Thermal Tests of Target Materials in Gamma-tubes for Active Interrogation

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Motivation—Active interrogation of nuclear materials involves probing an object with high-energy photons or neutrons and detecting the emitted fission neutron and gamma-ray signals. The source neutrons/photons are usually produced using large, high-energy accelerators such as radio frequency quadrupole or linear accelerators. However, the neutrons/photons can also be generated by much lower energy (p, γ) and (d, n) nuclear reactions (see Table 1), allowing for the development of much more compact and lower energy particle generators. Robust target materials for these low-energy sources need to be easy to fabricate, withstand the harsh radiation environment inside the source, and also have good thermal, electrical, and mechanical properties. We evaluated target materials for interrogation sources, by performing rapid thermal loading and high power density tests that reach conditions expected during source operation.

Accomplishment—Rapid thermal loading and high power density tests were performed on LiF, Li_2O, and CaF_2 films on Cu, and $LiNbO_3$, B_4C, and LaB_6 crystals. Following the tests, the targets were analyzed with scanning electron and cross-sectional microscopies to assess possible physical or structural damage. At 700°C, the CaF_2 film degenerated to a powder, and the LiF film became more crystalline. Elemental analysis during electron microscopy showed very little loss of fluorine. *In situ* X-Ray Diffraction (XRD), during 850°C heating in vacuum, showed Li metal formation at a temperature greater than 700°C. Elemental analysis showed that all F was lost. Li metal has a very low melting point of 180°C. LiF may be a candidate target for the $^{19}F(p,\alpha\gamma)^{16}O$ reaction at 340 kV, but only at or below a temperature of 700°C. The target would have to be cooled and the proton beam spot spread to reduce the power density and keep the operating temperature at or below 700°C. Furthermore, a buffer layer film over the Cu source substrate is necessary to eliminate reaction of F with the Cu. LiF is not recommended as a candidate for the the $^{7}Li(p, \gamma)$ reaction at 441 kV because the gammas produced from the $^{19}F(p,\alpha\gamma)^{16}O$ reaction at 340 kV would overwhelm it. Li_2O may be a good candidate if the target material is never exposed to air, but this may not be feasible. Microscopic examination of B_4C, and LaB_6 indicate these are possible target materials for the $^{11}B(p,\gamma)^{12}C$ reaction, if the beam could be spread to reduce the power density load.

Significance—Target source photons are usually produced using high-energy accelerators. However, with the use of low energy (p, γ) nuclear reaction resonances (See Table 1), compact gamma generators can be developed that produce high-energy mono-energetic gamma-rays [1,2]. Robust B-containing target materials can be found (e.g. B_4C, and LaB_6) that are easy to fabricate and can withstand the harsh beam heating and radiation environments inside the gamma generator. At this time, no robust F containing material has been found unless the operating temperature can be kept below 700°C.

Sponsors for various phases of this work include: Laboratory Directed Research & Development

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Nuclear reactions for neutron/gamma interrogation sources.

Reaction	Interrogation Particle	Cross Section
$^{11}B(p,\gamma)^{12}C$	12-MeV gammas	0.16 mb @ 163 kV
$^{19}F(p,\alpha\gamma)^{16}O$	6-MeV gammas	160 mb @ 340 kV
$^{7}Li(p,\gamma)^{8}Be$	15/18 MeV gammas	6 mb @ 441 kV
$^{7}Li(d,n)^{8}Be$	13 MeV neutrons	50 mb @ 300 keV

References:

1) A.J. Antolak, B.L. Doyle, K.N. Leung, D.H. Morse, P. Provencio, "Active Interrogation Using Low-Energy Nuclear Reactions", (Proceedings of SPIE: Penetrating Radiation Systems and Applications VII, F.P. Doty, H.B. Barber, and H. Roehrig, Editors) v. 5923 (2005) 592303-1.

2) B.A. Ludewigt, A.J. Antolak, E. Henestroza, J.W. Kwan, M. Leitner, K.-N. Leung, W. Waldron, S. Wilde, "Coaxial Mono-Energetic Gamma Generator for Active Interrogation", AIP Conference Proceedings: CAARI2008, (2008).