Nuclear Instruments and Methods in Physics Research A241 (1985) 207–209
North-Holland, Amsterdam

A 6130 keV GAMMA-RAY SOURCE USING THE $^{13}C(\alpha, n)^{16}O$ REACTION

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Received 4 June 1985

A high energy gamma-ray source has been produced by mixing the alpha emitter ^{238}Pu with ^{13}C to produce the 6130 keV gamma-ray from the de-excitation of the second excited state in ^{16}O. The gamma-ray spectrum and emission rate have been measured and the neutron emission rate and mean energy have been determined.

A reliable high energy (> 3.5 MeV) gamma-ray source was required to investigate the energy resolution and efficiency of a variety of gamma-ray detectors. The production of a suitable source has previously been reported [1]. It made use of the $^{13}C(\alpha, n)^{16}O$ reaction to produce a 6130 keV gamma-ray and its advantages over other possible sources were discussed in ref. [1]. A similar source has now been produced but using ^{238}Pu as the alpha emitter rather than ^{244}Cm. Careful measurements of the gamma-ray and neutron emission have been carried out for this source. ^{238}Pu was chosen in preference to ^{244}Cm primarily because it was easier to handle, having a much lower spontaneous fission rate. It is also cheaper than ^{244}Cm, has a longer half-life and was readily available. Its principal disadvantage is that the two main energies of the alpha particles which are emitted from ^{238}Pu are 5.499 and 5.455 MeV compared with the 5.80 MeV particle from ^{244}Cm. However, the excitation function for the reaction does not vary rapidly over this energy range [2] and so the source strength was expected to be comparable with that obtained using ^{244}Cm.

The source consisted of 10 mg of PuO_2 (6×10^9 Bq) having an isotopic content of ~92% ^{238}Pu and 7% ^{239}Pu, mixed intimately with 200 mg of carbon enriched to 99% of ^{13}C. This mixture was pressed inside an aluminium closed-end tube at about 150 N mm^{-2} and a second closely fitting aluminium tube was pressed on top with a shaped plunger. The open ends of the tubes were folded over using a crimping tool and the capsule so formed was pressed again. The capsule containing the pellet of $PuO_2/^{13}C$ was removed from the die, brushed to remove loose powder and fitted into a stainless steel cup. A lid was pressed in place and the rim welded using an argon arc. After decontamination, the entire capsule was placed in a secondary stainless steel capsule, welded, leak tested and checked for contamination. The completed assembly formed a cylinder 2 cm long and 1 cm in diameter. The radiological hazard was assessed and found to be small; 5 μSv h^{-1} from neutrons and < 2 μSv h^{-1} from gamma-rays, as measured at a distance of 30 cm from the source. There was no detectable contamination on the exterior of the source.

The gamma-ray spectrum from the source was recorded using a 110-cm^3 n-type Ge detector. The source was placed 25 cm from the front face of the detector and next to a calibrated ^{60}Co source in order to allow the emission rate of the 6130 keV gamma-ray to be determined. The spectrum for gamma-rays > 1 MeV obtained after counting for ~ 10 h is shown in fig. 1, and the high energy part of the spectrum is shown in more detail in fig. 2. No background has been subtracted in either of the figures. The 6130 keV peak with its single and double escape peaks is clearly seen, the next nearest line of any notable strength being the 2615 keV Th C'' line which is due to contamination of ^{236}Pu in the ^{238}Pu.

The efficiency of the Ge detector had been measured previously using the method of Kane and Mariscotti [3]. Calibrated sources were used to measure the efficiency up to about 3.5 MeV and the relative efficiency was determined above this energy by observing gamma-rays of known strengths emitted following thermal neutron capture in a variety of materials. Using this efficiency calibration, the emission rate of the 6130 keV line could be compared with the ^{60}Co source giving an estimate of 770 (± 10%) Bq for the strength of this gamma-ray.

The neutron emission from the source was measured by placing it in a large oil-moderated BF_3 detector assembly which has already been described [4]. This indicated an emission rate of 4.5×10^4 (± 2%) neutrons s^{-1} and a mean energy for the neutrons of (4.0 ± 0.1) MeV.

The source emits neutrons by two process, spontaneous fission and (α, n) reactions. The number of neu-

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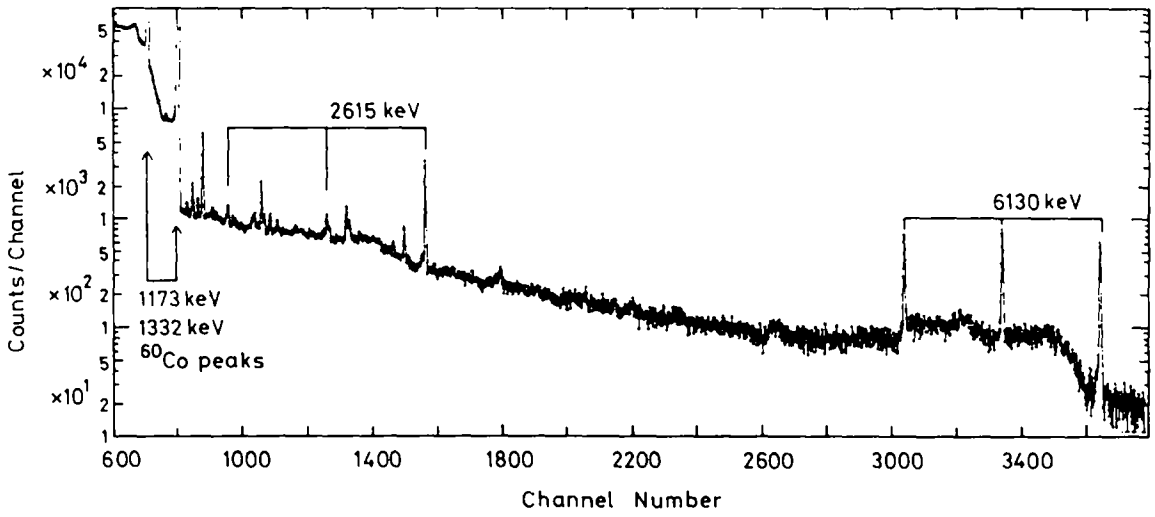

Fig. 1. The gamma-ray spectrum obtained after ~10 h with the $^{238}Pu/^{13}C$ source placed 25 cm from the front face of a 110-cm^3 n-type Ge detector. All events detected with energies >1 MeV are shown; no background has been subtracted. The peaks at 1173 and 1332 keV which go off-scale are due to the presence of the ^{60}Co calibration source.

trons arising from spontaneous fission, estimated to be no more than 30 s^{-1}, is negligible compared to the number from the (α, n) reaction. Alpha particles of all energies below 5.5 MeV are present as a result of their slowing down in the source material. When absorbed by ^{13}C, they excite states in ^{17}O between 6.4 and 10.6 MeV which decay by neutron emission to states in ^{16}O. As a result, neutrons are produced with a wide spectrum of energies.

The neutron spectrum from a thick carbon target following bombardment by 5.5 MeV alpha particles has been studied previously by Jacobs and Liskien [5], and the value they obtained for the mean neutron energy ((4.05 ± 0.14) MeV) is in good agreement with the present measurement. Following absorption in ^{13}C of an alpha particle with energy between 5.02 and 6.14 MeV, neutrons arise from decays to either the 0^+ ground state, the 0^+ state at 6049 keV or the 3 state at 6130 keV in ^{16}O. The 3^- state decays producing the gamma-ray of interest, whereas the 0^+ first excited state decays by pair internal conversion. The low energy peak which Jacobs and Liskien observed in the neutron spectrum is due to the decays to the first and second excited states in ^{16}O. It accounts for approximately 15% of the total number of neutrons, indicating that, for this source, about 7×10^3 neutrons s^{-1} arise from decays to these

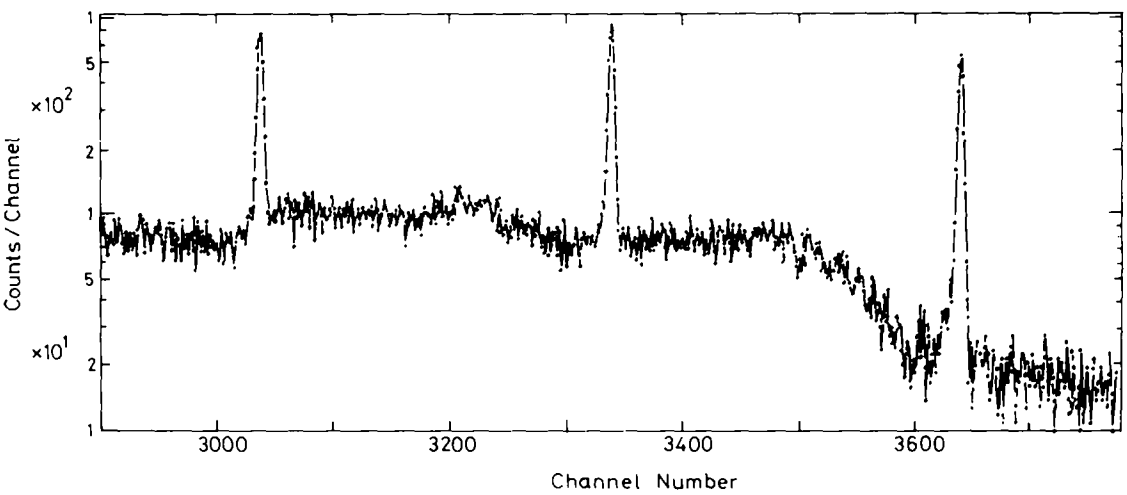

Fig. 2. An expansion of the high-energy region of fig. 1.

two states. Assuming other modes of decay are negligible, it may be taken that the 6130 keV gamma-ray emission rate of $\sim 770\ s^{-1}$ is equal to the rate at which decay takes place to the 3^- state in ^{16}O. This suggests an average branching ratio of about 7 to 1 for decay from the states between 10.2 and 10.6 MeV in ^{17}O to the first and second excited states respectively in ^{16}O.

Acknowledgments

I would like to thank Mr. J.W. Isaacs of AERE Chemistry Division for manufacturing the source and Mr. N.P. Hawkes for assisting with the measurements of the neutron emission rates.

References

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