# Development of a New Measurement System for Primary Knockon Atoms (PKA)



| | |
|---|---|
| 著者 | Tsai P.E., Iwamoto Y., Hagiwara M., Sato T., Satoh D., Abe S., Itoh M., Watabe H. |
| journal or publication title | CYRIC annual report |
| volume | 2016-2017 |
| page range | 53-56 |
| year | 2017 |
| URL | http://hdl.handle.net/10097/00128059 |

# II. 9. Development of a New Measurement System for Primary Knock-on Atoms (PKA)

*Tsai P.E.[1,*], Iwamoto Y.[1], Hagiwara M.[2], Sato T.[1], Satoh D.[1], Abe S.[1], Itoh M.[3], and Watabe H.[3]*

*[1]Nuclear Science and Engineering Center, Japan Atomic Energy Agency*
*[2]Radiation Science Center, High Energy Accelerator Research Organization*
*[3]Cyclotron and Radioisotope Center, Tohoku University*

## Introduction

Primary knock-on atoms (PKAs) created in spallation reactions are critical for various applications, particularly for radiation damage assessment in accelerator facilities and in space environment. PKAs have a continuous mass distribution from target nuclide down to one atomic mass unit (amu) and a wide energy distribution from a few tens of MeV down to sub-MeV. The PKA energy spectra and its yields are one of the fundamental parameters for radiation damage calculation models[1)]. Yet the experimental data up to date are still limited, due to the high measurement thresholds and the insufficient mass resolutions to identify PKA species in the conventional experimental setups using solid state detectors[2)].

To provide the important experimental PKA data, we proposed a new measurement system consisting of two fast timing detectors for time of flight (ToF) measurement, and one dE-E gas ionization chamber (GIC) for stopping power (dE) and total kinetic energy (E) measurement.

## Detectors and experimental setup

Each fast timing detector, as shown in Fig. 1, consists of (i) an ultrathin carbon foil (3-6 μg/cm$^2$) for creating secondary electrons (SE) when PKAs pass through it with minimal energy losses, (ii) an accelerating grid for SE, (iii) an electrostatic mirror for reflecting the SE traveling direction, and (iv) a microchannel plate (MCP) detector for collecting the reflected SE and creating fast signals with ~600-ps full width at half maximum (FWHM).

[*]*Present address: 2-4, Shirakata, Tokai, Ibaraki 319-1195, Japan*

The dE-E energy detector is a customized gas ionization chamber (Fig. 2) filled with isobutane gas at pressures between 15 and 50 mbar. The low-noise preamplifiers are placed inside the gas chamber to reduce the noise level. This customized gas ionization chamber features (i) a 50-nm thick silicon nitride window to minimize the PKA energy losses, and (ii) two segments of anodes and cathodes with the lengths of 2 cm and 10 cm, respectively, to measure the stopping powers and the total kinetic energies of PKAs in a single detector chamber. The gas pressure can be regulated by the gas flow system to fit different PKA species and different initial kinetic energies of PKA.

The first timing detector is located right behind the thin target foil, and the second one is 15 cm apart from it, followed by the dE-E GIC. The whole measurement system is placed inside the scattering chamber in vacuum.

**Feasibility study and tests**

The expected performance of the new PKA measurement system regarding the measurement thresholds, energy resolutions, and mass resolutions was simulated and evaluated by the general-purpose Monte Carlo radiation transport code, PHITS[3)] version 2.85, with the implemented INCL-4.6 model for proton-induced nuclear reactions, and ATIMA for stopping power and energy loss calculations of charged particles.

Figure 3 shows an example of the PHITS simulation results of the ToF vs E relationship (on the left) and the dE vs E relationship (on the right) from a thin carbon foil bombarded by 70-MeV protons. By combining these two relationships, the PKA isotopes can be identified, and the PKA energies can then be determined by ToF given the known distance and the measured flight time. From the PHITS simulations for carbon targets, it is found that the PKA masses can be separated above ~1.5-2 MeV (~0.15 MeV/nucleon) for all isotopes heavier than alpha.

In the first prototype test of the ToF detector performed at CYRIC in July 2017, we substituted the GIC with a 250-μm silicon strip detector (SSD), as the experimental setup shown in Figure 1, to focus on the test of the timing detectors only. However, the triple coincidence rate of the three detectors were lower than expected, possibly due to poor alignment of the three detectors, the non-uniform electric fields created by the electrostatic mirror that lower the timing detector efficiency, and/or the high noise contribution to the timing detectors. The measurement system is hence under modification based on the feasibility test results.

## Acknowledgments

This study was supported by JSPS KEKENHI Grant Number JP17K14918.

### References

1) Lu W, Gallmeier F, Geoghegan P, Ferguson P, and Wechsler M, *J Nucl Mater* **431**, (2012) 33.
2) Westfall G, Sextro R, Poskanzer A, Zebelman A, Butler G, and Hyde E, *Phys Rev C* **17** (1978) 1368.
3) Sato T, Iwamoto Y, Hashimoto S, Ogawa T, Furuta T, Abe S, Kai T, Tsai P, Matsuda N, Iwase H, Shigyo N, Sihver L and Niita K, *J Nucl Sci Technol* **55** (2018) 684.

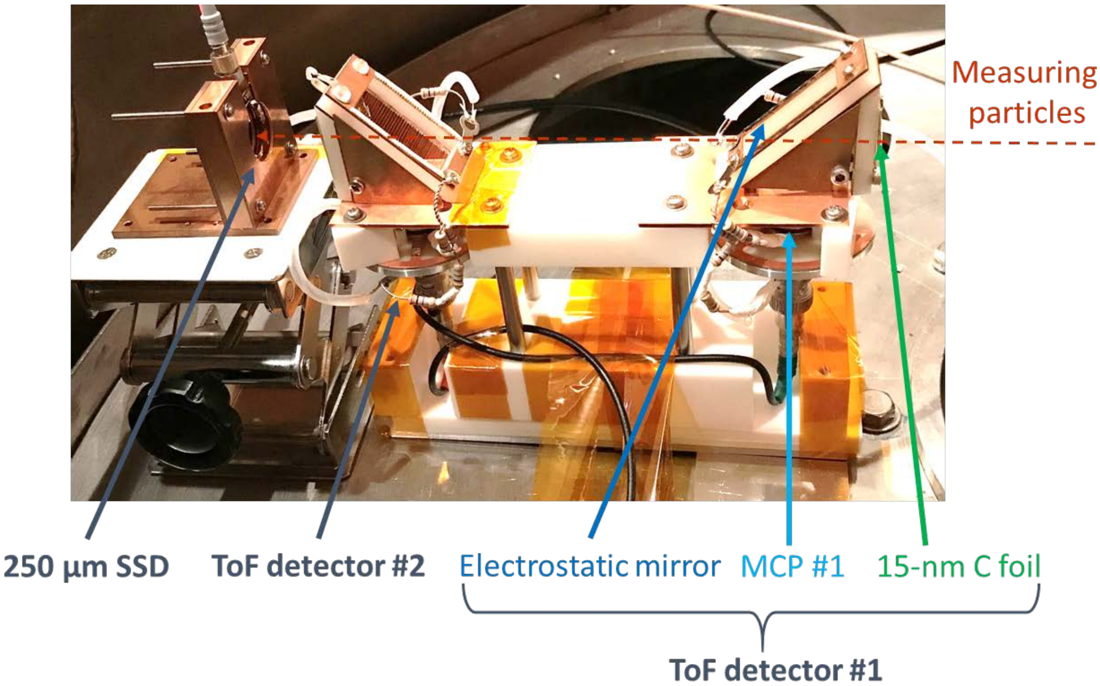


Figure 1. The experimental setup at CYRIC for the feasibility test of the new PKA measurement system.

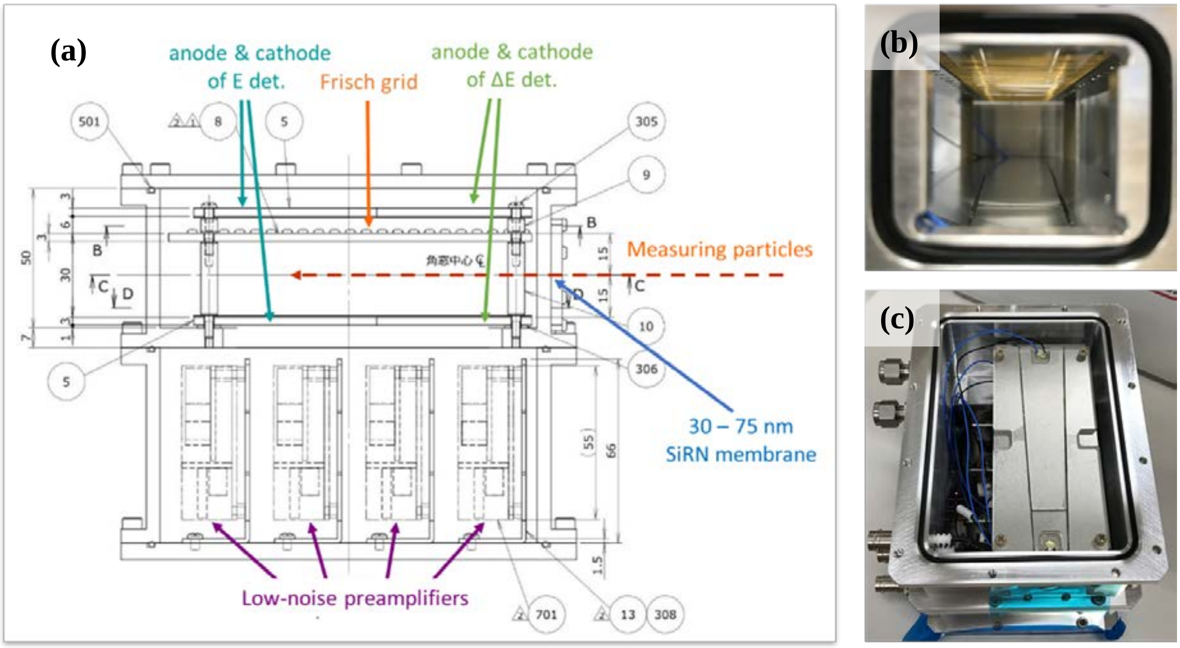


Figure 2. (a) Design of the gas ionization chamber (GIC). (b) View from the GIC window showing the Frisch grid on the top and the cathodes on the bottom. (c) Top view of the two anodes.

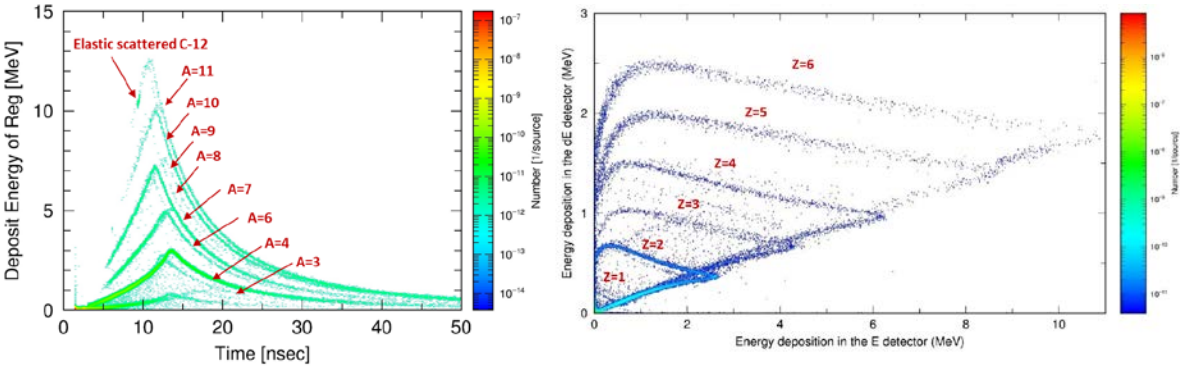


Figure 3. The ToF-E relationship (left) and the dE-E relationship (right) simulated by PHITS for 70-MeV protons bombarding a thin $^{12}C$ target.