Development of Muon Imaging by accelerator muons

Y. Miyake[1], Y. Nagatani[1], M. Tampo[1], S. Doiuchi[1], A.D. Pant[1], S. Takeshita[1], I. Umegaki[1], T. Imai[2], H. Okabe[3], K. Shimomura[1]

[1]High Energy Accelerator Research Organization (KEK), Institute of Material Structure Science (IMSS), Muon Science Laboratory (MSL), 203-1 Shirakata, Tokai-mura, Naka-gun, Ibaraki,319-1106, Japan
[2]Sokendai, Graduate University for advanced studies,
[3] Institute for Materials Research, Tohoku University,
2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

 # a corresponding author: yasuhiro.miyake@kek.jp

Subatomic particles called muons fall from the sky on the palm at a frequency of 1 muon/sec. These cosmic ray muons have a high penetrating power and are used to take images of mountains to predict eruptions [1], search for hidden spaces inside huge pyramids [2] and observe nuclear fuel debris melted down in nuclear reactor accidents [3].

High-speed charged particles (such as electrons) are scattered in matter by the electric field of the atomic nucleus producing the Bremsstrahlung X-rays (light). Since the efficiency of Bremsstrahlung is inversely proportional to the square of the mass, in principle, $\mu^{\pm}$ which is 200 times heavier than an electron, can produce 40000 times less Bremsstrahlung than an electron. On the other hand, the fast protons (9 times heavier than muons) undergo nuclear reactions in matter and are transformed into pions and K-mesons. Although $\mu^{\pm}$ has a mass between that of an electron and a proton, it neither change into other particles nor easily scattered. This is the physical reason for their excellent permeability.

We succeeded in the three-dimensional (3D) muon imaging for the PVC doll placed in a copper cylinder, as well as imaging of the magnetic field distribution in the Nd-magnet, using intense accelerator muons available at J-PARC [4]. At the symposium we are going to report the current status of J-PARC, Muon Science Establishment (MUSE) and in particular, activity on the 3D muon imaging at J-PARC to improve special resolution.

References

[1] K. Nagamine, M. Iwasaki, K. Shimomura, K. Ishida, “Method of probing inner-structure of geophysical substance with the horizontal cosmic-ray muons and possible application to volcanic eruption prediction", *Nuclear Instruments and Methods in Physics Research* A, **356**(2-3), 585-595 (1995).
[2] S. Procureur, K. Morishima, M. Kuno, Y. Manabe, N. Kitagawa, A. Nishio, H. Gomez, D. Attié, A. Sakakibara, K. Hikata, M. Moto, “Precise characterization of a corridor-shaped structure in Khufu’s Pyramid by observation of cosmic-ray muons”, *Nature Communication,* **14,** 1144 (2023).
[3] H. Fujii, M. Gi, K. Hara, S. Hashimoto, K. Hayashi, H. Kakuno, H. Kodama, M. Mizokami, S. Mizokami, K. Nagamine, K. Sato, “Investigation of the status of Unit 2 nuclear reactor of the Fukushima Daiichi by Cosmic Muon Radiography”, *Prog. Theor. Exp. Phys*., 023C01 (2021).
[4] Y. Nagatani, et al., *to be submitted*.