Dose Calibrator Linearity Testing Using an Improved Attenuator System

William M. Oswald, Thomas J. Herold, Mark E. Wilson, and Joseph C. Hung

Department of Diagnostic Radiology, Mayo Clinic, Rochester, Minnesota and College of Biological Sciences, University of Minnesota, St. Paul, Minnesota

Nuclear Regulatory Commission (NRC) guidelines state that dose calibrators must be tested for linearity upon installation and quarterly thereafter over a range of activities from 10 μCi (370 kBq) to the highest dose administered to the patient (300 mCi [11.1 GBq] of iodine-131 for therapy at our institution). The simplest method of linearity testing utilizes commercial attenuator kits. These kits consist of different attenuator tubes plus a central tube that remains in the dose calibrator during the entire testing process. The disadvantage of these kits is that the test has to be performed twice, once with a high activity source and a second time with a lower activity source, to cover the full range of activities required by the NRC. We have designed two accessory tubes that can be used in conjunction with a commercial attenuator system, thereby covering the range of activity required by the NRC with a single source of technetium-99m. It takes less than 4 min to complete the entire measurement with this improved linearity test kit.

Linearity testing is required by the U.S. Nuclear Regulatory Commission (NRC) to test the dose calibrator's ability to determine a wide range of radioactivity in a truly linear fashion. As stated in the *NRC Rules and Regulations* (*1*), this testing must be performed over a range of activities from 10 μCi (370 kBq) to the highest dose administered to the patient, with an acceptable linearity error of not more than 10%. However, the NRC's "Modified Procedure for Calibrating Dose Calibrator" in the *NRC Regulatory Guide 10.8* (*2*) suggests that this action level be reduced to 5% and that the range of activity be extended to the largest activity normally assayed in a prepared radiopharmaceutical kit, in a unit dosage, or in a radiopharmaceutical therapy.

In our institution, the highest dose administered to a patient for therapeutic purposes is 300 mCi (11.1 GBq) of iodine-131 (^{131}I), and the maximum activity used in the preparation of a radiopharmaceutical kit is 300 mCi (11.1 GBq) of technetium-99m (^{99m}Tc). The *NRC Rules and Regulations* (*1*) does not specifically define which radioisotope should be used for the dose calibrator linearity testing. Although the *NRC Regulatory Guide 10.8* (*2*) does suggest that ^{99m}Tc should be used as the test source, the question can be raised as to whether it is acceptable to use 300 mCi (11.1 GBq) of ^{99m}Tc to perform linearity checks, given a maximum patient therapeutic dose of 300 mCi (11.1 GBq) of ^{131}I in our institution. Due to the impracticality of employing ^{131}I for linearity evaluation, we feel that an adjusted ^{99m}Tc dose needs to be utilized to remain in compliance with NRC guidelines (*1,2*). We found that an adjusted ^{99m}Tc dose of 430 mCi (15.9 GBq) must be used to replace 300 mCi (11.1 GBq) of ^{131}I for checking the linearity of a dose calibrator (*3*).

There are several methods for checking the linearity of the dose calibrator. The most accurate is the decay method (*4*), which consists of multiple measurements of the same radionuclide source over an extended time period, typically requiring two to three days. Recently, the shield method has gained in popularity (*5*). This method employs a series of lead sleeves varying in thicknesses. These sleeves attenuate the radioactive source to different degrees, thus simulating decay of the source. While the shield method has the advantage of being quick and reliable, the Calicheck™ kit (Calcorp, Cleveland, OH), which we use for linearity testing, is not able to sufficiently attenuate the 430-mCi (15.9-GBq) ^{99m}Tc source to <10 μCi (370 kBq).

In order to comply with NRC requirements (*1,2*), one can apply one of two possible solutions to this problem. One method utilizes two sources, a low activity source and a high activity source: The linearity test is performed twice to cover the entire required range (*6,7*). The other method is to use thicker lead sleeves in order to attenuate the 430-mCi (15.9-GBq) ^{99m}Tc source to <10 μCi (370 kBq). The first method requires two different sets of measurements: this involves additional radiation exposure to personnel and may be time-consuming if one has several dose calibrators that need linearity testing. In addition, the need to use different correction methods to establish attenuator calibration factors for both high and low activity sources (*7*) would complicate the application of the two-source shield method. We have, therefore, designed two additional accessory sleeves to be used in conjunction with the Calicheck™ kit. The purpose of this study was to evaluate the performance of this improved attenuator

For reprints contact: Joseph C. Hung, PhD, Diagnostic Nuclear Medicine, Department of Radiology, Mayo Clinic, 200 First Street SW, Rochester, MN 55905.

system for dose calibrator linearity testing with a single ^{99m}Tc source.

MATERIALS AND METHODS

All linearity tests were performed in Capintec dose calibrators (CRC® -5, 5R, 12, 12R, Capintec, Ramsey, NJ). A 30-ml serum vial filled with 2 ml of sodium pertechnetate, varying in activity from 432 mCi (16.0 GBq) to 436 mCi (16.1 GBq), was used as the source activity. The dose calibrators had been checked for constancy (daily), accuracy (monthly), and geometry (at installation) with satisfactory results. The high voltage battery potentials were checked and were between 140 and 155 V, and the zero settings and background were properly adjusted before the measurements.

Decay Method. In order to calibrate the new attenuator system, the dose calibrators were tested for linearity with the decay method. Initially, the ^{99m}Tc source was measured at 8 A.M. in the dose calibrator and the net activity and time were noted. Repeat assays were taken at noon, 2 P.M., and 4 P.M., and the activities and times were recorded. These assays were continued during subsequent days until the activity of the source was below the 10 μCi (370 kBq) requirement. Next a time-activity curve of the data was drawn on semilog graph paper and a "best fit" straight line was drawn though the data points. The linearity of the dose calibrator was determined by selecting the farthest point from the line and calculating its deviation according to the following equation: (observed activity − fitted activity)/fitted activity. If the worst deviation of any of these data points was more than ±5% (*2*), the dose calibrator was not linear.

New Shield Method. Two additional attenuator tubes were designed and manufactured for use with the Calicheck™ kit (Fig. 1). These two tubes were constructed of lead with thicknesses of 2 mm and 3 mm, respectively. According to the NRC's "Model Procedure for Calibrating Dose Calibrator" (*2*), any new set of lead sleeves must be calibrated before it can be used for linearity testing. This started with the linearity test as described in the decay method. After making the first assay of the decay method, the vial was transferred to the base tube of the Calicheck™ kit. We then placed each colored tube as well as combinations of our two attenuator tubes and the colored tubes over the central base tube.

The results of the measurements of activity were recorded and an "equivalent decay time" for each tube or tube combination was found with the use of the "best fit" line generated by the decay method, and by associating each simulated activity with the decay time on the semilog graph paper. These "equivalent decay times" were then utilized in subsequent linearity measurements to determine whether or not the dose calibrator was linear within ± 5% (*2*). The times for performing the linearity tests with the new shield method were also recorded. The *NRC Regulatory Guide 10.8* (*2*) suggests that this procedure must be completed within 6 min.

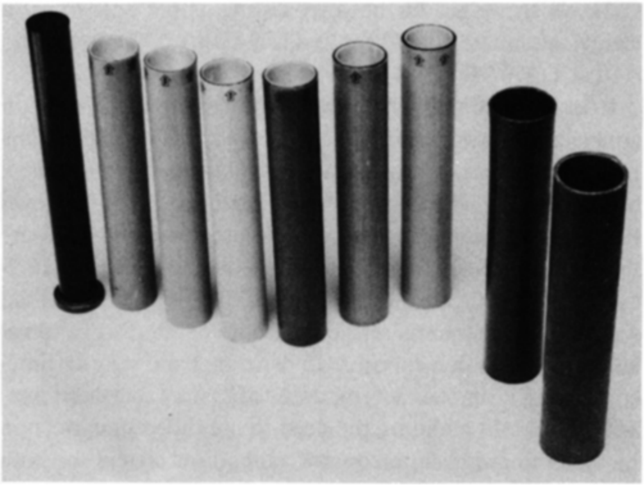

FIG. 1. The new lead sleeve shielding system for dose calibrator linearity testing. A base tube with six colored tubes from the Calicheck™ kit are pictured with the two new attenuator tubes on the right. The new sleeves are constructed with two different thicknesses of lead, 2 mm (top) and 3 mm (bottom).

RESULTS

Decay Method. All dose calibrators were found to be linear over the required 430-mCi (15.9-GBq) to 10-μCi (370-kBq) range of activity. Figure 2 presents an example of the best fit straight line of dose calibrator linearity using the decay method. The graph indicates that all observed data points were within the recommended ± 5% deviation from the value of the straight line. The largest linearity error from the best fit line was −1.93%, which was well within the ± 5% range.

New Shield Method. The inside diameters of the two new lead tubes were large enough to fit over any of the six colored tubes from the Calicheck™ kit. After experimenting with various combinations of these attenuator tubes in measuring a 430-mCi (15.9-GBq) ^{99m}Tc source, we found that the yellow tube in combination with each of the two new lead sleeves supplied enough attenuation to obtain an intermediate reading (~138 μCi [5.1 MBq]) and a reading below the required 10 μCi (370 kBq) (~9 μCi [333 kBq]). The equivalent decay times for single tubes or tube combinations (black, red, orange, yellow, green, blue, purple, yellow plus 2-mm tube, and

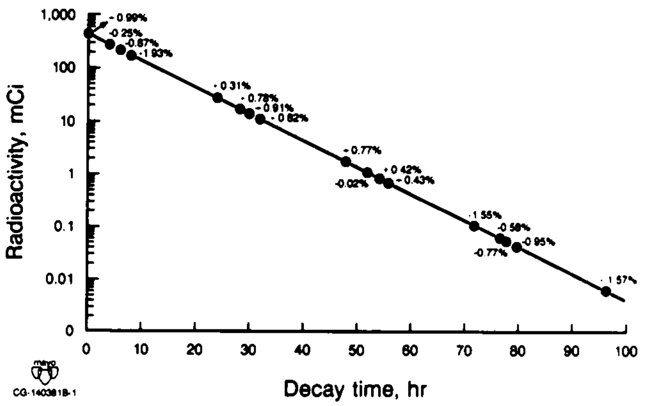

FIG. 2. Semilog plot of a dose calibrator linearity test using the decay method. The best fit straight line (ln y = −0.115 x +6.063) was used to determine the percent deviation for each decay time point.

yellow plus 3-mm tube) were determined to be ~0, 4.83, 9.86, 20.02, 27.58, 43.07, 53.60, 69.77, and 93.73 hr, respectively, after the initial assay of the ^{99m}Tc source.

Figure 3 demonstrates a linear response of a dose calibrator determined by the new shield method. All results were below the suggested ± 5% deviation range from the best fit straight line. The worst deviation (−1.86%) was found at the lowest activity level. The average time to perform the linearity measurement with this new attenuator system was 3.82 ± 0.38 min (n = 15), well within the 6-min limit stated in the *NRC Regulatory Guide 10.8* (*2*).

DISCUSSION

At our institution, we administer up to 300 mCi (11.1 GBq) of ^{131}I for therapeutic purposes and a maximum activity of 300 mCi (11.1 GBq) of ^{99m}Tc can be used to reconstitute a radiopharmaceutical kit. In accordance with either *NRC Rules and Regulations*, part 35.50 (*1*) or *NRC Regulatory Guide 10.8* (*2*), we believe that the linearity of a dose calibrator must be tested over an activity range of 300 mCi (11.1 GBq) to 10 μCi (370 kBq). The question arises as to which radioisotope to use for this linearity testing. Should ^{131}I be used or is it permissible to use ^{99m}Tc? The use of ^{131}I for linearity evaluation with the decay method is quite impractical due to the long half-life of this radioisotope. The high energy of ^{131}I also makes the shield method of linearity testing a difficult task requiring multiple sources of varying activity. Due to the impracticality of using ^{131}I for checking linearity on a dose calibrator, we chose to use ^{99m}Tc as the test source.

Since the dose calibrator is basically an ionization chamber and does not employ the "window" principle, it was decided that the ^{99m}Tc source should be measured at the same setting as that used for ^{131}I in order to determine a factor for converting the activity of ^{131}I to ^{99m}Tc. This conversion factor ($^{99m}Tc/^{131}I$) was calculated to be 1.43 ± 0.01 (n = 130) (*3*). Therefore, if the highest patient dose is 300 mCi (11.1 GBq) of ^{131}I, ~430 mCi (15.9 GBq) of ^{99m}Tc should be used to perform linearity testing on the dose calibrator.

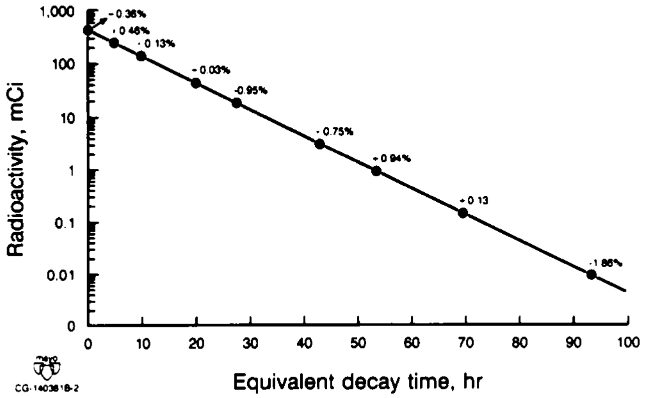

FIG. 3. Semilog graph of a dose calibrator linearity test using the new shield method. The percent deviation for each equivalent decay time point was calculated from the best fit straight line (ln y = −0.115 x + 6.097).

Once we had decided on the amount and type of radioisotope, the next issue was to determine which method of linearity testing should be used routinely. We have eleven dose calibrators in our institution and the time needed to perform linearity testing is definitely a factor. Due to this concern, the decay method was reserved only for the initial confirmation of linearity and not for the routine application. The method that best suited our needs was the shield method. Unfortunately, neither of the two commercial linearity test kits (Calicheck™ or Lineator, Atomic Products Corp., Shirley, NY) can attenuate 430 mCi (15.9 GBq) of ^{99m}Tc to below 10 μCi (370 kBq). It would require two sets of measurements using high and low activity sources to perform the linearity check (*6,7*), resulting in increased time to perform the test and unnecessary personnel radiation exposure.

By manufacturing two additional lead sleeves that could be used in combination with the six commercial tubes (Calicheck™), we only had to perform the linearity test once with a single source of activity. This not only saved time but also reduced the radiation exposure to the nuclear medicine personnel, compared with the manipulation of two radioactive sources. The additional sleeves gave us the capability of attenuating a 430-mCi (15.9-GBq) ^{99m}Tc source down to 10 μCi (370 kBq).

The background measurement is crucial when performing the linearity test with this new shield method. It is very important to subtract the background activity from each measurement, especially when reading the activity on the low end of the range. These new lead sleeves have inside diameters large enough to fit over any of the Calicheck™ tubes, while the outside diameters of both sleeves are still small enough to fit in the dose calibrator. Various combinations of sleeves can be applied to attenuate ^{99m}Tc activities up to 1.85 Ci (68.45 GBq) (the 3-mm sleeve plus purple tube). This should clearly encompass the activity range requirements specified in the *NRC Regulatory Guide 10.8* (*2*).

The average time for the completion of linearity measurement with the new sleeves was ~4 min, which meets the NRC recommendation for completing the test in less than 6 min (*2*).

In conclusion, we have found that this new system for linearity evaluation, using a combination of commercial and in-house manufactured attenuator shields, is an efficient and effective way of performing regular dose calibrator linearity testing. The new versatile method for linearity testing saves time and decreases personnel's radiation exposure, while still satisfying all the requirements of the NRC.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the valuable help of Mr. Warren N. Lenz, division of engineering and technical services, Mayo Clinic, in manufacturing the two accessory lead tubes, and we would like to thank Ms Vicki S. Krage for assisting in the submission of this manuscript. Legal assistance from Mr. Scott E. Kaese, Mayo Medical Ventures, in seeking license for the modified attenuator tubes was also greatly appreciated.

This work was presented at the 38th Annual Meeting of The Society of Nuclear Medicine in Cincinnati, Ohio, on June 12, 1991.

REFERENCES

1. Possession, use, calibration, and check of dose calibrator. *U.S. Nuclear Regulatory Commission, Rules and Regulations, Code of Federal Regulations*, Energy, Title 10, Part 35.50. November 30, 1988.
2. Model procedure for calibrating dose calibrator. *U.S. Nuclear Regulatory Commission, Guide for the Preparation of Application for Medical Programs, Regulatory Guide 10.8*, Appendix C, 1987.
3. Oswald WM, Wilson ME, Hung JC. Dose calibrator linearity testing: a new perspective. (Abstract.) *J Nucl Med Technol* 1991;19:122.
4. Chu RYL. Accuracy of dose calibrator linearity test. (Letter.) *Health Phys* 1988;55:95–96.
5. Davis DA, Giomuso CA, Miller WH, et al. Dose calibrator activity linearity evaluations with ALARA exposures. *J Nucl Med Technol* 1981;9:188–190.
6. Dydek GJ, Blue PW, Tyler HN Jr. Comparison of attenuators for linearity testing of the dose calibrator. *J Nucl Med Technol* 1988;16:111–115.
7. Merritt ER. Attenuator calibration factors using high and low activity sources. *J Nucl Med Technol* 1989;17:66–69.