FACTA UNIVERSITATIS
Series: **Physics, Chemistry and Technology** Vol. 14, N° 2, 2016, pp. 105 - 113
DOI: 10.2298/FUPCT1602105S

QUALITY CONTROL IN RADIATION PROCESSING IN THE VINČA INSTITUTE RADIATION PLANT- CASE STUDY[†]

UDC 539.16

Bojana Šećerov[*], Danijela Stančov, Mirjana Radenković, Miroslav Dramićanin

Vinča Institute of Nuclear Sciences, POB 522, University of Belgrade, Belgrade, Serbia

Abstract. *The irradiation process control has to define facility parameters, validation of product and routine control of the irradiation process during exploitation. To meet the regulations, it is necessary to stop the exploitation and do the qualification exercises after changes in the source loading, source geometry or product transport system. In order to save time, the new combined approach has been analyzed for qualification of sterilization process used in the Vinča Institute Radiation Plant. The absorbed dose is calculated assuming that the irradiation process runs with specified parameters. The results of absorbed dose measurements in an experiment done during the sterilization process were used for dose calculations. The calculated absorbed doses are compared with measured ones. The criterion for a positive qualification is the superposition of calculated and measured values. Two different types of dosimeters are used for measurements: ethanol-chlorobenzene and alanine. The measurement traceability is achieved through the calibration by the Riso National Laboratory, Denmark. In this case study, the determined dwell time for target dose is 450s. 1.23 is dose uniformity ratio in the box with plastic products with dose minimum at the bottom corners in the center and dose maximum at the top of the surface plane of the box parallel to the source. The calculated and measured absorbed doses show the same difference of 13% between the surface and the central plane in the box. The dose reproducibility for irradiation process is 3.5%.*

Key words: *quality control, cobalt-60, ethanol-chlorobenzene dosimetry, alanine dosimetry*

Received January 1st, 2016; accepted November 29th, 2016
[†] **Acknowledgement**: This study is supported by the Serbian Ministry of Education, Science and Technological Development within Projects III 45020 and III 43009 and by APV Provincial Secretariat for Science and Technological Development of the Republic of Serbia through Project no. 114-451-3583.
Dedicated to Professor Radosav Palić on the occasion of his 70th birthday.
[*] **Corresponding author**: Bojana Šećerov
Vinča Institute of Nuclear Sciences, POB 522, University of Belgrade, 11001 Belgrade, Serbia
E-mail: bojana@vinca.rs.

1. INTRODUCTION

Radiation processing is the term used to describe a range of treatments made by ionizing radiation aimed to improve products and to increase their value. It covers many areas, such as radiation sterilization, food irradiation or polymer modification.

The Radiation Plant of the Vinča Institute of Nuclear Sciences was designed jointly by the Commission Energie Atomique and Conservatome, France, and the conveyor system was built by ABP Company, Paris. It is designed for either continuous or batch operation (Marković at al. 1977). The plant has been using ^{60}Co as irradiation source predominantly for sterilization of medical devices since 1978. Recently, a lot of activities were undertaken to implement the international standards: ISO/ASTM 51702 (2013) and ISO 11137 in (2006) in its domain of responsibility into the Radiation Plant operation.

One of the most important goals of the standard implementation is adequate irradiator qualification including determination of its effectiveness in delivering known, reproducible and controllable absorbed doses. According to ISO 11137 (2006), it is achieved through installation qualification, operational qualification and performance qualification, while ISO/ASTM 51702 (2013) uses terms installation qualification and process qualification for the same level of qualification and validation of irradiation process that is the evidence of differences in terminology. The installation qualification in ISO/ASTM 51702 (2013) is defined as qualification to establish baseline data for evaluating the effectiveness, predictability, and reproducibility of the system within the range of conditions under which the facility will operate. It generally corresponds to the scope of installation and operational qualification in ISO11137 (2006) where the purpose of installation qualification is demonstration that the irradiator has been supplied and installed in accordance with its specifications, and the operational qualification that the irradiator, as installed, is capable of operating and delivering appropriate doses within defined acceptance criteria. Although ISO 11137 (2006) considered standard requirements in more details, the process qualification (ISO/ASTM 51702) and the performance qualification (ISO 11137) defined the same relationship between the irradiator and the product that affects the dose distribution. Both standards require a dose mapping exercise to identify locations and magnitude of minimum and maximum doses in product and at least three measurements to allow determination of variability of dose and dose distribution between containers. Implementation of these procedures is necessary before the first use of the irradiation facility as it was done in the Vinča Radiation Plant (Radak at al. 1979). However, the standard recommendation is to complete the irradiation process qualification after each change in the source loading, source geometry or product transport system. Considering disruption during the qualification exercises here we will suggest a new combined approach of calculating dose for given case of irradiation and comparison of the calculated doses with measured ones, in order to achieve the same level of the irradiation process qualification with savings in material and time.

2. MATERIALS AND METHODS

The Radiation Plant, described in more detail elsewhere (Marković at al. 1977), consists of the irradiation room with ^{60}Co source, associated storage pool and shielding; product handling areas and a shuffle-dwell conveyor system designed for either continuous or batch

operation. Schematic diagram of the arrangement of product boxes around the radiation source is presented in Figure 1.

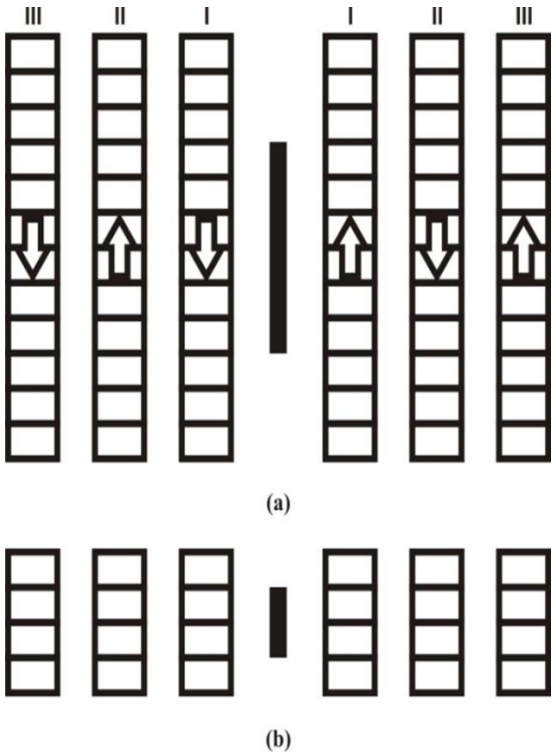

Fig. 1 Horizontal (*a*) and vertical (*b*) arrangements and movements of box carriers within the irradiation room

At the present time, the source frame (1 m x 3 m) is loaded with 6.88 x 1015 Bq ^{60}Co source placed into the source rods (diameter 11.1 mm, length 451 mm). Several generations of source rods are arranged in this source frame in two vertical levels. An automatic conveyor carries boxes (46 cm x 46 cm x 43 cm) through the source. A single irradiation run consists of four sequential irradiation cycles. In each cycle a given box passes through the irradiation room at one of four vertical levels organized in 6 rows (3 rows on each side of the source) each with 12 horizontal positions enabling irradiation of each box in the same manner.

2.1. Process parameters setting after the change in the source loading

The irradiation run (marked VII-MMXII in the Vinča Radiation Plant log) consisting of plastic products was used for the run parameter settings. Dwell time was calculated from the relation:

$$\frac{t_b}{t_a} = \frac{A_a}{A_b} \tag{1}$$

where t_b is dwell time before source loading, t_a dwell time after source loading, A_a source activity after source loading, and A_b source activity before source loading. Calculated dwell time was 416 s for delivery of approximately 25 kGy of absorbed dose. The irradiation run was split into two parts. In the first part, the dwell time was 200 s, i.e. approximately half of calculated dwell time.

Two pairs of two different types of dosimeters were put in 6 boxes along with products in the expected minimum absorbed dose location. The ethanol-chlorobenzene (ECB) dosimeters had been previously prepared in the Vinča Institute in accordance with the corresponding standard (ISO/ASTM 51538) and placed in 2 ml glass flame-sealed pharmaceutical ampoules. The other type, alanine dosimeters (Aerial, Illkirch, France) are shaped as tablets with diameter 3 mm, thickness 1.5 mm and mass between 37.5 – 37.6mg.

Following the first part of irradiation run, the reading of one pair of two different types of dosimeters was done using previously obtained calibration curve (Šećerov and Bačić, 2011). The measurement traceability is achieved by the Riso National Laboratory, Denmark, with alanine as a transfer dosimeter in in-plant calibration (ISO/ASTM 51261, Sharpe P. and Miller A., 2009.). The reading of dosimeters was done using the OK-302/2 oscillotitrator (ISO/ASTM 51538) for ECB and MiniScope MS300 ESR (Electron Spin Resonance) spectrometer with AER'EDE Version 2.0.4. software for absorbed dose calculation for alanine dosimeters. The ESR measurement parameters were: center field 334.8 mT; modulation amplitude 0.6 mT; microwave power 10 mW; magnetic field sweep width 2.1 mT; sweep time 12 s; scan number 5; gain 2; phase 180. The uncertainty of dose measurements is 3% for ECB dosimeters (Šećerov and Bačić, 2011), and 2.1% for L-alanine dosimeters (Šećerov at al. 2016).

According to the obtained results, the dwell time of the second part of irradiation run was calculated for target dose 26 kGy. The other pair of dosimeters was measured after completion of the second part of irradiation run.

2.2. Process qualification after changes in the source loading

During this procedure, dwell time was determined for plastic product loading, i.e. for density of approximately 0.15 g/cm3. The product loading configuration is arbitrary, but homogeneous as much as possible inside the box (46 cm × 46 cm × 43 cm). For dose mapping inside the boxes with different plastic products the irradiation run XV-MMXII was used and dwell time was set to 454 s. The dosimeters were alanine tablets placed in the box with products, in the center and at the box surface plane parallel to the source plane. After the irradiation, the reading of the dosimeters was done again with a MiniScope MS300 ESR spectrometer using the same parameters mentioned in 2.1. and the software for dose calculation.

2.3. Routine process control

Routine process control is part of the verification process aimed to verify that the irradiation process is done in accordance with prescribed parameters (ISO/ASTM 51702). The irradiation run XV-MMXII had five ECB dosimeters, each placed in one of five boxes

with different plastic products in the expected minimum dose location. After the irradiation run dosimeters were measured by the OK-302/2 oscillotitrator using the previously obtained calibration curve (Šećerov and Bačić, 2011).

2.4. Dose distribution measurements

L-alanine pellet dosimeters were placed in the central part of the standard box (46 cm × 46 cm ×43 cm) containing a plastic product in three positions: 1) plane facing the source, 2) center and 3) back plane from the source. The boxes with dosimeters were loaded into three carriers positioned at the beginning of each subsequent row and then irradiated for 12 consecutive dwell times (509 s) in irradiation run XXIII-MMXIII so that each carrier reached the opposite end of its row. The dose calculation was done based on the readings for alanine dosimeters following all 12 irradiation steps. The calibration curve for this purpose was obtained from the reading results of alanine dosimeters irradiated by ^{60}Co for internal calibration with applied doses known from Fricke dosimeter measurements (ISO/ASTM 51026).

This experimental set-up enables the calculation of the absorbed dose for each irradiation run. The absorbed dose in the central position in the box is thus obtained by summing up the absorbed dose values in the central position for all four boxes in all three rows and represent one half of a complete dose due to irradiation run for one box. The absorbed dose for the box surface plane for a complete irradiation run is obtained by summing up the total sum of the front and back plane of the box as the box position is changed for 180^0 facing the source rods, passing from one row to the next one.

3. Results and Discussion

3.1. Process parameters settings after changes in the source loading

The results of absorbed dose measurements for irradiation run VII-MMXII after the first part of irradiation run were 11.6 kGy ± 2.6% for measurements by alanine dosimeters and 11.6 kGy ± 3.2% by ECB dosimeters. The corresponding dwell time for the second part of irradiation run was 250 s, calculated from equation (1) for target dose of 26 kGy. The results after completion of the second irradiation part were 25.9 kGy ± 3.2% measured with alanine dosimeters and 26.3 kGy ± 3.3% with ECB dosimeters. Summing these two dwell times, the new dwell time after source loading should be 450 s for target dose. The dwell time value is scheduled to be increased by 1% each month to compensate for the decrease in source activity caused by radioactive decay.

3.2. Process qualification after changes in the source loading

The absorbed dose values obtained by measurements following the completion of irradiation run XV-MMXII are presented in Figure 2. It is evident that the maximum dose values are achieved at the top of the inside surface plane of the box. The relationship between the maximum (D_{max}) and minimum (D_{min}) doses gives the rate of dose homogeneity defined as the dose uniformity ratio (ISO/ASTM 51702). The dose uniformity ratio (D_{max}/D_{min}) for the surface plane in the box is 1.08, which means that the dose distribution is mostly uniform in the plane. The minimum dose areas are at the bottom corners in the centre plane. The better

dose homogeneity is achieved in the centre plane with the dose uniformity radio of 1.06. The dose uniformity ratio in the whole box is 1.23. Looking at the central positions in two plains, the absorbed dose in the centre plane is 13% lower than at the box surface plane.

Front (back) plane

32kGy	31.4kGy	30.7kGy
30.7kGy	31.2 kGy	30.7kGy
29.8 kGy	30.7 kGy	29.6kGy

Centre plane

26.1 kGy	27.1 kGy	26.2kGy
26,9 kGy	27.5 kGy	27.4kGy
26 kGy	26.3 kGy	26kGy

Fig. 2 Absorbed dose (kGy) in box with plastic product after irradiation cycle.

3.3. Dose distribution measurements

The results of both the depth and the height absorbed dose distribution during the irradiation run marked XXIII-MMXIII after first 12 steps has been presented in Figure 3.

The absorbed doses are summarized for each row in each of the three positions and listed in Table 1.

The total sum of the absorbed doses in the central position is equal to one half of the absorbed dose for a complete irradiation run in this position, i.e. 26.84 kGy is the calculated absorbed dose for the central plane of the box for complete irradiation run.

The total sum of the front and back plane of the box gives the calculated absorbed dose for the edge of the box for a complete irradiation run, and it is 30.25 kGy. This value is 13 % higher than the dose in the central position and relates to the dose uniformity in the box with plastic products. The same result was obtained in the process qualification exercise presented in Figure 2. This is the verification that the irradiation process is carried out properly as installed, within acceptable criteria that according to ISO 11137 Standard should be done through the operational qualification.

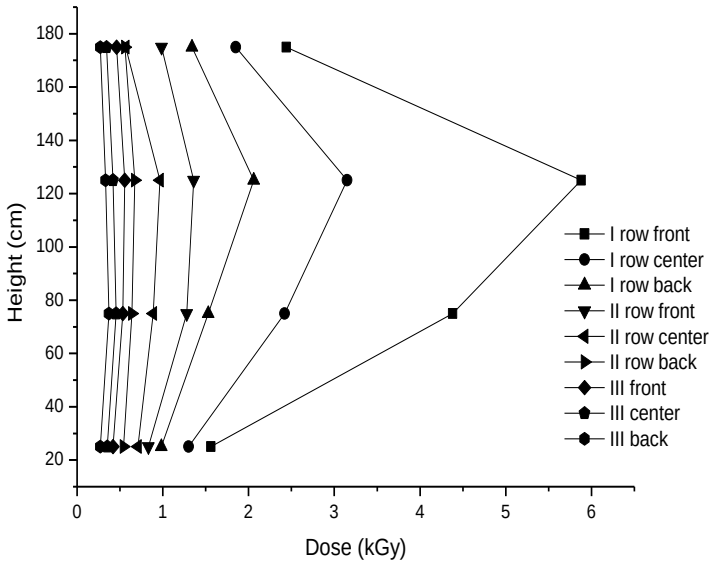

Fig. 3 Height and depth dose distribution in the three rows of carriers

Table 1. The sum of absorbed doses in one row in the same position after 12 steps

Row	Sum of doses center (kGy)	Total center (kGy)	Sum of doses front (kGy)	Total front (kGy)	Sum of doses back (kGy)	Total back (kGy)
I	8.72		14.26		5.91	
II	3.13	13.42	4.46	20.69	2.41	9.56
III	1.57		1.97		1.24	

Determination of dose distribution among rows: 65% of the absorbed dose in the first row, 23% in the second and 12% in the third row is done based on the dose distribution results summarized in Table 1 and Figure 3. The height dose distribution in one carrier was obtained by summing all absorbed doses at each height level. In this case the dose distribution is calculated for one and a half of the complete irradiation run. The dose distribution among height levels starting with the lowest is: 16%, 29%, 35%, 20%.

3.4. Routine process control

The average absorbed dose value obtained by measurements of ECB dosimeters placed in locations with a minimum estimated dose during the XV-MMXII irradiation run was 26.6 kGy ± 3.5%. The difference between measurements is caused by variation in both the process operation and the product densities. The value of 3.5% can be used as the uncertainty of the minimum absorbed dose in the sterilization process of plastic products since the same result was obtained in irradiation run VII-MMXII during the process parameters determination. This confirms the estimation of the rate of dose reproducibility to be ±3.5% in the sterilization process of different plastic products with the same density.

4. CONCLUSION

Standard requirements for qualification of the sterilization process in later stages of the irradiator operation may be reached using the proposed procedure as illustrated in the Vinča Institute Radiation Plant case study. The dwell time determination was performed during the regular sterilization run by splitting it into two parts where the correction may be performed in the second part. The new dwell time is determined to 450 s for the target dose. Both operational qualification and process qualification may be performed during the regular sterilization run saving the time and with minimum interruption of the operation. In the studied case, the obtained dose uniformity ratio in the box with plastic products is 1.23. The operational qualification requirements are implemented when the calculated dose for given parameter settings corresponds to the measured values in the process qualification. The calculated absorbed dose in central position for one irradiation run is 26.84 kGy for the central plane and 30.25 kGy for the surface plane of the box with products. The difference between these calculated absorbed doses is 13% and is equal to the difference between the same positions measured in the dose mapping experiment. The standard deviation of the absorbed dose determined during routine process control can be taken as dose reproducibility for a given irradiation process. It is 3.5% in the studied case.

REFERENCES

ISO/ASTM 51026-15 Standard practice for using the Fricke dosimetry system

ISO/ASTM 51261-13. Standard practice for calibration on routine dosimetry systems for radiation processing

ISO/ASTM 51538-09. Standard practice for use of the ethanol-cholrobenzene dosimetry system

ISO/ASTM 51702-13. Standard practice for dosimetry in gamma irradiation facility for radiation processing

ISO 11137 2006. Sterilization of health care product – Radiation: Part 1: Requirements for development, validation and routine control of a sterilization process for medical devices. ISO 11137-1, 2006, Geneva. Part 2: Establishing the sterilization dose. ISO 11137-2, 2006, Geneva. Part 3: Guidance on dosimetric aspects. ISO 11137-2, 2006, Geneva

Marković V. M., Eymery R., and Yuan H. C.,1977. A new approach to ^{60}Co plant design for introduction of radiation sterilization in developing countries. Radiat. Phys.Chem.9, pp. 625-631

Radak B. B., Marković V. M. and McLaughlin W. L., 1979. Dosimetry for the commissioning of a versatile irradiation plant. Radiat. Phys.Chem. 14, pp. 449-456

Šećerov B. and Bačić G., 2011. Calibration of routine dosimeters in radiation processing: validation procedure for in-plant calibration. Nuclear Technology & Radiation Protection 26, pp. 271-274

Šećerov B., Radenković M., Dramićanin M., 2016. Uncertainty and routine use of Aerial L-alanine - Electron spin resonance dosimetry system. Radiation Measurements (2016). http: //dx.doi.org/ 10.1016/j.radmeas.2016.03.003

Sharpe P. and Miller A., 2009. Guidelines for calibration of routine dosimetry systems for use in radiation processing. NPL Report CIRM 29, available at http://www.chemdos.npl.co.uk/dosc/NPLReportsCIRM29.pdf

KONTROLA KVALITETA U TEHNOLOGIJI OBRADE ZRAČENJEM – STUDIJA SLUČAJA RADIJACIONE JEDINICE U INSTITUTU „VINČA”

Kontrola procesa ozračivanja mora da definiše parametre postrojenja, validaciju proizvoda i rutinsku kontrolu procesa tokom eksploatacije. Da bi se ispunili zahteve propisa, neophodno je prekinuti eksploataciju i uraditi kvalifikaciju procesa ozračivanja posle svake dopune izvora, promene geometrije izvora ili transportnog sistema. U cilju uštede vremena, analiziran je novi kombinovani pristup kvalifikacije procesa sterilizacije u Radijacionoj jedinici Instituta "Vinča". Apsorbovana doza je

izračunavana pretpostavljajući da proces teče po zadatim parametrima. Za izračunavanje koriste se rezultati merenja apsorbovane doze u eksperimentu koji je izveden u toku procesa sterilizacije. Izračunate apsorbovane doze upoređuju se sa izmerenim. Kriterijum za pozitivnu kvalifikaciju procesa je slaganje izračunatih i izmerenih vrednosti. Za merenja su korišćena dva tipa dozimetara: etanol-hlorbenzen i alanin. Merna sledljivost je postignuta preko kalibracije u RISO nacionalnoj laboratoriji u Danskoj. U ovoj studiji, određena je dužina koraka za ciljanu dozu od 450s. 1,23 je odnos homogenosti doze u kutiji sa plastičnim proizvodima, sa minimumom doze u donjim uglovima centralne ravni i maksimalnom dozom na vrhu ivice kutije u ravni paralelnoj sa izvorom. Izračunate i izmerene apsorbovane doze pokazuju istu razliku od 13% izmedju površinske i centralne ravni kutije. Reproduktivnost doze za proces ozračivanja je 3,5%.

Ključne reči: *kontrola kvaliteta, kobalt-60, etanol-hlorbenzen dozimetrija, alaninska dozimetrija*