Measurement of the strength of iodine-125 seed moving at unknown speed during implantation in brachytherapy

Kenichi TANAKA[1],*, Satoru ENDO[2], Kunihiko TATEOKA[1], Osamu ASANUMA[3], Ken-ichi KAMO[1], Kaori SATO[2], Hiromitsu TAKEDA[2], Masaru TAKAGI[4], Masato HAREYAMA[5] and Jun TAKADA[1]

[1]Department of Medicine, Graduate School of Sapporo Medical University, South 1, West 17, Chuo-ward, Sapporo, Hokkaido 060-8556, Japan

[2]Department of Quantum Energy Applications, Graduate School of Engineering, Hiroshima University, 1-4-1, Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8527, Japan

[3]Division of Radiology and Nuclear Medicine, Sapporo Medical University Hospital, South 1, West 17, Chuo-ward, Sapporo, Hokkaido 060-8556, Japan

[4]Hyogo Ion Beam Medical Center, 1-2-1, Kouto, Shingu, Tatsuno, Hyogo 679-5165, Japan

[5]Teishin-kai Radiation Therapy Institute, 1-6, North 44, East 8, Higashi-ward, Sapporo, Hokkaido 007-0844, Japan

*Corresponding author. Division of Physics, Department of Liberal Arts and Sciences, Center of Medical Education, Sapporo Medical University, South 1, West 17, Chuo-ward, Sapporo Hokkaido 060-8556 Japan. Tel: +81-11-611-2111; Fax: +81-11-644-2001; Email: tanakaken@sapmed.ac.jp

The aim of this study is to demonstrate the feasibility of estimating the strength of the moving radiation source during patient implantation. The requirement for the counting time was investigated by comparing the results of the measurements for the static source with those for the source moving at 2, 5, 10 and 20 cm s^{-1}. The utilized source was ^{125}I with an air-kerma strength of 0.432 U (μGym^{2}h^{-1}). The detector utilized was a plastic scintillation detector (8 cm $\times$ 5 cm $\times$ 2 cm in thickness) set at 8 cm away from the needle to guide the source. Experiments were conducted in order to determine the most desirable counting time. Analysis using the maximum of the measured values while the source passed through the needle indicated that the results for the moving source increased more than those for the static source as the counting time decreased. The combined standard uncertainty, with the coverage factor of 1, was within 4% at the counting time of 100 ms. This investigation supported the feasibility of the method proposed for estimating the source strength during the implantation procedure, regardless of the source speed. The method proposed is a potential option for reducing the risk of accidental replacements of sources with those of incorrect strengths.

Keywords: brachytherapy; ^{125}I; source strength; moving source

INTRODUCTION

In low-dose-rate brachytherapy, there are generally many sources implanted in the human body. Its dosimetry has been actively researched in the USA and other countries [1–9]. Based on the abundant data obtained through experiments and calculations, the American Association of Physicists in Medicine Task Group No. 43 Updated Protocol (AAPM-TG43U1) and its subsequent updates is the recommended dosimetry formalism for interstitial low-energy brachytherapy treatments [10]. The use of the TG43U1 formalism requires knowledge of the strengths of all the sources implanted. In accordance, AAPM published a guideline by Task Group 64 (TG64) with related recommendations, which requires that source strengths be measured by the users (e.g. medical physicists) [11, 12]. In the guideline, a 3% difference between the mean of a batch as measured by the user and the manufacturer should be investigated, and a 5% difference should be discussed with the manufacturer. The measurement by the user is conducted in advance of the implantation, and those sources having correct strength are utilized for the implantation. Through
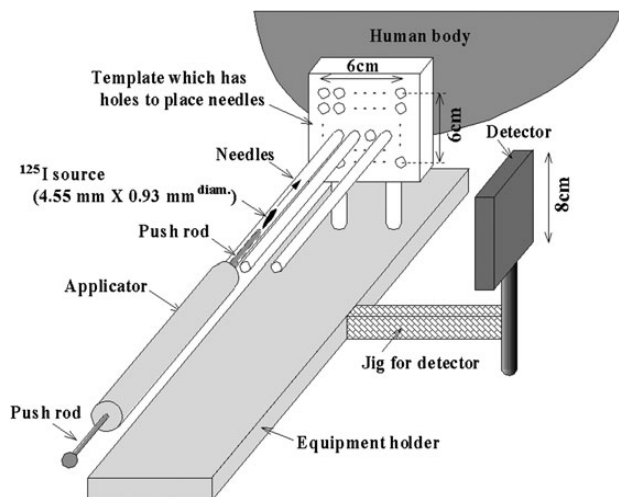
Fig. 1. Geometrical sketch of the proposed measurement for the implantation of ^{125}I source to the prostate. The figure is not drawn to scale. In this example, the detector has the height of 8 cm, which is larger than the region to place needles, 6cm.

these activities, the brachytherapy doses are kept at an appropriate level.

However, if the user makes a mistake in carrying out the guideline, the dose precision will become worse. One potential of mistakes is the replacement of sources at the different strengths utilized. TG64 also recommends that the users should measure 10% or more (ideally all) of the sources. In other words, a maximum of 90% of the sources are not measured by the users before usage. As the number of the measured sources increases, the quality assurance (QA) of the source strength, of course, becomes more reliable. In practice, a certain number of the sources would be measured, considering the tradeoff between the reliability and time or labor in accomplishing the QA procedure.

As a backup of QA, this study proposes a method of estimating the strength of the source while it is being implanted. Figure 1 illustrates the geometry of the proposed measurement for the implantation of an ^{125}I source in the prostate, for example. The sources are implanted in the human body using the applicator and push rod, through the needles. We propose that the detector is located near the needles and measures the amount of the X-rays from the ^{125}I during implantation. Using the measured signal, the source strength can be estimated. The needles are placed within a region of 6 cm × 6 cm, using the 'template', which has many holes separated by a constant interval of 5 mm. In the example illustrated in Fig. 1, the detector has a height of 8 cm so that the detector will cover the needle positions.

By performing the proposed measurement, one can detect human errors such as accidental replacements of the sources with those having incorrect strength. Another merit of the proposed method is that inappropriate strength may be detected among the sources that were not measured before

the implantation. If sources with inappropriate strength can be detected, it becomes possible to modify the treatment planning just after the implantation. For example, if the strength of the source actually implanted is found to be lower than the original treatment planning, one can increase the source so that the dose reaches the prescription. On the other hand, if the source strength is higher than the planning, one can reevaluate patient dosage early and prepare for the potential radiation damage to normal tissues irradiated. It may be possible to reduce the dose by increasing the distance between the sources.

The feasibility of this estimation technique has been previously suggested for a ^{125}I seed implanted through a single needle [13, 14]. The present study investigates the feasibility from a practical viewpoint, including the statistic uncertainty of the measured signals, using a detector applicable to the multi-needle geometry similar to the actual implantation.

MATERIALS AND METHODS

Principle for estimating moving-source strength
In actual implantations, the source is guided into the patient through the needle. The speed of the source varies because the source is moved manually. The measurement system for a constant speed is already commercially available, however, it is not applicable to the varied source speed. The methodology used to measure the source strength irrespective of the source speed was to perform the short-time measurement. The measurement should be started and finished while the source is in the region where the efficiency of the detector is constant. Examples of the parameters such as length of the region, counting time, distance between the detector and the source, are described in the following sections. During actual implantation, this region would be set at the exposed portion of the needle outside the patient.

Experiment
The source utilized was the ^{125}I seed (Oncoseed 6711, GE Healthcare Medi-Physics Inc., Arlington Heights, IL). At first, the air-kerma strength of the source was measured with a well-type ionization chamber (HDR1000 Plus, Standard Imaging Inc., Middleton, WI) to be 0.432 U. Here, the symbol U denotes the unit combination μGym^2h^{-1}, as defined in TG43U1 [10]. This means that the source had the air-kerma rate of 0.432 μGyh^{-1} at a distance of 1 m from the source in air, perpendicularly to the central axis of the cylindrical source. The chamber utilized was calibrated at the University of Wisconsin, a member of the Accredited Dosimetry Calibration Laboratory.

Following this measurement, the requirement for the counting time to estimate the strength regardless of the source speed was investigated. Among the components in Fig. 1, this study used one needle, one source, an applicator, a push rod and a detector. The experimental setup is shown
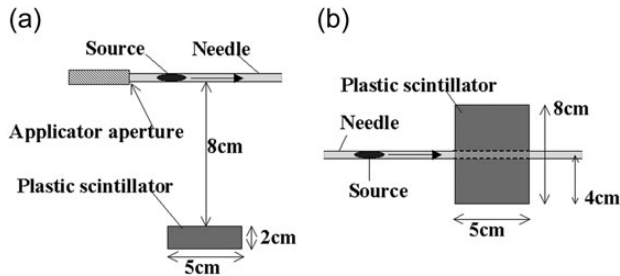
Fig. 2. Experimental setup: (**a**) top view; and (**b**) side view. Figures are not drawn to scale.

in Fig. 2. This is a simulation of the geometry in Fig. 1. The source was moved into the needle (#918201, Bard Inc., Murray Hill, NJ) by an applicator and a push rod (200-TPV, Mick Radio-Nuclear Instruments Inc., Mount Vernon, NY). The position and speed of the source were controlled with an electric actuator (EZS3D025-A, Oriental Motor Inc., Tokyo, Japan) connected to the push rod. In this experiment, the source was not implanted but moved only in a needle. The detector utilized was a plastic scintillation detector (G-tech Inc., Saitama, Japan) consisting of the scintillator (EJ200, Eljen Technology Inc., Sweetwater, TX), with dimensions of $8\ \mathrm{cm} \times 5\ \mathrm{cm} \times 2\ \mathrm{cm}$, and the photomultiplier tube (H7416, Hamamatsu Photonics Inc., Shizuoka, Japan). The height of the scintillator, 8 cm, was chosen so that the detector was applicable to the multineedle geometry shown in Fig. 1. The detector was operated at -1500 V. For the clearance around the needle and applicator, the detector was set at 8 cm from the needle. The signal from the photomultiplier tube was then analyzed with the amplifier (4417, Clear Pulse Inc., Tokyo, Japan) and single channel analyzer (1150, Clear Pulse Inc.), in turn, and finally counted with the scaler (3340, Clear Pulse Inc.).

The response of the detector, dependent on source position along the needle, was first measured for the static source. In this case, 1-s measurements were conducted 10 times. Following this, the reading for the moving source was investigated for its dependence on the counting time. The source speed was set at a constant value of 2, 5, 10 and 20 cm s^{-1} as examples of manual implantations, and the measurements were repeated five times at each source speed. The results were compared between the moving and static sources in order to estimate how much the measured value varied as the source speed changed.

RESULTS

The detector responses measured for the static source (dependent on its position) are shown in Fig. 3. The error bars show the standard deviation for 10 measurements. The counting rate of the background signal was 29 ± 5 cps, and this was subtracted from that of the signal for the static
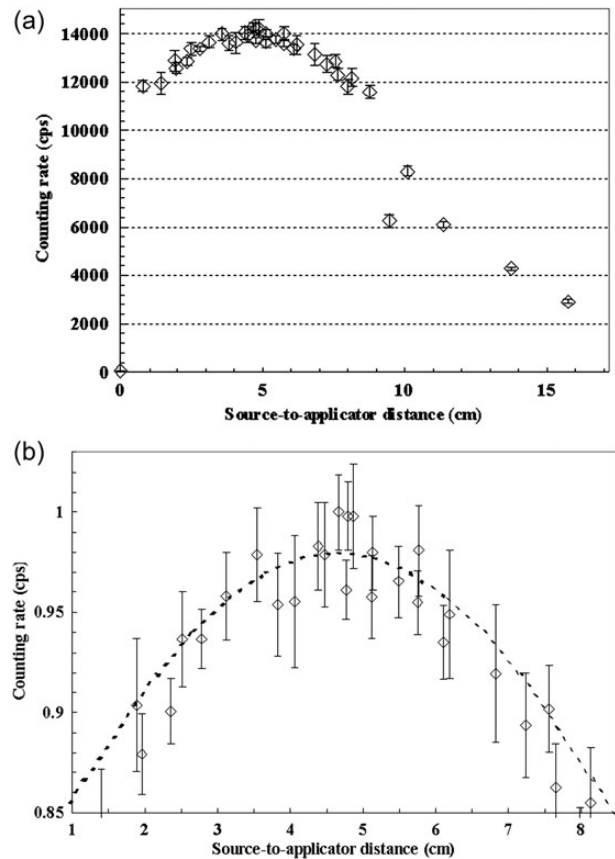
Fig. 3. Dependence of counting rate on source position: (**a**) raw data, and (**b**) relative distribution normalized at 4.66 cm where the counting ratio reaches its maximum of 14 245 cps. Dashed line is a visual guide.

source, shown in Fig. 3. After the source came out of the applicator, the reading rapidly increased, and the maximum among the measured values was 14 245 cps at 4.66 cm. The decrease in reading at around 10 cm was due to shielding by a part of the applicator. In order to show the relative change in the counting rate, the distribution is shown in Fig. 3b after normalization at 4.66 cm to the unity. The dashed line is a visual guide. This is the integration of the function $1/r^2$ with the dimensions of the detector ($8\ \mathrm{cm} \times 5\ \mathrm{cm} \times 2\ \mathrm{cm}$), where r denotes the distance from the source to the detector. The change in the counting rate was about 5% at positions from approximately 3–6 cm (3-cm length), and 10% from about 2–7 cm (5-cm length).

From the principle of this method, it was necessary to start and stop the measurement while the source was in the region where the detector response was constant. We tested the measurement times of 50 ms, 100 ms, 200 ms and 300 ms, during which the source moved 1 cm, 2 cm, 4 cm and 6 cm at 20 cm s^{-1}, respectively.

Raw data for the moving source at the counting time for the duration 100 ms is shown in Fig. 4. The measurements for the moving sources were performed as five runs. From

the measured values of each run, the maximum was utilized in further analyses, assuming that the source reached the position with the highest detector response when the maximum count for each run was obtained. The values in Table 1 for the moving source are the average and standard deviation of the maximum for each of the five runs. For the static source, the counting rate of 14 245 cps in Fig. 3 at the 4.66 cm position was converted to the value for the counting times of 50 ms, 100 ms, 200 ms and 300 ms, as shown in Table 1. Assuming that the true result was obtained with the conventional static source measurement, the ratio of the results for the moving source to that for the static source (moving/static) are shown in Fig. 5 in order to investigate how accurate the result for the moving source was. Among the counting times utilized, the 200 ms results corresponded with the ratio (moving/static) of 0.98 ± 0.04.

By way of comparison, the result at the 300-ms counting time is also shown in Fig. 5. In this case, the value measured for the moving source was drastically lower than that for the static source. This is because the counting time was too long to keep the source inside the aforementioned 3 cm-long region with the detector response changing by 5%, or the 4 cm-long region with the detector response changing by 10%. In this case, the source moved 6 cm during the measurement and reached the region with a lower detector response.

Among the counting times utilized, relatively good agreements were observed between the ratios (moving/static) of 1.00 ± 0.02 for 50 ms and 1.00 ± 0.04 for 100 ms. For these counting times, the lower source speeds of 2 cm s^{-1}, 5 cm s^{-1} and 10 cm s^{-1} were also tested. The results are shown in Fig. 6. The result for the moving source increased as the speed decreased. This is due to the fluctuation in the rate of

the decay process. At 2 cm s^{-1}, e.g., 30 readings were available at the counting time of 50 ms, and 15 readings at 100 ms, while the source passed a 3 cm-long region with the detector response change of 5%. As mentioned before, the result for the moving source was the maximum for each run, while that for the static source was the average of 10 measurements. This is a potential origin of systematic error (Type A) of this principle [15]. This cannot be corrected because the source speed is supposed to be unknown in actual implantations. The measured values for a counting were about 700 counts at 100 ms and 1400 counts at 200 ms, with standard deviations of about 4 and 3%, respectively. Reflecting this as an aspect of the origin of the uncertainty, the ratio (moving/static) has a standard deviation of 1.8–5.8% for 50 ms, and 2.2–3.7% for 100 ms [15]. The combined standard uncertainty (CSU) for the coverage factor, k (set at 1), was estimated using the procedure by Dolan $et\ al.$ [16]. The components considered were the influence of the uncertainty of the source speed (Type A) and the fluctuation of the counting rate ratio (moving/static) among the five runs (Type B). The results are listed in Table 2. For Type A, a rectangular probability distribution was assumed for source speed from 2–20 cm s^{-1}. Type B uncertainty was from 1.8% at 20 cm s^{-1} to 5.8% at 10 cm s^{-1} for 50 ms counting, and 2.2% at 2 cm s^{-1} to 3.7% at 20 cm s^{-1} for 100 ms. The maximum of Type B uncertainty for each counting time is listed in Table 2. Finally, Type A and Type B components were combined in quadrature to obtain the CSU ($k = 1$). The CSU ($k = 1$) for the source speed of 2–20 cm s^{-1} was 6.2% for 50 ms and 4.0% for 100 ms. In guideline TG64, the tolerance difference of the source strengths between the measurement by the user and the statement by the manufacturer is 3–5%. The precision of the source strength estimation demonstrated in this study is similar to this tolerance level.
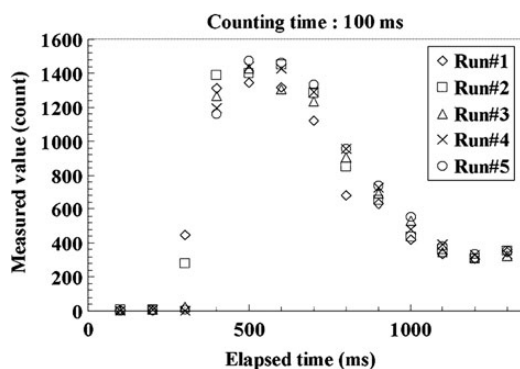
DISCUSSION

At 20 cm s^{-1}, the source moves 1 cm in 50 ms, and 2 cm in 100 ms. In the actual implantations, this measurement will be performed when the exposed portion of the needle outside the patient has sufficient length. TG64 requires that the users should measure 10% or more of the sources. In several cases, the exposed portion is expected to be long enough within the frequency of 10% or more. Another option is to change the counting time, dependent on the length of the exposed portion, and that will influence the precision of this method.

Fig. 4. Measured value at counting time of 100 ms for source moving at 20 cm s^{-1}.

Table 1. Measured values (count) for static and moving sources

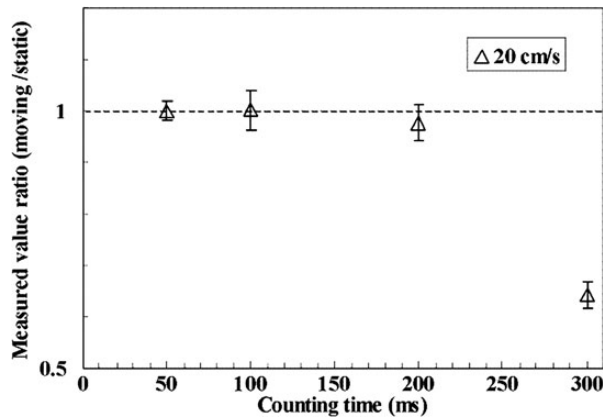| Measurement time (ms)	50	100	200	300
Static source	711 ± 9	1422 ± 19	2843 ± 38	4265 ± 57
Source moving at 20 cm s^{-1}	710 ± 9	1424 ± 49	2776 ± 94	2742 ± 106

Fig. 5. Comparison of measured values of moving source to static source at 20 cm s^{-1}.
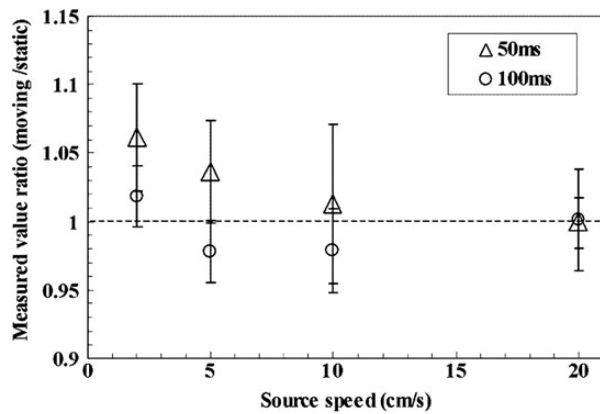

Fig. 6. Measured value ratio of moving to static source at varied source speed for 50 ms and 100 ms counting.

Table 2. Uncertainty estimates

Components	Measurement time	
	50	**100**
Type A: Error due to unknown source speed (2–20 cm s^{-1}) (%)	2.3	1.4
Type B: Fluctuation of the counting rate ratio (moving/static) among five runs (%)	5.8	3.7
Combined standard uncertainty ($k = 1$) (%)	6.2	4.0

The proposed method offers a check of the strength of the source that is actually being implanted during the implantations. One merit of this approach is that incidents involving human error, such as accidentally using sources with inappropriate strength, can be detected. This could be potentially useful in brachytherapy cases involving mixed source strengths, mixed isotopes, and mechanized delivery of the sources. For example, in treatments with mixed source strengths, one of the most likely types of mistake is the replacement of a source with one of a different strength. In this situation, the difference in the strength of the sources is generally > 3–5%, which is the tolerance recommended in TG64, and the proposed method may be able to detect this mistake, even if the precision and frequency achieved do not match the recommendation in TG64.

CONCLUSION

This report suggests a proposed method as feasible for estimating source strength during the implantation procedure, regardless of the source speed. The combined standard uncertainty, with the coverage factor of 1, was within 4% accuracy in estimating the strength of ^{125}I seed with an air kerma of 0.432 U moving at values between 2 and 20 cm s^{-1} for the geometry described in this study at the counting time of 100 ms. The main factors determining the accuracy of the proposed method, i.e. distance between the detector and the source pathway and counting time, should be chosen depending on the available clinical geometry and the required tolerence level of the source strength. The method proposed is a potential QA backup option for source strength.

ACKNOWLEDGEMENTS

FUNDING

REFERENCES

1. Nath R, Anderson L-L, Luxton G *et al*. Dosimetry of interstitial brachytherapy sources: recommendation of the AAPM Radiation Therapy Committee Task Group No. 43. *Med Phys* 1995;**22**:209–34.
2. Tanaka K, Tateoka K, Asanuma O *et al*. A dosimetry study of the Oncoseed 6711 using glass rod dosimeters and EGS5 Monte Carlo code in a geometry lacking radiation equilibrium scatter conditions. *Med Phys* 2011;**38**:3069–76.
3. Deufel C, Furutani K-M, Thomson R-M *et al*. Mathematical solutions of the TG-43 geometry function for curved line, ring,

disk, sphere, dome and annulus sources, and applications for quality assurance. *Phys Med Biol* 2011;**56**:5429–44.

4. Chen Z-J, Nath R. A systematic evaluation of the dose-rate constant determined by photon spectrometry for 21 different models of low-energy photon-emitting brachytherapy sources. *Phys Med Biol* 2010;**55**:6089–104.

5. Westendorp H, Kattevilder R, van 't Riet A *et al*. Objective automated assessment of time trends in prostate edema after ^{125}I implantation. *Brachytherapy* 2012;**11**:327–33.

6. Keyes M, Spadinger I, Liu M *et al*. Rectal toxicity and rectal dosimetry in low-dose-rate ^{125}I permanent prostate implants: a long-term study in 1006 patients. *Brachytherapy* 2012;**11**:199–208.

7. Jarusevicius L, Inciura A, Juozaityte E *et al*. Comparison of implant quality between loose and intra-operatively linked iodine-125 seeds in prostate cancer brachytherapy. *J Radiat Res* 2012;**53**:439–46.

8. Yoshida K, Ueda M, Yamazaki H *et al*. Interstitial brachytherapy using virtual planning and doppler transrectal ultrasonography guidance for internal iliac lymph node metastasis. *J Radiat Res* 2012;**53**:154–8.

9. Hanada T, Yorozu A, Ohashi T *et al*. Evaluation of the dosimetric parameters for ^{125}I brachytherapy determined in prostate medium using CT images. *J Radiat Res* 2010;**51**:553–61.

10. Rivard M-J, Coursey B-M, DeWerd L-A *et al*. Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations. *Med Phys* 2004;**31**:633–74.

11. Yu Y, Anderson L-L, Li Z *et al*. Permanent prostate seed implant brachytherapy: report of the American Association of Physicists in Medicine Task Group No. 64. *Med Phys* 1999;**26**:2054–76.

12. Butler WM, Bice W-S, Jr, DeWerd L-A *et al*. Third-party brachytherapy source calibrations and physicist responsibilities: report of the AAPM Low Energy Brachytherapy Source Calibration Working Group. *Med Phys* 2008;**35**:3860–5.

13. Tanaka K, Tateoka K, Asanuma O *et al*. Feasibility study of a novel technique to measure instantly the strength of ^{125}I seeds being implanted. *Med Phys* 2011;**38**:3578.

14. Tanaka K, Tateoka K, Asanuma O *et al*. Development of strength evaluation method of moving sources for brachytherapy. *Jp J Med Phys* 2011;**31**:209 (in Japanese).

15. Taylor BN, Kuyatt CE. Guidelines for evaluating and expressing the uncertainty of NIST measurement results. NIST Technical Note 1297. Washington, DC: US Government Printing Office, 1994, 1–25.

16. Dolan J, Li Z, Williamson J-F *et al*. Monte Carlo and experimental dosimetry of an ^{125}I brachytherapy seed. *Med Phys* 2006;**33**:4675–84.