Prompt Beta Spectroscopy as a Diagnostic for Mix in Ignited NIF Capsules

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The National Ignition Facility (NIF) technology is designed to drive deuterium-tritium (DT) internal confinement fusion (ICF) targets to ignition using indirect radiation from laser beam energy captured in a hohlraum. Hydrodynamical instabilities at interfaces in the ICF capsule leading to mixing between the DT fuel and the ablator shell material are of fundamental physical interest and can affect the performance characteristics of the capsule. In this project we have been examining a new radiochemical diagnostics for mix processes in ICF capsules with plastic or Be (0.9% Cu) ablator shells.

A microscopic understanding of mixing remains one of the key issues for ICF. We examined the possibility of studying mix of the ablator shell into the DT fuel by measuring the number of interactions of tritons with the shell material. The promising reactions emit high-energy betas, and we have proposed prompt beta spectroscopy as a new probe of mix. For the plastic ablator shells we considered the $^{18}O(t,n)^{20}F(\beta^-)$, and $^{13}C(t,\alpha)^{12}B(\beta^-)$ reactions, and for the Be ablator shells the $^{9}Be(t,\alpha)\ ^{8}Li(\beta^-)$ and $^{9}Be(t,p)^{11}Be(\beta^-)$ reactions.

The energetic tritons in the above reactions are produced by collisions with high-energy neutrons from the central DT burn. The number of knock-on tritons scales with the high-energy neutron production. Some of these energetic tritons go on to fuse with deuterium, some will escape, but a significant fraction will react with detector nuclei in the shell. Stopping of these energetic tritons reduces the probability of reaction with nuclei in the shell. If the shell material is intimately mixed with the fuel, the reaction yields are enhanced by the ratio of the mixing length (the thickness of the mixed region) to the triton stopping length in the unmixed fuel. Therefore, the total number of reactions of knock-on tritons with shell material is a measure of the mixing.

We carried out a detailed analysis of the effects of mixing processes on the t + *shell* reactions and found that atomic mix gives rise to an order of magnitude enhancement in the reaction yield. Thus, triton-induced reactions leading to prompt high-energy beta-decay signals can provide an important diagnostic for mixing in ICF capsules. The predicted number of such reactions, at the yields and neutron fluences expected at the NIF facility, is sufficient for a detectable radiochemical signature of mixing processes. Our estimates for the interaction of high-energy knock-on tritons with shell material suggest that an adequate number of beta-emitters are produced to provide a unique prompt diagnostic for mix between the fuel region and the shell material. The reaction yields for the t + *shell* reactions of interest are enhanced by the ratio of the mixing length to the triton stopping length, and this leads to increased reaction yields of more than an order of magnitude over the no-mix situation. Table 1 lists and summarizes our estimated $t + {}^{9}Be$, $t + {}^{18}O$ and $t + {}^{13}C$ reaction yields for the different mix scenarios.

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Expected Reaction Yields

Reaction	Q-value	β energy	Half-life	σ_0	No Mix	Chunk Mix	Atomic Mix
$^{9}Be(t,\alpha)^{8}Li$	2.93 MeV	13.0 MeV	840 ms	200 mb	1.4×10^{12}	2.8×10^{12}	9.3×10^{13}
$^{9}Be(t,p)^{11}Be$	-1.17 MeV	11.5 MeV 54.7%	13.8 s	1 mb	4.0×10^{9}	8.2×10^{9}	3.6×10^{11}
		9.4 MeV (+2.13 MeV γ) 31.4%					
$^{18}O(t,n)^{20}F$	6.10 MeV	5.3 MeV (+1.63 MeV γ)	11.0 s	100 mb	1.4×10^{8}	2.8×10^{8}	9.3×10^{9}
$^{13}C(t,\alpha)^{12}B$	2.28 MeV	13.37 MeV	20 ms	100 mb	5.4×10^{9}	1.1×10^{10}	3.5×10^{11}

Table 1—
A summary of our estimated t + ^{9}Be, t + ^{18}O and t + ^{13}C reaction yields for the different mix scenarios.