Practical Considerations for the Calibration of Low Energy/Low Activity Seeds

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Abstract

The popularity of permanent brachytherapy implants for prostate cancer has resulted in the introduction of a large number of new designs for low energy photon emitting radioactive seeds and a large number of institutions working with these seeds. NIST has developed the Wide Angle Free Air Chamber (WAFAC) and a system to quickly process new seed designs through this calibration standard. Standards are then transferred to the community through the AAPM ADCL system. Two issues unique to measuring these low energy/low activity seeds in the reentrant well chambers used as transfer standards by ADCL's and clinics are (1) precision measurement of low currents and (2) the strong energy response of these chambers. To address the first problem we will present details of our computerized timing system for determining current from integrated charge measurements using existing clinical equipment. The second issue, the energy response of chambers of different models has not yet been adequately addressed. Currently the recommended procedure is to have transfer chambers calibrated for each model of seed to be used in the clinic. We present data of the response of two of our chambers to a variety of ^{103}Pd and ^{125}I seeds that addresses this issue. The data demonstrates that chambers respond similarly for all 4 models of ^{103}Pd sources. For ^{125}I seeds the chamber response is a function of the design of the seed. This information is helpful to clinical physicists to better understand their calibration and equipment needs for low energy/low intensity isotopes.

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Introduction

Permanent prostate implants with low energy seeds have increased dramatically in the United States in the past 5 years. There are now 7 models of ^{125}I and 4 models of ^{103}Pd seeds available. Proper dosimetry of low energy implants require calibration of seeds in terms of air kerma strength traceable to the National Institute of Standards and Technology's (NIST) Wide Angle Free Air Chamber (WAFAC). There are two problems with maintaining a local standard for these isotopes. The first is that the current generated in ionization chambers for the source strength used in prostate implants is in the pA range. In this range even the best electrometers and chambers are challenged by noise on current scales. The second problem is the need to maintain a standard for each type of seed. The large number of available seeds makes this time and cost prohibitive.

We have developed a system that uses nC charge scales on electrometers to measure pA currents with a high degree of precision. These nC scales are commonly used in Megavoltage calibration. This system uses a Windows 95/98 system combined with either a computer-controlled electrometer or an analog electrometer with commonly available computer controlled voltmeters.

One obstacle to Intel X86 compatible PC based computerized timing has been the low resolution, 1/16th second, and the low accuracy (+/- 1 min/month) of the real time clock in PC's. The Windows

Application Programming Interface (API) provides functions to accesses multimedia timers. These timers are intended to synchronize multimedia events (sound, motion, etc) and have precision at the 1 msec level. The computer can sample the multimedia timer, trigger a reading, and then sample the timer again giving a very good estimate of the time when the reading was triggered. The uncertainty in timing is then dominated by the conversion time of the A/D circuitry in the external device and bus transit times for the triggering signal. Our system uses the difference between two readings at two times so the variability in these times is the real cause of uncertainty. We have found that we can time readings as short as 75 seconds with a reproducibility in the determined current at the 0.1% level.

Low energy seeds are made with titanium encapsulation with the radioactive element (^{125}I or ^{103}Pd) absorbed onto various materials ranging from silver rods to resin beads. X-ray markers of different materials are also present in many of these seeds. The materials present in the seed affect the spectra of the radiation emitted and thus the response of reentrant chambers as compared with the WAFAC. We have collected the response of two very different reentrant chambers to a variety of low energy seeds as a function of seed construction.

Materials and Methods

Sources:

NIST has established a system for calibrating low energy seeds that facilitates the transfer of these standards to the community. Five seeds of each new design are submitted to NIST by the manufacturer, these seeds are then calibrated using the WAFAC. Two seeds are immediately returned to the manufacturer the other three are sent to the AAPM Accredited Dosimetry Calibration Laboratories (ADCL's) before being returned to the manufacturer. These seeds were used in this work and are listed in Tables 1 and 2.

Ion Chambers:

Two reentrant ion chambers where used, a PRM HDRC-1 and an in-house chamber. Both of these chambers are open to the atmosphere and have standard BNC triax connectors for signal and bias connection. The PRM chamber is cylindrical and has an internal volume of 0.145 liters and has a 6.4 mm diameter central well, and a 2.5 cm outer diameter The central well has a 0.4 mm wall thickness. This chamber is Aluminum with acrylic insulators. The in-house chamber is spherical with a cylindrical well and has a collecting volume of 2 liters. The inner well is 21 mm in diameter and has a wall thickness of 4.5 mm, including a guard ring and inner electrode. This chamber is constructed of AE plastic (C552) with Teflon insulators. Both chambers were calibrated with the sources in the central "sweet spot", isoresponse region. Sources were placed in acrylic holders that held the long axis of the source along the long axis of the well an acrylic spacer was used to set the height of the seed holder in the well.

Computers, Electrometer and Digital Voltmeters:

A variety of windows PC’s were used in this work ranging from a 66 MHz 486SX IBM Ambra to a 400 MHz Perntium II Compaq Deskpro as well as a variety of Toshiba and Compaq laptops. All work was done in the Windows 95/98 operating system in Microsoft Excel 97’s version of Visual Basic for Applications (VBA). The timing function used is TimeGetTime() a system API call. Instruments were controlled either directly through an RS-232 serial port or through a Keithely model 500 RS-232 to IEEE-488 converter. The serial port was controlled from VBA through a third party dynamic link library (DLL).

Keithley 602 and 617 electrometers were used in this work, both of these are true electrometers using an op-amp feedback system to charge a high quality capacitor. The signal produced by the Keithley 602’s were read out using computer controlled voltmeters. The Keithley 617’s have built-in A/D circuitry and were read out directly through the supplied IEEE-488 port using the RS-232 to IEEE-488 converter referenced above. Three different voltmeters were used an HP34401A, a HP3478A and a Fluke 8842A, all are 5½ digit or greater. The voltmeters and the Keithley 617 were set to manual ranging, single trigger mode to minimize delay between triggering and evaluation of a reading. In the first part of this work the voltmeters were connected so they would readout positive values to further increase A/D conversion time. This was later abandoned since it did not affect the quality of the results. An alternative readout device tested was an ADAM 4012D A/D converter, a small, low cost, optically isolated A/D converter. This is a 3½ digit device and it’s precision was not adequate for the ADCL but it is small enough to be mounted to the back of a K602 and would be appropriate for clinical use.

Evaluation of the seeds:

Three seeds of each design where used to assign factors to the chambers. The seeds were marked to designate one end. During the first part of this work each seed was evaluated with the marked end towards the top of the well and then towards the bottom of the well. In July of 1999 Larry Bryson of K&S Associates was able to demonstrate that physical agitation of these seeds could cause a change in the apparent air-kerma of 2%. For this reason we started measuring each seed at each orientation at least three times shaking the seeds between measurements. The air-kerma strength determined by NIST for each seed was then decayed, using the assumed ½ life stated by NIST, to the time of measurement. This decayed air-kerma strength was divided by the current generated in the chamber corrected to standard conditions (22 C and 760 mm Hg) to determine the chamber response (N_k). The three determinations of N_k were then averaged to assign a factor to the chamber. The uncertainty of the determination was estimated by the spread in the N_k values from the three seeds. At least one of the three seeds was re-measured by a different physicist using a different electrometer.

$$N_k = \frac{\text{A.K.}}{\left(\frac{\Delta M}{\Delta T}\right)\cdot k_{TP} \cdot k_{ele}}$$

Equation 1: N_k is the chamber calibration factor in units of air-kerma strength per unit current (μGym^2)/(hr A)) . A.K. is the air-kerma strength in units of μGym^2/hr provided by NIST and decayed to the time of measurement. ($\Delta M/\Delta T$) is the change in charge per unit time and is units of rdg/sec. K_{TP} is temperature pressure correction factor and k_{ele} is electrometer correction factor is units of C/rdg.

Results/Conclusion

The response of the two chambers to a variety of low energy seeds is presented in tables 1 and 2. The uncertainties presented in the tables are the spread in the determined N_k values from the three seeds used for each determination. The uncertainties in the measured currents were an order of magnitude smaller than the spread in N_k from the three seeds submitted and can therefore be neglected. NIST claims to have an expanded combined relative uncertainty of less than 2% with a coverage factor of 2.

The response of both chambers fell into various groupings. The N_k values for all 4 models of ^{103}Pd seeds are fall within 2% of the mean value. However, the majority of the N_k values for ^{125}I fell into two groups. The N_k values for other ^{125}I sources were close but not in these groups. We have no explanation for this. In the case of the seeds from International Isotopes, 2 different models of seeds, with no documented change in construction, yielded N_k values different by over 10%. This suggests a significant change in the design of the seed.

The response of the 2 chambers are very similar despite the factor of 10 difference in collecting volume. This can be partially explained by inverse square, by the time you reach the outer wall of the smaller chamber the number of ionization’s per unit volume has decreased to less than 0.1% of this value at the surface of the seed. Extra volume does not affect signal in a linear manner. The ratio of ^{137}Cs factors for these chambers is about 2.3 (not presented here) and is within 2% of the ratio expected from purely geometric concerns. The ratio of the responses for low energy seeds is much closer, most likely due to attenuation in the thick guard and central electrode of the large volume A.E. plastic chamber.

The energy dependence of the two very different chambers are similar suggesting small differences in construction may not affect the energy response of a chamber. Therefore type testing of chambers may be appropriate, even for low energy sources.

In conclusion:

- For well-characterized chambers, calibration for each model of seed may not be necessary.
- Large volume does not mean large signal for re-entrant chambers
- The addition of low cost ($250 - $1000) computer capture interfaces to existing electrometers can enable high quality measurements of currents in the pA, prostate seed, range.

Notes on Implementation of Computer Control

1. The timegettime() function works in Windows NT/2000 but uses a default system precision than can be as large as 5 msec, you should consult the Microsoft Developers Network web site and perform a search on multimedia timers to better understand this.

2. The RS-232 serial port control was done through a third part dynamic link library (DLL) was done since control of serial ports was very complicated in Windows 3.1 and the initial releases of Visual

Basic. Developers of new application may be better suited using the Microsoft routines to control the serial port, this may save money and ensure future compatibility.

3. Any system using computer controlled timing should be commissioned based on a NIST traceable timer prior to clinical work. Traceable stopwatches are available from either Fisher scientific or Radioshack for $30 - $50.

Manufacturer	Model	Carrier	X-Ray marker	Date	N_k (μGym^2/hr/nA)	
					AE Chamber	HDRC1
North American Scientific, Inc.	IoGold	Resin beads	Gold	9/11/98	155.3	
				3/10/99	155.6 +/- 0.4%	165.6 +/- 0.6%
				1/10/00	155.01 +/- 0.1%	166.3 +/- 0.5%
International Isotopes	Isostar IS-12501	Silver iodide on titanium beads		2/23/99	186.2 +/- 0.5%	213.4 +/- 0.5
				1/10/00	184.0 +/- 2.5	209.4 +/1 2.8
	I^3			2/23/99	163.0 +/- 2	179.0 +/- 2.2
Best Medical International	2301	carbon coated tungston		6/15/99	155.4 +/- 0.9	166.2 +/- 1.0
Bebig Isotopentechnik	I125.S06	?		4/8/99	155.3 +/- 0.5	167.5 +/- 0.7
Mils Biopharmaceuticals	125SH	Silver Spheres	Silver	8/3/99	186.2 +/- 0.9	212.2 +/- 0.9
Medi-Physics, Inc.	6702	Resin beads		9/11/98	168.2	
	6711	Silver rod		9/11/98	150.6	

Table 1: ^{125}I seeds and determined calibration factors (N_k) for the two ADCL chambers. Uncertainties expressed are the spread in determined N_k values from the three seeds submitted for each determination.

Manufacturer	Model	Carrier	X-Ray marker	Date	N_k(μGym^2/hr/nA)	
					AE Chamber	HDRC1
North American Scientific, Inc.	MED3633	Resin beads	Gold	3/8/99	276.6 +/- 0.6%	366.54+/-
Best Medical International	2335	Resin Beads	Tungsten	9/30/99	282.4 +/- 1.1%	374.9+/- 1.5%
Theragenics Corporation	Theraseed	Graphite pellets	Lead	4/6/99	280.2 +/- 1.9%	371.4+/-2.2%
				8/4/99	280.2+/-1.7%	375.7+/-1.2%
International Brachytherapy	Intrasource103	Titanium	Platinum/ iridium	5/20/99	289.3+/-1.1%	377.8+/-0.6%

Table 2: ^{103}Pd seeds and determined calibration factors (N_k)for the two ADCL chambers. Uncertainties expressed are the spread in determined N_k values from the three seeds submitted for each determination.

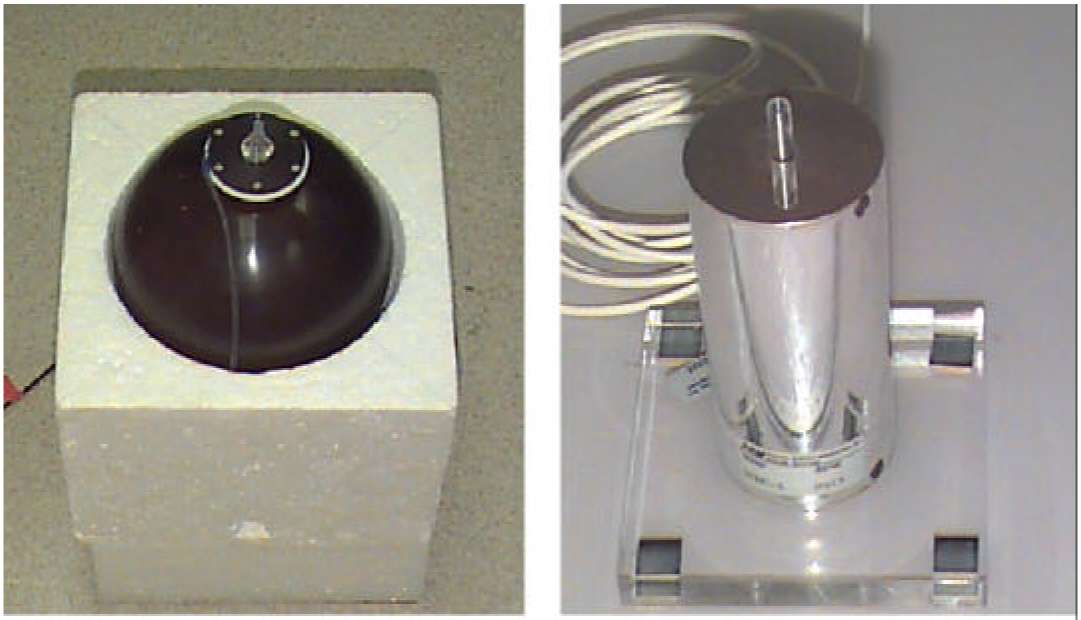

Figure 1: The two re-entrant well chambers used is this work: Left: In-house 3 liter AE plastic chamber with a 4 cm well. Right: PRM HDRC-1 0.2 liter chamber with a 0.7 cm well. The ^{137}Cs factors for these chamber vary with volume as expected, but the ^{125}I and ^{103}Pd factors are equivalent.

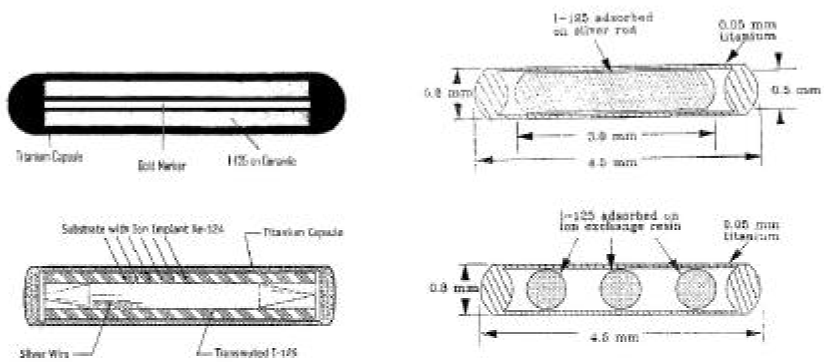

Figure 2: The internal designs of several models of ^{125}I seeds: Note the wide variety of materials and construction techniques.

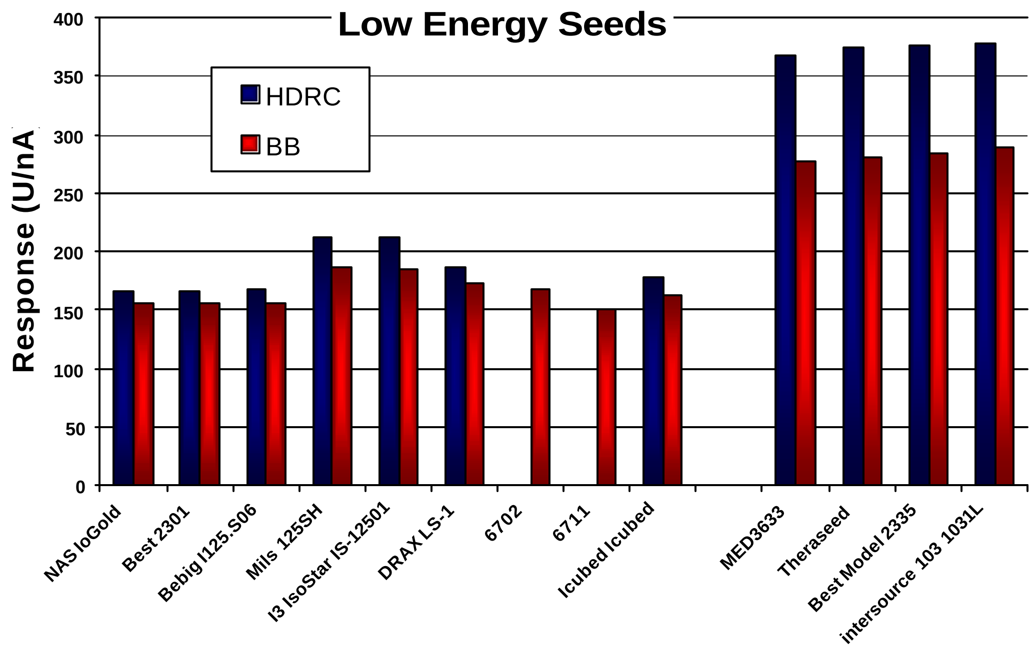

Figure 3: Calibration factors for our two chambers for all low energy seeds received prior to February 2000: It should be noted that the Y-axis is response, which is the inverse of signal. It should also be noted that there is a wide range in values for ^{125}I seeds and a single value, with some noise, for ^{103}Pd seeds.

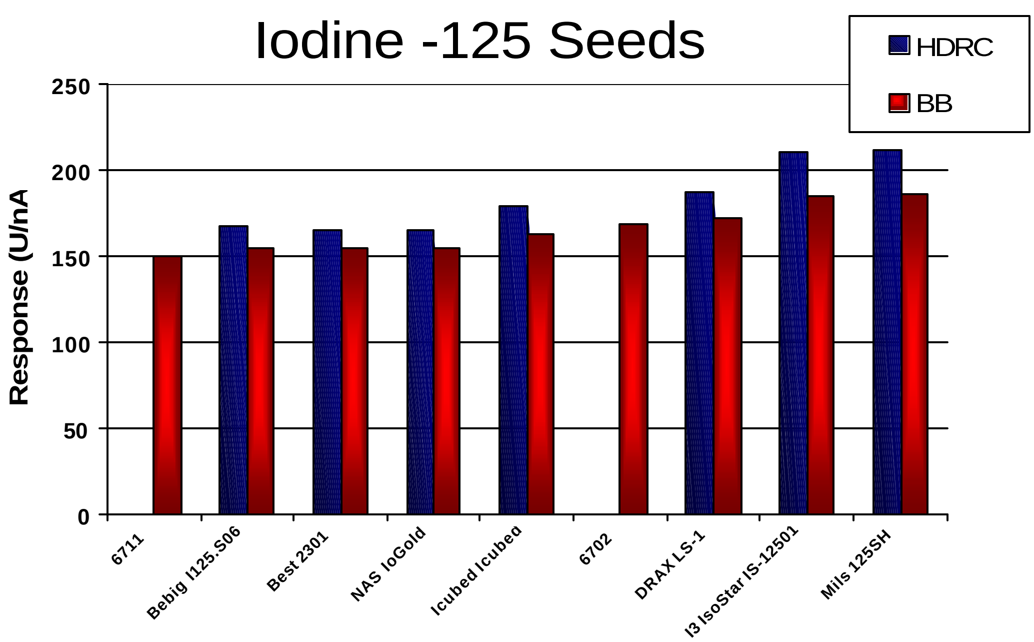

Figure 4: Calibration factors for our two chambers for ^{125}I seeds sorted by chamber response: From this graph it is clear that chamber response for ^{125}I falls into three distinct groups. The data in table 1 suggests that some of this grouping is due to the presence or lack of silver in the seed construction.

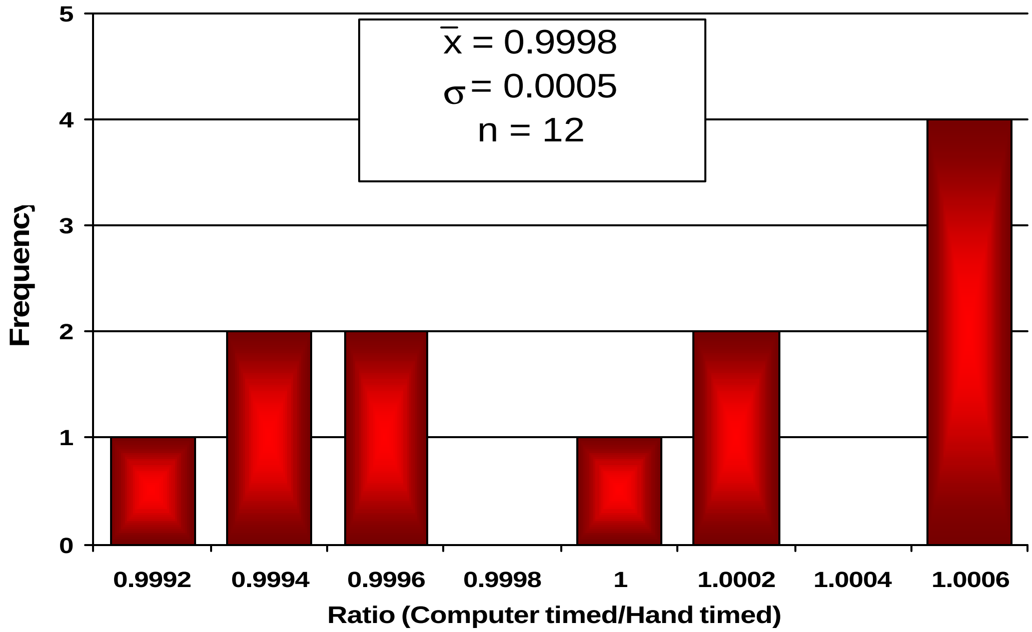

Figure 5: Commissioning/verification of our computer timing system: Measurements were made with our standard ^{137}Cs tube on a number of occasions using both our manual and our computer timing techniques. The manual timing is done with a NIST traceable stopwatch and enables us to perform traceable current measurements with a calibrated charge scale. This graph demonstrates that the computer timing agrees with the traceable stopwatch within measurement precision.