BACKGROUND CORRECTIONS IN THE QUALITY CHECKING OF LOW LEVEL RADIOACTIVE WASTE FOR PLUTONIUM USING PASSIVE NEUTRON COINCIDENCE COUNTING

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ABSTRACT

The neutron coincidence rates detected in the quality checking of low level radioactive waste using passive neutron coincidence counting caused by cosmic radiation are comparable with the neutron coincidence rates of the allowed amounts of plutonium within the waste. The detection of the cosmic induced coincidence rates is discussed and the filtering of high multiplicity events outlined. The results of research into the variation of low multiplicity background neutron coincidence rates, measured in the quality checking of low level radioactive waste packages using passive neutron coincidence counting, with waste matrix are presented. A method for calculating the background coincidence rates of waste packages is detailed.

INTRODUCTION

The independent quality checking of low level radioactive waste (LLW) in England and Wales is performed at the Waste Quality Checking Laboratory (WQCL) at Winfrith, Dorset, which is operated by NNC Limited on behalf of the Environment Agency. Recently, WQCL has acquired a passive neutron coincidence counter (PNCC) in order to monitor the alpha emitting plutonium contents of LLW destined for disposal at BNFL's Drigg facility.

Passive neutron coincidence counting determines the rate of the coincident neutrons emitted from a waste package. The true coincidence rate, i.e. the coincidence count rate corrected for accidental coincidences, is then equated to either the mass of the even isotopes of plutonium within the waste package or to the mass of ^{240}Pu which would result in the same coincident rate as the even isotopes of Pu present within the waste package, $^{240}Pu_{eq}$. With appropriate information, the total plutonium alpha activity of the waste package may then be calculated from the measured value of $^{240}Pu_{eq}$.

The majority of LLW generated in the UK is packaged in 200 litre drums and WQCL's PNCC is optimally configured to assay such drums. For a typical consignment of drummed LLW produced by a typical nuclear reactor, the Drigg Conditions for Acceptance allow about 0.6 mg of $^{240}Pu_{eq}$ per drum. This value is comparable to the accidental (background) coincidence rates measured in even well designed instruments. The accidental coincidence rate is caused by the detection of cosmic radiation and its interactions with the instrument and the waste package and must be corrected for in the quality checking of LLW.

This paper presents the results of WQCL's research into quantifying the variation of background coincidence rates with waste matrix.

BACKGROUND CORRECTIONS

Cosmic rays appear as showers of coincident particles and the direct detection of these results in a coincident count rate. In addition, spallation caused by the interaction of cosmic particles with the nuclei of the materials of the construction of the instrument and/or the waste package may generate additional bursts of neutrons. Both of the above effects give rise to high multiplicity events. The mean multiplicity of the neutrons emitted in the spontaneous fission of plutonium is about 2. Therefore, high multiplicity events detected by PNCCs can only be caused by cosmic radiation. WQCL's PNCC filters out such high multiplicity events using a software approach which compares the number of neutrons detected in relatively small windows of time to a user-defined mean multiplicity [1-6]. The filtering is applied by evaluating the filter criterion to windows which start with every detected neutron. If a window is rejected all of the neutrons detected within it are ignored and the evaluation continues with the next detected neutron following the rejected window. This allows the efficient filtering of detected high multiplicity events.

However, the background neutrons may be moderated by the instrument and/or the waste package being assayed, resulting in a coincident rate with a mean multiplicity comparable to that of the spontaneous fission of plutonium. The intensity of the cosmic radiation reaching the Earth's surface depends on atmospheric pressure. Research into the variation of the cosmic ray induced background coincidence rate with atmospheric pressure has been conducted by WQCL and presented elsewhere [5,6].

Further research into the variation of background coincidence rates with waste matrix has been conducted by WQCL using drums of simulated waste. The simulated waste comprised of steel and concrete. 200 litre drums containing simulated matrices comprising varying quantities of these two materials were assayed using 4 hour count times. The results showed that the variations in background coincidence rates with waste matrix and atmospheric pressure can be considered separately. The results, pressure corrected to 1013 hPa, are presented in Figure 1, where the error bars represent the computed uncertainty at the 95.5% confidence level.

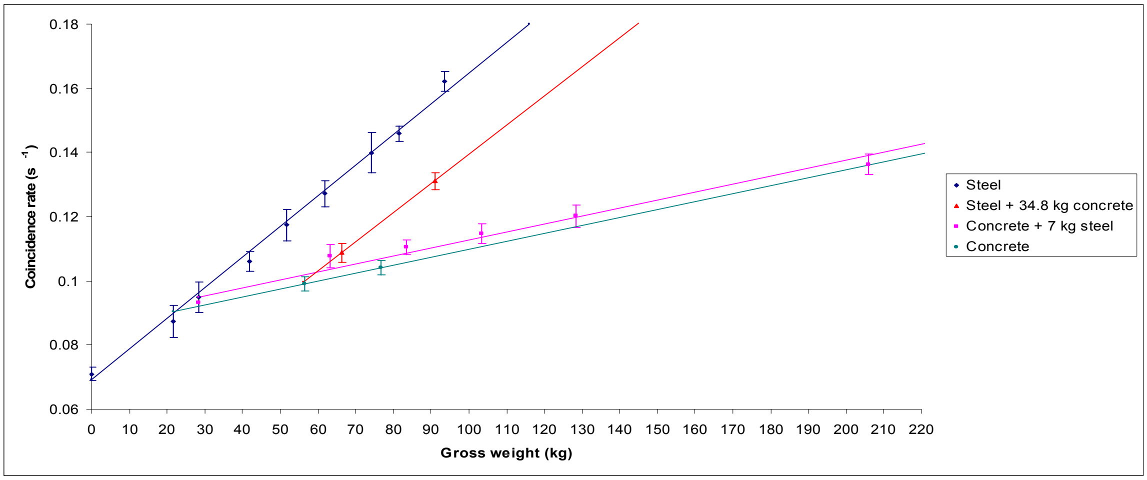

Fig. 1 Coincidence rate as a function of gross package weight at 1013 hPa

The data presented in Figure 1 can be grouped into four categories: The blue data points and line correspond to simulated waste matrices comprising all steel, the red data points and line correspond to matrices comprising a fixed amount of concrete (34.8 kg) with varying amounts of steel, the purple data points and line correspond to matrices comprising a fixed amount of steel (7 kg) with varying amounts of concrete and the green data points and line correspond to simulated waste matrices comprising varying amounts of all concrete.

The lines through each data set correspond to the lines of best fit through the data sets, taking into consideration the uncertainties on the data points. The lines of best fit through the all steel (blue) and varying amounts of steel with a fixed amount of concrete (red) data sets are parallel. As are the lines of best fit through the all concrete (green) and varying amounts of concrete with a fixed amount of steel (purple) data sets. Note that, continuing the lines beyond their lower extremities represents non-physical situations. The line of best fit for the all concrete data set terminates at 21.5 kg, the weight of the drum. Likewise, the lines of best fit through the varying amounts of concrete with a fixed amount of steel terminates at 28.5 kg and through the varying amounts of steel with fixed amount of concrete terminates at 56.3 kg. The line of best fit for the all steel data is extended to zero weight as the drum is made of steel.

The equations for the lines of best fit are given by the equation

$$C = a + b(W - \overline{W}), \qquad \text{(Eq. 1)}$$

where C is the coincidence rate of a package of gross weight W. The constants a, b and $\overline{W}$ for each line of Figure 1 are given in Table I.

Table I Constants for the Lines of Best Fit

Matrix	a	b	$\overline{W}$
Steel	0.115 ± 0.002	0.00095 ± 0.00002	48.0
Steel + 34.8 kg concrete	0.112 ± 0.002	0.00091 ± 0.00002	69.5
Concrete + 7 kg steel	0.107 ± 0.002	0.00025 ± 0.00002	77.3
Concrete	0.102 ± 0.002	0.00025 ± 0.00003	67.0

The coincidence rate at zero weight corresponds to the coincidence rate of an empty measuring instrument. Subtracting the coincidence rate of the empty instrument from the coincidence rate measured in the assay of a waste package represents the coincidence rate of the waste package measured in the ideal situation of the absence of a measuring instrument.

Analysis of the data presented in Figure 1 and Table I shows that the difference in coincidence rates between a drum containing a certain amount of concrete and a drum containing the same amount of concrete plus 7 kg of steel equals the coincidence rate of 7 kg of steel measured in an ideal situation. From the data presented in Table I, the coincidence rate of 7 kg of steel measured in an ideal situation is $0.007 \pm 0.003\ \mathrm{s}^{-1}$. Also from the data presented in Table I, and noting that an empty drum weighs 21.5 kg, the measured coincidence rate of a drum containing 34.8 kg of concrete (56.3 kg gross package weight using the concrete data) is $0.099 \pm 0.002\ \mathrm{s}^{-1}$ and the measured coincidence rate of a drum containing 34.8 kg of concrete and 7 kg of steel (63.3 kg gross package weight using the concrete + 7 kg steel data) is $0.104 \pm 0.002\ \mathrm{s}^{-1}$. The sum of the coincidence rates of 7 kg of steel measured in an ideal situation and a drum containing 34.8 kg concrete is $0.106 \pm 0.003\ \mathrm{s}^{-1}$, which equals the measured coincidence rate of a drum containing 34.8 kg of concrete and 7 kg of steel ($0.104 \pm 0.002\ \mathrm{s}^{-1}$), within the quoted uncertainty. Similarly, the difference in coincidence rates between a drum containing a certain amount of steel and a drum containing the same amount of steel plus 34.8 kg of concrete equals the coincidence rate of 34.8 kg of concrete measured in an ideal situation.

The above analysis leads to the equation

$$R = \sum_{i=1}^{N} R_i, \qquad \text{(Eq. 2)}$$

where $\boldsymbol{R}$ is the coincidence rate of a waste package measured in an ideal measuring situation, $\boldsymbol{R}_i$ is the coincidence rate of the i^{th} constituent of the waste package measured in an ideal situation and N is the number of constituent materials forming the waste package. The total background coincidence rate of an assay is then

$$R_T = R + R_I,$$

where $\boldsymbol{R_I}$ is the coincidence rate of the measuring instrument, corresponding to the coincidence rate at zero gross package weight in Figure 1.

CONCLUSIONS

The research conducted by WQCL into background coincidence rates has shown that the variations in background coincidence rates with waste matrix and atmospheric pressure can be considered separately. This paper has presented a method for calculating the accidental background coincidence rates of waste packages at a reference atmospheric pressure based on knowledge of their waste matrices. Combining the two methods allows the determination of the background coincidence rates of waste packages in their quality checking.

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