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Remarks on detecting high-energy deuterium–tritium fusion gamma rays using a gas Cherenkov detector

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Abstract

As fusion ignition conditions are approached using the national ignition facility (NIF), independent high-bandwidth gamma-ray fusion burn measurements become essential complements to information obtained from neutron diagnostics. The 16.75-MeV gamma rays that accompany deuterium–tritium (d + t) fusion can be detected using a high-bandwidth gaseous carbon dioxide Cherenkov threshold detector. The detection energy threshold was set by the CO_2 gas pressure. A 1-GHz detector system was fielded successfully at the Omega laser facility, demonstrating unambiguous detection of high-energy fusion gamma rays from high-yield d + t implosions. An experiment to detect the ~12.5 MeV d–t fusion gamma ray is described.

Keywords: Fusion; d + t; ^{5}He; R-matrix; Cherenkov; Omega; Gamma rays

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1. Historical perspective

For at least two decades, the magnetic and inertial fusion communities have pursued the measurement of high-energy fusion gamma rays as a direct indication of thermonuclear burn. High-energy gamma-ray measurements involving production threshold properties of Cherenkov detectors have been studied (Ladish et al., 1986; Moran, 1985; Petrasso et al., 1988; Lewis et al., 1992). Attempts to observe these high-energy fusion gamma rays from inertial fusion capsule implosions involved experiments using the NOVA laser at the Lawrence Livermore National Laboratory. Lerche (1995) concentrated on solid-material Cherenkov detector systems that indicated some advantages in conversion to Cherenkov optical light. Caldwell et al. (1997) used a gallium–arsenide detector to detect neutron *and* gamma-ray output from high-yield implosions. Collectively, these experiments indicated that if quality burn-history measurements are to be available for experiments at the NIF, approaches with energy thresholding and greater bandwidth will be necessary. This capability could be realized using gas Cherenkov detectors (GCDs) designed to give a time history of high-energy fusion gamma rays, thereby leading to an improved understanding of the d + t burn physics and capsule

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performance. Unambiguous observation of fusion burn gamma rays using GCDs at moderate bandwidth is a significant step toward a high-bandwidth instrument.

2. Nuclear physics

Fusion of deuterium with tritium produces an excited ^{5}He* nucleus, which then has several possible de-excitation modes (Ajzenberg Selove, 1988). The most common mode emits a 14.1-MeV neutron and a 3.5-MeV alpha particle. Fig. 1 shows the calculated gamma-ray spectrum one would expect to see from the decay of the narrow $J^\pi = 3/2^+$ resonance just above the d + t threshold in ^{5}He* to its ground state ($3/2^-$) and first excited state ($1/2^-$). The spectrum was calculated using a two-body resonance model for the 3-body (gamma + neutron + alpha) final state, taking into account the two lowest n-alpha resonances ($3/2^-$ and $1/2^-$). The relevant states are shown in the ^{5}He level diagram, Fig. 2. The peaks in the calculated γ spectrum correspond approximately to the energy differences shown on the diagram. The gamma-ray modes emit at 16.75 MeV to the ground state and possibly at ~12 MeV to a broad level near 4 MeV. However, there is considerable uncertainty about the location of the broad $1/2^-$ level (~4 MeV). The relative strengths of the ground- and first-excited-state transitions in the calculated spectrum were taken from a measurement of the mirror ^{5}Li system in which the two peaks could be separated (Buss et al., 1968). There are broad states in ^{5}He above the highest one shown, but they are unlikely to be excited in our experiments.

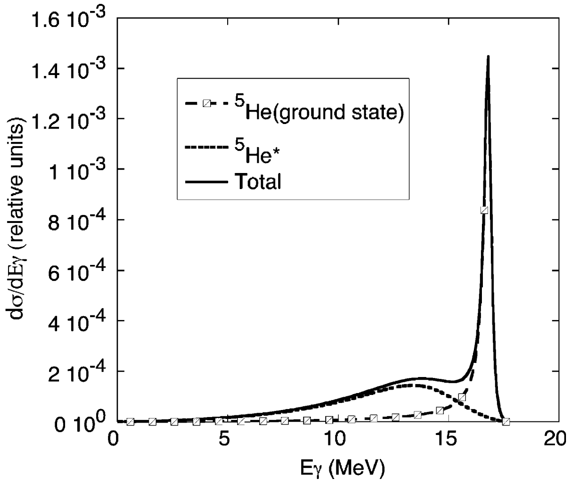

Fig. 1. Theoretical gamma-ray spectrum for the deuterium–tritium fusion reaction.

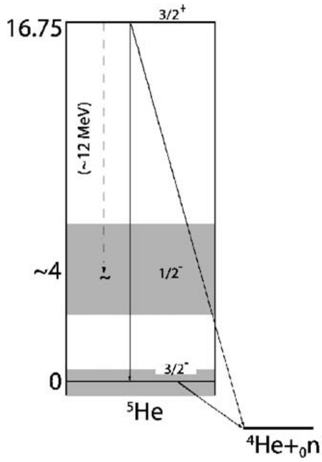

Fig. 2. Partial nuclear-level diagram of excited ^{5}He relevant to the deuterium–tritium fusion reaction.

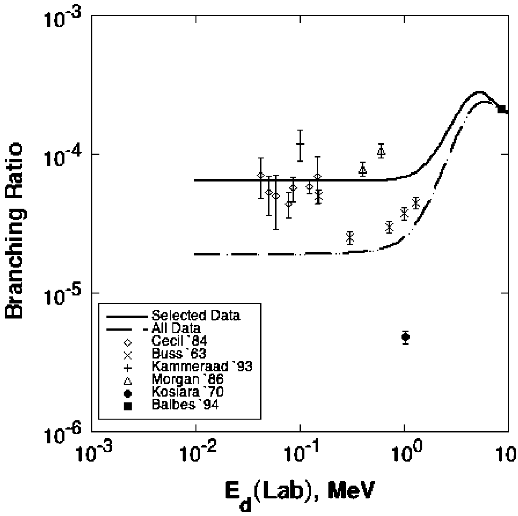

Fig. 3. Compilation of branching-ratio data from past deuterium–tritium fusion accelerator experiments. E_d indicates the accelerator beam energy in MeV; dashed lines indicate least squares data fits to all or selected data.

Recent values for the ^{5}He branching ratio (16.75-MeV gamma rays per 14-MeV neutron) vary from 5×10^{-5} to 1×10^{-4} (Kammeraad et al., 1993; Morgan et al., 1986; Cecil et al., 1985; Balbes et al., 1994), and are shown in Fig. 3. The calculated curves are from an R-matrix analysis of data from all reactions in the ^{5}He system, including d + t capture. The dashed curve is a fit to all the branching ratio data shown, and the solid curve resulted from fitting only the most recent data (Kammeraad et al., 1993; Morgan et al., 1986; Cecil et al., 1985; Balbes et al., 1994). Because of this unfavorable branching ratio, high-yield d + t implosions ($>10^{12}$ neutrons) are required to provide high-energy