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NEW INDUSTRIAL APPLICATION BEAMLINE FOR THE cERL IN KEK

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Abstract

A new beam line of the electron beam irradiation for industrial applications is constructed at the cERL (compact Energy Recovery Linac) in KEK. In these applications, only north straight sections of cERL consisting of the injector and main LINAC is used to prepare the electron beam. The test for the radio isotope production and electron beam irradiation for the materials are firstly planned with very small beam current without energy recovery. The construction was finished in March 2019. We passed the facility inspection of the Nuclear Regulation Authority in April. Preliminary experiments with vacant targets are under way and the first irradiation experiments will be planned in June. In this paper, we show the design and commissioning results of this new beam line.

INTRODUCTION

The cERL is the superconducting linac based accelerator with the recirculation loop for the energy recovery [1]. Recently, the industrial application of the superconducting linear accelerator seems to be promising. The new beamline is constructed in cERL to make advantage of the high averaged CW current from the superconducting LINAC for the electron beam irradiation. There are two main subjects of the new beamline; the generation test of the Mo-99 radioisotope from Mo-100 for the medical use and the reforming test of the used asphalt.

The radio isotope of Mo-99 of the half-life of 66 hours decays to the Tc-99m of the half-life of 6 hours. Tc-99m is widely used for the medical imaging. In Japan, Mo-99 was partially generated with atomic reactors but is fully imported now. Almost all Japanese reactors for the isotope generation are very old and the domestic production with reactors seems to be very difficult in future. With the high averaged current beam from the superconducting accelerator, we can generate all amount of required Mo-99 in Japan with single accelerator. The normal conducting accelerators are already used for the Mo-99 generation [2, 3] in Japan and in the world [4-7]. Our final target is the commercial facility design for Mo99 production to satisfy all Japanese demand with superconducting LINAC. For design of the commercial facility, the test experiments are planned in cERL.

The beamline construction is fully funded by a private company, Accelerator Incorporated [8]. The company requested to make irradiation beamline multi-purpose and the project for the asphalt reforming becomes one of the main subjects of the beamline. The electron beam irradiation may recover the degenerated used asphalt [9] but the mechanism and details are not shown. Thus, the effect of the electron beam irradiation to the asphalt will be examined not only by the traditional method to measure the penetration and softening point but also by using multi quantum beam like the X-ray from the PF and the neutron from the J-PARC. To make the sample of the irradiated asphalt, we use the new beamline at cERL.

NEW BEAMLINE

The new beamline was constructed in the north part of cERL shown in Figure 1 and 2. For the production of Mo99, the beam energy is 17.5 MeV that is the highest available energy of present cERL and enough over the giant resonance energy of Mo-100(γ, n)Mo-99 reaction of about 14 MeV. On the other hand, to penetrate the depth of asphalt to about 2 cm, the beam energy is 10 MeV for the asphalt irradiation. The maximum averaged beam current is 10 μA for both irradiations.

When we deal the radioisotopes in open-air, it requires the severely protected facility. There are already two such kind of facilities in KEK. Thus, the generated isotopes are strictly kept in a sealed capsule and we only open the capsule at the Radioisotope Laboratory in KEK that is already existing with protection for open-air RI dealing. We fix the maximum amount of the generated Mo99 to enough small value not to radioactivate the air and water of the accelerator facility. By suppressing the maximum activation of the air to 10% of the regulation threshold, the large scale reforsatisfy the regulation. To enhance the enclosure of the generated isotopes, the concrete shielding (wall and floor) of the target rooms are painted with the epoxy coatings that prevent the penetration of the liquid to the concrete material and HEPA (High Efficiency Particulate Air) filters are add to the air exchange system of the accelerator shielding.

On the other hand, the 10 MeV beam for the asphalt do not contribute to the redioactivation of the target and the normal protection for the accelerator and beam dump are enough.

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To add the new beamline to the existing recirculation path, we use the alignment laser port of the first main bending magnet of the first arc to extract the electron beam. This port is just on the zero-degree straight line of the north straight section and originally attached to insert the alignment laser for fixing the main superconducting LINAC module. The minimum aperture at the exit is horizontally 30mm and vertically 10mm. We firstly fix the beam energy by using first bending magnet of the first arc and screen monitor. After fixing cavity parameters, the bending is switch off and degaussed. Finally, the electron beam go sprightly to the new beamline.

The beam current is measured by the electron gun power supply. The bunch charge can be measured by a faraday cup (FC) at the electron gun and a beam dump at the irradiation area. The irradiation dump FC can only be available when the target chamber is vacant. These devices with ordinary beam position monitors are used for the peak current and integrated irradiation power interlocks.

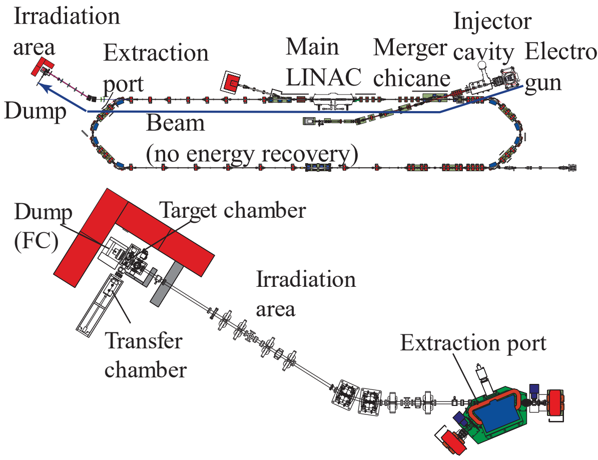

Figure 1: Layout of cERL and the irradiation area.

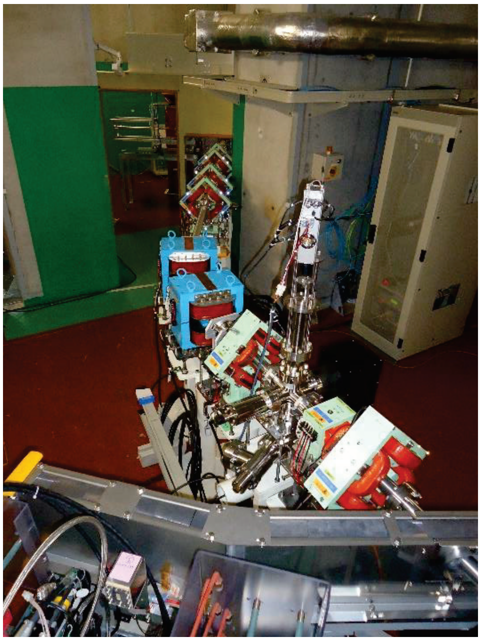

Figure 2: Picture of the new beamline.

To prevent the beam loss, the beam size should be kept small at the alignment laser port for the exit of the recirculation path. On the target, it is better to enlarge the beam size. For the optics matching with some flexibility, six quadrupoles are installed to the irradiation beamline. The target chamber, beam dump and shielding are installed to the northwest area that is originally designed as a main dump room of the cERL. At present, we only install half numbers of main LINAC cavities of the first cERL plan. The extraction chicane and the beam dump is fixed at the half way of the north straight section. To transport the beam from the north straight section to the irradiation area dump, two bending magnets of 16 degree bending angle each are used. By these binding magnets, the beam energy for the radioisotope production mode for Mo-99 and the irradiation research mode for the asphalt are distinguished.

The maximum amounts of the production of Mo-99 and Tc-99m are 100 MBq/day, 2 GBq/month and 8 GBq/year that is consistent of the RI Laboratory where we open the target capsule, measure the generated isotopes and will extract Tc-99m to test the extraction method. In order to estimate the RI production rate, we use FLUKA code (a high energy particle interaction code developed at CERN [10]). This estimation shows maximum production rate of Mo-99 in our system will be about 30 MBq/hour. For the precise count of the generated Mo-99 for example by the germanium detector, the order of 1 kBq generation is enough. We will use several µA beam with few minutes irradiation to generate sample Mo-99.

TARGET SYSTEM

To enclose the generated radioisotope, the target sample is fixed in the sealed capsule shown in Figure 3. The capsule is made of aluminium alloy because aluminium is relatively difficult material to be activated compared to other metals (e.g. copper) and has relatively high thermal conductivity. The capsule can hold samples up to φ38 mm ×L80 mm in size. Within this size limit, we can put various types of samples. The prepared capsule with inside sample is transferred to the irradiation area by the transfer chamber system that can be movable with casters and small shielding. The transfer system shown in Figure 4 consists of the vacuum room for the capsule and the long rod to move the capsule from the transfer chamber to the target chamber on the beam line. While we deal the capsule, it is always in the vacuum chamber. The double seal by the capsule itself and transfer or target chamber guarantee the enclosure of the generated radio isotope. After the capsule is moved to the target chamber by transfer chamber rod, the rod is removed, and the capsule is rotated to change the direction along the beamline. At this stage, the capsule was just on the lower water-cooling rotating stage. Finally, the upper cooling block above the capsule go down and push the capsule.

The capsule has the laid octagonal prism shape. To transfer the heat from capsule to the cooling block both up and down side of the capsule, the four oblique sides of the capsule were touched by the blocks. The oblique sides can be contacted with surface by surface with pushed force even with some manufacturing and alignment errors. The maximum power to the capsule is about 200 W at maximum in our case. Mock-up test of this cooling system was conducted by using electron beam welding machine. It was confirmed that the target can endure without problems even at 800 W heat input

The removable target system may unavoidably consist of some contamination. To maintain the performance of the superconducting cavity, the ultra-clean and high vacuum is essential. Thus, the vacuums of the target chamber and beamline are separated by a beryllium window with 0.5 mm thickness. The simulation shows the windows can sustained with both CW and burst (pulsed) mode operation.

COMMISSIONING

The construction of the beamline with target system began in July 2018 and finished in March 2019. After several inspections for the test operation, the test beam operation began on 5, May. The facility inspection of the Nuclear Regulation Authority was made on 12 April and we passed the inspection.

During the April operation, firstly the beam-based device calibration and beam tunings were made. After establishment of the stable and tuned beam transfer to the target area, the vacant target capsule was inserted and irradiated by the electron beam. Because the capsule was vacant, the beam loss was concentrated on the tail of the capsule. The tail cap of the capsule is removable to insert the sample. For the seal of the cap, this may be the most severe condition. In these conditions, the degeneration of the seal finally resulted in the leak of the capsule. Until the next experiment planned in June, the improvement of the capsule design especially of the seal method and materials is essential. In addition to vacant capsule test, we conducted the demonstration of RI production. This time, copper disk was chosen as irradiation target. Irradiation conditions are as follows; beam energy is 17.5 MeV, total amount of irradiation charge is 93 µC. We evaluate the Cu-64 amount by the germanium detector. Evaluated Cu-64 activity was 356 kBq that is well agreed with the simulations.

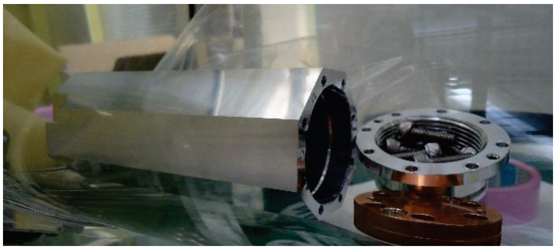

Figure 3: Picture of the target capsule.

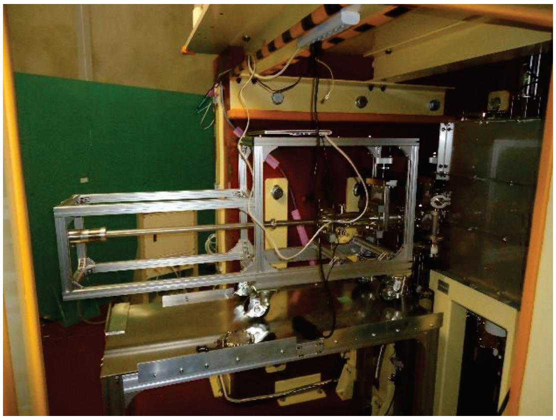

Figure 4: Transfer chamber with insertion rod attached to the target chamber.

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