THE RI BEAMS FROM THE TOKAI RADIOACTIVE ION ACCELERATOR COMPLEX (TRIAC)

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Abstract

Tokai Radioactive Ion Accelerator Complex (TRIAC) is an ISOL-based radioactive nuclear beam (RNB) facility, connected to the ISOL in the tandem accelerator at Tokai site of Japan Atomic Energy Agency (JAEA). At JAEA-tandem accelerator facility, we can produce radioactive nuclei by means of proton induced uranium fission, heavy ion fusion or transfer reaction. Since TRIAC was opened for use in 2005, we have provided RNBs of fission products and ^{8}Li.

For the production of ^{8}Li, we chose ^{13}C (^{7}Li, ^{8}Li) neutron transfer reaction by ^{7}Li primary beam and a 99% enriched ^{13}C sintered disk target. The release time of Li ions from the ^{13}C sintered target was measured to be 3.2 s. We are developing the RNB of ^{9}Li ($T_{1/2}$=178 ms) but the long release time caused a significant loss of the beam intensity. A boron nitride target which has fast release of Li is developed for ^{9}Li beam with intensity of 10^{4} ions/s after separation by JAEA-ISOL.

INTRODUCTION

The tandem accelerator of Japan Atomic Energy Agency (JAEA-Tandem accelerator) has been operated since 1982 for studies of nuclear physic, nuclear chemistry, atomic/molecular physics, solid state physics and material science. A superconducting linac was built as a booster in 1994 to advance these studies. Since 2005, we have been operating an ISOL-based radioactive nuclear beam facility, Tokai Radioactive Ion Accelerator Complex (TRIAC), connected to the ISOL in JAEA-Tandem accelerator (JAEA-ISOL).

The total operational time of these accelerators for FY2008 (From April 1, 2008 to March 31, 2009) was 210 days. The total experimental proposal and the usage of the beam times for FY2008 are summarized in Table 1 and Table 2, respectively.

Table 1: Experimental Proposal

Proposals accepted by the program advisory committee:	
In house staff proposals	13
Collaboration proposals	33
Number of experiment proposed	60
Total numbers of scientists participating in research	
from out side	258
in-house	251
Number of institutions presented	33

Table 2: Usage of Beam Times in Different Research Fields

Research field	Beam time	
	days	%
Nuclear physics	96	45.7
Nuclear chemistry	22	10.5
Atomic physics and material science	73	34.8
Accelerator development	19	9.0
total	210	

RNBs of fission products and ^{8}Li were supplied to TRIAC experiments for 23 days. Typical experiments are as follows:

- Measurement of Li diffusion coefficients in Li ionic conductors
- Search of highly excited state of ^{10}Be using deuteron elastic reaction to ^{8}Li
- R&D for JAEA-ISOL and TRIAC

This report presents the upgrade of JAEA-Tandem facility and status of TRIAC, especially target-ion source system of JAEA-ISOL.

UPGRADE OF JAEA-TANDEM FACILITY

In recent years, we have maintained and upgraded some apparatus of the tandem accelerator and the booster. Main upgrade works are as follows:

- Replacement of acceleration tubes with compressed ones. These tubes were treated by high-pressure water jet rinse to improve the high-voltage performance [1]. At this time, we provide ion beams at the maximum terminal voltage of 18 MV.
- Replacement of 180-degree analysing magnet at the high-voltage terminal. We also realigned all beam optical devices in the terminal and have improved the transmission efficiency of ion beams to 2-3 times and very close to 100 % for ions lighter than mass of about 40..
- Replacement of in-terminal ion source [2] to a permanent-magnet type 14.5 GHz ECR ion source, SUPERNANOGAN. Beam intensities were increased 3-5 times compared to the previous 10-GHz one. We have even accelerated Xe^{30+} from the high-voltage terminal.

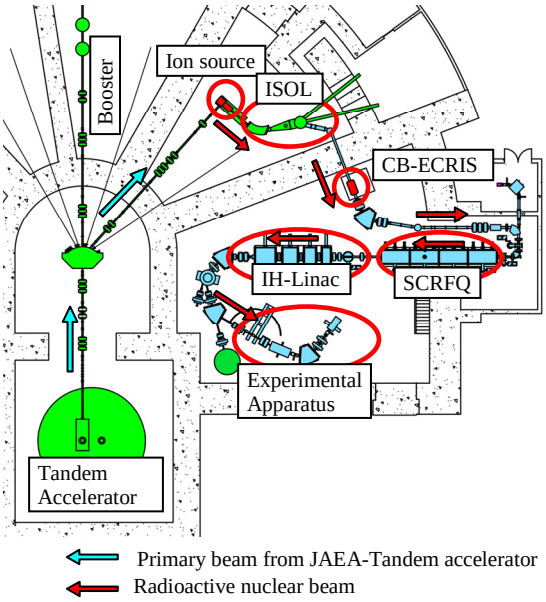

Figure 1: Layout of TRIAC.

- Treatment of degraded superconducting resonators by using high-pressure water jet rinse to recover acceleration electric fields (E_{acc}). The average of E_{acc} at RF power of 4.0 W improved from 4.96 MV/m to 6.53 MV/m.
- We fabricated a prototype low beta superconducting twin quarter wave resonator and carried out off-line test.

STATUS OF TRIAC

The layout of TRIAC is given in Figure 1. TRIAC is based on an isotope separator on line (ISOL) and the radioactive nuclei are produced via proton-induced fission of ^{238}U or heavy-ion reactions with the primary beams from the JAEA-Tandem accelerator. The produced radioactive nuclei are singly charged and mass-separated with the JAEA-ISOL. They are fed to the 18GHz electron cyclotron resonance ion-source for charge-breeding (CB-ECRIS), where the singly charged ions are converted to multi-charged ions. The charge-bred radioactive ions, usually with a mass to charge-state ratio of around 7 (A/q ~7), are extracted again and fed to the linear-accelerator (linac) complex for re-acceleration. The linac complex consisting of two linacs, a split-coaxial radio-frequency quadrupole (SCRFQ) linac and an interdigital-H (IH) linac, can accelerate the RNB to the energy necessary for experiments. The acceleration of the RNBs charge-bred by CB-ECRIS was the first time over the world and the overall efficiency of transmission of ISOL to experimental hall was about 2%. The basic parameters of TRIAC are summarized in Table 3.

Table 3: Basic Parameters of TRIAC

Primary Beam	Ion (energy/intensity)	p (34 MeV / 1μA) ^{7}Li (68 MeV/300 pnA) ^{19}F (78 MeV/100 pnA), etc.
Production target		UCx, BN, Mo, etc.
ISOL	Ion source	FEBIAD, SI type
	Mass resolution	1200
Charge Breeder	Ion source	ECRIS
	Frequency / power	18 GHz / 1 kW
Linac Complex	Injection energy	2.1 keV/u
	Output energy (variable)	0.14-1.09 MeV/u
: SCRFQ linac	Frequency	25.96 MHz
	output energy	178.4 keV/u (A/q≤28)
	duty cycle	100% (A/q≤16), 30% (A/q=28)
: IH linac	Frequency	51.92 MHz
	output energy	0.14-1.09 MeV/u (A/q≤9)
	duty cycle	100% (A/q≤9)

ISOTOPE SEPARATOR ON-LINE

Target-Ion Source System

Originally, the JAEA-ISOL is utilized for the study of decay properties of nuclei far from stability. To supply an intense RNB to the CB-ECRIS, we have developed two types of ion sources, surface ionization type ion source for ionization of alkali, alkaline earth and rare-earth elements and FEBIAD type one for ionization of gaseous and volatile elements. Additionally, we have developed a target-ion source system to produce medium-heavy neutron rich RNBs with proton-induced fission of ^{238}U and a thin-window ion source system for heavy-ion reaction products for each type. Using these ion sources, more than 100 isotopes of 21 elements have been ionized and mass-separated. [3]

A glassy graphite fiber was chosen as a base material for making a uranium carbide target for the target-ion source system. A typical uranium carbide target was prepared at a uranium density of 600-mg/cm^2 U. A target container was filled with glassy graphite fiber (ϕ =11 μm, GC-20, Tokai Carbon Co.) as the base material and uranyl nitrate solution was impregnated. After drying-out, the target was out-gassed and converted to oxide form at 600 ^{o}C in argon atmosphere before insertion into the ion source. The target is loaded to the ion source system and sintered as uranium carbide.

The surface ionization type target-ion source system was used for the production of neutron rich Rb, Sr, In, Cs and Ba ion beams. The uranium carbide target was bombarded with a 33-MeV proton beam (25 MeV on target) with intensity of about 1 μA. A typical separation yield with this ion source was 1.8 x 10^7 ions/s for ^{93}Rb, 6 x 10^7

ions/s for ^{94}Sr, 2.5 x 10^6 ions/s for ^{143}Cs and 3 x 10^6 ions/s for ^{143}Ba; the value was normalized to the uranium-target thickness of 1 g/cm^2 and 1 μA primary proton beam current. Particular application of this ion source was separation of neutron rich ^{A}Eu isotopes around A~160. New isotopes ^{163,164,165,166}Eu have been identified with this ion source.

The forced electron beam induced arc-discharge (FEBIAD) ion source type-B2 with a uranium target container was used for the production of neutron rich Kr, Xe and volatile elements ion beams. A typical separation yield with this ion source was 1.4 x 10^6 ions/s for ^{91}Kr, 2.6 x 10^6 ions/s for ^{138}Xe, 5.2 x 10^6 ions/s for ^{123}In and 2.5 x 10^5 ions/s for ^{132}Sn; the condition of normalization is same as the surface ionization type one.

Safety Handling System of Target-Ion Source Modules

In the ion sources, 2.6-g/cm^2 of ^{238}U is loadable maximum. We plan to produce the neutron-rich RNB by proton-induced fission with an intensity of 3 μA proton. After an irradiation for 5 days in this condition, the dose equivalent rate is estimated to be 40 mSv/h at 1 m from the ion source. Therefore, we have built a system of carrying and storing target-ion source in safety.

At the convenience of handling, the target-ion source system is united into one module with the irradiation vacuum housing. The target-ion source module is designed to a vacuum-tight by itself:

- The primary beam entrance port is sealed with 5-μm thick HARVAR foil.
- On the RNB extraction side of the housing, a pneumatic valve is installed and closed before carrying the module.
- Electric feed-throughs, gas and water connections are coupled to quick connectors.

This module could be handled by a remote carrying device and stored in a shielding cell to cool residual radioactivity. By use of this handling system, we can carry and store the target-ion source module without radioactive contamination around the irradiation area.

Development of Target-Ion source System

A short-lived isotope beam, ^{9}Li ($T_{1/2}$=178 ms), is required with intensity of more than 5 x 10^3 ions/s on the target at the end of TRIAC to the study of highly-excited state of ^{11}Be. For the production of ^{8}Li ($T_{1/2}$=838 ms), we have chosen ^{13}C (^{7}Li, ^{8}Li) neutron transfer reaction by ^{7}Li primary beam and a 99% enriched ^{13}C sintered disk target. The 99% enriched ^{13}C thick graphite disk was mounted to the catcher position of the surface ionization type ion source with 3-μm thick tungsten-window. The target was bombarded with a 67-MeV ^{7}Li^{3+} beam with intensity of about 100 pnA. In this condition, the separation yield of ^{8}Li was evaluated to be 1 x 10^6 ions/s. However, the separation yield of ^{9}Li ($T_{1/2}$=178 ms) was reduced to 10^2 ions/s. We thought that the long release time caused a significant loss of the ^{9}Li beam intensity. A release profile of Li from the target/catcher/ion-source system was measured using the heavy ion implantation technique [6]. As shown in Figure 2, the fast component of release profile of Li ions from the ^{13}C sintered target was 3.2 s. In a search for high-temperature-resistant target material for the production of ^{9}Li, we found out that boron nitride (BN) has a short release time of Li; as shown in Figure 2, the fast component release profile was 120 ms. With a hot pressed BN sheet target, we obtained a ^{9}Li beam with an intensity of 10^4 ions/s after separation by JAEA-ISOL.

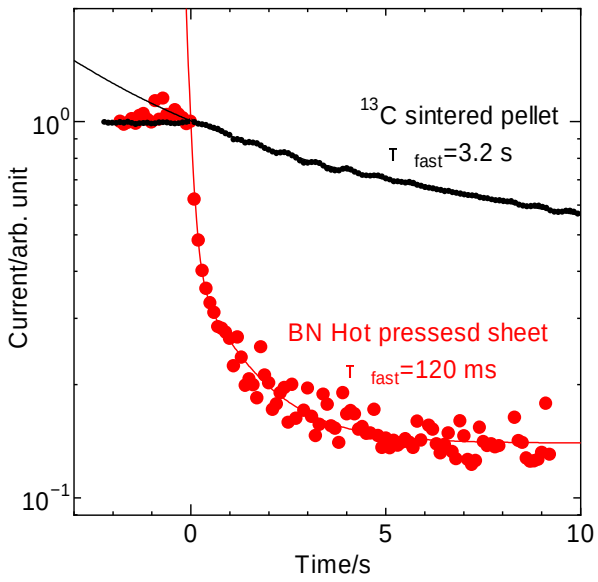

Figure 2: Release profile of Li from the surface ionization type ion source.

The FEBIAD-B2 type target-ion source has separation efficiencies of about 8% for long-lived In isotopes. However, the efficiencies depend strongly on the half-lives and decrease to about 0.4% for $^{129m+g}$In ($T_{1/2}$=1.29/0.59 s). This result consists with the long release time of In, τ = 7 s, at the target-ion source temperature of 1550 °C. It is expected to accelerate diffusion, adsorption and effusion processes by raising the temperature of the target-ion source system; a short release time of In, τ=1.7 s, was achieved by the surface ionization type one at the temperature of 2100 °C. [4] In the FEBIAD-B2 type, the target container is connected to a top of the target heating cathode capsule; the temperature reaches 1550 °C. For the separation of short-lived isotopes around ^{132}Sn, the FEBAID-E type ion source [5] with a uranium target container has been newly developed [3]; the FEBIAD-E type ion source is operated at the temperature of 1700-2000 °C. To raise the temperature of the target to 2000 °C, it is heated by an electron bombardment from a couple of tungsten filaments surrounding the target container. An on-line test and preliminary separation yield search is performed. Measurements of release profiles of several elements are in progress.

OUTLOOK

Continuous upgrade enabled JAEA-Tandem facility to deliver a variety beams for experiments. Until now, TRIAC facility provides relatively weak intensity and low energy RNBs. However, we have produced good results by using ^{8}Li beam which is specialty of TRAIC facility. It is expected to allow further applications and progresses especially by use of the RNBs of medium-heavy neutron-rich isotopes. Development of the target-ion source system is one of the highest priority issues on operation of RNB facility. We will carry on the development for the facility.

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