Permissible Concentration in Air of Xenon-127: Concise Communication

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This paper reviews the method of calculation, and the criteria involved, in the determination of the maximum permissible concentrations of inert gases in ambient air. The results show that because the original calculations for Xe-133 included both photon and particulate dose, the permissible levels for Xe-127 are only slightly less than the levels established for Xe-133.

J Nucl Med 19: 105–106, 1978

The advantages of Xe-127 for ventilation lung imaging have been pointed out by Hoffer, et al. (*1*) and Coates and Nahmias (*2*). Goddard and Ackery (*3*) have considered the aspects of patient dosimetry and have found results favorable to Xe-127 when compared with Xe-133, although their results would have to be modified somewhat if the dose contribution from contaminants is to be considered. Xenon-127 is not without disadvantages. Two of the physical characteristics that add to its clinical efficacy are the 36.4-day half-life and the high photon yield. These same characteristics complicate the radiation shielding problems as compared with Xe-133. In addition, it would appear that the high photon yield might require that the maximum permissible concentration (MPC) for Xe-127 in ambient air be significantly less than the MPC for Xe-133.

The Code of Federal Regulations, Title 10, Part 20 (10 CFR 20), does not include Xe-127 in the table that gives the MPC for radionuclides in air and water. The table does contain, however, three classifications for unlisted radionuclides. The classifications are based on half-life and mode of decay. For Xe-127, the limits would be 3×10^{-9} μCi/cm^3 for a restricted area and 1×10^{-10} μCi/cm^3 for an unrestricted area. These demanding requirements are $\frac{1}{3000}$ of those for Xe-133. The corresponding tables of state agencies, which would license the accelerator-produced Xe-127, are based on the tables of 10 CFR 20. Thus, it is necessary for an institution either to meet the very stringent limits for unlisted radionuclides or to estimate and justify an MPC for Xe-127.

Xenon is an inert gas, and as such the MPC in air is based on submersion in an infinite cloud of the gas, not on the concentration in any particular organ. In an infinite cloud, the energy liberated per gram is in equilibrium with the energy absorbed per gram. For such a case, the MPC is given by

$$\text{MPC} = \frac{1}{\Delta} \times \rho_{\text{air}} \times \frac{1}{S_a{}^t} \times \frac{1}{T} \times \text{MPD} \times 2, \quad (1)$$

where Δ is the appropriate equilibrium dose constant (g-rads/μCi-hr); ρ_{air} is the density of air (g/cm^3); $S_a{}^t$ is the relative stopping power of tissue/air ($\sim$1.1); T is the exposure time involved (40 hr/wk, restricted; 168 hr/wk, unrestricted; and MPD is the maximum permissible dose (0.1 rem/wk, restricted; 0.01 rem/wk, unrestricted). The final factor of 2 is used because a hemisphere of activity is involved.

For a restricted area, equation (1) becomes

$$\text{MPC} = \frac{5.86 \times 10^{-6}}{\Delta} \ \mu\text{Ci/cm}^3, \quad (2)$$

and for an unrestricted area it becomes

$$\text{MPC} = \frac{1.40 \times 10^{-7}}{\Delta} \ \mu\text{Ci/cm}^3. \quad (3)$$

Table 1 summarizes the equilibrium dose-constant data for both Xe-127 and Xe-133 in MIRD Pamphlet 10 (*4*). Note that the ratio of the equilibrium dose constants for penetrating radiation leads one to expect that the MPC values for Xe-127 would be about 16% of the values for Xe-133.

To ensure that Eqn (1) was consistent with the method used in deriving the MPC values in 10 CFR

Received May 2, 1977; revision accepted Aug. 9, 1977.

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TABLE 1. DOSIMETRY DATA

	Equilibrium dose constant (g-rad/μCi-hr)		Mean energy per disintegration (MeV)		Xe-127 / Xe-133
	Xe-133	Xe-127	Xe-133	Xe-127	
Total	0.388	0.668	0.182	0.314	1.72
Non-penetrating	0.292	0.070	0.137	0.033	0.240
Penetrating	0.096	0.598	0.045	0.281	6.24
Penetrating + particulate ≥ 0.1 MeV	0.306	0.648	0.144	0.304	2.11

TABLE 2. MPC VALUES FOR Xe-133 (μCi/cm³)

		Equilibrium dose constant	
	10 CFR 20*	Penetrating	Total
Restricted area	1×10^{-5}	6.11×10^{-5}	1.51×10^{-5}
Unrestricted area	3×10^{-7}	1.46×10^{-6}	3.61×10^{-7}

* Values given to one significant figure.

20, it was applied first to Xe-133. Table 2 compares the values calculated using the penetrating and the total equilibrium dose constants with the published limits of 10 CFR 20. Note that the values derived from the total equilibrium dose constant are much closer to the 10 CFR 20 limits than are those derived from only the penetrating equilibrium dose constant. This prompted an investigation into the criteria and assumptions used to arrive at the MPC values for inert gases.

Most of the current MPC values for radionuclides were published in two sources. The first is National Bureau of Standards (NBS) Handbook 69 (*5*) which, with some modifications, was issued as National Council on Radiation Protection and Measurements (NCRP) Report 22 (*6*). Both of these include a table of the MPC values and some basic standards for radiation protection. The methods of calculation and basic assumptions are not included in either publication.

The second source is the International Commission on Radiological Protection (ICRP), Report of Committee II (*7*). That report includes the tables, methods, assumptions, and equations involved. The equation used in the ICRP report is the equivalent of Eqn (1). The following pertinent conditions are stated explicitly for inert gases: the limiting factor is the whole-body dose to a person surrounded by a hemispherical, infinite cloud of radioactive gas; in addition to penetrating radiation, all beta radiations with a transition energy ≥ 0.1 MeV are included in the whole-body calculation. Although not stated explicitly, one can infer that the fraction of the energy lost to conversion and Auger electrons is included, even though for Xe-133 these electrons do not meet the 0.1-MeV criterion. (For the MPC calculation of Xe-133, the ICRP report gives the average energy per disintegration as 0.19 MeV. Compare that with the value of 0.18 given in Table 1 using the total equilibrium dose constant, and with 0.14 for penetrating and particulate ≥0.1 MeV. The 0.01-MeV discrepancy results from the difference between the ICRP and MIRD mean beta-particle energies.) Thus the original MPC calculation for Xe-133 included the contribution from all the particulate radiations.

For Xe-127, if one wishes to remain consistent with the original ICRP policy, equations (2) and (3) should be used with the equilibrium dose constant that includes conversion electrons with energy ≥0.1 MeV. From Table 1, this value is 0.648 g-rads/μCi-hr. The MPC values for Xe-127 so calculated are 9×10^{-6} μCi/cm³ for a restricted area and 2×10^{-7} μCi/cm³ for an unrestricted area. Thus, a clinical facility that uses Xe-133 with any reasonable factor of safety in the MPC values will be able to use Xe-127 without modification of the gas-handling system, except perhaps for additional shielding.

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