Secondary $\gamma$-ray decays from partial-wave $T$ matrix with $R$-matrix applications to $^{15}\text{N}(p,\alpha_1\gamma)^{12}\text{C}$

The secondary $\gamma$ rays emitted following a nuclear reaction are often relatively straightforward to detect experimentally. Despite the large volume of such data, a practical formalism for describing these $\gamma$ rays in terms of partial-wave $T$-matrix elements has never been given.

\[
\frac{d\sigma}{d\Omega_{\gamma}} = \frac{1}{(2I_a + 1)(2I_a + 1)} \frac{\pi}{k_{ua}^2} \sum_k (2k + 1)^{1/2} R_k \frac{P_k(\cos \theta_{\gamma})}{4\pi} H_k,
\]

\[
H_k = \sum_{J_1J_2L_1L_2S_1S_2} (-1)^{J_1+S_1} (2J_1 + 1)(2J_2 + 1)(2S_1 + 1)(2S_2 + 1)^{1/2}
\times (k\ell_{1}00|\ell_{2}0) W(kI_Bs'_{1}l_B;I_Bs'_{1}) W(k's_{1}J_{2}l'_{2};s'_{2}J_{2}) W(kJ_{1}l_{2}s_{1};J_{2}l_{1}) T_{bB_{1}S_{1}\ell_{1}L_{1}}^{I_{1}L_{1}} T_{bB_{2}S_{2}\ell_{2}L_{2}}^{I_{2}L_{2}}.
\]

\[
R_k(LL'I_{B}I_{C}) = (2I_B + 1)^{1/2}(2L + 1)^{1/2}
\times (2L' + 1)^{1/2} (-1)^{b-k+l-L'+k+l+1}
\times (L'L1 - 1|0) W(LL'I_{B}I_{B};k_{I_{C}}).
\]

The partial-wave formalism is applicable when $R$-matrix methods are used to describe the reaction in question. We have supplied the needed framework, and it is demonstrated by the application to the $^{15}\text{N}(p,\alpha_1\gamma)^{12}\text{C}$ reaction through the JINA $R$-matrix code AZURE2.