3. Simon D, Koehrle J, Schmutzler C, Mainz K, Reiners C, Röher HD. Redifferentiation therapy of differentiated thyroid carcinoma with retinoic acid: basics and first clinical results. *Exp Clin Endocrinol Diabetes* 1996;104(suppl 4):13–15.
4. DeGroot LJ, Kaplan EL, McCormick, M, Straus FH. Natural history, treatment, and course of papillary thyroid carcinoma. *J Clin Endocrinol Metab* 1990;71:414–424.
5. Schlumberger M, Challeton C, De Vathaire F, et al. Radioactive iodine treatment external radiotherapy for lung and bone metastases from thyroid carcinoma. *J Nucl Med* 1996;37:598–605.
6. Krishna L, Dadparvar S, Brady LW, et al. Paradoxic changes in iodine-131 scintigraphic findings in advanced follicular thyroid cancer. *J Nucl Med* 1993;34:1574–1576.
7. Biersack HJ, Helpap B, Koch U, Janson R, Baumgarten C, Winkler C. Should treatment of highly differentiated thyroid carcinoma be conservative? *Nuklearmedizin* 1983;22:20–23.
8. Harada T, Mimura T, Ito K, et al. Divergent histology in the primary and metastatic lesions of thyroid carcinoma. *Nippon Ganka Gakkai Zasshi* 1983;84:758–761.
9. Van Herle AJ, Agatep M, Padua DN, et al. Effects of 13-cis-retinoic acid on growth and differentiation of human follicular carcinoma cells in vitro. *J Clin Endocrinol Metab* 1990;71:755–763.
10. Schreck R, Schnieders F, Schmutzler C, Köhrle J. Retinoids stimulate type I iodothyronine 5'-deiodinase activity in human follicular thyroid carcinoma cell lines. *J Clin Endocrinol Metab* 1994;79:791–798.
11. Rosai J, Carcangiu ML, Delellis RA. *Atlas of tumor pathology, third series, fascicle 5: tumors of the thyroid gland.* Washington, DC: Armed Forces Institute of Pathology; 1992.
12. Ahuja S, Schiller S, Ernst H. An autoradiographic study of postoperatively labelled thyroid tissue and iodine storage. *Eur J Nucl Med* 1991;18:791–795.
13. Oyen WJG, Mudde AH, van den Broek WJM, Corstens FHM. Metastatic follicular carcinoma of the thyroid: reappearance of radioiodine uptake. *J Nucl Med* 1995;36:613–615.
14. Grünwald F, Schomburg A, Bender H, et al. Fluorine-18 fluorodeoxyglucose positron emission tomography in the follow-up of differentiated thyroid cancer. *Eur J Nucl Med* 1996;23:312–319.
15. Feine U, Lietzenmayer R, Hanke JP, Held J, Wöhrle H, Müller-Schauenburg W. Fluorine-18-FDG and iodine-131-iodide uptake in thyroid cancer. *J Nucl Med* 1996;37:1468–1472.
16. Kubota R, Kubota K, Yamada S, Tada M, Ido T, Tamahashi N. Active and passive mechanisms of [Fluorine-18]fluorodeoxyglucose uptake by proliferating and prenecrotic cancer cells in vivo: a microautoradiographic study. *J Nucl Med* 1994;35:1067–1075.
17. Kubota M, Tsuda T, Minase T, Nakada K, Furudate M. Autoradiographic analysis of [^{14}C]deoxy-D-glucose in thyroid cancer xenografts: a comparative study with pathologic correlation. *Ann Nucl Med* 1991;8:75–83.
18. Börner AR, Weckesser M, Langen KJ, Müller-Gärtner HW. Erste Erfahrungen mit Isotretinoin bei metastasierenden, differenzierten Schilddrüsenkarzinomen [Abstract]. *Nuklearmedizin* 1997;36:A67.
19. Menzel C, Grünwald F, Schomburg A, et al. "High-dose" radioiodine therapy in advanced differentiated thyroid carcinoma. *J Nucl Med* 1996;37:1496–1503.

Remotely Pollable Geiger-Müller Detector for Continuous Monitoring of Iodine-131 Therapy Patients

L.S. Zuckier, B. Boardman and Q.H. Zhao

Department of Nuclear Medicine, Albert Einstein College of Medicine, Bronx, New York; and Aware Electronics, Wilmington, Delaware

In many countries, patients treated with therapeutic amounts of ^{131}I are hospitalized because of radiation safety considerations. To determine when they can return home, radiation levels are intermittently monitored at bedside using a handheld Geiger-Müller (GM) counter, although this procedure can be cumbersome and inexact. **Methods:** We have developed and tested a remotely pollable system for continuous radiation monitoring of ^{131}I therapy inpatients, using readily available hardware and standard telephone lines. The remote detector system, consisting of a palmtop IBM-compatible personal computer, specialized software, PCMCIA modem and miniature serial port-based GM detector, is placed opposite the patient's bed at a fixed distance, and continuous 1-min acquisitions are started. Initially and at least twice daily, the remote palmtop is contacted by modem, and all interval data are uploaded onto the operator's base computer over the telephone line, including measurements taken with the patient in a predetermined standardized position. Continuous minute-to-minute data may be viewed in native form or can be imported into graphing and spreadsheet programs. Points acquired with the patient in standardized position are specially marked to highlight the constant geometry used. The ratio of initial counting rate to administered dose is used to estimate residual ^{131}I body burden by proportionality. Display of data as a semilogarithmic plot facilitates extrapolation of the activity curves and prediction of the patient's earliest time of discharge. **Results:** We have characterized the remote GM detector system to confirm accuracy, counting rate linearity and reliability of data transfer. We describe examples that illustrate the applicability and usefulness of this method for remote monitoring of inpatient ^{131}I therapy levels. **Conclusion:** Monitoring patients with the described remotely pollable GM detector is an accurate and easy-to-implement technique that could conceivably lead to shortened hospital stays for ^{131}I therapy inpatients. Continuous quantitative data obtained are useful for kinetic and dosimetric analyses, which may be applied to study other gamma-emitting radiopharmaceuticals as well. The flexibility of the technique may permit its use in the monitoring of therapy on an outpatient basis, where allowed.

Key Words: Geiger-Müller detector; remote monitoring; iodine-131 therapy

J Nucl Med 1998; 39:1558–1562

Radioactive ^{131}I is an effective and established mode of therapy for thyroid neoplasia (*1,2*). An accepted tenet of radiation safety is that benefit afforded to patients by therapeutic administration of ^{131}I must be balanced by societal considerations regarding radiation exposure to individuals who do not derive direct gain, such as family members, coworkers and incidentally exposed persons (*3–5*). To address this concern, most national regulatory agencies have required segregation and hospitalization of patients who receive what is defined as a significant amount of radionuclide. For example, in the United States, patients receiving 1110 MBq (30 mCi) or more of ^{131}I have, until recently, been confined to the hospital (*6*), resulting in an estimated 15,000 admissions annually (Mallinckrodt, Inc., personal communication). These regulations were revised based on predicted exposure rates to family members, to limit the likely exposure of other individuals to no more that 5 millisieverts (0.5 rem) (*7*). The allowable body burden of ^{131}I at discharge is unique to each patient and depends on the family situation and the patient's need for supportive care (*8*). In many

Received Oct. 2, 1997; revision accepted Dec. 19, 1997.
For correspondence or reprints contact: L.S. Zuckier, MD, Department of Nuclear Medicine, Albert Einstein College of Medicine, 1300 Morris Park Ave., Bronx, NY 10461.

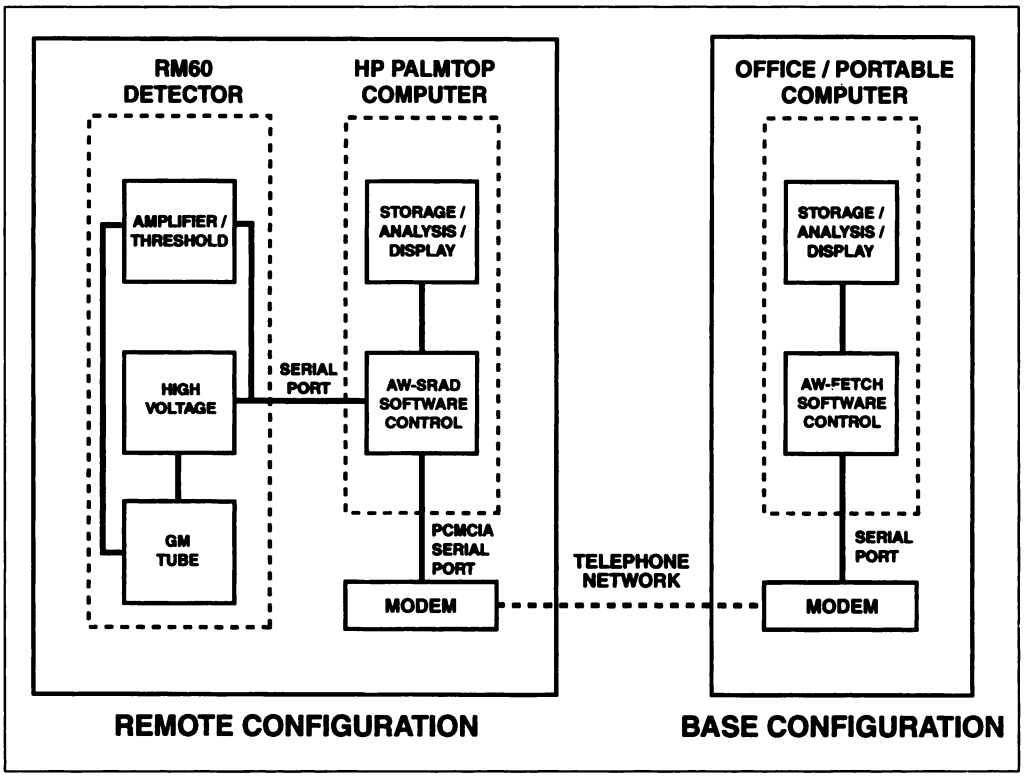

FIGURE 1. Schematic representation of remote and base components of Geiger-Müller monitoring system. Continuous data from remote bedside computer may be uploaded to one or more base computers using an intermittent telephone connection between modems (dashed line).

European countries, regulatory limits are more stringent than in the United States, making use of radioactive iodine an even more costly and inconvenient mode of therapy.

As a general rule, radiation safety regulations dictate that patients may return home when their whole-body burden of radioiodine drops below the regulatory threshold; whole-body burden of ^{131}I, when used to determine discharge, may be calculated from radiation levels using proportionality of the initial counting rate with the known administered dose or the exposure rate constant for ^{131}I (*9*). To determine when these discharge criterion are met, hospitalized patients are intermittently monitored with a handheld Geiger-Müller (GM) counter or other type of ionization device, although bedside monitoring has several limitations. Trained personnel must be present to take measurements at least daily, which is taxing and inconvenient, especially over weekends and holidays. The generally accepted practice of measuring radioactivity at a 1-m distance from the patient contributes to occupational exposure of the staff. Finally, exact positioning of the GM counter relative to the patient is somewhat subjective and imprecise, limited by methodologic variations between different staff members, sampling error and the operator's desire to promptly complete measurements and minimize contact.

We have therefore developed, tested and initiated use of a remotely pollable GM detector for continuous monitoring of hospital inpatients administered therapeutic ^{131}I. In this article, we describe the configuration of our device and illustrate its feasibility and usage.

MATERIALS AND METHODS

Remote and Base Devices

The remote detector system (Figs. 1 and 2) features a small, commercially available, GM tube-based radiation detector (RM-

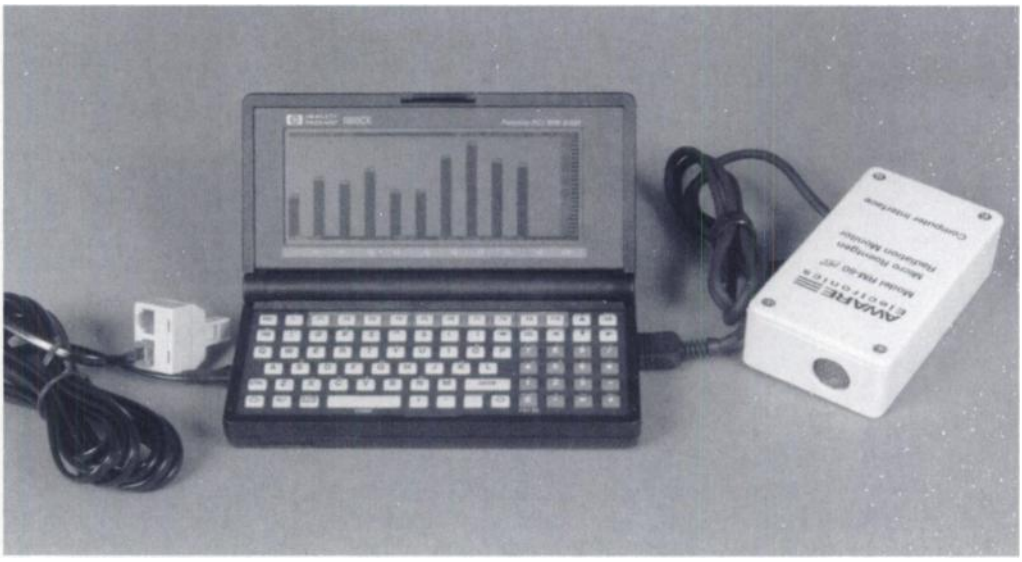

FIGURE 2. Remote Geiger-Müller system. Overall dimensions of the compact detector and palmtop computer are 11.18 × 6.20 × 2.69 cm and 16 × 8.64 × 2.54 cm, respectively. The modem card, inserted into the built-in PCMCIA slot at the left of the computer, is attached to a telephone cable and a Y-type telephone line splitter. Typical AW-SRAD data, in bar graph format, appear on the palmtop screen.

60; Aware Electronics Corp., Wilmington, DE) that interfaces with the serial port of IBM-compatible personal computers (PCs). This detector contains a halogen-quenched self-regenerating stainless steel GM tube with mica window, calibrated with ^{137}Cs by the manufacturer to an accuracy of within 5%. The energy response is relatively flat when photons with energies ≥200 keV are measured. Output may be displayed as cpm or as μrad/hr, using an adjustable calibration factor. We have interfaced the RM-60 to either of two models of miniature, commercially available, IBM-compatible palmtop computers (200LX or 1000CX; Hewlett-Packard Co., Corvallis, OR) that use standard IBM-PC architecture yet are unobtrusive in the hospital room. Standard software provided with the detector (AW-SRAD; Aware Electronics Corp.) is used to control acquisition, display and data storage and can accommodate counting rates as high as 32,715 cpm, corresponding to an exposure rate of ~31.2 mrem/hr.

For purposes of remote polling, the palmtop computer is connected to the patient's telephone line using one of various low-power type II PCMCIA modems and a Y-type telephone line splitter. A variety of modem-equipped IBM-compatible computers (including palmtop, laptop and desktop models) have been used as base stations to remotely retrieve, capture and display the data using communications software created for this purpose (AW-FETCH; Aware Electronics Corp.). This software, optimized for use with the RM-60 and palmtop, incorporates CRC error correction and password protection features to ensure reliability and security of the patient data. The remote computer can be set to mark the last point in the AW-SRAD data file, thereby allowing it to be highlighted when subsequently viewed.

Data are displayed on the base computer using specialized graphing software designed for the RM-60 files (AW-GRAPH; Aware Electronics Corp.) or may be imported into standard spreadsheet programs such as Lotus 1-2-3 (Release 2.4, Palmtop Version; Lotus Development Corp., Cambridge, MA) for analysis and display.

Characterization and Validation

We have characterized the detector and computer assembly in a series of measurements to determine counting rate linearity, accuracy and reliability of data transfer. To evaluate the counting rate linearity of the RM-60 palmtop system, a 555-MBq (15-mCi) source of ^{99m}Tc-TcO_4^- was advanced toward the RM-60 detector until the counting rate maximum of 32,765 cpm was reached. The activity was then decayed at this position over the course of 4 days as serial 1-min acquisitions were obtained. Measured counting rates were compared to theoretical values, based on extrapolating the background-corrected counting rate at 24 hr to earlier and later time points. Because the GM detector does not discriminate photon energy, this measure of dead time, as a function of counting rate, is applicable to other radionuclides, including ^{131}I.

Using the built-in ^{137}Cs calibration factor, we also compared measured and expected counting rates of a known ^{131}I source placed 10 m away from the detector. A dose of 2183 MBq (59 mCi) ^{131}I-NaI, contained in two capsules, were placed 60 cm above the floor on the surface of a cardboard platform, located 10 m away from an RM-60 radiation detector interfaced to a 1000LX palmtop computer. Duplicate 1-min acquisitions were obtained, and averaged values were compared with the expected counting rate based on the exposure rate constant (Γ_{20}) for ^{131}I of 2.16 rad × cm^2/mCi × hr (*9*).

Clinical Studies

In the monitoring protocol we used, the RM-60 detector was positioned opposite and perpendicular to the midportion of the patient's bed at a distance of ~2 m. Before administration of the therapeutic dose of radioactive iodine, the procedures for polling

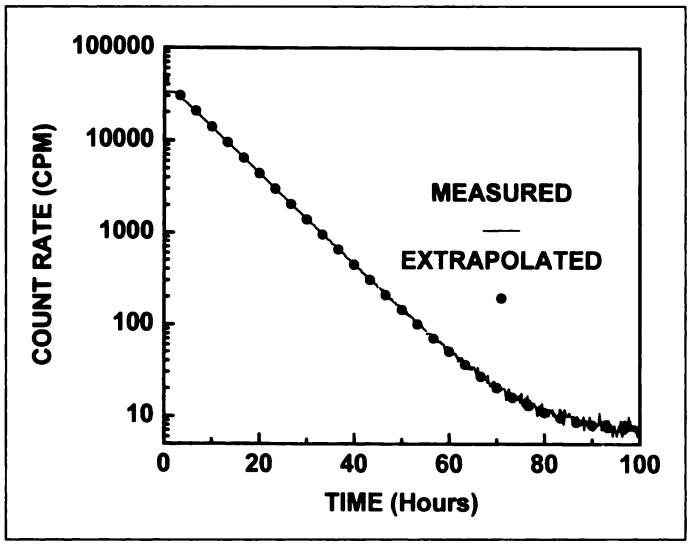

FIGURE 3. Raw counting rate during decay of 555 MBq (15 mCi) ^{99m}Tc. Each point is the average of ten 1-min acquisitions, without subtraction of background. Marked points represent idealized counting rate values based on extrapolation of the 24-hr measurements. Although difficult to appreciate on the present scale, the measured counting rate is 5% less than that predicted at the highest counting rates.

data were thoroughly rehearsed with the patient to forestall any subsequent difficulties. Serial 1-min acquisitions were initiated. After administration of the ^{131}I and at least twice daily thereafter, the patient was contacted by telephone and was requested to lie centered in bed for 3 min in a relatively standardized position, ignoring subsequent phone calls within this period. After 2 min, the base computer called the patient's telephone number and was automatically answered by the remote palmtop computer on the fourth ring. Preassigned passwords were exchanged, and the last data point before contact was specially marked within the remote file, indicating the orientation of the patient in the standardized position (i.e., centered in bed). The base computer then updated its AW-SRAD data file, appending new data only, and the telephone connection was terminated.

The whole-body burden of ^{131}I was calculated from the continuous radiation levels using proportionality of the initial reading with the amount of activity administered. The use of count ratios negates any concerns regarding geometry of the measurements and obviates the need to use a calibration factor. Residual ^{131}I, as a function of time, was displayed in semilogarithmic format on the base computer using AW-GRAPH or the Quattro Pro spreadsheet program (Quattro Pro for Windows, Version 1.0; Borland International, Scotts Valley, CA).

RESULTS

Characterization and Validation

The observed counting rate during decay of ^{99m}Tc is displayed in Figure 3. Maximal counting rates were decreased by ~5% compared to rates extrapolated from data collected 24 hr later. Based on this curve, at the clinically relevant counting rates of 9000 cpm expected when measuring a 5550-MBq (150 mCi) dose of ^{131}I at 2 m, dead-time losses would be <2%. Measurements of an ^{131}I source located 10 m from the detector resulted in an exposure rate of 146 μR/hr, which was 12.4% higher than that expected based on the exposure rate constant alone (*9*).

Patient Examples

The remote monitoring protocol has been successfully performed on eight therapy patients to date, with doses of ^{131}I

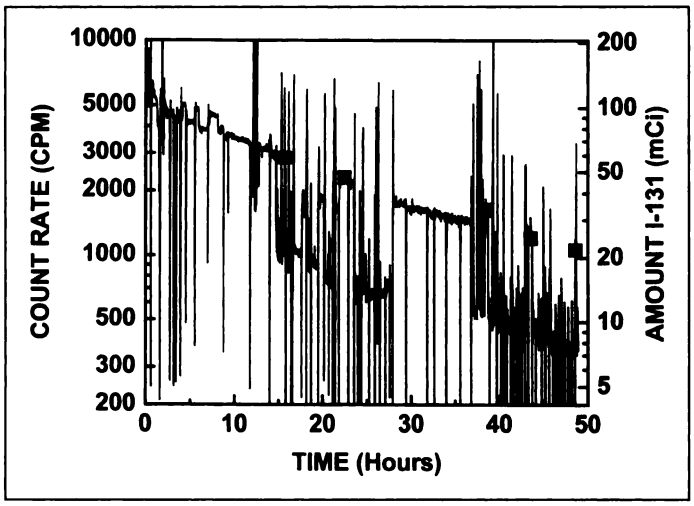

FIGURE 4. A 52-yr-old man was administered 4000 MBq (108 mCi) ^{131}I. Semilogarithmic plot of continuous radioactivity measurements (tracing) and superimposed standardized points (squares) clearly demonstrate two parallel lines, the upper corresponding to the patient lying in bed, and the lower to the patient seated in a chair that was located slightly further away from the detector. The corresponding amount of retained ^{131}I is plotted on the second y-axis (see text for details of calculation). Sharp decreases in counting rate correspond to the patient moving away from the detector to the far side of the room (toward the bathroom), while increases above baseline represent movement toward the window and detector.

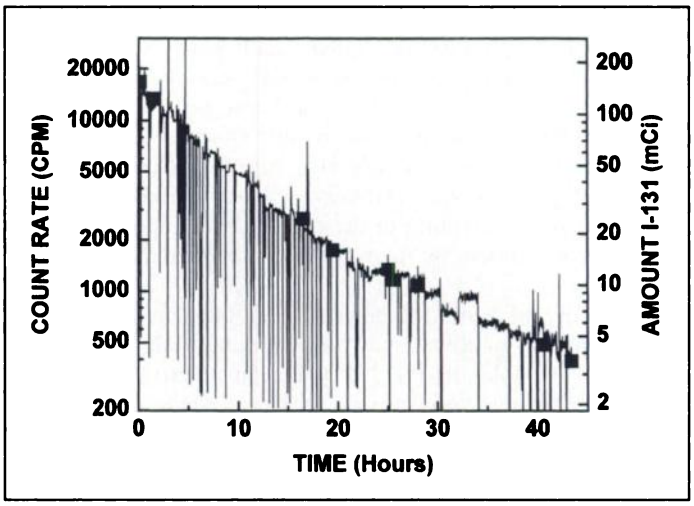

FIGURE 5. A 45-yr-old non-English-speaking woman administered 5700 MBq (154 mCi) ^{131}I for ablation of thyroid remnants and therapy of regional lymph node metastases. Semilogarithmic plot of radioactivity measurements (tracing) and superimposed standardized points (squares) demonstrates a gradual 30-fold decrease in counting rate over a 2-day period. The corresponding amount of retained ^{131}I is plotted on the second y-axis. Despite having regurgitated into the sink some 4 hr after administration of radioiodine, no sharp decrease in activity is noted at this time point, indicating that significant amounts of radionuclide were not lost.

ranging from 1.48 to 9.62 GBq (40–260 mCi). No difficulties in monitoring or data transmission were noted, with a typical download time for 8 hr of data of 10 sec. In all cases, discharge time, based on remote monitoring, was confirmed as accurate based on bedside measurements by the radiation safety officer. Two specific examples illustrate the usefulness of the technique.

Example 1. A 52-yr-old man had recent subtotal thyroidectomy performed for resection of papillary carcinoma, with evidence of local lymph node involvement, but no distal metastases. A dose of 4.00 GBq (108 mCi) ^{131}I was administered for ablation and therapy on an inpatient basis, and remote monitoring was performed. On a semilogarithmic plot, the continuous tracing described a double parallel line appearance (Fig. 4). The upper line overlaps the standardized points and corresponds to the patient in bed, whereas the lower curve corresponds to periods when the patient was seated in a chair. The remote data indicated that it was permissible to discharge the patient home after 48 hr, which was confirmed by daily independent measurements by the radiation safety officer using a handheld GM probe.

Example 2. A 45-yr-old non-English-speaking woman was administered 5.70 GBq (154 mCi) ^{131}I in capsular form for ablation of thyroid remnants and therapy of regional lymph node metastases. Remote monitoring was successfully initiated after careful demonstration and rehearsal of the protocol using a translator. On the day after therapy, the patient informed the staff that she regurgitated into the sink approximately 4 hr after administration of the radioiodine. Inspection of the continuous activity tracing from the day of therapy (Fig. 5) failed to demonstrate any large decrement in counts at this time, suggesting that there was insignificant loss of activity during this episode. Calculation of discharge time by remote monitoring corresponded to independent measurements made at bedside by the radiation safety officer.

DISCUSSION

We describe a convenient and relatively inexpensive method of remotely monitoring ^{131}I therapy patients, based on commercially available components, specifically the compact AWARE GM counter, HP palmtop computer and PCMCIA modem. Using customized software, this device has been remotely polled over standard telephone lines, with rapid and accurate data transfer. The technique can either be used to determine the dose equivalent rate at a fixed distance from the patient or as a means of calculating whole-body retention of ^{131}I by proportionality. The second method, as we have shown, has the advantage of factoring out the effects of geometric efficiency and the need to use the ^{137}Cs calibration factor. In the eight patients followed in this manner, remote monitoring always corresponded to independently performed bedside measurements.

We have shown that the counting characteristics of the device are suitable for monitoring ^{131}I therapy, with a near-linear counting rate response and minimal dead time over the usable count range. Expected counting rates are within the useful range of the instrument. If the initial counting rate were to approach the software-derived maximum of 32,765 cpm, which would be immediately apparent to the operator at the baseline time point, the device can be moved further away from the patient until the limit is no longer exceeded, thereby extending the useful counting rate range. Based on the range of clinically used doses, it is unlikely that this would occur with a detector at least 2 m from the patient. The moderate discrepancies noted between measured and expected exposure rates when measuring an ^{131}I source at 10 m can be ascribed to nonideal broad-beam geometry and buildup of radiation. The energy-response curve for the detector is relatively flat from 200 keV upward, so that use of the ^{137}Cs calibration would not be expected to introduce significant error. One might argue that the difficulty in replicating the theoretical relationship between counting rate and distance in a simulated clinical situation highlights the superiority of measuring counting rate at a fixed geometry and calculating the retained ^{131}I burden by proportionality of the initial counting rate and administered dose.

Additional benefits of the remote GM detector include an accurate and objective "hard-copy" record of radioactivity measurements, which is useful for documentation. Data accu-

mulated over a continuous 24-hr basis are also immediately portrayable in graphic format, which facilitates predicting time of discharge. When displayed on a semilogarithmic plot, the exponential disappearance of counts conforms to a linear appearance, which lends itself to extrapolation. Use of the bed as a standardized position has also proven helpful, in that hypothyroid patients are relatively sedentary and frequently remain in bed, contributing to the overall linear appearance of decay and complementing the rigorously obtained standardized points.

Because use of a remote detector facilitates frequent measurement and the graphic display of continuous data lends itself to accurate extrapolation, it is likely that, in at least some cases, the current technique will decrease the overall length of hospital stay and, thereby, reduce costs. Based on this relatively high cost of patient hospitalization, the initial outlay for monitoring equipment is minor. Accurate prediction of discharge would also allow patients to better anticipate their return home, thereby decreasing anxiety stemming from uncertainty about length of hospitalization.

In Europe, the trend toward increased hospitalization for thyroid therapy would lead to a large market for a remote monitoring device. In the U.S., in nonagreement states that follow the revised U.S. Nuclear Regulatory Commission regulations, many patients formerly confined to the hospital may be treated on an outpatient basis. Nonetheless, there will always be a need for inpatient therapy, based on the amount given, patient independence and the home environment, especially when larger doses are given. An intriguing, yet unexplored, use of a remote detector would be for monitoring therapy on an outpatient basis (*10*), where radiation levels could be carefully polled over the telephone and appropriate instructions relayed to the patient; such a protocol would depend on regulatory approval. Because of the modular nature of the counting system, it would be technically possible to substitute a radio or cellular modem for the standard telephone modem that we used, to poll the remote detector in the absence of a hard-wired telephone connection.

The continuous tracings of activity are also of interest, in that they contain information not available by the usual method of intermittent GM readings. For example, the frequency of bathroom visits is readily discernible from the tracings, indicated by sharp decreases in counting rate, corresponding to the patient moving away from the detector to the far side of the room, followed by discrete decrements in the new baseline, corresponding to emptying of the urinary bladder. Unexpected decreases in activity, such as if the patient regurgitated a significant portion of the therapy dose into the sink or toilet, would be apparent as a very large discontinuity in the counting rate measurements. The continuous nature of the data also allows for accurate curve-fitting and dosimetric analyses, which could be useful in the study of new gamma-emitting radiopharmaceuticals, such as those used in radioimmunotherapy.

Although the method we describe is accurate and improves convenience of measuring radioactivity levels in ^{131}I therapy patients, it is not intended to replace direct interaction with these patients, which is a necessary component of good medical practice. An illustration of this point is the second case discussed, where interaction with the patient disclosed the episode of regurgitation, which could then be evaluated by inspection of the continuous radioactivity tracing.

CONCLUSION

We describe an accurate and easy-to-implement method for continuous monitoring of radiation levels from ^{131}I therapy patients, using readily available hardware components. In addition to simplifying the task of therapy monitoring, this method provides information that is not available when standardized monitoring techniques are used and facilitates prediction of the time of discharge. The flexibility of the technique may enable its use in other facets of nuclear medicine therapy, including monitoring of other gamma-emitting radiopharmaceuticals to determine dosimetry and pharmacokinetics and, potentially, outpatient ^{131}I thyroid therapy.

ACKNOWLEDGMENTS

Bryan Boardman is a principal of AWARE Electronics, Inc., which provided specialized software and RM-60 hardware used in this study. Appreciation is extended to Thaddeus Computing, Inc., for use of loaner HP palmtop computers, to ACE Technologies, Inc., for providing PCMCIA modems and to Nancy Levitt, Buck Lock and the Hewlett-Packard Co., Corporate Philanthropy, for an equipment grant, which facilitated development of this project. Acknowledgment is also extended to Dr. Sherman Heller and the Radiation Safety Staff at Montefiore Medical Center for their professional and caring management of ^{131}I therapy patients.

REFERENCES

1. Sweeney DC, Johnston GS. Radioiodine therapy for thyroid cancer. *Endocrinol Metab Clin North Am* 1995;24:803–839.
2. Mazzaferri EL, Robyn J. Postsurgical management of differentiated thyroid carcinoma. *Otolaryngol Clin North Am* 1996;29:637–662.
3. Culver CM, Dworkin HJ. Radiation safety considerations for post-iodine-131 thyroid cancer therapy. *J Nucl Med* 1992;33:1402–1405.
4. Mountford PJ, O'Doherty MJ. Restrictions following iodine-131 treatment: a time for change or more data required? *Eur J Nucl Med* 1994;21:903–905.
5. Mohammadi H, Saghari M. Hospital discharge policy in thyroid cancer patients treated with ^{131}I: the effect of changing from fixed time to exposure rate threshold. *Health Phys* 1997;72:476–480.
6. Release of patients or human research subjects containing radiopharmaceuticals or permanent implants. In: *Code of federal regulations*, Title 10, Part 35, Section 75. Washington, DC: Office of the Federal Register, National Archives and Records Administration; 1995:541.
7. Release of patients or human research subjects containing radiopharmaceuticals or permanent implants. In: *Code of federal regulations*, Revised, Title 10, Part 35, Section 75. Washington, DC: Office of the Federal Register, National Archives and Records Administration; 1997.
8. U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research. *Release of patients administered radioactive materials*, Regulatory Guide 8.39. Washington, DC: U.S. Government Printing Office; 1997.
9. Sorenson JA, Phelps ME. Radiation safety and health physics. In: *Physics in nuclear medicine*. New York: Grune and Stratton; 1980:345–364.
10. Allen HC Jr, Zielinski JD. 430 non-hospitalized thyroid cancer patients treated with single doses 50–400 mCi [Abstract]. *J Nucl Med* 1990;31:784.