilities and the variation coefficients for the dose response of five samples were within about ±1 % at all facilities (Kojima and Tanaka, 1989). This result demosnstrated that the PS-alanine/ESR dosimeter system has excellent characteristics for transfer dosimetry.

SCHEME OF THE NEW TRACEABILITY SYSTEM OF DOSIMETRY IN JAPAN

Now the official traceability systems for processing-level dosimetry are under investigation in Japan according to the New Measurement Law enforced in November 1993. In case this traceability system is completed , the parallel-plate cavity ionization chamber of TRCRE is expected to play a role of the primary standard dosimeter (National subsiduary standard instrument) in Japan. The specified alanine dosimeter is expected to be nominated for the reference standard dosimeter (Secondary standard instrument), which will have a role for the calibration of routine dosimeters used in gamma-rays and electron-beam irradiation industries. These dosimeter systems would provide the traceability from industry to national standards as shown in Fig. 4. It is important that they must be compatible with the dosimetry system of other countries through the international intercomparisons.

Table 1 Reference dosimeters used in Japan

Dosimeter	Readout System	Useful Absorbed Dose	Remarks
Gamma-rays			
Ionization chamber	Ammeter	10 to 3 $\times 10^4$ Gy/h	Parallel plate or cylindrical
Solar cell	Ammeter	10 to 10^5 Gy/h	Radiation resistant cell
Ceric-cerous sulphate solution	UV spectrophotometer or electrochemical potentiometer	10^3 to 10^5 Gy	
Ferous-sulphate solution (Fricke)	UV spectrophotometer	10 to 4 $\times 10^2$ Gy	
Alanine	ESR spectrometer	1 to 10^5	Polystyrene-molded
Electron beam			
Calorimeter	Thermometer	10^3 to 10^5 Gy	
Electron current-densitometry	Ammeter	0.01 to 10 μA/cm^2	

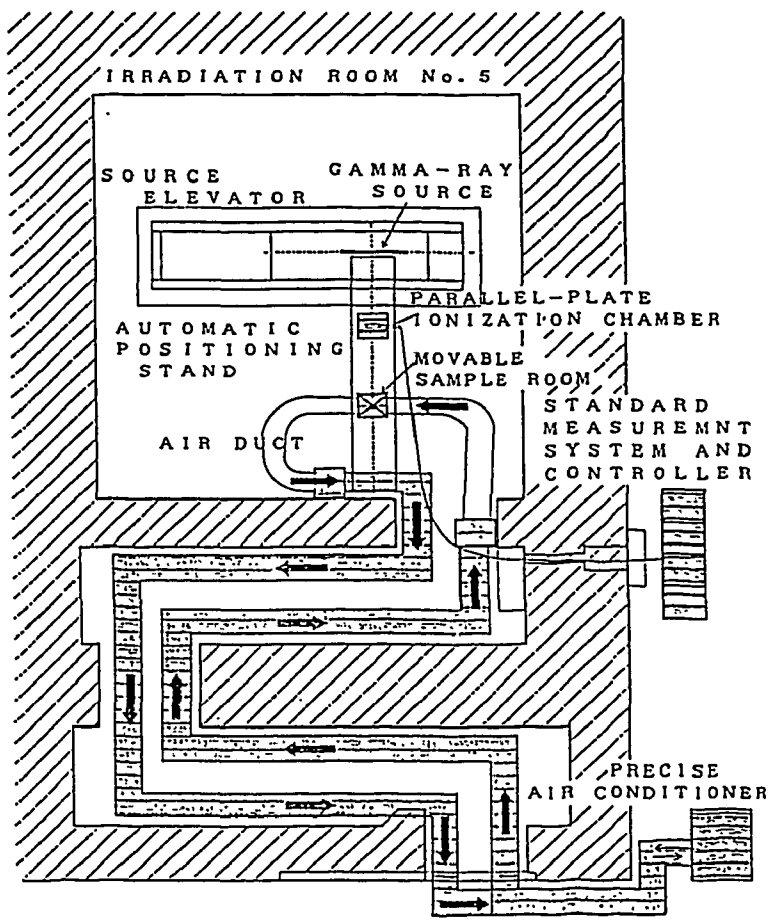

Fig. 1 Plan view of the high-dose gamma radiation calibration laboratory in TRCRE, JAERI (Tachibana et al. 1989)

Table 2 Routine dosimeters used in irradiation industries in Japan

Dosimeter	Readout System	Useful Absorbed Dose(Gy)	Remarks
Dyed polymethyl-methacrylate	Visible spectrophotometer	10^3 to 5×10^4	"Red Perspex4034" for γ-rays
Undyed (clear) polymethylmethacrylate	UV spectrophotometer	10^3 to 10^5	"Radix RN15" for γ-rays
Ceric-cerous sulphate solution	Potentiometer	10^3 to 10^5	for γ-rays
Ferous-sulphate solution (Fri .ke)	UV spectrophotometer	10 to 4×10^2	Potato irradiation for γ-rays
Alanine	ESR spectrometer	1 to 10^5	Polystyrene-molded
Cellulose triacetate	UV spectrophotometer Special reader	10^4 to 3×10^5	"FTR-125" for EB
Radiochromic dye films	Visible spectrophotometer Special reader	10^3 to 10^5	"FWT-60" for EB

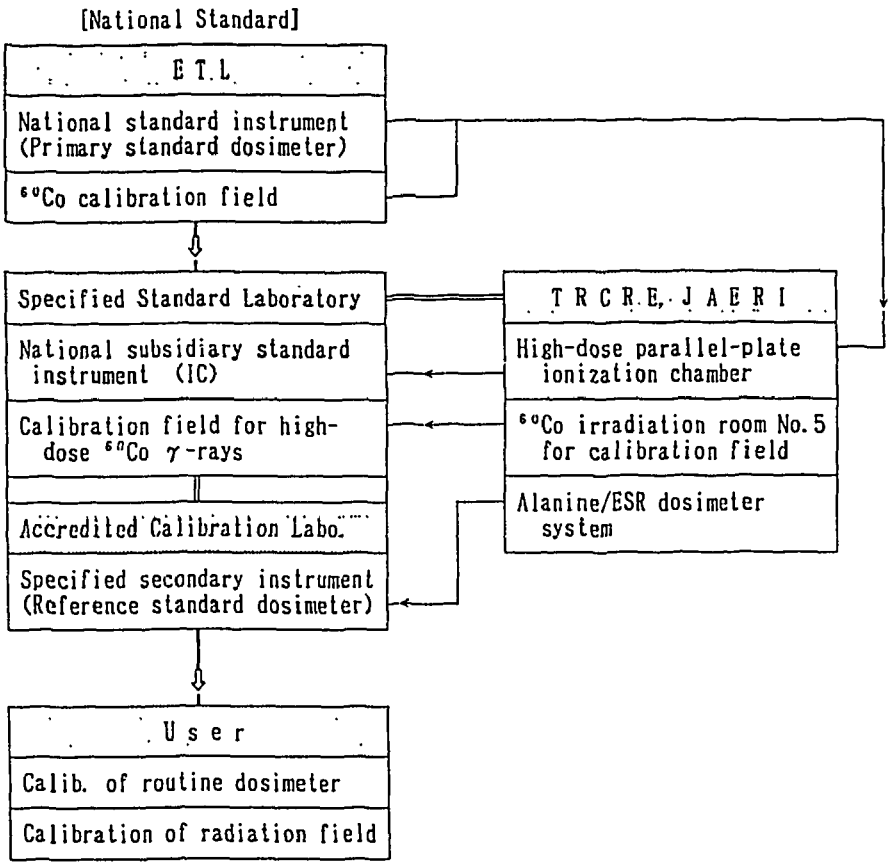

Fig. 2 Traceability system of high-dose dosimetry in Japan under consideration

REFERENCES

ASTM E 1607-94 (1994). Standard practice for use of the alanine-EPR dosimetry. Annual Book of ASTM Standards, Vol 12.02, p. 855

Kawashima, K, K. Hoshino and M. Matsui (1978). Fricke dosimeters. "Practical Methods for processing-level radiation dosimetry " edited by Y. Moriuchi (RADA) p. 27 (in Japanese)

Kojima, T., R. Tanaka, Y. Morita, and T. Seguchi (1985). Alanine dosimeters using polymers as binders. Appl. Radiat. Isot. 77, 517

Kojima, T and R. Tanaka (1989). Polymer-alanine dosimeter and compact reader. Appl. Radiat. Isot. 40, 851

Kojima, T., N. Haneda, S. Mitomo, H. Tachibana and R. Tanaka (1992). The gamma-ray response of clear polymethylmethacrylate dosimeter Radix RN15®. Appl. Radiat. Isot. 43, 1197

Matsuda, K. and S. Nagai (1991). Studies on the radiation-induced coloration mechanism of the cellulose triacetate film dosimeter. Appl. Radiat. Isot., 42, 1215

Tachibana, H., T. Kojima, R. Tanaka and K. Yoshida (1989). Standard dosimetry and irradiation system for high-dose rates gamma-rays. Proc. of the 26th Annual Meeting on Radioisotopes in the Physical Sciences and Industries, p. 82 (in Japanese)

Tamura, N., R. Tanaka, S. Mitomo, S. Matsuda, and S. Nagai (1981). Properties of cellulose triacetate dose meter. Radiat. Phys. Chem., 18, 947

Tanaka, R., S. Tajima, and A. Usami (1976). A simplified instrument for solid-state high-gamma dosimetry. Appl. Radiat. Isot., 27, 73

Tanaka, R., S. Mitomo, and N. Tamura (1984). Effects of temperature, relative humidity, and dose rate on the sensitivity of cellulose triacetate dosimeters for electrons and γ-rays. Appl. Radiat. Isot., 35, 875

Tanaka, R., H. Kaneko, N. Tamura, A. Katoh, and Y. Moriuchi (1985). Standard measurement of processing level gamma ray dose rates with a parallel-plate ionization Chamber. High-Dose Dosimetry (Proc. Symp. Vienna, 1984), IAEA, Vienna, p. 203

Tanaka, R., H. Sunaga, I. Kuriyama and Y. Moriuchi (1989). Intercomparison study on low energy electron beam dosimetry. Radiat. Phys. Chem., 33, 407

Tanaka, R., H. Sunaga, T. Kojima (1991). Simultaneous electron energy and dosimeter calibration method for an electron beam irradiator. High Dose Dosimetry for Radiation Processing (Proc. Symp. Vienna, 1990), IAEA, Vienna, p. 189