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Present status of the radioactive nuclear beam facility at KEK-Tanashi and the E-arena in the KEK–JAERI joint project

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Abstract

The performance of the RNB facility at KEK-Tanashi, which is a pilot facility for the E-arena in the KEK–JAERI joint project, is presented. The muonic X-ray spectroscopy of unstable nuclei by combining the RNB with muon-beam from the M-arena in the joint project is introduced. © 2002 Elsevier Science B.V. All rights reserved.

1. RNB facility in KEK-Tanashi

The facility consists of (a) a target and ion-source system, where radioactive nuclei are produced using the light-ion beam from the SF-cyclotron with $K = 68$, (b) a high-resolution isotope separator and 60 m beam-transport line (BTL), and (c) heavy-ion linacs, that is the split-coaxial RFQ (SCRFQ) and the inter-digital H-type (IH1) linacs [1]. The first RNB of $^{19}\mathrm{Ne}^{2+}$ ($T_{1/2} = 17$ s) was successfully accelerated in 1997 and was transported to a target position for an astrophysical experiment. So far, various acceleration tests using unstable and stable nuclear beams have been performed in order to investigate the performance of the linac complex. The measured transmission efficiency for accelerated ions is about 90% in accordance with the simulation using the code PARMTEQ-H [5]. A variable output energy from 0.170 MeV/u to 1.05 MeV/u by the IH1 linac was also

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confirmed by adjusting the gap voltage and rf-phase of each tank. All of the transmission efficiencies at various acceleration energies were over 80%.

We have also made considerable efforts to improve the transport efficiency of the 60 m BTL connecting an ISOL to the SCRFQ linac and the extraction efficiency of the production target–ion-source system. The transport efficiency of the 60 m BTL has greatly been improved by installing a newly developed ion-optical device consisting of 16 symmetrical electrodes, which realize various electric multipole fields from the dipole field to the hexadecapole one. This device was installed as a steering deflector just downstream to the ISOL extraction chamber. The other one was placed between the exit of the BTL and the SCRFQ linac as a quadrupole focussing device.

Table 1 summarizes the overall efficiency of the KEK-Tanashi RNB facility. It is noted that the linac acceleration scheme has a high acceleration efficiency in comparison with the cyclotron acceleration scheme, even though the beam intensity is considerably reduced due to the finite duty-factor (30%) of the SCRFQ linac. With the help of the existence of the bunching effect [4], the actual bunching efficiency was two times higher than the duty factor.

Table 2 summarizes the RNB species accelerated so far. As for the beam development and the preparation for some astrophysical experiments, the detailed descriptions can be found in Refs. [6,7], respectively. This facility was closed in September 1999, and all of

Table 1
Efficiency of the RNB facility at KEK-Tanashi for $^{19}Ne^{2+}$ beam

Content	KEK-Tanashi	Louvain-la-Neuve [2,3]
Primary beam	30 MeV, 2 µA	30 MeV, 200 µA
Production yield	0.32×10^{-3}	0.78×10^{-3}
Extraction efficiency (%)	30	50
Ionization efficiency (%)	27	10
Bunching efficiency (%)	60	–
Transport efficiency (%)	65	–
Acceleration efficiency (%)	85	4
Overall efficiency (%)	2.7	0.2
RNB intensity (pps/µA)	5×10^{7}	1×10^{7}

Table 2
Summary of RNB species available at the KEK-Tanashi

Elements (half-life)	Beam intensity at ISOL exit (pps/µA)	Target	Primary beam	Ion source
$^{19}Ne^{2+}$ (17.2 s)	2×10^{8}	LiF	Proton 30 MeV	ECR
$^{18}Ne^{2+}$ (1.67 s)	1×10^{6}	LiF	Proton 40 MeV	ECR
$^{38}K^{1+}$ (7.61 m)	3×10^{8}	CaF_2	^{3}He 70 MeV	Surface(Re)
$^{37}K^{1+}$ (1.23 s)	1×10^{7}	CaF_2	^{3}He 70 MeV	Surface(Re)
$^{21}Na^{1+}$ (22.5 s)	$5 \times 10^{6*}$	CaF_2	^{3}He 70 MeV	Surface(Ir)
$^{20}Na^{1+}$ (0.45 s)	$3 \times 10^{5*}$	CaF_2	^{3}He 70 MeV	Surface(Ir)

* These values should be multiplied by factor 2.5 for expected ones with Re-ionizer on the basis of the off-line test.

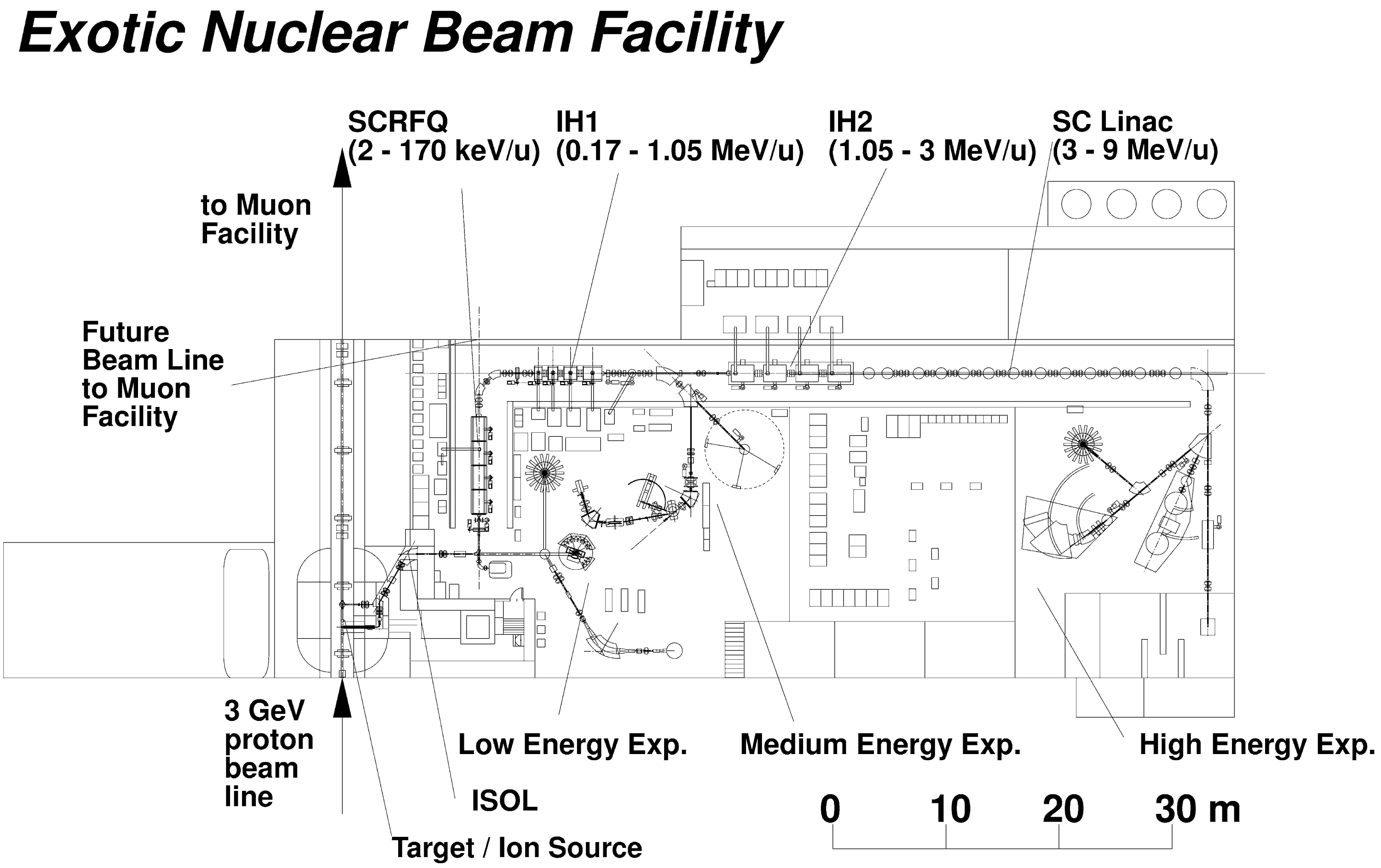

Fig. 1. Plan view of the E-arena.

the instruments are being planned to be transferred to the Tandem facility of JAERI for resumption of the research activities.

2. E-arena in the KEK-JAERI joint project

The E-arena is a second-generation RNB facility based on an ISOL and the linac post-accelerator scheme [9]. It uses a 333 μA proton beam from 3 GeV PS to supply a high-quality intense RNB of various energies from nearly zero to 9 MeV/u. The production target is designed for a maximum beam loss of 50 kW. The aim of this arena is to open a new region of research in nuclear physics, nuclear astrophysics as well as multidisciplinary fields of science by means of RNB. A schematic layout of the E-arena experimental hall is shown in Fig. 1. It is noted that the ISOL, SCRFQ and IH1 linacs have already been constructed and are successfully in operation as mentioned above. They will be moved to the proposed facility, when completed, together with the Super Conducting (S.C.) linac presently working at Tandem facility of JAERI [8].

The charge distribution of nuclei is one of the most important physical quantities to understand the nuclear structure. Muonic X-ray spectroscopy is a versatile tool to determine mean charge radii of nuclei, since X-ray transition energies in muonic atoms are largely affected by the size of the nuclei. The joint project will open a unique opportunity to apply this tool to unstable nuclei by coupling RNB from the E-arena and μ^--beam from the M-arena [9].

It is well known, that negative muons implanted into a material tend to be captured by higher-Z atoms in it. Therefore radioactive muonic atoms can be formed by stopping μ^--beam and RNB in the same solid deuterium layer. We are planning to accomplish this, using the double layers stopper consisting of a solid hydrogen layer with several mm thickness and a solid deuterium layer with several micron thickness, which is often used in muon catalyzed fusion experiments [10]. When the energetic negative muon stopped in the hydrogen layer mixed with deuterons, some of converted dμ-atoms from pμ-atoms finally move from the hydrogen layer to the thin deuterium layer by the help of the Ramsauer–Townsend effect to establish the concentration of dμ-atoms. Hence muons of dμ-atoms would be transferred to the radioactive atoms with higher-Z to form the radioactive muonic atoms, if the radioactive atoms are implanted in the same deuterium layer simultaneously. According to our preliminary estimation, assuming 10^{10} s^{-1} μ^--beam available in the M-arena, we expect formation of 10^8/s and 10^2/s muonic atoms of doubly magic nuclei ^{56}Ni and ^{132}Sn, respectively.

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