FORMULATION OF THE GAMMA PILE-UP EFFECT IN FISSION COUNTERS*

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The neutron response of fission counters (FC) exposed to very high gamma fluxes is strongly degraded by the pile-up of undesired gamma ray detections.¹⁻² An expression was derived and experimentally verified to express the amplitude distribution of the gamma pile-up (GPU) as a function of the gamma flux ϕ_γ and detector parameters such as the electron collection time τ . As a result of this study, FC users and designers should be able to accurately predict the GPU effect in their reactor applications.

For a pulse detector operated in the current mode, individual pulses can be approximated as rectangular current pulses of amplitude q/τ and duration τ , q being the electrical charge collected as a result of a detection.³ For a fission counter, the charge q_n produced by a fission (neutron interaction) is $\sim 10^3$ greater than that produced by a gamma interaction q_γ . Accordingly, a single neutron pulse can, in principle, be separated from a single gamma pulse by pulse height discrimination. However, in large gamma fluxes the gamma pulse rate $\phi_\gamma r_\gamma$ (where r_γ is the pulse rate per flux unit) is so high that gamma pulses cannot be detected individually. For example, at 10^6 r/hr, $\phi_\gamma r_\gamma$ would be about 3×10^{11} pulses/sec, and if the electron collection

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time were 10^{-7} sec, an average of 3×10^4 gamma interactions would occur (pile-up) per unit time τ . In such a gamma field, the output current from the counter would be continuous, with a mean component and a fluctuating component due to the statistical nature of the detection process. The mean component of the gamma-induced signal could be blocked with a high-pass filter, but the amplitude of the fluctuating component could be large enough to pass through the pulse height discriminator and, hence, contribute to the observed counts.

To determine the dependence of the observed gamma counts on the gamma pulse rate $\phi_{\gamma r \gamma}$ and the properties of the detector, we first considered the mean number of gamma pulses in time 2τ , which is $2\phi_{\gamma r \gamma} \tau$. Because the events are randomly distributed, they obey Poisson's distribution; the standard deviation of the number of events is $(2\phi_{\gamma r \gamma} \tau)^{1/2}$. Each gamma pulse has a mean height of $\bar{q}_{\gamma}/\tau$; accordingly, the standard deviation of the amplitude of the gamma-induced current $\sigma_{\gamma}(i)$ is

$$\sigma_{\gamma}(i) = \frac{\bar{q}_{\gamma}}{\tau} (2\phi_{\gamma r \gamma} \tau)^{1/2} = \left(\frac{2\phi_{\gamma r \gamma}}{\tau} \right)^{1/2} \bar{q}_{\gamma}. \quad (1)$$

Using the properties of the normal distribution function, we constructed a GPU function vs discriminator setting in standard deviation units. Then we verified the shape and amplitude of this analytic GPU distribution with experimentally observed GPU distributions.

Analysis of Eq. (1) implies that the GPU distribution function is proportional to $\phi_{\gamma}^{1/2}$ and $\tau^{-1/2}$ (instead of being proportional to ϕ_{γ} and independent of τ , as

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accepted prior to this study). This dependence of the GPU distribution on $\phi_Y^{1/2}$ and $\tau^{-1/2}$ was verified experimentally using the neutron detection system described in ref. 2. In particular, when the gamma flux field was increased a factor of 5, the observed average amplitude of the GPU distribution increased a factor of 2.10, which compares favorably with the predicted factor of $\sqrt{5} = 2.24$. The $\tau^{-1/2}$ dependence of the GPU was evaluated by varying the gas filling composition of the same FC (95% Ar + 5% CO₂ vs 99% Ar + 1% N₂, yielding measured collection times τ of 85 and 105 nsec, respectively). When the average amplitude of the GPU distribution was measured at 10^7 r/hr with both gas fillings, the average amplitude was 1.11 times greater for the FC filled with the faster gas. This ratio of 1.11 is precisely equal to $(85/105)^{-1/2}$.

We have demonstrated that the GPU effect can be understood and predicted by considering the statistical nature of the detection process. In particular, the analytical and experimental GPU distribution vs pulse height setting agree well, and the GPU distribution function is proportional to $\phi_Y^{1/2}$ and $\tau^{-1/2}$.

References

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