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In situ gamma spectroscopy of spent nuclear fuel using a CdTe detector

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Abstract

Gamma spectroscopy using a room temperature CdTe detector has been carried out in the proximity of a spent nuclear fuel rod. In this context, a compact and transportable monitor, incorporating a planar CdTe crystal was constructed and installed inside the $\beta-\gamma$ hot cell. It provided effective shielding for the crystal against the intense background. Gamma spectra, with an energy resolution (FWHM) of 7.2 keV at 662 keV, were obtained in 600 s counting time, which would allow verification of the burnup to within 10% and cooling time of the fuel to within 3% of the declared values by applying specific isotopic correlations. The good spatial resolution has allowed the use of the monitor as a gamma scanning device.

1. Introduction

Knowledge of the fissile material inventory of spent nuclear fuel and safety considerations during its transport and storage require verification of the fuel burnup. Presently, there is an increasing interest for the application of compact detectors to remote and unattended monitoring and assaying of nuclear material. The use of semiconductor compounds, e.g. CdTe and CdZnTe, has been explored for gamma spectroscopy on spent nuclear fuel [1–3]. The interest in these compounds stems from their small size and operation at room temperature resulting in portable monitors for the assay of spent fuel under wet and dry conditions.

The possibility to use a CdTe detector for gamma spectroscopy of nuclear material has already been investigated at the Institute for Transuranium Elements [2,4]. Fundamental studies and gamma spectroscopy of individual spent nuclear fuel rods were performed inside a $\beta-\gamma$ hot cell. These were carried out on low burnup (<25 GW d/t) fuel with a low gamma radiation background (5 to 7 yr cooling time). On the basis of these preliminary studies, a compact monitor was constructed and installed inside the hot cell for gamma spectroscopy on extended burnup fuel, in the presence of intense gamma background. Hence, verification of the declared burnup and cooling time of spent nuclear fuel was performed, as well as gamma scanning along the fuel length. Moreover, the operation of the CdTe detector in the proximity of spent nuclear fuel and its long term behaviour in an intense gamma radiation field could be assessed. This paper presents the findings from these studies.

2. Experimental

The $\beta-\gamma$ hot cell where this work was performed is used to store several spent nuclear fuel rods of standard and extended burnup from PWR and BWR power stations. The stored rods gave rise to a very high gamma radiation background inside the hot cell. Gamma spectroscopy was carried out on rods with an extended burnup (>45 GW d/t) and cooling time of less than 4 yr.

A planar CdTe detector (9 mm^2 active surface, 2 mm thickness, operating voltage 120 V) was housed in a probe. The wall of the probe is made of a mixture of lead and tungsten. The CdTe probe is connected by a LEMO connector to the electronic modules situated outside the hot cell, through a cable of 12 m length. The amplifier used combined normal amplification and electronic pulse processing (Charge Loss Corrector (CLC)) which resulted in improved energy resolution and peak to noise ratio [2]. The energy resolution (FWHM) was 7.2 keV at 662 keV measured outside the hot cell with a ^{137}Cs standard radioactive source. The orientation of the active surface of the CdTe crystal is parallel to the central axis of the cylindrical probe, i.e. sidewise.

The probe is mounted in a monitor of cylindrical lead shield (Fig. 1). The fuel rod to be measured is held parallel to the top surface of the monitor and can be translated horizontally on its supporting stand for scanning. The

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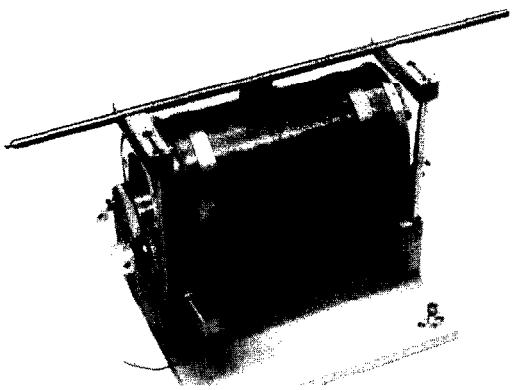

Fig. 1. Picture of the monitor with the collimator and dummy fuel rod in position.

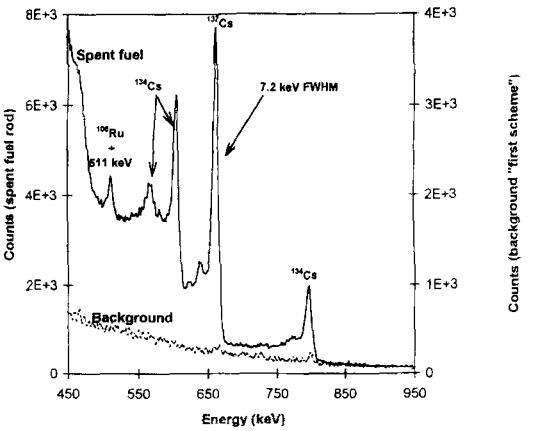

Fig. 3. Gamma spectrum of a spent nuclear fuel rod and the background obtained inside the hot cell.

monitor can also be rotated by a motor, around its central axis in order to study fuel situated in its neighbourhood. A compromise had to be made in the design between the lead thickness for background reduction and the weight because of handling limitations of the manipulators inside the hot cell where the work was carried out. Nevertheless, a compact and transportable monitor was realised.

The gamma radiation is collimated onto the CdTe crystal through a bore hole collimator that is fitted into the lead shielding. The collimator, made of tungsten, extends from the outer surface of the shield to the probe. A fine hole aligned along the hole in the probe wall, collimates the gamma radiation emitted by the fuel onto the crystal. The most important components of the monitor are indicated in Fig. 2.

3. Results and discussion

Prior to being installed inside the $\beta-\gamma$ hot cell, the probe was mounted in the monitor. The orientation of the bore hole collimator for gamma spectroscopy is upwards. The effectiveness of the shielding in reducing the gamma radiation background on the CdTe detector was assessed under two different schemes. Firstly, several stored fuel rods were placed at the side of the monitor with their highest burnup region (half way along the active length) 1 m away. In this way the detector background is maximised. The gamma spectrum from this experiment arrangement is shown in Fig. 3. Secondly, a fuel rod, placed on its supporting stand, was displaced away from the collimator

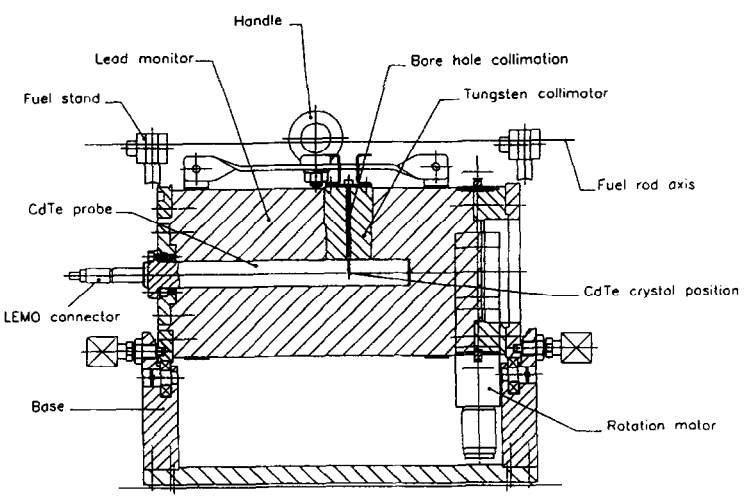

Fig. 2. A side view design of the monitor where the most important components are indicated.

hole until it could not be seen by the detector, thus simulating a neighbouring rod to the one analysed in an assembly. The gamma background under this scheme was similar to that in Fig. 3. There were no photopeaks in the energy region of interest (>500 keV), i.e. originating from fission products such as ^{134}Cs (605, 796 and 802 keV) and ^{137}Cs (662 keV).

Gamma spectrometry on individual fuel rods was performed each time with the rod placed above the collimator on its supporting stand. The gamma spectrum (600 s counting time) obtained from an extended burnup rod with long cooling time is shown in Fig. 3 for the energy region 450 to 950 keV. Gamma rays from the fission products ^{134}Cs, ^{137}Cs and ^{106}Ru are identified in the spectrum. The 605 and 662 keV lines from ^{134}Cs and ^{137}Cs are well resolved; the 796 and 802 keV lines from ^{134}Cs form a doublet, which is also the case for the 512 keV of ^{106}Ru and 511 keV annihilation radiation. The gamma spectrum from the fuel is clearly raised above the background. The implications are twofold: (i) an effective shielding against the intense background of the hot cell has been achieved; and, (ii) axial and radial fission product distribution measurements can be performed by scanning of the fuel since no photopeaks can be observed when the rod is displaced away from the collimator hole.

The energy resolution (FWHM) at the 662 keV remains virtually the same as outside the hot cell at 7.2 keV, i.e. it is not influenced either by the high gamma background or the close proximity of the investigated rod. Furthermore, it has not altered over the period of the preliminary studies (1.5 yr) when the CdTe probe was in the hot cell. During this period, the crystal was stored 1.5 m away from several spent fuel rods with extended burnup. It was subjected to an estimate integrated dose of 10^9 neutrons.

The scope is to employ CdTe detectors within the nuclear fuel cycle to verify declarations of plant operators on the burnup and cooling time of spent fuel. Isotopic correlations suitable for interpretation of isotopic ratios were set up using the point depletion code KORIGEN [5]. The parameters to be verified are then extrapolated from the experimentally measured isotopic ratio via the isotopic correlations. The ratio ^{134}Cs/^{137}Cs is employed for this purpose (605 keV for ^{134}Cs and 662 keV for ^{137}Cs) for predictions of burnup and cooling time. The predictions are respectively within 10% and 3% of operator declared values.

Post-irradiation examination of spent nuclear fuel often requires knowledge on the distribution of fission products, e.g. ^{137}Cs, along its active length. The axial response is related to the burnup distribution, migration of fission products, gap between successive pellets and hence swelling of pellets. The capability of the monitor to perform axial gamma scanning on spent nuclear fuel was examined over a few pellets along a small region towards the end of the fuel. The possibility to distinguish the gap between

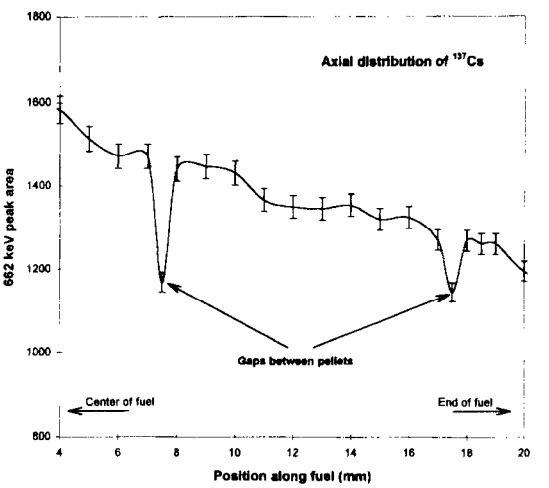

Fig. 4. Axial distribution of the ^{137}Cs along the spent nuclear fuel rod showing the gaps between successive pellets.

successive pellets is clearly demonstrated (Fig. 4) indicating a good spatial resolution of the monitor. The trend in the measured gamma signal towards the end of the active length is in accordance with the axial distribution of burnup in spent fuel [6].

4. Conclusions

Gamma spectroscopy has been carried out directly on spent nuclear fuel rods inside a β–γ hot cell by applying a small CdTe crystal in a high efficiency shielding setup. This has important implications for the safeguards determination of fuel parameters such as burnup and cooling time and opens the possibility of unattended and remote operation. The capability to complement the gamma spectroscopy with passive neutron interrogation appears an attractive option. This stems from the improved accuracy (4%) which is achieved by the latter for the burnup prediction due to the high dependence of the neutron emission on the burnup [6].

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