COLLABORATION WITH INDUSTRY IN KOREA FOR MEDICAL ACCELERATORS

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Abstract

Accelerators related industrial activities in Korea for medical as well as basic and applied science applications are introduced, and technical development progress of accelerators with industrial collaboration is presented. The growth of accelerator industries in Korea has started since the construction of Pohang Light Source in early 1990's. The gained industrial expertise and experience have applied in development of medical accelerators by collaborating national research institutes. Main development of medical accelerators has been cyclotrons, and a new development project of hadron therapy, called KHIMA, was launched in 2010. For this project, industrial collaborations with their gained expertise become essential for the success of the project. Two proton therapy systems were imported by NCC in 2005 and by SMC in 2013 and are under patient treatment. The first formal medical accelerator company in Korea was established in 2015, and more are expected to come in near future.

INTRODUCTION

There are nearly 20,000 particle accelerators in operation worldwide. About 50% of running accelerators are used for medical applications. The main application areas of modern medical accelerators can be categorized as (1) electron linacs for conventional radiation therapy with electron and photon beams, (2) low-energy cyclotrons for the production of radioisotopes, and (3) medium-energy cyclotrons and synchrotrons for oncological hadrontherapy [1].

In Korea, about 230 medical accelerators are in operation. Among them, about 180 are linear accelerators [2]. All of the medical linear accelerators are imported units. There are some research and development activities for the medical linear accelerators in Korea, but those activities and related industrial collaborations will not be covered here. The survey result of cyclotrons for radioisotope production in Korea shows that total 36 units are in operation as of 2011. Ten out of the total units are constructed in Korea and 26 are imported units as shown in Table 1 [3]. Cyclotrons for proton therapy were not included in this survey.

Table 1: The Operation Status of Cyclotrons for Radioisotope Production in Korea (2011) [3]

Energy Range	11~15 MeV	16~20 MeV	30 MeV~	Total
Domestic	9	-	1	10
Imported	13	12	1	26
Total	22	12	2	36

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The Korea Institute of Radiological and Medical Sciences (KIRAMS), which was firstly established in 1963 to promote the medical application of atomic energy in Korea, has played a leading role in radiation medicine as well as in the treatment and research of cancer in Korea. A 50 MeV medical cyclotron (MC50), built by Scanditronix and the first cyclotron facility in Korea, was installed at the Korean Cancer Centre Hospital (KCCH) of KIRAMS in 1986. The cyclotron has provided an inhouse source of radio-isotopes and had also been used for neutron therapy [4]. In 2004, the KIRAMS installed a new 30 MeV cyclotron (Cyclone-30). This used solely for production of radioisotopes [5]. An R&D project to develop a 13-MeV cyclotron for production of 18F-isotope in the PET application was initiated in 1997. The developed domestic cyclotrons were installed and have been in operation at several regional hospitals in Korea. Table 2 shows the major parameters of the 13 MeV cyclotron developed [4]. KIRAMS also developed a 30 MeV cyclotron (KIRAMS-30) and delivered to Advanced Radiation Technology Institute in Jeongup-city, Korea in 2006 [6]. The main functions of the KIRAMS-30 are the production of gamma emitting radio nuclides and fast neutron generation. The main parameters of the KIRAMS-30 are shown in Table 3.

Table 2: Main Parameters: 13 MeV Cyclotron [4]

Parameter	Unit	Value
Maximum energy	MeV	13
Beam species		H^-
Number of sectors		4
Ion source Internal		PIG
Average B field at 13 MeV	kG	12.98
Harmonic number		4
Radio frequency	MHz	70
Maximum orbit distance	cm	41.4
Beam current	μA	50

Table 3: Main Parameters: 30 MeV Cyclotron [6]

Parameter	Unit	Value
Ion Source		Multi-cusp type
Beam species		H^-
Extracted Energy	MeV	15-30
Magnet Center Field	T	1.05
Harmonic number		4
Radio frequency	MHz	63.96
Magnet Diameter	m	2.7
Beam current	μA	500
Beam Transport Line Length	m	6

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As of May 2016, there are two proton therapy systems, which are based on cyclotrons, are under patient treatment in Korea; National Cancer Center (NCC) Proton Therapy Center in Ilsan, Korea, and Proton Therapy System in Samsung Medical Center (SMC-PTS) in Seoul, Korea. Since 2010, a heavy ion medical accelerator development project has been started to construct a 430 MeV/u synchrotron for cancer treatment with mainly carbon beams in Gijang county of Busan metropolitan city, Korea. These three large particle cancer therapy facilities are introduced with some detail in the next section.

PARTICLE THERAPY ACTIVITIES IN KOREA

The proton therapy facility at the NCC Proton Therapy Center in Ilsan, Korea was started its installation from 2005 and finished commissioning in early 2007. The system was manufactured and installed by IBA (IBA Proteus 235). The center has treated patients with advanced radiation therapy since March 2007 [7, 8]. The major parameters of the NCC cyclotron are listed in Table 4. In Fig. 1, the overall layout of the center is shown. It has one horizontal fixed beam, two gantries, and one experimental line.

Table 4: Major Parameters of the NCC Cyclotron [9]

Parameter	Value
Energy	230 MeV
Beam current	1-300 nA
Yoke diameter	4.3 m
Weight	220 tons
Intensity modulation	15 µ sec (20-80 %)
Radio frequency	106.1 MHz
Harmonic mode	4

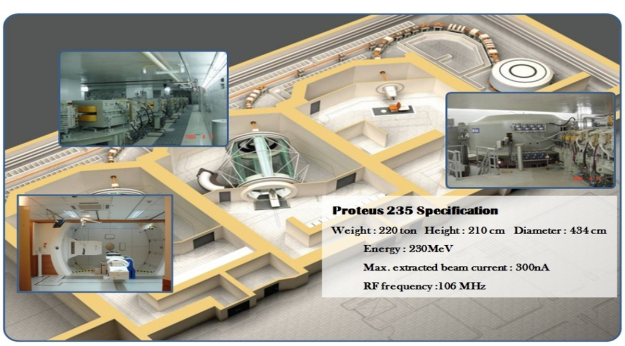

Figure 1: National Cancer Center (NCC) Proton Therapy Center Cyclotron in Ilsan, Korea [7].

The proton therapy system at SMC (SMC-PTS), which is located in Seoul, is the first private-hospital based proton therapy center in Korea. The project was launched in 2007 and purchasing contract was signed with Sumitomo Heavy Industries Ltd. in 2011. After ground breaking in 2011, the system started installation from 2013. The system was handed over to the SMC near the end of 2015. Since then, the center has started wobbling treatment. From March 2016, the center has also started scanning treatment [10]. The SMC-PTS has a cyclotron (230 MeV) and two treatment rooms: one treatment room is equipped with a multi-purpose nozzle and the other treatment room is equipped with a dedicated pencil beam scanning nozzle. Both treatment rooms have isocentric gantries that have irradiation nozzles. The maximum radius of the gantry is 5.3 m and the mass of rotating part is 120 tons. The proton beam energy can be adjusted from 70 MeV to the maximum 230 MeV. The maximum field size of the nozzle is 25 cm × 25 cm in wobbling mode, and 24 cm × 24 cm in scanning mode. The maximum range without a scatterer is 32 g/cm^2 and the range can be adjusted in steps of 0.1 g/cm^2. The proton accelerator at SMC-PTS is a normal conducting azimuthally varying field (AVF) cyclotron. The magnetic field of the cyclotron ranges from 0.9 T (valley) to 2.9 T (hill). The diameter of the cyclotron is 4.3 m and the weight of the cyclotron is approximately 220 tons. The RF frequency used in the system is 106 MHz [11]. In Fig. 2, layout of the SMC-PTS is shown.

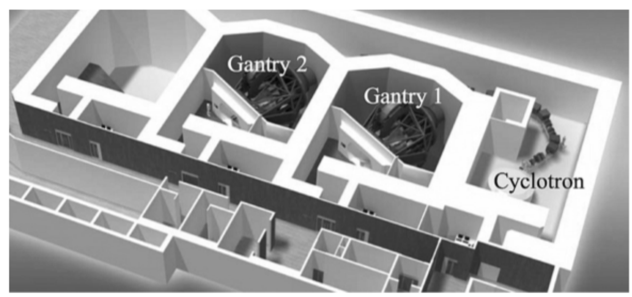

Figure 2: The proton therapy system at Samsung Medical Center (SMC-PTC) layout [11].

In 2010, the KIRAMS started a heavy ion medical accelerator project to construct the first such facility in Korea, called Korea Heavy Ion Medical Accelerator (KHIMA) project. The project is supported by MIST (Ministry of Science, ICT and Future Planning), Busan Metropolitan City, and Gijang County. The facility site is located at the Gijang County of the Busan Metropolitan City, which is about 400 km south-east of Seoul. The KHIMA is a cancer therapy facility based on a synchrotron which can accelerate up to 430 MeV/u for carbon beam and up to 230 MeV/u for proton beam. The facility is consisted of five main systems: injector linac, synchrotron, HEBT, irradiation system, and treatment rooms. The injector linac includes ECRIS, low energy beam transport (LEBT), RFQ and IH-DTL, and medium energy beam transport (MEBT) [12]. The facility will have three treatment rooms and one research room. Layout of the KHIMA accelerator is shown in Fig. 3. In Table 4, major parameters of the KHIMA are listed. The bird's eye view of the KHIMA site is shown in Fig. 4. The construction of the site building will be completed in May 2016.

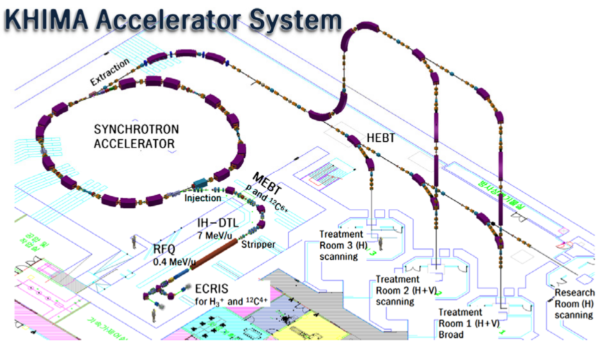

Figure 3: Layout of the KHIMA.

Table 4: Major Parameters of the KHIMA

Parameter	Value
Type of ion	$^{1}H_3^{+}$ for proton and $^{12}C^{4+}$ for carbon at ECRIS
Beam particle species	p, ^{12}C
Injection	Multi-turn injection
Extraction	RF-KO slow-extraction
Energy range	60-230 MeV for proton 110-430 MeV/u for carbon
Beam Range	3.0 g/㎠ to 27.0 g/㎠
Beam intensity	$1x10^8 \sim 1x10^{10}$ protons/spill at Isocenter $4x10^6 \sim 4x10^8$ carbons/spill at Isocenter Nominal number of spills : 60 spills in 2~3 min
Dose rate	2 Gy/min for 1 liter
Beam size	4 to 10 ㎜ FWHM
Field Size	20x20 ㎠
Irradiation Room	1 H (scanning), 1 H+V (scanning), 1 H+V (SOBP(TBD)), 1 H (scanning, Research)
Machine Dimension	37.9 x 66.4 x 17.6(H) m

Figure 4: Bird's Eye View of the KHIMA Site.

INDUSTRIAL COLLABORATION ACTIVITIES FOR ACCELERATOR IN KOREA

Tang reported accelerator industry status of Asia in 2010 [13]. In his report, three organizations in Korea were listed as the accelerator industries: EB-Tech, POSTECH, and Sam Young Unitech. Out of these three, the Sam Young Unitech is the only one in private business sector that is involved in medical accelerators. The company has cyclotron manufacturing activities. The technology was transferred from KIRAMS. EB-Tech has been in beam irradiation business for some time, but not in medical accelerator business. The POSTECH is operating 3rd generation light source and is not in a private business sector, but rather in a public research and development sector in Korea.

The accelerator related business in Korea has flourished since 1994, in which the Pohang Light Source (PLS) was constructed. Since the completion of the PLS, there has been several large scale national projects to construct national science infra. From 2014, the Proton Engineering Frontier Project (PEFP) has been in operation. The Pohang Accelerator Laboratory (PAL) upgraded the PLS to PLS-II in 2011, and completed the 4th generation XFEL facility construction in 2015 that is under commissioning in 2016. A new large scale heavy ion accelerator project, RAON, has been under progress in Korea [14]. During the process in research and development of accelerators, about 400 large and small industries have been involved in the accelerator business. These industries have formed an industrial ecosystem with about sixteen major companies. Related technologies in the accelerator related ecosystem are ultra-high vacuum, cryogenic, superconducting, large scale high level control system, special materials, fine machining, diagnostics and instruments, high stability cooling systems, high precision magnet power supplies, high and low power RF and low lever RF controls, survey and alignment, high precision magnets, mechanical components such as girders and stages, etc. However, there exist no companies that could manage overall accelerator systems, either for basic R&D or for medical purposes. EB-Tech is a company that could handle manufacturing industrial accelerator systems for beam irradiation, but not yet involved in medical area [15]. Most of the current accelerator related industries are maintaining their accelerator business by collaborating with national R&D institutions and applying their experience and specialty in national large scale projects. The growth rate of accelerator related industries in Korea is in good shape and expected to grow further.

Dawonsys is one of representing accelerator related companies is Korea. The company is specialized in the field of power electronics and mainly participates in high technology projects such as nuclear fusion reactors, electron and ion accelerators, etc. In 2015, Dawonsys established a subsidiary company that pursues a business specialized in medical accelerator development and manufacturing [16]. This subsidiary company of Dawonsys be-

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comes effectively the first formal medical accelerator business in Korea. Vizrotech is also another representing accelerator related company in Korea. The company is specialized in manufacturing accelerating structures such as S-band accelerating column, RFQ, normal and superconducting RF cavities, etc. The company can manage overall engineering process from design, manufacturing, measurement, installation, and operation. The company has a special engineering service division to handle the accelerator engineering and others such as fusion, aerospace, plasma, etc. Their goal is to be one of top global companies in the field of accelerator business [17]. However, the company does not yet set a business exclusively on medical accelerators even though they have high potential and interest in the business. Other than those two, there are more representing accelerator companies. However, there seems no exclusive interest in establishing the medical accelerator business yet.

The accelerator business in Korea has been grown for the last twenty years, mainly on basic and applied science areas with fairly good public support and funding. In order to obtain sustainable and even strengthen public funding and support, it is essential to prove that the forefront accelerator technology is highly beneficial to public, especially in the medical field. Thus promoting accelerator industries in Korea by collaborating and transferring cutting edge technologies from national research institutes is highly desirable. We hope to see more new and leading medical accelerator business activities at Korea in near future.

CONCLUSION

Collaboration with industry in Korea for accelerators has been active since the beginning of PLS construction in 1990's. With this collaboration experience, the tradition has continued when the KHIMA project started in 2010. In 2015, a subsidiary company for exclusively on medical accelerator business was formally established in Korea by Dowonsys. There are several companies with high interest and potential to establish medical accelerator business and expect to see more industries solely devoted to medical accelerator business in near future.

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