Possibility of ∼2 particle nA neutron-rich Xe, Kr beams for exploring the island of stability

M. Wada[*1,*2]

The search for the "island of stability (IoS)," predicted to lie beyond known superheavy nuclides (SHN), is a critical challenge in nuclear physics. Some models suggest that nuclides within this island could have lifetimes comparable to the age of the solar system, making their discovery in nature conceivable.[1)] Current SHN are produced via fusion reactions between stable nuclear beams and stable or actinide targets, but the sum of proton and neutron numbers imposes limitations. Neutron-rich nuclear beams are required to approach the IoS. Theoretical predictions indicate that forming a compound nuclide beyond the IoS could enhance survival probability by up to 10^6.[2)]

Figure 1 shows compound nuclides from realistic neutron-rich beams ($^{90-93}$Kr, $^{140-142}$Xe) and stable nuclear targets, significantly shifting toward the neutron-rich side and closer to the IoS. Reaction cross-sections for $^{140-142}$Xe + ^{150}Nd and $^{140-142}$Xe + ^{154}Sm are estimated at nanobarns,[3)] suggesting that 10^{10} pps beams could yield one event every five days with a 0.5 mg/cm^2 target and 10% detection efficiency.

Henning suggested generating neutron-rich isotopes through uranium fission induced by ^{18}O beam from the SRC for ISOL-type experiments.[4)] A 2 particle μA beam is expected to ignite $\sim 10^{14}$ fissions per second, with 1%–2% branching ratios for $^{90-93}$Kr and $^{140-142}$Xe, yielding 10^{12} neutron-rich isotopes per second for each.

Conventional RI re-acceleration systems encounter challenges in producing particle nA-level RI beams. We propose a specialized system targeting noble gases (Fig. 2): Noble gases evaporated from a porous uranium carbide target are evacuated using a pump and introduced into an ECR ion source, where they are ionized to appropriate charge states and energies suitable for linear acceleration. The transit time of the evaporated gas through the ion source is shorter than 1 s. Therefore, short-lived nuclides with lifetimes of approximately 1 s are viable candidates for acceleration. Based on an electrostatic FODO lattice structure, a low-energy beam transport (LEBT) system transports the ions over >100 m to the existing linear accelerator.[5)] LINACs can simultaneously accelerate ions with slightly varying charge-to-mass ratios, and a QQDQDQQ achromatic beam transport system enables multiple isotopes to be irradiated together. The total acceleration efficiency for gas elements can be 1% considering past results for metallic ions of ^{48}Ca (a 0.5 g calcium material continuously provides 1 particle μA beam for a month, corresponding to a 0.3% throughput efficiency). Thus, with the above yield, neutron-rich nuclear beams at 10^{10} pps (∼2 particle nA) can be irradiated on a target to produce SHN.

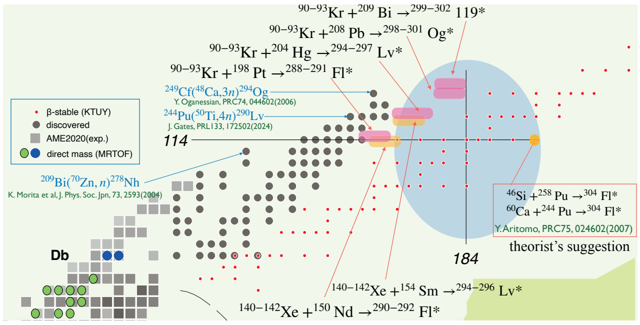

Fig. 1. Nuclear chart for SHN toward the IoS region.

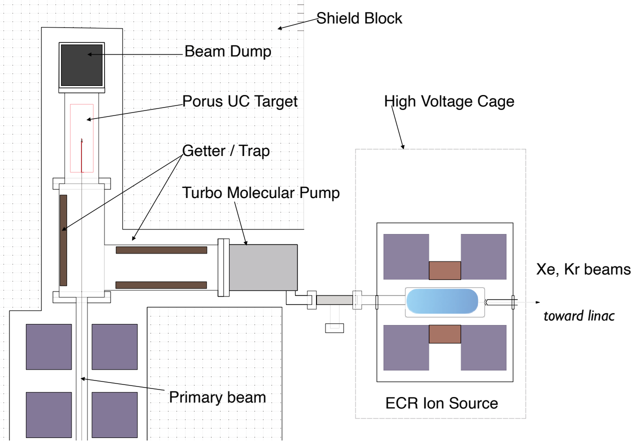

Fig. 2. Sketch of target and ion source configuration.

Identifying SHN remains challenging. For instance, ^{291}Fl might have β- and α-decay half-lives of 10 min and >5 hours, respectively, making α-decay chain observations impractical. However, precision mass spectrometry using multi-reflection time-of-flight can identify SHN by mass, simultaneously monitoring multiple nuclides, making it ideal for rare isotope exploration.[6)]

Development of targets and ion sources, improvement of reaction rate predictions, and increased detection efficiency remain challenges. However, the potential outcomes are highly significant. Generating neutron-rich beams with combinations such as AVF and SRC can enable fragmentation reactions of neutron-rich Kr and Xe to reach the r-process path in medium-heavy nuclides.

References

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*1 Wako Nuclear Science Center (WNSC), IPNS, KEK
*2 Institute of Modern Physics, Chinese Academy of Sciences

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