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Original Article

Ultrasound guided I–125 permanent prostate implants: seed calibration and radiation exposure levels

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Abstract

Purpose: (1) To present data on I–125 seed calibration in a clinical setting so that reasonable tolerance levels can be set for the discrepancy in seed strength between manufacturer specified value and institution measured value; (2) To present data on measured exposure rates and estimate radiation exposure levels associated with I–125 prostate implants.

Methods and Materials: Ten percent of each batch for 50 batches of I–125 seeds were calibrated using an HDR 1000 PLUS well chamber with a single source holder. Exposure rates due to I–125 were measured by survey meters with a scintillation probe designed for low energy photon counting, as well as a survey meter of the ionization chamber type. Exposure rates of an unshielded I–125 seed, a needle loaded with three seeds, and 54 prostate implant patients immediately after the implant were obtained.

Results: Compared to the manufacturer stated midrange seed strength for a batch of seeds, the average seed strength of sampled seeds had maximum deviations of ±8%, however for 45 out of 50 batches the deviation was less than ±5%. Measured single seed strength deviated up to ±12% from the manufacturer stated midrange value, and between –11% to 7% from the mean of the sampled batch. The exposure rate of a 1.39×10^{7} Bq (0.375 mCi) unshielded I–125 seed was about 1.548×10^{-8}C/kgh (0.06 mR/h) at 1 m, and 1.29×10^{-6}C/kgh (5 mR/h) at 10 cm. For a needle loaded with three seeds, the exposure rate was 1.29×10^{-8}C/kgh (0.05 mR/h) at the handle, and 1.29×10^{-7}C/kgh (0.5 mR/h) along the shaft. For patients implanted with I–125 seeds in the prostate, the average exposure rate was 3.61×10^{-8}C/kgh (0.14 mR/h) at 1m, and 4.13×10^{-7}C/kgh (1.6 mR/h) at the pelvis surface.

Conclusions: For the mean seed strength a first action level should be set at a deviation of at least 5% deviation from the manufacturer stated midrange value. For individual seeds, a first action level set at 10% deviation from the manufacturer stated midrange value seems reasonable. A person performing I–125 seed calibration or seed loading could receive up to 0.5 mSv (50 mR) per case to the hands. In the first year following an I–125 prostate implant, the spouse of the patient could receive slightly over 1mSv from the I–125 in the patient. A co-worker should not receive more than 0.5 mSv from the patient.

Keywords

I–125; prostate; implant; brachytherapy; calibration; exposure

INTRODUCTION

Ultrasound guided transperineal prostate implant was pioneered by Holm et al.[1] in 1983, and was introduced to North America by Ragde et al.[2] in 1985. In this technique, radioactive I–125 or Pd–103 seeds are implanted into the prostate using either preloaded needles or a Mick applicator under the guidance of ultrasound imaging. Encouraged by promising results in terms of freedom from biochemical failure and relatively low toxicity, many clinics in North America and Europe are now using this technique for the treatment of early stage prostate cancer.[3]

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Gamma rays or x-rays emitted by I–125 or Pd–103 seeds are very low in energy, with the average being 27.4 keV for Amersham model 6711 I–125 seeds and 21 keV for Pd–103 seeds.[4] The low energy compared to the more conventional brachytherapy sources such as Cs–137 and Ir–192 makes I–125 or Pd–103 seeds more difficult to calibrate accurately. The National Institute of Standards and Technology (NIST) in the US has changed the I–125 air-kerma strength standard in January 1999, and a NIST standard for Pd–103 has been introduced only recently.

Quality assurance standards for brachytherapy sources in documents such as AAPM TG–56 report[5] and TG–40 report[6] are based principally on data for Cs–137 and Ir–192 sources. These reports recommend that for a batch of seeds, the measured mean seed strength should be within 3% of the manufacturer's specified value, and the measured strength for an individual seed should have a maximum 5% deviation from the mean. Although I–125 sources have been used for prostate implants since the 1970s, the applicability of these recommended standards to low energy sources such as I–125 and Pd–103 has still not been established. We present our I–125 seed calibration data here in the hope that it will help in setting up proper standards for I–125. Also, there is a lack of published data on exposure rates associated with I–125 prostate implants. We put forward our results so that estimates of staff and public exposure levels can be made based on measured data.

METHODS AND MATERIALS

Seed calibration

At our institution we use model 6711 I–125 seeds from Nycomed Amersham for prostate implants. Before July 1999, Nycomed Amersham specified the seed strength in ranges of apparent activity in mCi, where the definition of mCi is in terms of the NIST 85 standard. Since July 1999 Nycomed Amersham has adopted the NIST 99 standard for the air kerma strength for I–125 seeds. All the data in this paper were acquired before July 1999, hence the definition of mCi is in NIST 85 standard. We have used seeds in the 0.47–0.50 mCi range, and more recently seeds in the 0.40–0.42 mCi range. Following the recommendation of the AAPM Task Group 56,[5] at least 10% of each batch of seeds are assayed in the clinic to verify the seed strength stated by the manufacturer. The seeds are assayed individually in a single source holder, using an HDR 1000 PLUS well chamber from Standard Imaging, and a model 35614EBS Keithley electrometer. The use of the single source holder ensures that each seed is measured in the same geometry with respect to the well chamber. The well chamber and the electrometer were separately calibrated by an Accredited Dosimetry Calibration Laboratory (ADCL) in the U.S. The well chamber was calibrated with our single source holder to ensure that the measurement geometry is the same as in our clinic. The I–125 calibration for the well chamber is classified by the ADCL as class III, which means that the accuracy is ±5% with a confidence limit of 95%. The electrometer calibration is specified by the ADCL to have an accuracy of ±0.5% in the range of 10–1999 pA, although when we perform a single seed calibration using the current mode the reading is in the 2–3 pA range.

The seed can be calibrated either in charge collection mode or in current mode. We have calibrated seeds using both modes in parallel, and found that the results agree within 1%. Since using the current mode makes the calibration much faster, we have chosen to use that mode for routine seed calibration.

Survey meters for the measurement of exposure rates from I–125 seeds

Ion chamber type survey meters calibrated with Cs–137 typically under-respond by more than 50% at I–125 photon energies. TG–56 recommends that a survey meter with a scintillation probe designed for low energy photon counting should be used. Following this recommendation, we acquired a Ludlum model 3 survey meter with a model 44–3 low energy gamma scintillator. The meter was calibrated by the manufacturer using a 2812 Bq (0.076 μCi) Iodine 129 source, which emits photons with energies from a few keV to 40 keV. The specification of the calibration accuracy is ±10%. Upon receiving the survey meter, we performed an in house calibration check with an I–125 source whose apparent activity was known to be 1.52×10^7 Bq (0.41 mCi), and found that the measured exposure rate at 1m from the source on the bisector axis of the seed agreed with the calculated value within 3%.

While the Ludlum survey meter is very sensitive to low level exposure, it is limited to measuring a

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maximum exposure rate of 1.29×10^{-7}C/kgh (0.5 mR/h). Some of the exposure rates we need to measure are above this level, therefore we made use of an ion chamber type Nuclear Enterprises PDR1 survey meter. By comparing exposure rate readings with the Ludlum survey meter, we found that the Nuclear Enterprises survey meter reading required a multiplication factor of 2.4 for I–125 photons. This survey meter is used for measurements of I–125 exposure rates greater than 1.29×10^{-7}C/kgh (0.5 mR/h).

More recently we have acquired another survey meter, the BICRON Micro Rem LE meter. The manufacturer states that this survey meter has a tissue equivalent scintillator, and with the low energy option it can measure gamma and X-rays from 17 keV to 1.3 MeV. The main advantage of this meter is the wide range of readings possible, from 0.04 μSv/h up to 2 mSv/h. The meter was calibrated by the manufacturer using Cs–137, and the accuracy specification is within 10% at Cs–137 energy when the reading is within 20% to 100% of full scale. We tested the response of this meter at I–125 energy by measuring the exposure rate of a 1.39×10^7 Bq (0.375 mCi) I–125 seed at different distances. The results were compared to calculated values as well as to readings obtained by the Ludlum meter. We find that the Micro Rem LE meter under-responds by 40–50% compared to the Ludlum meter and calculated values (i.e. the reading from the Micro Rem LE meter is only about half of the reading from the Ludlum meter). This is contrary to the energy response curve in the user's manual, which showed a fairly flat response in the whole range from 17 keV to 1.3 MeV, with a 10% under-response in the low energy end. Upon this finding we contacted the manufacturer and obtained manufacturer's own test results. While the manufacturer did not perform any test for I–125 (average energy 27.4 keV for model 6711 seeds), the test results supplied by the manufacturer show that at 20 keV the meter under-responds by 53%, and at 38 keV the meter over-responds by 5%. These data in conjunction with our own convinced us that the energy response curve in the user's manual is erroneous. To correct for the discovered under-response, a multiplication factor of 1.8 is applied for I–125 exposure rates measured with this meter. (The meter is labeled in μRem/h. The factor 1.8 includes a conversion factor from Rem to Roentgen at I–125 energy.)

Survey meter for the measurement of exposure rates from a C-arm X-ray fluoroscopy unit

During the implant procedure we use a C-arm X-ray fluoroscopy unit (Siemens ARCOSKOP 110-OP) to help visualize needles and seeds. The exposure rate from this X-ray unit was measured by a Berthold LB1200 survey meter calibrated annually by a company approved by the Atomic Energy Control Board of Canada.

Measurement of exposure rates around patients

At our institution, we perform an exposure rate measurement on every patient after the patient is transferred to the recovery room. According to the NRC Regulatory Guide 8.39,[7] the patient can be released based on administered activity if the administered I–125 activity is less than 9 mCi. Since I–125 prostate implants always exceed this amount of administered activity, with typical values of around 40 mCi, exposure rate measurement on the patient is necessary.

Although NRC only requires the exposure rate at 1m from the patient, we have measured the exposure rate on the surface of the abdomen as well, in order to gain a sense of the maximum possible exposure to persons around the patient. For the measurement at 1m, a survey meter is held with the detector window toward the abdomen of the patient. For the measurement on the surface of the abdomen, it is usually carried out when the patient is on the bed wearing a hospital gown with a bed sheet covering the abdomen.

RESULTS

Seed calibration

The assay results of 50 batches of seeds are presented in Figures 1–3. For batches 1–46 the seed apparent activity range specified by the manufacturer is 0.47–0.50 mCi, and for batches 47 and higher, the apparent activity range is 0.40–0.42 mCi. Typically one batch has about 90 seeds, and 9–10 seeds are individually assayed. Figure 1 shows the mean seed strength of assayed seeds expressed as the percent deviation from the manufacturer specified midrange value. Two batches had a mean value at about ±8% deviation from the specified midrange value. Forty five out of 50 batches had a

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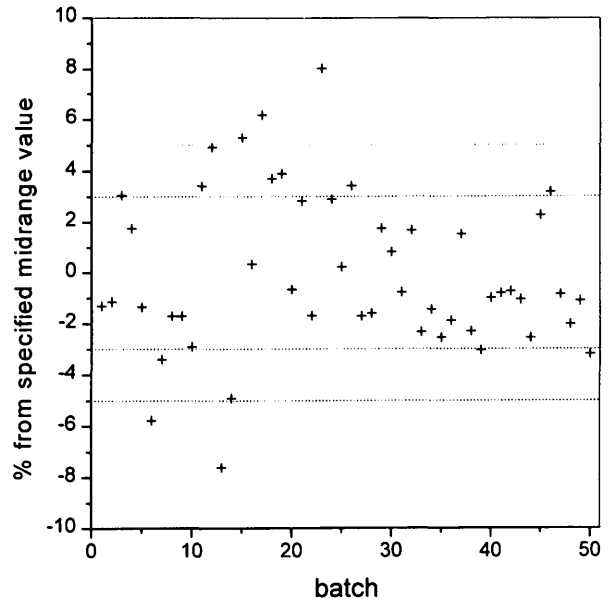

Figure 1. Measured average seed strength, expressed as percentage deviation from the vendor specified midrange seed strength.

mean value within the ±5% level, and 34 out of 50 batches had a mean value within the ±3% level. The batches in Figure 1 are numbered chronologically covering a time period of 14 months. It appears that the more recent batches have smaller deviations in the mean seed strength from specified midrange values.

Figure 2 shows the maximum and minimum seed strength values among the seeds assayed for a batch. In Figure 2a the results are expressed as the percent deviation from the manufacturer's specified midrange value. Deviations up to about ±12% have been found. In Figure 2b the results are expressed as the percent deviation from the mean of assayed seeds, and the values range from –11 to 7 %, much greater than the TG–56 value.

Figure 3 shows the sample standard deviation σ_{n-1}, which is an indicator of the spread in measured values for sampled seeds. Most of the values are in the 2–4% range, with a maximum of 4.7%.

Exposure rates from unshielded seeds

Measured exposure rates for an unshielded I–125 seed are listed in Table 1, along with calculated values assuming a point source. Note that when we established that a multiplication factor of 1.8 is needed for the Micro Rem LE meter readings, it was based on direct comparisons with the

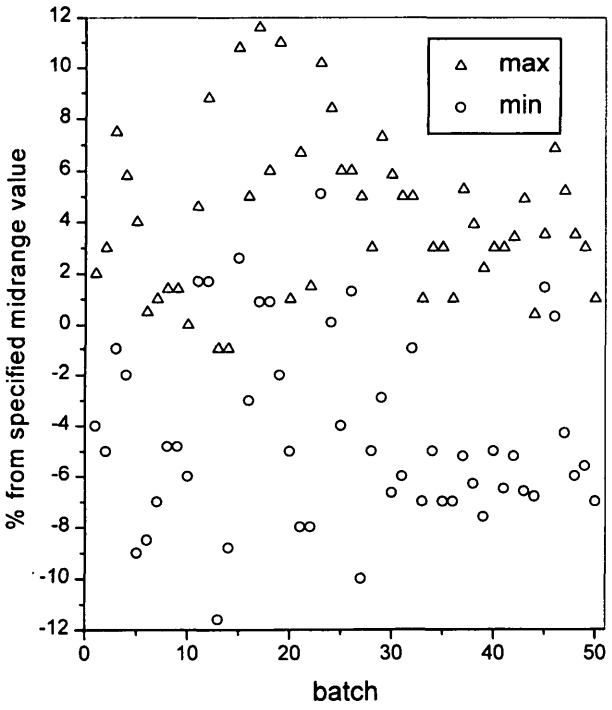

Figure 2a. Maximum and minimum seed strengths expressed as percentage deviation from the vendor specified midrange seed strength, expressed as percentage deviation from the mean of assayed seeds.

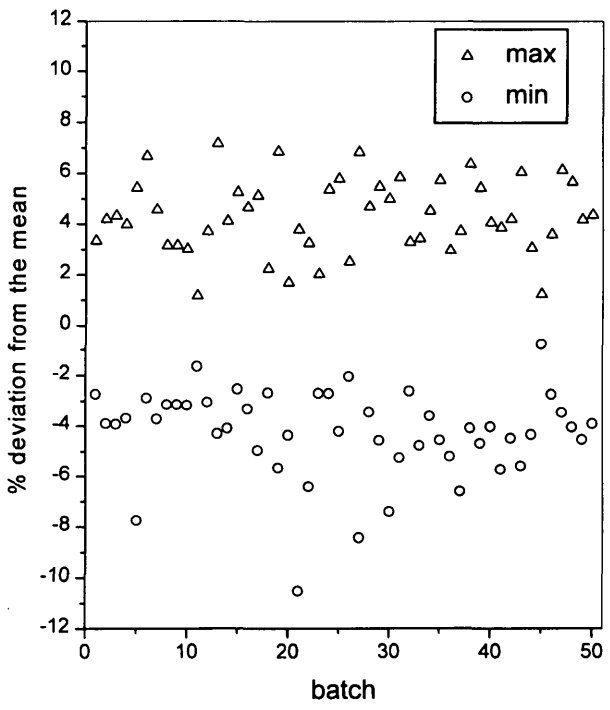

Figure 2b. Maximum and minimum seed strengths expressed as percentage deviation from the mean of assayed seeds.

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Table 1 Exposure rates of one 1.39x10⁷ Bq (0.375 mCi) I-125 seed. The measurement was performed with a Micro Rem LE meter, and a multiplication factor of 1.8 was applied to the nominal meter reading to correct the under-response of the meter. The calculated values were obtained by using a point source model AΓ/r², where A is the total apparent activity, Γ = 1.51 Rcm²mCi⁻¹h⁻¹ from TG-43, and r is the distance.

Distance (cm)	Scale used	Exposure rate 10–4C/kgh (mR/h)	Calculated value 10–4C/kgh (mR/h)	% difference
8	x100	19(7.2)	23(9.0)	−20
10	x100	12(4.5)	15(5.7)	−20
15	x10	5.9(2.3)	6.7(2.6)	−10
20	x10	3.4(1.3)	3.6(1.4)	−10
30	x10	1.8(0.68)	1.7(0.64)	7
50	x1	0.54(0.21)	0.59(0.23)	−10
60	x1	0.39(0.15)	0.41(0.16)	−4
100	x1	0.150(0.058)	0.147(0.057)	2

Ludlum meter. But because the maximum exposure rate that can be measured by the Ludlum meter is 1.29x10⁻⁷ C/kgh (0.5 mR/h), such a comparison was possible for the x1 and x10 scales but not for higher scales on the Micro Rem LE meter. In Table 1 the measured and calculated exposure rates at 8 cm and 10 cm differ by 20%. Since the x100 scale was used for these two measurements, the large difference could be attributed to the likelihood that the x100 scale requires a multiplication factor different from 1.8. Other factors that could have contributed to the error include the lack of correction for scatter and attenuation of radiation in the air, and uncertainty in the Γ value. Note that we performed the measurement on the bisector axis of the seed so that our results would not be affected by the anisotropy in radiation fluence.[8]

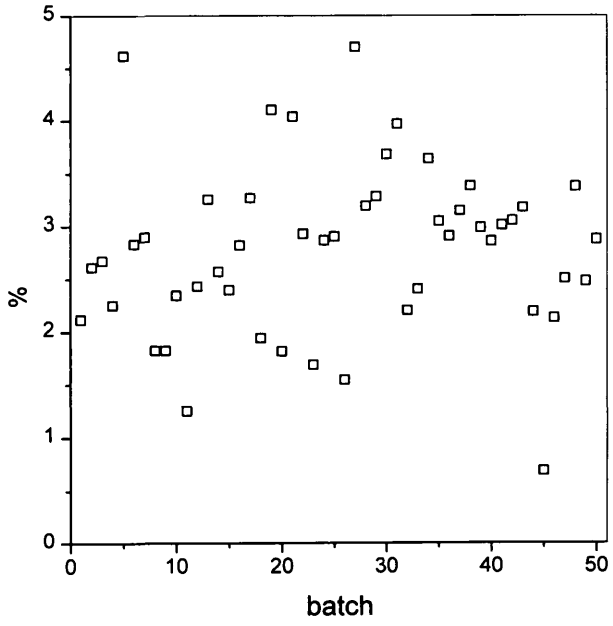

Figure 3. Standard deviation of seed strengths, expressed as the percentage of the vendor specified midrange seed strength.

Exposure rates from a loaded needle

When preloaded needles are used for prostate implants, the average number of seeds per needle is about three. Three I–125 seeds of nominal apparent activity 1.79x10⁷ Bq (0.485 mCi) per seed were loaded into an MD TECH 18 gauge needle for exposure rate measurements. The needle was prepared as if it was going to be used by the physician, with the three seeds in 1 cm spacing and the stylet pushed in. The results are: 6.2x10⁻⁶C/kgh (24 mR/h) at the tip, 1.29x10⁻⁷ C/kgh (0.5 mR/h) right beside the shaft where the seeds are located, and 1.29x10⁻⁸C/kgh (0.05 mR/h) at the handle.

Exposure rates from a needle cradle

Once the needles have been loaded with seeds, we place them in a needle cradle (Standard Imaging). We performed a measurement when 31 needles containing a total of 93 seeds (nominal apparent activity 1.78x10⁷ Bq or 0.48 mCi per seed) were inserted in the needle cradle. The exposure rate is the highest at the back of the needle cradle, at 2.06x10⁻⁶C/kgh (8 mR/h). At the side the rate is 3.87x10⁻⁷C/kgh (1.5 mR/h), and in the front (with cover off) it is only 1.29x10⁻⁹C/kgh (5μR/h). At 1 meter from the back of the needle cradle, the exposure rate is 2.06x10⁻⁸C/kgh (0.08 mR/h).

Exposure rates from prostate implant patients

Measured exposure rates on 54 prostate implant patients are presented in Figures 4 and 5. As shown in Figure 4, the exposure rate at 1m from the

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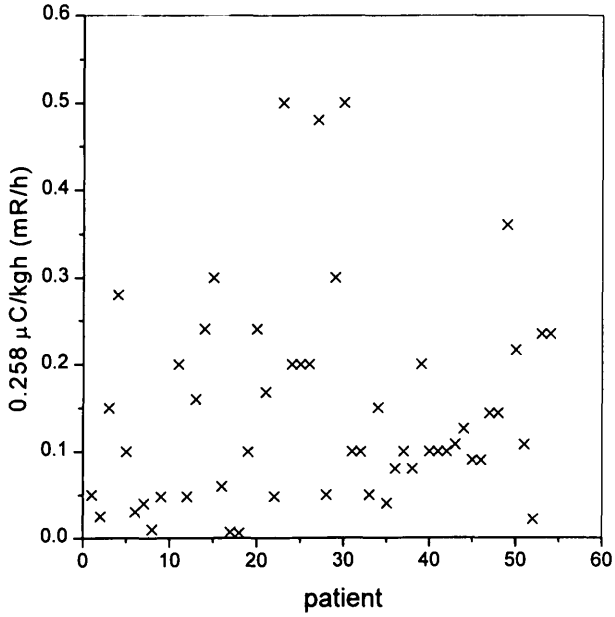

Figure 4. Exposure rates at 1 meter from the pelvis of patients implanted with I-125 seeds in the prostate. For the first 42 patients, a Ludlum meter was used. For patients numbered 43 and higher, a Micro Rem LE meter was used, and a multiplication factor of 1.8 was applied to correct for the meter underresponse.

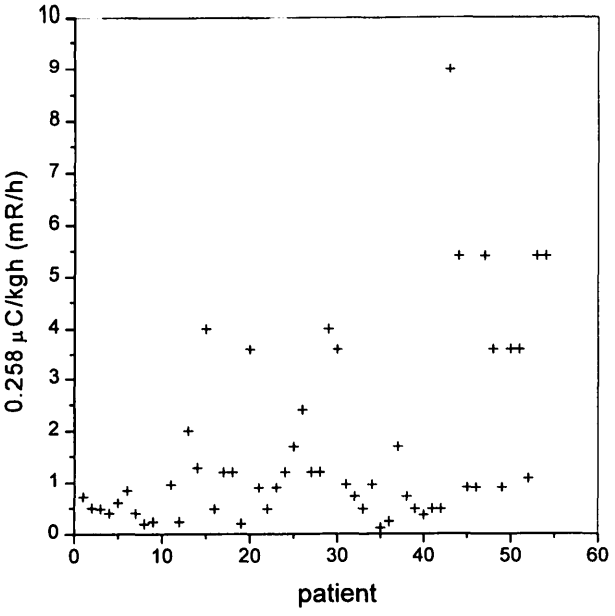

Figure 5. Exposure rates on the surface of the abdomen of patients implanted with I-125 seeds in the prostate. For the first 42 patients, a Ludlum meter was used if the exposure rate did not exceed 1.29x10^{-7} C/kgh (0.5 mR/h), otherwise a Nuclear Enterprises PDR1 survey meter was used with a correction factor of 2.4 multiplied to the meter reading. For patients numbered 43 and higher, a Micro Rem LE meter was used, and a multiplication factor of 1.8 was applied to correct for the meter underresponse.

patient's pelvis can be up to 1.29x10^{-7}C/kgh (0.5 mR/h), with an average value of 3.61x10^{-8}C/kgh (0.14 mR/h), and a standard deviation of 3.10x10^{-8}C/kgh (0.12 mR/h). The exposure rate on the surface of the abdomen is shown in Figure 5, with an average value of 4.13x10^{-7}C/kgh (1.6 mR/h), and a standard deviation of 4.39x10^{-7}C/kgh (1.7 mR/h). We have seen considerable variation in the results from patient to patient, which could likely be due to variations in the patient's shape and size, since the half value layer of the radiation emitted by I–125 seeds is about 2 cm of tissue. A high reading on the surface of the abdomen did not always correspond to a high reading at 1m, and vice versa, probably because the measurement at 1m is more dependent on how the survey meter is oriented toward the patient. The measurement on the surface of the abdomen is probably more accurate.

Exposure rate from a C-arm X-ray fluoroscopy unit

During the implant procedure our staff wear lead aprons and thyroid shields to protect from the radiation produced by the X-ray unit. The highest radiation level is received by the head of the physician, who sits closest to the patient and the direct X-ray field. When the beam is on, the exposure rate right beside the physician's head is measured to be about 2.58x10^{-5} C/kgh (100 mR/h). The accumulative beam on time for an implant is about 5 minutes.

DISCUSSION

Seed calibration tolerance levels

TG–56 and TG–40 recommend that, for brachytherapy sources in general, the tolerance between manufacturer and institution calibrations should be 3% for the mean of a batch, and individual sources should not deviate more than 5% from the mean. These recommendations were made based principally on data for Cs–137 and Ir–192 sources. The ADCL I–125 calibration for our well chamber had a ±5% error (two standard deviations). The NIST 85 standard for the I–125 air kerma strength also had a ±3–5% error. Adding these two sources of error in quadrature would yield a 6–7% error margin. In addition, seed suppliers such as Nycomed Amersham specified their sources in ranges. For example, we have used I–125 seeds in the 0.47–50 mCi range, which means an individual seed can have a ±3% deviation from the midrange

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value of 0.485 mCi. Seeds in other ranges can have an even wider range of deviations.

A recent survey[3] indicates that the acceptance criterion for user calibration in U.S. clinics ranges from 2–20%. Based on our results and the sources of uncertainties that exist at present, we feel that the tolerance level for the mean of a batch of seeds should be at least ±5%, and the tolerance level for individual seeds should be at least ±10%, from the manufacturer stated midrange value. These levels of tolerance should not affect the quality of the I–125 prostate implants. Typically, I–125 prostate implants are prescribed to 144 Gy (TG–43 dosimetry) minimum peripheral dose (mPD). The mPD isodose line is located in a region of high dose gradient, which is usually ⩾15 Gy/mm. This means that a 10% difference in dose corresponds to a shift of ⩽1 mm in the mPD isodose line. On the other hand, it has been reported[9] that the error in seed placement is usually a few millimeters. The limitations of mPD as a dose prescription reference due to the mPD isodose line being located in a region of high dose gradient have been discussed in the literature.[10]

Estimated staff exposure levels

If preloaded needles are used, staff exposure to radiation from the seeds is present during the following steps: (a) seed calibration; (b) needle loading; (c) needle planting. During steps (a) and (b), the operator stands behind a shield, only the hands are in the direct field of radiation. If the Mick applicator is used, seeds are stored in magazines and as a result staff exposure from steps (b) and (c) are virtually eliminated.

Seed calibration

When we receive seeds, we use the seed sorter (Standard Imaging) for seed sorting and storage. This device has 10 wells, and we usually place 10 seeds in one well. A typical implant will use 70–95 seeds. By making use of this device, during seed calibration or needle loading, our staff is exposed to a maximum of 10 unshielded seeds at one time. While picking up seeds with tweezers, the hand is about 8 cm from the seeds. Assuming 30 minutes of direct hand exposure to 10 seeds per case, at 1.29×10^{-5} C/kgh (50 mR/h), this translates to 0.25 mSv. The total exposure to the hand is estimated to be up to 0.50 mSv when other activities such as pouring seeds from the bottle and sorting the seeds are considered.

Needle loading

We perform needle loading with the seed slider and seed sorter (Standard Imaging). Although a needle loading session can be more than one hour for one implant, a lot of the time is spent on preparation while all of the seeds are in shielded positions. Assuming an average of 30 needles per implant, 1 minute to load one needle, and hands at 8 cm from unshielded seeds, we estimate that a seed loader's hand can receive up to 0.25–0.50 mSv per implant.

Our estimates for the exposure to the hand are consistent with the numbers recorded by TLD ring badges. Our ring badges can detect a dose over 0.1 mSv. The recorded numbers for radiation exposure vary between persons, with nonzero readings for some and zero for others, a reflection of the speed each individual works with seeds. The highest radiation exposure to the ring badge we have recorded is 0.4 mSv per implant, which includes radiation from both seed calibration and needle loading.

Needle planting

The physician who inserts needles into the patient receives the most radiation during the procedure, from holding preloaded needles and from scattered radiation of the fluoroscopy unit. The needle cradle's front end is positioned toward the physician, so exposure from the needle cradle is negligible.

Assuming 30 needles per implant, 3 seeds per needle, and the physician holding the needle for one minute per needle, at 1.29×10^{-8} C/kgh (0.05 mR/h) at the handle and 1.29×10^{-7} C/kgh (0.5 mR/h) at the shaft, the physician's hands could receive 6.45×10^{-9} C/kg–6.45×10^{-8} C/kg (0.025–0.25 mR) per implant. We note that the NRC occupational exposure annual dose limit for extremity is 500 mSv (or 50,000 mR).

The accumulated beam-on time of the C-arm X-ray unit is approximately 5 minutes per implant. At a rate of 2.58×10^{-5} C/kgh (100 mR/h), the physician's eyes and head will receive about 0.1 mSv per implant. Using a tissue weighting factor

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of 0.025,[11] this translates to a whole body effective dose of 0.0025 mSv. We note that ICRP60 recommends an annual equivalent dose limit in the lens of the eye of 15 mSv for the public, and 150 mSv for occupational exposure, while for the whole body effective dose the limit is 1 mSv for the public and 20 mSv for occupational exposure. The physician can perform about 150 implants a year before the dose limit for the lens of the eye for the public is reached.

Estimated exposure levels to patient's immediate family and coworkers

In the first year following the I–125 implant, the exposure received by those people who have daily contact with the patient can be calculated from the formula[7]

$$H = 20R_0T, \quad \text{Eq. (1)}$$

where H is the dose equivalent received in the first year in mSv, R_0 is the initial exposure rate immediately after the implant in mR/h, and T is the occupancy factor which accounts for the fraction of time spent with the patient in the first year. This formula is derived from the law of exponential decay, integrating for one full year using the half-life of 59.4 days for I–125. In NRC Regulatory Guide 8.39,[7] H is set at 5mSv, T is set to ¼, and a patient release criterion of R_0 under 1 mR/h at 1m from an I–125 implant patient is specified.

The person who potentially could receive the highest exposure from the patient is the patient's spouse. Assuming the spouse sleeps with the patient 8 hours a day hence T = 1/3, and using an initial exposure rate of 4.13×10^{-7} C/kgh (1.6 mR/h) at pelvis surface, we arrive at a value of 11 mSv. However, we must bear in mind such an estimate is very exaggerated because most parts of the spouse's body should be at a considerable distance from the patient's pelvis. Also, when the patient sleeps with the side or back facing the spouse, the exposure rate to the spouse should be much lower. An estimate based on the exposure rate at 1m should be a more realistic reflection of the possible exposure to the spouse. Using $R_0 = 3.61 \times 10^{-8}$ C/kgh (0.14 mR/h) and T = 1/3, one finds that the spouse is likely to receive 0.9 mSv in the first year from sleeping together with the patient. The overall exposure to the spouse could be more than 1mSv but should be less than 5 mSv. Since the half value layer of I–125 radiation is about 2 cm of tissue, the above quoted numbers only reflect the dose received by shallow tissues. To arrive at the whole body effective dose, one should apply a weighting factor of about 0.3 or less.

A co-worker of the patient is very unlikely to be within 1m range of the patient for more than 6 hours a day every day. With the assumption of 5 working days a week, 6 hours a day exposure at 1m from patient, T = (5/7)(1/4), and an initial exposure rate of $.61 \times 10^{-8}$ C/kgh (0.14 mR/h), the shallow tissues of the coworker could receive 0.5 mSv in the year following the patient's implant. If the co-worker keeps a larger distance from the patient, the amount of exposure can be kept much lower.

In summary, we recommend that in a clinic the first action level for I–125 seed calibration should be at least 5% deviation from the manufacturer's stated midrange value for the mean of the batch, and 10% for a single seed. Radiation exposure levels to staff are low. Radiation exposure to the public from an I–125 prostate implant patient is also low, with his spouse being the only person who could possibly receive more than 1 mSv, but no one would receive more than 5 mSv. We also find that survey meters calibrated with a Cs–137 source typically under-respond at I–125 energies by a factor of about 2. This problem could be eliminated if a low energy source such as I–129 is used to calibrate the survey meter. We suggest that survey meter manufacturers and calibration agencies should offer I–129 calibration for survey meters used to survey exposure rates due to I–125.

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