Production of radioactive ion beams for TAMUTRAP facility

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Last year, most of the time was dedicated to the investigation of an efficient way to produce proton-rich nuclei around 20 to 40 mass regions, which are of particular interest for the TAMUTRAP initial research program [1]. The TAMUTRAP facility can receive the low energy radioactive ion beams vertically either by light-ion guide (LIG) [2] or heavy-ion guide (HIG). The LIG technique is currently being implemented at the Cyclotron Institute as part of the institute's upgrade project. Currently, the K150 cyclotron is able to deliver a high-intensity beam of lighter ions (*p*, *d*, and α) as compared to heavier ions (>4 amu). The intensity of lighter ions is around 2-3 pμA. Due to this reason it was decided to proceed with light-ion guide method for producing RIB for TAMUTRAP.

In the light-ion guide technique, the reaction products from a nuclear reaction are thermalized in a very pure noble gas (He) where they stay as ions due to the high ionization potential of the stopping gas. Ions are flushed out of the ion guide via a differential pumping section where they are skimmed from the neutral gas with electric fields. The LIG technique for the proton-induced reaction is currently being commissioned at the Institute to produce and accelerate radioactive species mainly from (*p*, *n*) reactions for other research programs. For the TAMUTRAP program, the proton-rich nuclei of interest can only be produced via ^{3}He-induced nuclear reactions. The range of reaction products in helium for these reaction products is longer compared to those produced via proton-induced reactions. Therefore, a prototype of a new gas cell and low energy beamline, "^{3}He-LIG", was designed and built. To bring the beam to the TAMUTRAP facility, extraction from the new gas cell is in the direction opposite the existing LIG facility. Fig. 1 shows the design of the prototype ^{3}He-LIG system.

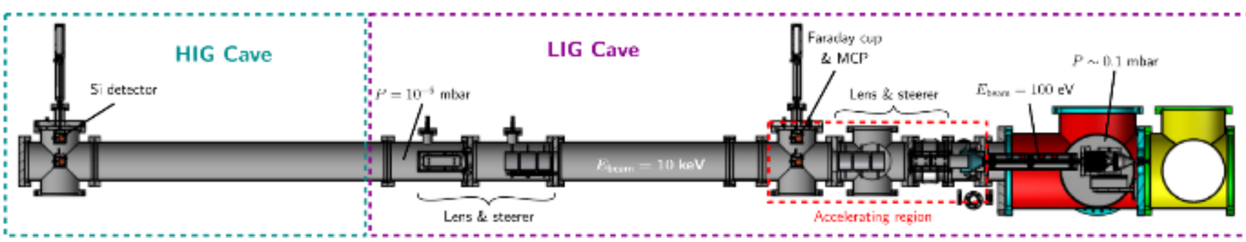

Fig. 1. The design of a new light ion guide towards the TAMUTRAP facility.

Two types of gas cells were designed and tested online: (a) the first design of gas cell uses the gas flow alone to extract the ions through an exit hole. (b) the second gas cell design includes an RF voltage structure gas cell, using a combination of gas flow, RF voltage, and DC potential gradient towards the exit hole of the gas cell. Both gas cells were tested online using a ^{3}He primary beam. In particular, ^{25}Si is of interest to the TAMUTRAP research program and so its production was extensively studied. The ^{3}He beam at 10 MeV/u was bombarded on $^{24(nat)}$Mg target for producing ^{25}Si. The reaction products were extracted from the gas cell by using electric fields and a helium gas jet via a sextupole ion guide (SPIG). Following the extraction, ions in charge state *q* were electrostatically accelerated to 10*q* keV of energy and guided further towards the detection system by using a combination of the Einzel lens and *x*-*y* steerers. The detection system consisted of a thin aluminum foil placed in front of a 500 μm-thick silicon detector. This detector was used to detect the charged particles (β, *p*, α) from the decay of the extracted RIB stopped in the aluminum foil. Several minor modifications were implemented between different runs in the extraction section of the beamline. These modifications improved the vacuum in the extraction section leading to an increase in the total rate (activity) of the silicon detector – an order of magnitude improvement. As one can clearly see in Fig. 2, the three most intense proton peaks which are emitted in

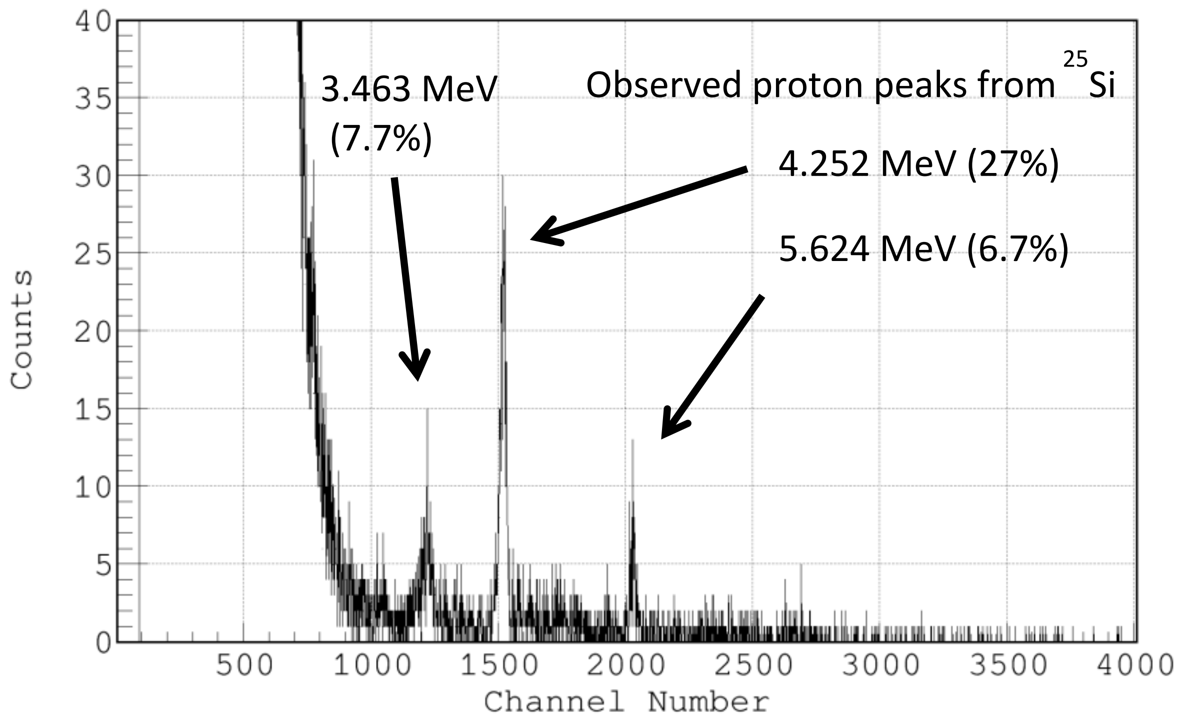

Fig. 2. Decay spectrum observed in the silicon detector. The three intense proton peaks which are emitted from the decay of ^{25}Si are clearly observed.

the decay of ^{25}Si was observed in the silicon detector confirming the production of ^{25}Si isotope. Based on last year's theoretical and experimental investigation, the production rates of the nuclei of interest are tabulated in Table I.

Table I. Estimated production rates of the T = 2 and T = 1/2 nuclei of interest for the TAMUTRAP research program. All nuclei are planned to be produced via ^{3}He induced fusion-evaporation reaction.

Nuclei T=1/2	Target	Rate at the target chamber	Nuclei T=2	Target	Rate at the target chamber
^{21}Mg	^{20}Ne	2.8×10^5	^{20}Mg	^{20}Ne	3.8×10^3
^{25}Si	^{24}Mg	1.5×10^5	^{24}Si	^{24}Mg	3.1×10^3
^{29}S	^{28}Si	0.8×10^5	^{28}S	^{28}Si	2.7×10^3
^{33}Ar	^{32}S	0.9×10^5	^{32}Ar	^{32}S	0.9×10^3
^{37}Ca	^{36}Ar	0.2×10^5	^{36}Ca	^{36}Ar	0.2×10^3

The results presented were obtained using the gas cell without the RF structure. The design including the RF structure has unfortunately so far been inconclusive. Online, we saw a greater overall current out of the RF-cell comparted to the 1st design, however the activity on the Si detector did not show proton peaks. This indicates the extraction time out of the larger RF-cell is presently too long to efficiently transport short-lived ions. It is worth noting that offline tests yielded a transmission efficiency of around 10%. We know of a number of improvements that may greatly improve the extraction time, and plan to perform a more detailed investigation in the near future.

An upgraded gas-only cell and improved low-energy beamline are currently being designed to further increase the extraction efficiency, and also to ensure the emittance of the beam out of He-LIG will match the acceptance of the LSTAR isobar separator currently being designed [3].

[1] P.D.Shidling *et al.*, Hyperfine Interact. **240**, 40 (2019).

[2] G. Tabacaru *et al.*, Rev. Sci. Instr. **83**, 02A905 (2012).

[3] G. Chubarian *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2019-2020), p. IV-93.