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Activity measurements of barrels filled with radioactive waste

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In barrels with radioactive waste radioactivity may be inhomogeneously distributed. Since the inhomogeneity may be unknown, when measuring the activity of the barrel it is advantageous to use the radiation emitted from it. Consequently, robust methods, capable of yielding the results that are independent on the distribution of the radioactivity within the barrel, must be used.

Gamma-rays emitted from the barrel attenuate in the material within the barrel before escaping from it. Since attenuation coefficients are decreasing functions of energy for multi-gamma-ray emitters it is possible to deduce the amount of material penetrated by measuring their attenuation as a function of energy. This is done with gamma-ray spectrometry by measuring the apparent activity $A(E) = N(E)/T/\varepsilon0(E)/P(E)$, where N(E) denotes the number of counts in the peak at the energy E, T the counting time, $\varepsilon0$ the efficiency of the spectrometer and P the probability for emitting the gamma-ray in a nuclear decay. If for $\varepsilon0(E)$ the efficiency of a non-attenuating source is used, the energy dependence of the detector's response to gamma-rays is taken into account to a large degree. It follows then that e.g. for a source placed on the surface of the barrel the apparent activity is independent on energy. It should be observed that the apparent activity is undetermined to a scaling factor since $\varepsilon0$ is rather arbitrary. The apparent activity is proportional to the flux of gamma-rays through the detector. It is proportional to the flux density, because it is normalized to the efficiency, which measures the volume or the cross section of the sensitive volume of the detector. Also, it is proportional to the activity since it is normalized to the rate of the decaying nuclei.

It is easy to see that a source, homogeneously distributed within the barrel, causes an apparent activity increasing slowly with energy already at low energies. On the other hand, the apparent activity for a point source located inside the barrel at a distance from its surface tends to zero at low energies since here the attenuation of gamma-rays is large. At high energies, the apparent activity of a source embedded into the material within the barrel increases fast with energy. It follows then that from the energy dependence it is possible to extract three apparent activities: one corresponding to the surface contamination, the second corresponding to the contamination homogeneously distributed within the barrel and the third to a point source within the barrel located at a distance from its surface. Since the apparent activity is decomposed into three fractions, so are the count rates. Using the efficiencies, calculated by e.g. ISOCS software, corresponding to the three sources it is possible to arrive at the three activities. The total activity of the drum is the sum of the three activities and its uncertainty is determined from the uncertainties of three activities taking into account the correlations.

With this method four unknowns are necessary to determine: the three activities and the location of the point source. Therefore only gamma-ray emitters radiating at at least four energies in a large energy interval can be measured. The robustness of the method is demonstrated on test data for the radionuclides belonging to the thorium decay chain. It is shown that at count rate uncertainties of 2% the uncertainty of the total activity is less than 100% for the worst case which is represented by two point sources, one weak at the surface of the barrel and a strong one located deep within it.

The method described above will be developed and validated as one of the contributions to the EMRP project MetroNORM. The aim of the project is to develop novel instrumentation and methods for accurate, traceable and standardized measurements of NORM material. This method will make it possible to considerably improve the ability to determine total activity of inhomogeneously distributed NORM waste in drums.

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