# RIBF ULIC Symposium/mini-WS Report

* English only

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| Title | [RIBF-ULIC-miniWS-016]<br>Mini-workshop on radiative neutron capture reactions for r-process |
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## Summary of discussions and its (expected) results:

Determination of (n,γ) reaction rates for r-process is challenging but is necessary for understanding reaction path and mechanism of the r-process. Iwasa explained a project to measure direct components of (n,γ) reaction rates around double closed nuclei $^{78}$Ni and $^{132}$Sn with the asymptotic normalization method (ANC) using (d,p) reactions in reverse kinematics, because the Coulomb dissociation method cannot be used in many reactions due to restriction of spin and parity and existence of bound excited states. Exact beam intensity and yields should be discussed carefully later. We are planning to use a $D_2$ active target and silicon detectors for proton detection. By measuring tracks of incident beam and protons produced (d,p) reactions with $D_2$ active target, reaction point can be determined event by event so that better incident beam energy resolution is expected than that used $CD_2$ targets. Thick target can be used. Energy and angular resolutions of protons are expected to be better. Background from contaminant nuclei in the target is reduced. Prof. Motobayashi suggested that there are problems to study (p,γ) reaction using ANC method at high energy. We should check this reason before starting (d,p) studies. Otsuki reported recent results of network calculation for the r-process. She mentioned that direct capture reactions plays important role in (n,γ) reactions for the r-process. This is because reaction rates of compound process decreases at neutron-rich region although those of direct capture process are almost constant. Reaction path of r-process depends on nucleosynthesis environment. To search for crucial (n,γ) reactions, influence of cross sections of several (n,γ) reactions to final yield are studied. Final yields are significantly changed when $^{132,133}$Sn(n,γ) cross sections are changed, but are not significantly changed for $^{75}$Mn,$^{76}$Fe,$^{77}$Co,$^{78}$Ni, $^{130,131}$Sn,$^{134,135}$Sn(n,γ). Further studies to find crucial (n,γ) reactions will be performed. Lee reported results of DWBA calculations for (d,p) and (α,$^{3}$He) reactions. To satisfy peripheral condition, incident energy should be less than 20 and 40MeV/u for (d,p) and (α,$^{3}$He) reactions, respectively. Prof. Kubono suggested that peripheral nature should be discussed in DWBA calculation. It is not clear that (n,γ) reactions occur at peripheral region. Sumikama reported recent experimental proposal to produce low energy RI beam. Using three degraders in Big RIPS, secondary beams lower than 10 MeV/u can be produced with reasonable intensity. However, the energy distribution is wide and it is impossible to measure the beam energy event by event. Iwasa reported Monte Carlo simulation results for the $^{132}$Sn(d,p) reaction. To identify excitation energy with 0.2MeV resolution in σ, resolutions of incident beam energy and scatted proton energy and angle should be lower than 0.2%[ σ], 1%[FWHM], and 5 degree[σ] at 30MeV/u, respectively. Note that energy straggling in the target before reactions occurs should be included incident beam energy resolution. To improve the resolution, incident beams with lower energy or high resolution proton-energy detectors are needed. The excitation-energy resolution at 10MeV/u is obtained to be 70keV in σ. Li explained the ANC method and demonstrated that experimental results using ANC method and future plan in China. Michimasa demonstrated the SHARAQ spectrometer and diamond detector, and their recent results. High resolution measurements can be performed using correction using beam momentum tagging. Feasibility of $^{132}$Sn(d,p) reactions are discussed using DWBA calculation results of energy and angular distribution of $^{132}$Sn(d,p) reactions at 5,10,30 and 50MeV/u. Ota demonstrated $D_2$ active target using CAT for (d,2p) and (d,d') reaction in reverse kinematics and application to (d,p) reaction.

Necessity of $D_2$ active target and energy tagging of incident beam were discussed. Avoiding possible damage of silicon detectors in $D_2$ gas, ion-implantation silicon detector should be used. Prof. Ishihara pointed out γ measurements are better to identify excited states. However, γ detection is expected to be small when $D_2$ gas target is used to obtain information of angular momentum transfer. Prof. Kubono suggested that transition also to the ground state is measured in the ANC method and gamma measurement cannot be performed for the transition to the ground state.

Fruitful discussion was performed and problems which should be overcome are clarified. To produce a high-intensity RI beam at low energy with energy measurement with 0.2% resolution in σ and to develop high-resolution detectors for proton detection, direct neutron capture reaction for the r-process will be studied with the asymptotic normalization coefficient method at RIBF.

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Please attach other documents as needed.