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The Science of Nuclear Materials Detection using gamma-ray beams: Nuclear Resonance Fluorescence[1]

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An atomic nucleus is excited by absorption of incident photons with an energy the same as the excitation energy of the level, and subsequently a gamma-ray is emitted as it de-excites. This phenomenon is called Nuclear Resonance Fluorescence and mostly used for studies on Nuclear Physics field. By measuring the NRF gamma-rays, we can identify nuclear species in any materials because the energies of the NRF gamma-rays uniquely depend on the nuclear species. For example, ^{235}U has an excitation level at 1733 keV. If we irradiate a material including ^{235}U with a gamma-ray tuned at this excitation level, the material absorbs the gamma-ray and re-emits another gamma-ray immediately to move back towards the ground state. Therefore we can detect the ^{235}U by measuring the re-emitted (NRF) gamma-rays. Several inspection methods using gamma-rays, which can penetrate a thick shielding have been proposed and examined. Bertozzi and Ledoux have proposed an application of nuclear resonance fluorescence (NRF) by using bremsstrahlung radiations. However the signal-to-noise (SN) ratio of the NRF measurement with the bremsstrahlung radiation is, in general, low. Only a part of the incident photons makes NRF with a narrow resonant band (meV-eV) whereas most of incident radiation is scattered by atomic processes in which the reaction rate is higher than that of NRF by several orders of magnitudes and causes a background. Thus, the NRF with a gamma-ray quasi-monochromatic radiation beam is proposed. The monochromatic gamma-rays are generated by using laser Compton scattering (LCS) of electrons and intense laser photons by putting a collimator to restrict the gamma-ray divergence downstream. The LCS gamma-ray, which is energy-tunable and monochromatic, is an optimum apparatus for NRF measurements We have been conducted NRF experiment for nuclear research, especially with high linear polarized gamma-ray generated by LCS, to survey the distribution of M1 strength in MeV region in LCS facility in AIST, Japan. As well, 1-D, 2-D isotope imaging by using LCS gamma-ray and NRF has been conducted. Since 2009 we have started a development of a non-destructive inspection system under the MEXT program in Japan. Series of experiments of the developing system have been conducted in HIGS facility in Duke University and JAEA Kansai Photon Science Institute. We will report on the recent result of these experiments in the workshop.

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