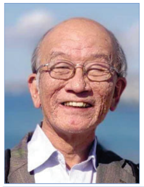
【Grant-in-Aid for Transformative Research Areas（A）】

New Horizons in Negative Muon Science: A Transdisciplinary Integration of Knowledge Bridging Matter, the Universe, and Humanity



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Project Information	Project Number : 26A205　　Project Period (FY) : 2026-2030 Keywords : Negative Muon, Non-destructive Elemental Analysis, Muon-induced Nuclear Transmutation

Purpose and Background of the Research

●Outline of the Research

This project aims to create a new field called "Negative Muon Integrated Science." By focusing on a subatomic particle known as the negative muon, we connect diverse disciplines ranging from physics, chemistry, and earth sciences to medicine and archaeology. To unlock the muon's endless potential for the benefit of society, we have assembled a team of exceptional researchers—from seasoned experts to the next generation of innovators—crossing the boundaries of their respective fields.

Japan is a world-class hub for muon research, uniquely home to two distinct muon production facilities. Rather than waiting for muons to naturally fall from space as cosmic rays, we utilize the powerful, artificially generated muons at these facilities. This allows us to lead the world in tackling original and pioneering research.

While a muon behaves similarly to an electron, it is about 200 times heavier. When this "heavy electron" hits a substance, it behaves quite differently than a normal electron. Our research focuses primarily on two phenomena of the negative muon:

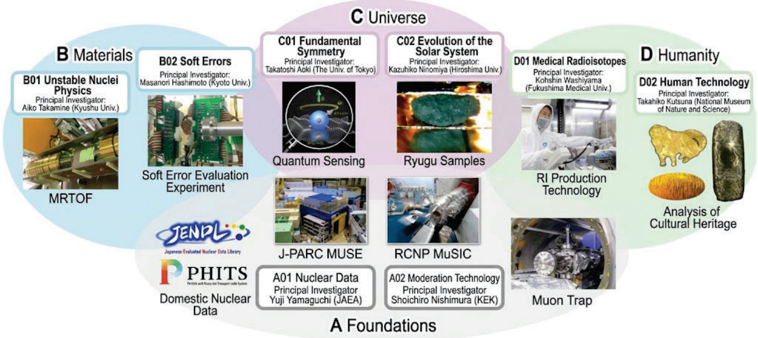

Figure 1. Overview of our research and cutting-edge case studies

●Non-destructive Analysis

Non-destructive analysis using negative muons is a revolutionary method for examining the elemental composition of an object without damaging it.

Unlike standard X-rays produced by electrons, muons have **extremely high penetrating power**. This allows us to look deep inside materials and investigate information hidden behind thick metal walls—tasks that were previously impossible. Furthermore, because this method can detect **any type of element**, we apply it to analyze irreplaceable items, such as precious cultural artifacts and samples returned from asteroids in space.

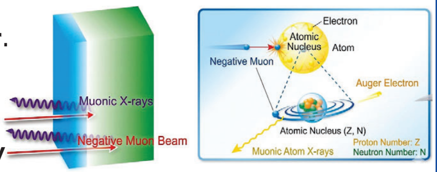

Figure 2. Muon penetration (left) and the mechanism of muonic X-ray emission (right)

●Selective Nuclear Transmutation

When a negative muon is captured by an atomic nucleus, a process called "muon capture" occurs, which converts a proton into a neutron. This reaction allows us to "transform" an atom into a different element with an atomic number one lower than the original. The greatest advantage of this method is the ability to pinpoint and create specific isotopes, a feat that is difficult to achieve with conventional nuclear collision methods.

By applying this principle, we are working to develop more efficient ways to produce new "medical radioisotopes (RI)" that are essential for cancer diagnosis and treatment. Furthermore, we aim to build a foundation for solving major challenges facing humanity and science. This includes fundamental particle physics, as well as developing countermeasures for "soft errors" (malfunctions in semiconductors caused by radiation).

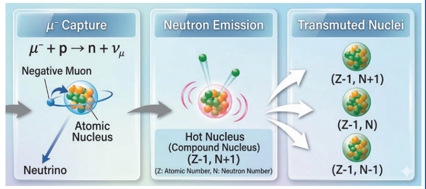

Figure 3. Conceptual diagram of selective nuclear transmutation

Expected Research Achievements

●Research Goals

This research aims to unravel the unique phenomena of negative muons to solve complex challenges in science and society. By pushing the limits of analysis and control, we use these subatomic particles to impact lives—from advancing cancer treatments to uncovering historical mysteries.

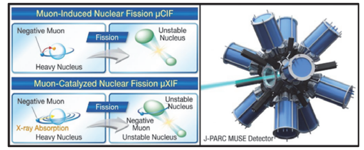

Figure 4. Muon-induced nuclear fission and detectors for efficient data collection

●Foundations and Materials

We are building the world's first database of muon-nucleus interactions and developing slow negative muon beams. This unique research helps clarify "soft error" mechanisms, ensuring the reliability of next-generation electronic devices.

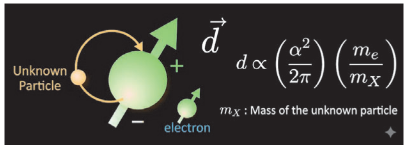

Figure 5. Quantum Sensing

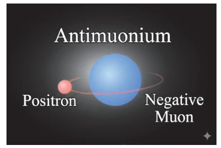

Figure 6. Antimuonium production

Figure 7. Muon- induced soft error

●Mysteries of the Universe

We explore negative muon phenomena to solve key challenges in science and society. By advancing analysis and control, we harness these particles to transform lives—from pioneering cancer treatments to solving historical mysteries.

Figure 8. Planetary and satellite exploration missions

●Humanity and Society

We are developing new ways to produce medical radioisotopes for cancer treatment and performing non-destructive analysis on cultural artifacts. By studying internal compositions without damage, we aim to clarify the progress and spread of science and technology throughout human history.

Figure 9. Medical RI (left) and Cultural Heritage (right)

Website(s)	http://mu-horizons.kek.jp