Measurement of Radiation Exposure Resulting from Using an Automated, Solvent-Extraction-Type, Technetium Generator

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Radiation monitoring of the fingers and torso during loading and "milking" of an automated solvent-extraction-type ^{99m}Tc generator showed that technologists received higher exposures than when using the more conventional elution-type generators. The wide range of exposure doses that were measured during various procedures indicated that continual emphasis on good practice would result in a significant reduction in the accumulated radiation exposure dose.

The Nuclear Medicine Service of the VA Hospital in Long Beach, Calif., decided to evaluate the in-lab performance of a commercially available (MEKTEC-99, IMAJ International Inc.) ^{99m}Tc generator which was based on an automated solvent-extraction method using methyl ethyl ketone (MEK). The generator type has special appeal for a busy clinic with a large case load. One important aspect of the evaluation was to assess the radiation exposure accrued by technologists during necessary interactions with the machine during its cycle under actual working conditions and compare the results to the ^{99m}Tc generator system, based on elution of an ion exchange column, which is already in use at the laboratory (MINITEC, E. R. Squibb & Sons, Inc.).

There are two points in any ^{99m}Tc generator cycle where significant radiation exposure to technologists is likely. Once a week a new charge of ^{99}Mo has to be supplied, and, on a daily basis, a ^{99m}Tc eluate is collected. In the MEK-automated system, in order to accomplish these tasks needles had to be inserted or removed through a rubber closure sealing the radionuclide containers. Some details of the automated extraction generator are shown in Fig. 1. Because of the nature of the manual manipulation involved, it was expected that the maximum exposure dose would be received at the hands, followed by the upper torso. This latter expectation arose because during the manual transfer the radionuclides were mostly contained in cylindrical shields with one end open.

In order to establish a dose-magnitude reference, it was also decided to monitor the exposure dose during preparation of the radiopharmaceuticals for injection. Measurements have been reported for handling ^{99m}Tc (*1–4*), but our measurements were to be made under actual working conditions for a distinct operation on a daily basis, rather than integrated over several operations over a relatively long period of time.

Methods

Two technologists (Subjects A and B) were monitored over a one-month interval. Both technologists were monitored identically by standard, commercial film badge dosimeters worn at the waist and on the right index finger (ring position). In addition, exposure was determined by means of thermoluminescent dosimeters (TLDs) contained in 1.4-mm-diam thin-walled plastic capsules (TLD-100, high sensitivity ribbon, approximately 25 mg, 3 × 3 × 1 mm, Harshaw Chemical Co.). The TLDs were located in pairs between the joints of the index fingers of both hands and on the lapel of the subject's jacket. Read out of the TLDs was accomplished by means of a Harshaw model 2000 thermoluminescence analyzer. The response of the TLDs was calibrated by reference to standard radionuclide sources. The relative response of these dosimeters is essentially independent of energy over the range of interest for radiations from ^{99m}Tc and ^{99}Mo. Based on the calibrations, the exposure measurements were believed to be accurate to better than ±7%.

Three distinct operations were separately monitored.

1. Loading of a new ^{99}Mo charge (weekly).
2. Milking of the generator, including addition of diluent in the case of the solvent-extracted ^{99m}Tc (daily).
3. Preparation of the ^{99m}Tc for injection up to and including drawing the radionuclide aliquot into the syringe (daily).

The quantity of ^{99m}Tc involved in the transfer operations was determined by means of a calibrated ionization

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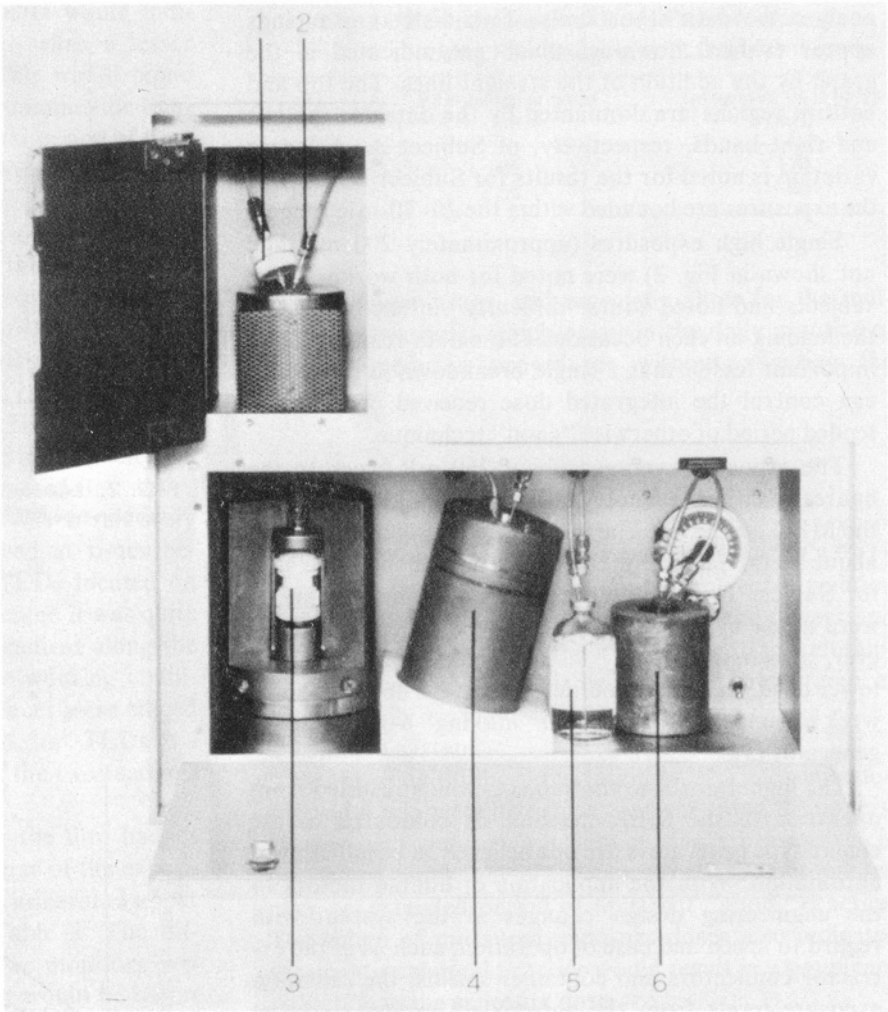

FIG. 1. Shielding details of interior of automated solvent-extraction-type technetium generator. **1.** Filter. **2.** Technetium-99m eluant drying oven, 2.5-cm Pb shield. **3.** Alumina column, 5-cm Pb shield. **4.** Molybdenum-99 input reservoir, 4-cm Pb shield. **5.** MEK solvent reservoir. **6.** Overflow bottle, 2.5-cm Pb shield.

chamber (Radioisotope Calibrator, Model CRC-6, E. R. Squibb & Sons, Inc.).

Results and Discussion

The measurements of exposure dose at the index fingers of each hand and the upper torso are summarized in Table 1. These exposures are only for loading of a new ^{99}Mo charge (for an approximately 1-Ci ^{99m}Tc generator) into the MEK-automated "milker." Similar measurements for the weekly setup of an ion exchange, eluant-type generator which contained 1 Ci of ^{99}Mo indicated an exposure to the fingers of less than 5 mR and an upper torso dose of less than 2 mR.

A relatively complex series of hand and arm movements is involved in loading a generator, and the residence time in each spatial position is related to the actual exposure dose received. No specific instructions were issued to either subject in regard to repeatability of movement, only with respect to the application of the dosimeters. The results were viewed on a qualitative rather than a quantitative statistical basis, looking for apparent trends and differences.

It is seen from Table 1 that there is a considerable exposure-dose difference between the two subjects and apparently good repeatability in the measurements in the case of one. The upper torso dose in the case of Subject B is a considerable fraction of the maximum permissible weekly dose in our hospital. Direct observation and comparison between the techniques of these two subjects indicated that a trade-off may be possible between exposure dose to the upper torso and exposure dose to the fingers.

The finger exposure dose to each subject as a function of the quantity of ^{99m}Tc "milked" from the MEK-automated extractor is shown in Fig. 2, where a considerable scatter of these data is seen. Again for the reasons already outlined, no attempt was made to

TABLE 1. Exposure Dose as Measured by TLDs During Loading of new ^{99}Mo Charge into MEK-Automated Generator

Subject	Exposure dose at index finger, right hand (mR)	Exposure dose at index finger, left hand (mR)	Exposure dose at upper torso (mR)
A	155	198	9
B	48	79	27
B	56	70	30

analyze the data statistically. Two distinct groupings appear evident, however, which are indicated in the graph by the addition of the straight lines. The top and bottom regions are dominated by the data for the left and right hands, respectively, of Subject A. A larger variation is noted for the results for Subject B. Most of the exposures are bounded within the 20–70-mR range.

Single high exposures (approximately 200 mR and not shown in Fig. 2) were noted for both workers. The subjects had noted some "difficulty" in accomplishing the loading on each occasion. These data reinforced the important lesson that a single breakdown in procedure can control the integrated dose received over an extended period of otherwise "good" technique.

The exposure averaged about 250 mR/week to the figures of either technologist for the "milking" cycle in the MEK generator. The upper torso exposure dose was about 40 mR/week for Subject A and about twice that for Subject B. No directly comparable measurements were made by us for the eluant-type generator. However, a radiation survey instrument indicated a much lower dose, and one manufacturer claims about 50 mR/week for finger exposure from "milking" a 0.5-Ci eluant generator (*5*).

The higher doses to the subjects which resulted from operation of the MEK machine as compared to the eluant-type generators are not believed to be inherent to automation. With the application of human factors to the engineering design changes in the system with regard to speed and ease of operation, such as in the extractor connectors and container shields, the radiation exposure levels from the automated system could be reduced significantly.

The measured exposure dose to the finder during preparation of the ^{99m}Tc for injection is shown as a function of quantity of nuclide handled in Fig. 3. The dosimeters were positioned as before and read after completion of the daily individual dose preparation. Approximately 20 individual syringes were prepared for ^{99m}Tc injection from a single milked charge. Syringe shields were used where appropriate. The data appear to separate into two distinct bands, with the higher dose region dominated by data from the left hand. There are several instances where the exposure dose was considerably less than the "average." This would indicate that an analysis of what constitutes good procedure and implementation of these procedures could result in a significant reduction in the integrated exposure dose from this operation.

The exposure dose at the upper torso as a function of quantity of ^{99m}Tc milked and used in the injection preparation operations is shown in Fig. 4. There appears to be no direct correlation between upper body exposure and level of radioisotope handled in the case of the milking operation, and most of the exposures were less than 10 mR. A trend (indicated by the line on the graph) appears evident in the case of prepa-

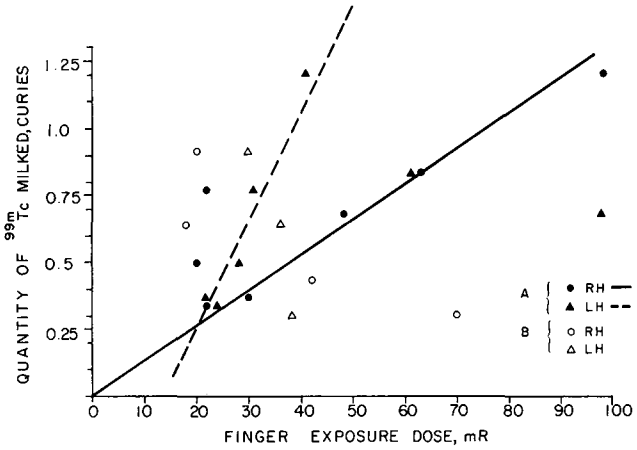

FIG. 2. Exposure dose to finger from milking automated solvent-extraction-type ^{99m}Tc generator.

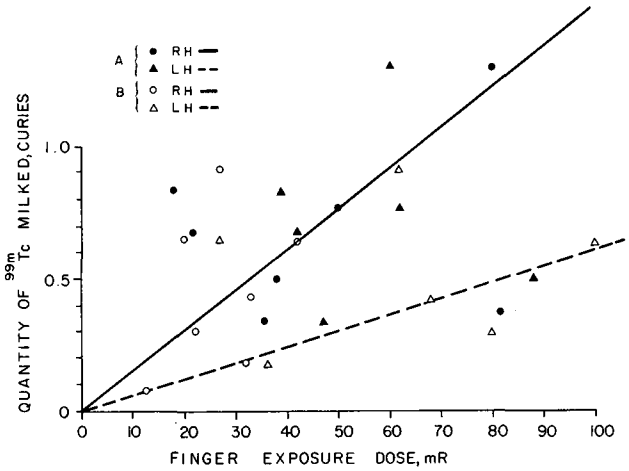

FIG. 3. Exposure dose to finger from preparing ^{99m}Tc for injection.

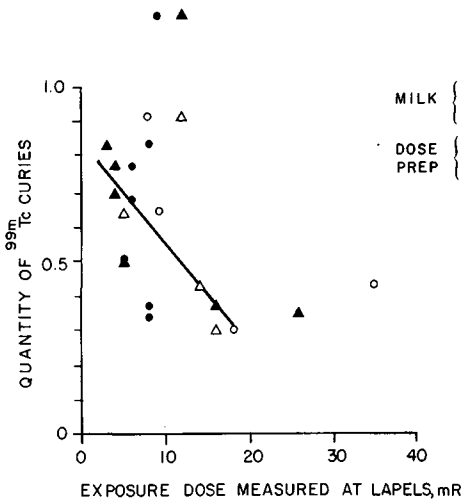

FIG. 4. Exposure dose to upper torso received during milking and preparation of ^{99m}Tc for injection.

ration of ^{99m}Tc for injection. The results would indicate an increase in radiation exposure when a lesser quantity of radionuclide is handled. This would come about if, with decreasing quantity of radionuclide handled, the nuclide was handled for a longer period of time or was handled closer to the torso. We believe that a likely explanation for part of the effect is that the radioactive decay of ^{99}Mo resulted in a decrease of the ^{99m}Tc generated with each milking. At the higher levels, a considerable excess over the daily requirements was available. As the total quantity of ^{99m}Tc milked decreased, the level approached the minimum daily requirement. As a result, more time and effort had to be spent to ensure complete withdrawal. This factor should be taken into account when the generator capacity requirement for a laboratory is to be estimated.

Another anomaly that was noted was a relatively poor exposure-dose agreement observed at times between supposedly duplicate pairs of TLDs located on the same finger. Preliminary tests indicated it was quite possible to have a considerable dose gradient along the finger when handling ^{99m}Tc under the working conditions as outlined. The apparent differences were traced to the separation distance of the "duplicate" TLDs in a high-gradient dose field. An average of the two readings was used in reporting the results.

The exposure dose as indicated by the film badges worn at waist level throughout the course of the experiments was in poor agreement with the integrated upper torso measurements, as shown in Table 2. The difference in body location between the two monitors precludes further comment, except that it would be better to wear the film badge at the collar rather than at the waist line when milking generators of this type.

The discrepancy between the ring film badge and the TLD measurements was even larger. The ring badge of Subject B showed an exposure of 75 mR, while the TLDs that were worn only during the actual indicated operation measured an exposure dose which was higher by at least a factor of ten. The ring film badge for Subject A was lost in processing by the vendor. These measurements indicate the unsatisfactory state of hand monitoring during nuclear medicine procedures. As was already pointed out several years ago (*1*), the types of ring film badges used presently are poorly accepted by technologists, are flimsy, and interfere with using gloves. A higher-quality ring structure incorporating a TLD has already been suggested (*1*) and is surely recommended on the basis of our results. In addition, for operations where relatively large dose gradients may be expected, a TLD incorporated into a thimble-type structure would be of use. The thimble would fit over the end of the finger and could be worn on either side of a glove. This would offer minimal interference with normal finger usage, and especially allow for the multiple handwashings which occur in the daily practice of nuclear medicine procedures without affecting the dosimeter.

TABLE 2. Comparison of Body Doses Measured Using Film Badge and TLDs

Subject	Film badge at waist (mR)	Integrated TLD at lapel (mR)
A	35	174
B	55	98

Summary and Conclusions

Radiation monitoring of separate operations over an extended period during loading and "milking" of a ^{99m}Tc generator based on an automated solvent-extraction cycle showed higher exposure doses to the fingers and torso when compared to the more conventional elution-type ^{99m}Tc generator. It is believed that the differences could readily be minimized by changes in design of the automated system.

Monitoring during preparation of ^{99m}Tc for injection showed a relatively high dose gradient along the fingers. It was also pointed out that a single breakdown in procedure could control the exposure dose accumulated over an extended period of apparent "good" practice. The range of measured exposure doses also indicated that continual good practice would result in a significant reduction in the exposure dose.

On the basis of the results, conventional ring film badges are not recommended for monitoring of the hands during preparation of ^{99m}Tc for injection. In addition, the lapel, rather than the waist, is a better site for monitoring the exposure dose during milking and preparation of nuclide for injection. The use of a finger thimble containing a TLD chip is suggested as a good monitor of maximum hand exposure.

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