Xenon-127m: A New Radionuclide for Applications in Nuclear Medicine

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Xenon-127m (^{127m}Xe) emits two gamma rays in cascade, with half-life of 69.2 ± 0.9 sec. The first has the energy of 172.5 keV, and is emitted from the nucleus in 38% of the decays. The second gamma ray has the energy of 124.8 keV and is emitted from the nucleus in 69% of the disintegrations. Together they furnish 107 easily collimated gamma rays per 100 decays. Xenon-127m is generated readily by bombarding nearly saturated aqueous solutions of sodium or potassium iodide with 14-MeV protons. The ^{127m}Xe is swept out continuously, as it is produced, by bubbling helium upward through the solutions. Up to ~ 100 mci/l are obtained from the resulting mixture of gases. The ^{127m}Xe + helium is admixed with about five volumes of air (or oxygen) and then driven continuously to a scintillation camera located ~ 200 yd distant. When the mixture of gases is inhaled, high quality images of the lungs are obtained by means of an Anger scintillation camera.

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Several radionuclides of noble gases, which have widely diverse physical properties, have been used in nuclear medicine. These include: 50-sec krypton-79m (^{79m}Kr), 35-hr ^{79}Kr, 13.3-sec ^{81m}Kr, 4.5-hr ^{85m}Kr, 10.7-yr ^{85}Kr, 36.4-day ^{127}Xe, and 5.3-day ^{133}Xe.

Our purpose is to describe another radionuclide, xenon-127m (^{127m}Xe), together with a convenient way to generate it continuously with a cyclotron. After approval of the Committee on Radiation and the Investigational Review Board of Memorial Sloan-Kettering Cancer Center, the evaluation of the production and use of ^{127m}Xe in normal volunteers was initiated. Some early experiences with it are described.

Xenon-127m decays with half-life of 69.2 ± 0.9 sec by emitting two gamma rays in cascade. The first has the energy of 172.5 keV, emitted from the nucleus in 38% of the disintegrations, with internal conversion of the remainder. The second gamma ray is emitted from the nucleus 0.28 sec later with energy of 124.8 keV in 69% of the decays (*1*), and the remainder converted internally. Thus, a total of 107 gamma rays with readily collimated energies are emitted in each 100 decays. This is four-fold greater than the 27 130-keV gamma rays furnished by ^{79m}Kr in every 100 decays (*2*).

The metastable state of ^{127m}Xe decays by isomeric transition into 36.4-day ^{127}Xe; and this in turn, decays into stable iodine-127 (*1*). The ratio of half-lives of ^{127m}Xe, to the ^{127}Xe is:

$$69.2/(36.4 \times 24 \times 60 \times 60) = 2.2 \times 10^{-5}.$$

This large difference in half-lives suggests that the copious amounts of ^{127m}Xe generated readily with a small in-hospital cyclotron (*3,4*) may be applied in biomedical studies before sufficient amounts of the ^{127}Xe accumulate to interfere because of the more energetic photons that ^{127}Xe emits. For applications such as single-photon emission computed tomography (SPECT), the 5.2-fold longer half-life of ^{127m}Xe over that of 13.3-sec ^{81m}Kr should prove to be advantageous (*5*). SPECT studies would, by necessity, be carried out by allowing sufficient administration time for the distribution of radioactivity to reach steady-state conditions before imaging. Control of the delivery of the gas is sufficient to allow this.

The energies of the two ^{127m}Xe gamma rays are nearly ideal for conventional imaging techniques by means of an Anger scintillation camera (*6*) or similar dynamic nuclear medicine imaging instruments. Since no gamma rays having higher energies than 172.5 keV are emitted during decay of ^{127m}Xe, its use provides improved resolution and lower radiation exposures than commonly used 5.3-day ^{133}Xe or 36.4-day ^{127}Xe.

MATERIALS AND METHODS

The nuclear reaction used is the one involved in the discovery of ^{127m}Xe, vis (*7,8*):

$$^{127}I(p,n)\ ^{127m}Xe$$

The Q-value is −1.33 MeV (*9*) and the threshold is 1.46 MeV.

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Xenon-127m was generated by bombarding nearly saturated aqueous solutions either of sodium iodide, or of potassium iodide, with protons having an incident energy of 14 MeV. A 40-ml target chamber of titanium, equipped with a 0.0025-cm thick titanium-foil window (*10*) to close the 1.27-cm deep recess in which the target solution is contained completely absorbed the incident 14 MeV protons.

The 69.2-sec ^{127m}Xe is continuously sparged (stripped) from the target solutions by flowing helium gas at the rate of ~ 250 ml/min from a supply tank into the bottom of the target chamber, upward through the solution, out of the top, and then through a trap filled with sodium hydroxide pellets. Purity was monitored during production by flowing the gas through a 125-ml reservoir located 25 cm above a high-resolution 30-cm^3 lithium-drifted Ge(Li) detector, which was connected to a 1,024-channel multichannel analyzer (MCA). Large amounts of 9.96-min nitrogen-13 (^{13}N) are simultaneously generated in the ^{16}O(p, ^{4}He) ^{13}N nuclear reaction. None of it appears in the gas phase; all of it remains in the target solution, presumably as [^{13}N]-NO_3 (*11*). The decay of a highly radioactive sample of the gases was followed in the gamma ray ionization chamber for more than ten half-lives of 69.2-sec ^{127m}Xe, and no emitters of gamma rays with shorter or longer half-lives were found. After decay overnight, gamma rays of long-lived radioactivity were not found.

The ^{127m}Xe + helium gas mixture flowing from the target solutions is combined with approximately five volumes of air (or oxygen) and then driven by tank pressure through a small-bore (0.3 cm ID) stainless steel tube for administration ~ 200 yd from the cyclotron.

The face of a large field of view scintillation camera equipped with a 1.3-cm thick NaI(T1) crystal and a lead collimator commonly used for imaging the 190-keV gamma rays emitted by 13.3-sec ^{81m}Kr is oriented vertically to the floor. The subject sits upright against the collimator face and breathes from the delivery tube the ^{127m}Xe + helium + air (or oxygen) mixture repeatedly to tidal volume and then exhales them again until the appropriate number of counts accumulate, usually 500 kilocounts.

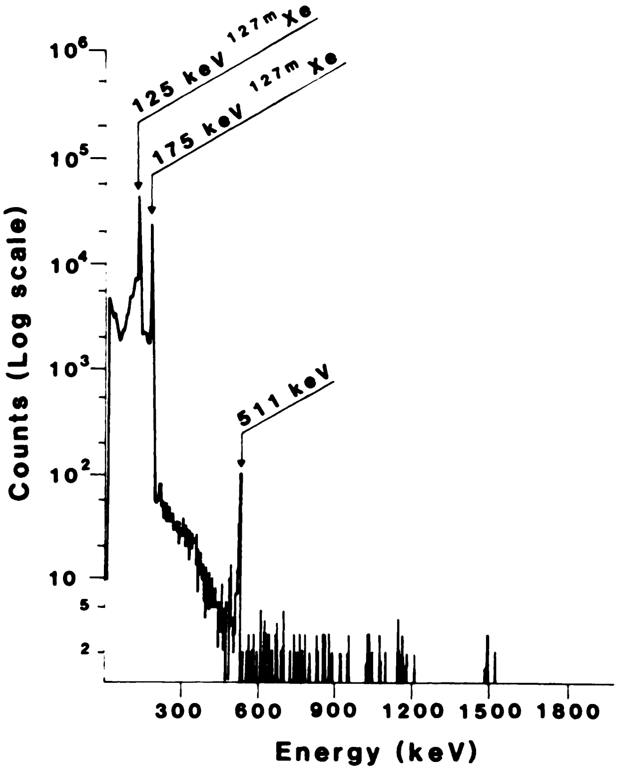

FIGURE 1
Semi-logarithmic plot of representative gamma-ray spectrum of 69.2-sec ^{127m}Xe. A high resolution 30-cm^3 lithium-drifted Ge(Li) detector was used, connected with 1,024-channel multichannel analyzer. Counts were taken during five minutes live time, with sample located 25 cm above detector. Pronounced photopeaks, at 124.9 keV (69% of decays) and at 172.5 keV (38%) is due to ^{127m}Xe (2). The 511 keV photopeak is due to background from running the cyclotron.

RESULTS

Figure 1 is a semi-logarithmic plot of a representative gamma-ray spectrum of the 69.2-sec ^{127m}Xe, mixed with helium, as used in these studies. The spectrum was made as described above. The two pronounced photopeaks, at 124.8 keV and 172.5 keV in Figure 1, are due to the 69.2-sec ^{127m}Xe. No photopeaks due to the gamma rays of 36.4-day ^{127}Xe, nor of any other gamma-ray emitter were found. The counts were taken during 5 min of MCA live time. The photopeak at 511 keV is part of the background radiation observed when the cyclotron is operating. The magnitude of the 511-keV photopeak in the spectrum shown in Figure 1 is the same as in spectra taken with no target gas flowing.

Figure 2A shows anterior images of both lungs of a normal volunteer. A faint image of the trachea appears in this projection. By appropriate threshholding and smoothing of the digital data, the image was enhanced and the trachea became even more discernible (not shown). The heart silhouette indentation of the left lung is visible also.

Figure 2B shows posterior images, made similarly, of both lungs of the same subject.

DISCUSSION

The energy difference between the 172.5-keV gamma ray of ^{127m}Xe and the 140.5-keV gamma ray of technetium-99m (^{99m}Tc) is sufficient to enable use of the windowing capability of the gamma camera to reject the 140.5-keV gamma ray. Thus, ventilation studies may be performed immediately following perfusion studies. Alternatively, to perform ventilation studies first, both gamma rays may be imaged.

The more than 45,000-fold greater ratio of half-lives of 36.4-day ^{127}Xe to that of 69.2-sec ^{127m}Xe is advantageous in comparison with the ~ 2,500-fold ratio of half-lives of ^{79}Kr to that of ^{79m}Kr (*3*). There is virtually no contamination of ^{127m}Xe with ^{127}Xe, as illustrated in Figure 1. Also, there is no shorter lived radionuclide of xenon with which to be concerned, as in the case with the 13.3-sec ^{81m}Kr contamination of ^{79m}Kr produced as described in a previous paper (*3*).

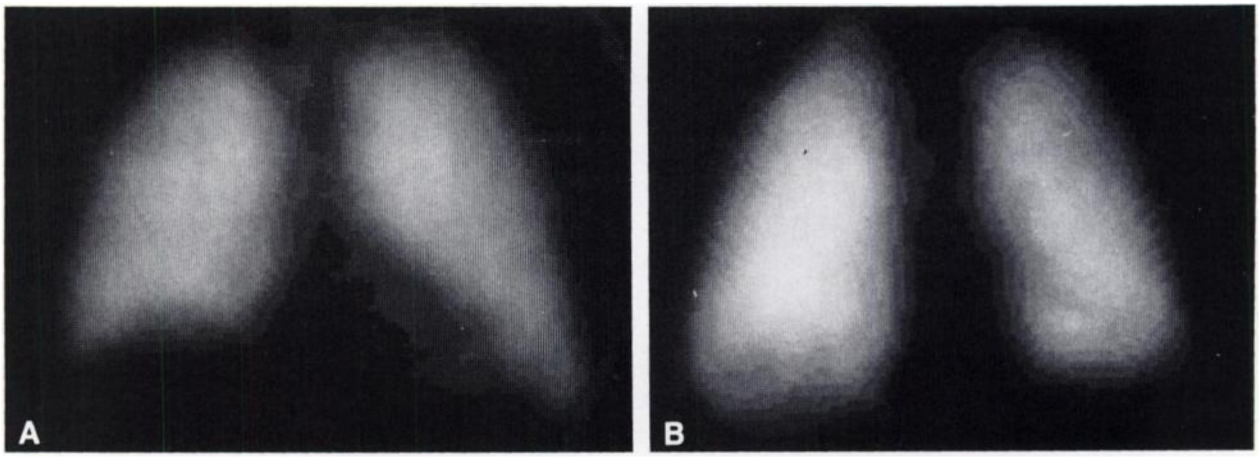

FIGURE 2
Anterior (A) and posterior (B) images of the lungs. The subject repeatedly inhaled ^{127m}Xe, admixed with helium and air, to tidal volume and then exhaled the gases again until 500 kilocounts accumulated. The chest was against collimator for anterior view, and the subject's back was against collimator for posterior view. Heart silhouette of left lung is apparent on anterior view, as expected. Note that trachea is faintly visible also.

Xenon-127m has several other practical advantages compared with 36.4-day ^{127}Xe. The latter emits ~ 88 gamma rays with energies in excess of 200 keV (*2*); and the long half-life leads to containment problems. With some commercial sources of ^{127}Xe, one may be required additionally to contend with contaminations by 8.9-day ^{129m}Xe and by 11.9-day ^{131m}Xe, soon after the xenon is received.

The calculated narrow-beam half-thickness in centimeters in water, sodium iodide, and lead of the two gamma rays emitted by ^{127m}Xe, are given in Table 1, based on graphical interpolations of the values of Hubbell (*12*). The 4.4-cm half-thickness of the 124.8-keV gamma ray in water compares favorably with the 4.5-cm half-thickness in water of the 140-keV photons of commonly imaged 6-hr ^{99m}Tc.

The values in brackets in the lower part of Table 1, the half-thicknesses in lead of the 140.5-keV gamma ray of ^{99m}Tc and of the 190-keV gamma ray of ^{81m}Kr, indicate septal penetration by the 172.5-keV gamma ray of ^{127m}Xe in the high-resolution collimator (^{99m}Tc). The collimator used to image the 190-keV gamma ray of ^{81m}Kr is quite adequate to collimate the 172.5-keV gamma ray of ^{127m}Xe as demonstrated in Figure 2.

TABLE 1
Calculated Narrow-Beam Half-Thicknesses of the Xenon-127m Gamma Rays

	124.8 KeV	172.5 KeV
Water	4.4 cm	4.9 cm
NaI	0.20 cm	0.42 cm
Lead	0.019 cm	0.044 cm

140-KeV of ^{99m}Tc in lead, 0.026 cm.
190-KeV of ^{81m}Kr in lead, 0.055 cm.

Preliminary findings indicate that the method to generate ^{127m}Xe or ^{79m}Kr by bombarding aqueous solutions of the halide salts is widely applicable. It has been extended to the generation of 17.2-sec neon-19 in useful amounts (*9*).

Radiation dosimetry estimates appear in Table 2. The calculations were made on the basis of values given in (*2*) and MIRD Pamphlet 5 (*13*). The basic assumption was that ^{127m}Xe is uniformly distributed in the lung; and that the nonpenetrating particulate dose is only significant in the lungs. Typical integrated administered doses would be ~ 20 mCi/min.

NOTE

William G. Myers, the principal author of this paper, whose imagination and originality inspired these efforts, died June 17, 1988 before communicating to the *Journal* his response to the reviewers' initial comments on this paper. The paper stands largely as he wrote it, but we have had to make some changes without his expert assistance. Prof. Myers, known affectionately to us as Bill, collaborated on a regular basis and produced many papers and abstracts with us between 1974 and 1988. We miss Bill very much. Without him, much of the "FUN" (as in FUNdamental) is gone from our research.

TABLE 2
Absorbed Doses from Xenon-127m

Target organs	rad/mCi-min	rad
Lungs	5×10^{-3}	1×10^{-1}
Tracheal lining	1.2×10^{-2}	2.4×10^{-1}
Gonads	3.7×10^{-5}	7.4×10^{-4}
Total body	3.7×10^{-5}	7.4×10^{-4}

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