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Standardization of xenon-127 and measurement of photon emission intensities

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HIGHLIGHTS

- ^{127}Xe standardized by internal gas counting using three proportional counters.
- Activity per unit volume measured with 0.7% relative uncertainty.
- Photon emission intensities derived using gamma-ray spectrometry.
- ^{127}Xe could be ^{133}Xe surrogate to calibrate remote radio–xenon monitoring stations.

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ABSTRACT

Xenon-127 was standardized by internal gas counting using three proportional counters in a differential arrangement to eliminate edge effects. The detection efficiency of the proportional counters was calculated by considering the cascade of events following the electron capture and associated gamma transitions. Activity per unit volume was measured with 0.7% relative standard uncertainty. Gamma-ray spectrometry was performed and absolute photon emission intensities were derived. This study shows that ^{127}Xe could be a surrogate for ^{133}Xe for the calibration of remote radio–xenon monitoring stations.

1. Introduction

The yield of production of xenon isotopes by fission of uranium and plutonium is high and, because of their chemical inertia, these radionuclides are very good tracers of civil and military nuclear activities. Xenon isotopes are used to calibrate monitoring instruments of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). Monitoring of radioactive noble gas mainly concerns ^{133}Xe, $^{131\,m}$Xe, $^{133\,m}$Xe and ^{135}Xe for the purpose of determining the nature of a nuclear event. However, these isotopes have short half-lives and so are not convenient for calibrating distant monitoring stations. Even though ^{127}Xe is not the radionuclide of interest for this purpose, it can be conveniently used for the control of these devices, due to its rather long half-life (36.4 (1) d) compared to the other xenon isotopes.

2. Decay scheme

Xe-127 decays by electron capture to excited levels of ^{127}I with a cascade of 5 main gamma ray emissions in the 57.6–375.0 keV energy range (Fig. 1), together with the characteristic X-rays of iodine. Only three transitions lead to allowed electron-capture decays, namely the 203, 375 and 618 keV states. Up-to-now, no other transition has been observed. The following comment can be found in Gehrke and Helmer (1977): "The electron-capture to the ground state is second forbidden for which the minimum log *ft* value is ~11 and thus the maximum intensity of the feeding branch is ~0.003%". The same comment can be applied for the electron-capture to the first excited state of ^{127}I since this transition is third forbidden unique.

Three measurements of relative γ-ray emission intensities and only one measurement of the absolute γ-ray emission intensities are available in the literature. The decay scheme of ^{127}Xe is therefore poorly known and must be improved for the practical use of this radionuclide for calibration purposes.

3. Standardization using triple gas counters

In this study, ^{127}Xe was standardized by internal gas counting using three proportional counters in a differential arrangement to eliminate end effects. A measurement using 4πγ detector can also be used (Vatin and Chauvenet, 1987) but we think that gas counting leads to more direct results.

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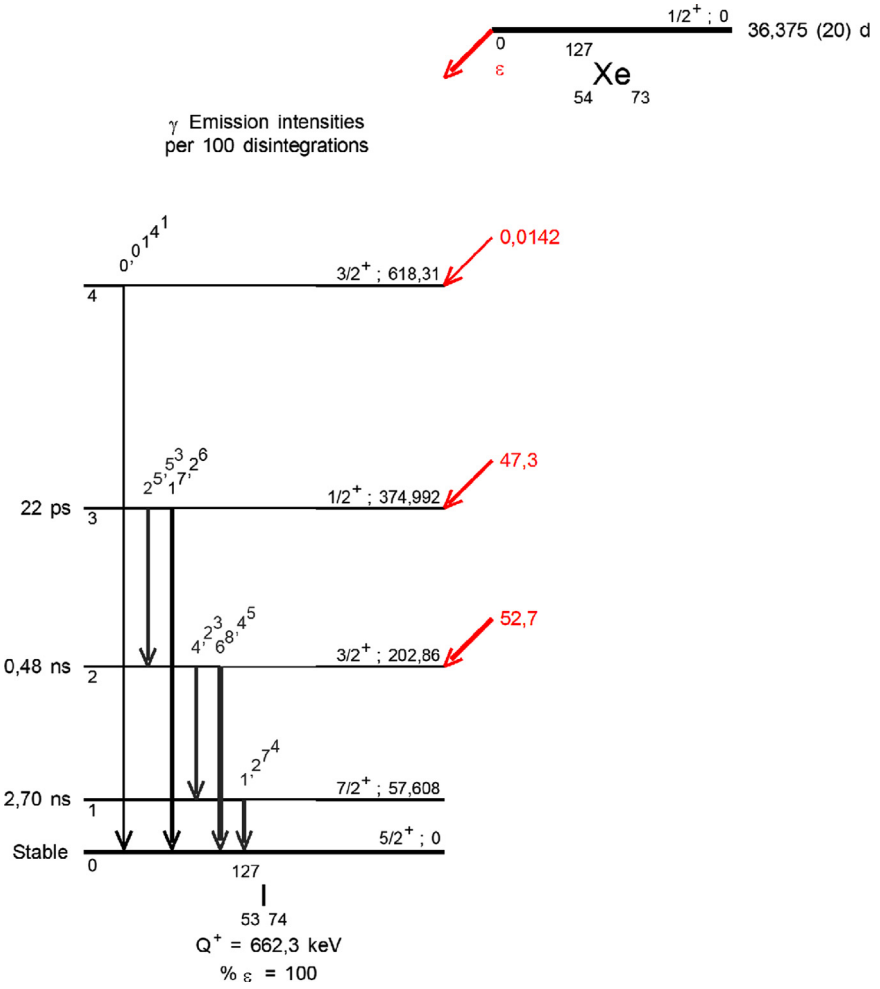

Fig. 1. ^{127}Xe decay scheme.

3.1. Source preparation

The radioactive source was prepared from the neutron irradiation of an enriched ^{126}Xe target. The measured sample was composed of xenon in nitrogen and contained ^{125}I as a radioactive impurity. This impurity was removed by the use of a filter made of silver wool and the radioactive purity was checked by gamma-ray spectrometry.

3.2. Measurement method

The internal gas counting system developed at the LNE-LNHB was described previously (Lansiart et al., 1993). It is composed of three proportional detectors with different lengths, an electronic subassembly and a gas handling equipment.

The detectors are identically constructed of stainless steel tubes of different lengths and their ends have guard rings which are in contact with the cathode. The counting gas is propane. Using these counters, three ideal detectors (without end effect) can be obtained by differential counting.

The electronic subassembly contains three counting channels and each channel is equipped with an extended dead-time circuit. The corrections due to this dead-time are made according to the live-time method. Additionally, each channel is connected to a multichannel analyzer board from a personal computer. The experimental energy spectrum given by each detector is stored in order to obtain differential spectra. The energy threshold of the counters are adjusted at 200 eV.

The gas handling equipment is used to sample the radioactive gas in a reference volume and mix it with the counting gas in the dilution volume. After homogenization, the mixture is transferred to the proportional counters.

3.3. Detection efficiency

The electronic re-arrangement following the electron capture and the gamma transitions both contribute to the detection efficiency of the proportional counter. The contribution of each process is evaluated hereafter. For the electron capture process, atomic rearrangements can lead to vacancies in various shells and thus, the detection efficiency is evaluated for each kind of vacancy, irrespective of the phenomenon creating this vacancy.

3.3.1. Electron vacancy in the N shells

The binding energy of the electrons of the N shell is ranging from 186 eV for the sub shell N1 to 50 eV to the subshell N5. The fluorescence yield is negligible and thus, the higher energy Auger electron is N1–N5–X, at 136 eV, that is lower than the energy threshold of the counter. It can be concluded that the detection efficiency of the capture of N electrons is negligible, thus $Ef_N = 0$.

3.3.2. Electron vacancy in the M shells

The binding energies of the electrons of the M shell are in the 1.07 keV–620 eV range for respectively M1–M5. The fluorescence yields are from a few 10^{-4} to 10^{-3} (McGuire, 1972, 1974) and thus