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KCCH Medical Cyclotron Operation for Neutron Therapy and Isotope Production (1989)

– A Technical Report –

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ABSTRACT

After four years of planning, equipment acquisition, facility construction and beam testing, the KCCH cyclotron facility was put into operation in November 1986. Now the KCCH cyclotron(MC–50) has been used for four years in neutron therapy and radioisotope production. Up to December 1989, 179(1852 sessions) patients have undergone neutron therapy. Radioisotope production for nuclear medicine use was started from March 1989 after extensive work to overcome target transport, target melting, beam diagnostic and chemical processing problems. This status report introduces the cyclotron facility, and the experiences of neutron therapy and isotope production with the MC-50 cyclotron. Besides, the operation results and the general troubles of the MC-50 during 1989 are summarized. Total operation time was 1252.5 hours. Four hundred hours were used for neutron therapy of 599 treatment sessions and 832.5 hours for radioisotope production. Total amount of produced raioisotope was 1695 mCi(Ga-67 : 1478 mCi, Tl-201 : 107 mCi, I-123 : 25 mCi, In-111:85 mCi). Twenty hours were used for scheduled beam testing. In 1989, 88.2% of the planned operation were performed on schedule and this rats is improved remarkably compared to 71.0% in 1988.

Key Words : *Cyclotron, Neutron therapy, Isotope production, Beam delivery, preventive maintenance, Operation.*

I. Introduction

The application of cyclotrons in medicine was foreseen very early in their development[1]. The two main uses were expected to be treatment of cancer with neutrons and production of artificial radionuclides. The first cyclotron designed exclusively for medical use is the one at Hammersmith Hospital. There are now at least thirty in different countries and many more which are applied to medical problems for part of the time. The interest in neutron therapy has been growing slowly but steadily over the past 20 years, while in the late sixties the Hammersmith Hospital, London, was the only institution seriously involved in this activity, there are now at least 18 centers around the world which are actively pursuing research and clinical programmes in the application of neutrons for treatment of cancer[2-7]. Moreover, a number of other academic and research institutions are engaged in physical and radiobiological research connected with neutron therapy. From a therapeutic point of view, a suitable neutron source should be able to provide enough dose rate at source to skin distance of about 100 cm, and has penetration at least equivalent to that of Co-60 gamma range. A typical neutron dose delivered per fraction ranges between 100 and 200 rads. Therefore, the neutron source should be able to deliver at least 20 to 30 rads/min. Also, in order to achieve a penetration equivalent to that of Co-60 range, one requires a neutron beam with a mean energy of at least around 15 MeV. Of course, higher dose rates and deeper penetration would be advantageous. Production of radioisotopes for diagnostic studies is by far the most well known medical appication of cyclotrons, and most medical cyclotrons are occupied in the production of various isotopes for research and routine work in nuclear medicine and nuclear biology. Generally, neutron-deficient, carrier free and short-lived isotopes, which cannot be produced in a reactor, are produced with cyclotrons[8-11]. C-11 and O-15 are particularly important and their use demands that the cyclotrons should be in the hospital. Positron emission tomography (PET) is now beginning to allow us to measure functional parameters in the brain, lung and heart. This is the most exciting subject in the nuclear medicine field[12-14].

This paper has outlined the present status of the medical cyclotron facility in the Korea Cancer Center Hospital (KCCH). This includes the beam delivery for neutron therapy and isotope production, treatment statistics for neutron therapy and thick target yields for radioisotope production in 1989.

II. Facility Description

The construction of the compact cyclotron as a variable energy 3-sector isochronous cyclotron is based on the requirement of medical and biological applications such as high beam currents at moderate energies, the ability to accelerate p, d, He-3 and α-particles, good focusing and extraction efficiency, easy handling, and compact structure. With initial two years of development, further two years of construction and testing by Scanditronix and one more year of operation at the Korea Cancer Center Hospital the MC-50 has proved to meet most of the user's requirements. Performances and characteristics of the machine can be summarized as follows in Table 1 and Table 2.

Table 1. Performances of the MC-50

Energy (MeV)		
Proton	18-52	
Deuteron	9-25.5	
Helium-3	24-67	
Helium-4	18-50.5	
Beam Current(μA)		
Particle	Internal	External
Proton	200	50
Deuteron	200	50
Helium-3	120	35
Helium-4	120	35

The beam transport system consists of one switching magnet for deflections from +52° to -52° and seven beam pipe connections. At present only two of the connections are in operation. The acce-

Table 2. Design Features of the MC-50.

Magnet	
Pole diameter	143 cm
Min. gap(hill)	11 cm
Max. gap(valley)	19.7 cm
Dimension	3.62m×1.55m×2.36m
No. of sector	3
Spiral angle	max. 55°
Main coil	320 turns, hollow Cu
Circular trim coil	10 pairs
Packing ratio	63%
Max. current	900 A
Power	126 kW
Max. average field	17.5 kGauss
Min. average field	10.5 kGauss
Max. hill field	20.5 kGauss
Field stability	10^{-5}
Current stability	10^{-5}
Cooling water	90 l/min
Water temp. rise	13℃
Water pressure drop	4 atm
Total weight	94 ton
Radiofrequency	
Dee electrode	2
Dee angle	90°
Dee voltage	40 kV
Min. aperture	2 cm
Frequency range	15.5-26.8 MHz
Mode	push-pull, push−push
Dee voltage stability	10^{-3}
Frequency stability	10^{-6}
Inter dee phase stability	1°
Cooling water	80 l/min
Tuning	resonator, flap
Orbit frequency	7.75-26.8 MHz
Energy gain	113, 160 keV/turn
Ion	
Type	P. I. G.
Location	internal, vertically introduced
Max. arc power	3kW
Gas consumption	0-5 SCCM
Extraction	
First channel	electrostatic deflector
Max. field	133 kV/cm
Angular span	45°
Second channel	electromagnetic
Max. current	1000 A
Angular span	35°
Vacuum	
Prevacuum pump	120 m^3/hr
Diffusion pump	2×4000 l/sec
Vacuum chamber	1500 l
Working pressure	$<10^{-5}$ mbar

ptance of the beam guiding system is sufficient to achieve a transparency of 90-95% with an emittance of the cyclotron of about 20πmm · mrad in the horizontal direction. The beam cross sections on the neutron target and the radioisotope target are less than 4×4 mm² and 20×20 mm², respectively. In case of isotope production, the beam energy in the range of 15-50 Mev is easily obtained by using the Al energy degrader without acceleration frequency change.

III. Beam Delivery

Under normal operating conditions, Monday is used for preventive maintenance, Tuesday, Wednesday and Thursday for neutron threapy, and Thursday night and Friday for radioisotope production. Figure 1 shows the weekly and accumulated beam delivery by the MC-50 in 1989. The accumulated beam delivery in 1989 was 28.95 mA · hr. The weekly average beam delivery was 0.56mA · hr/wk. The beam irradiation day can be divided as shown in Table 3. Table 3 shows the regular running of the cyclotron in 1989, compared with that in 1988. The lowest performance during the week 37 in Fig. 1 is due to a trouble of DMA(Direct Memory Access) interface card to the PDP 11/23+ computer.

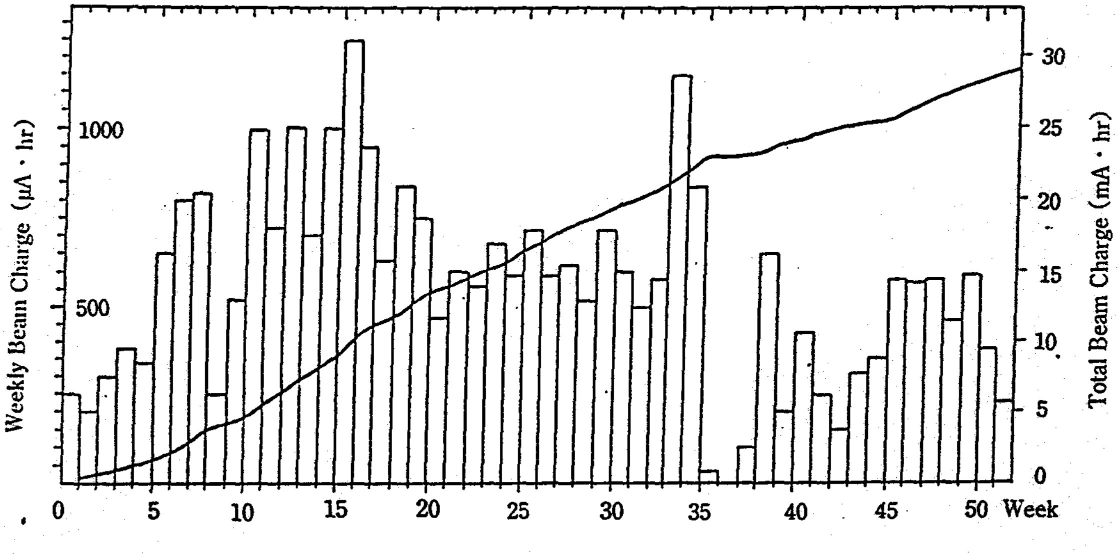
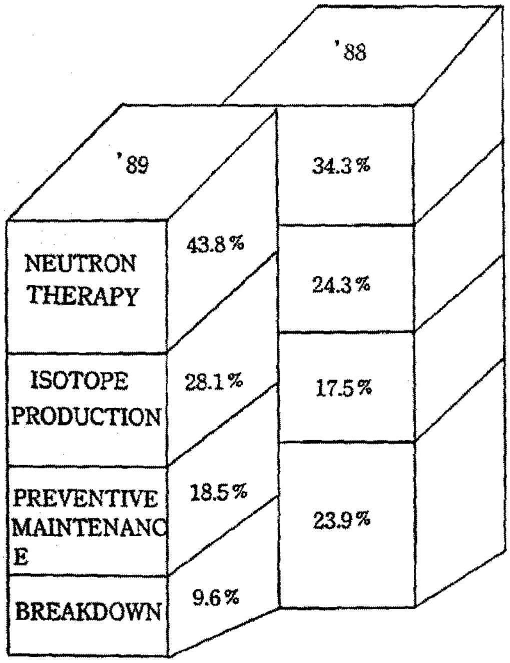


Fig. 1. Beam Delivery (1989).

IV. Neutron Therapy

The treatment room is equipped with an isocentric gantry with 360 degree rotational capability. This unit was built by ELVEN Precision, England, a subcontractor of Scanditronix. The treatment head contains a semi-thick beryllium target in which protons lose 50% of their initial energy. The remaining energy is deposited in the copper backing plate. Also, contained in the head are the beam flattening filters, the dual dosimetry system, the wedge filter system to produce asymmetric dose distributions and the beam defining lamp. The head carries a neutron collimator of book-end type which can be rotated around the beam axis. In order to make the 360 degree rotation of the gantry possible, a 3 m-deep pit is prepared to take up the head in its down position. This pit

Table 3. Cyclotron Utilization (1988, 1989).



is covered by a moving floor.

The standard patient treatment consists of 12 treatment sessions splitted over 4 weeks. Within one session a patient is irradiated from one to four different directions with different collimator set-ups. On the average the patients are treated with 2 fields. A two-field treatment takes on the average 30 minutes ; about 20 minutes for set up and a total "beam-on" time of 8 to 12 minutes depending on the available beam intensity and the prescribed dose.

Figure 2 shows the patient treatment statistics in 1989. The graph shows the number of scheduled treatment sessions and the actual number of performed treatments (hatched). The discrepancy is attributed to treatment demands and machine malfunctions. According to Fig. 2, the number of cancelled treatment sessions is average 5.6 sessions per month, which is about 10% of scheduled

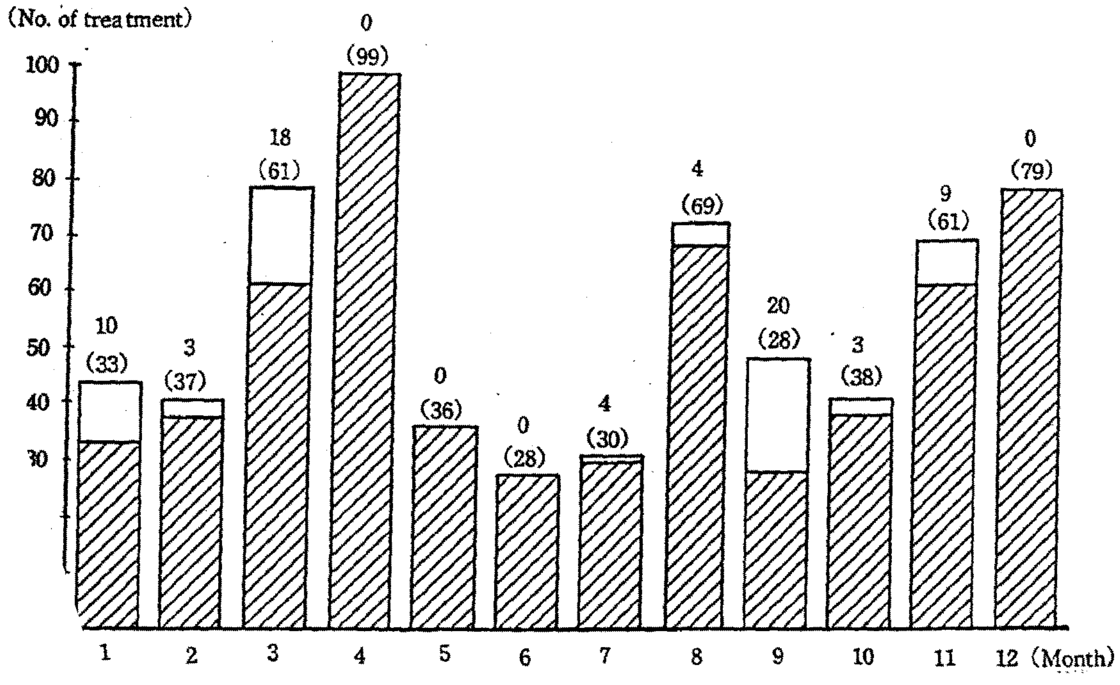
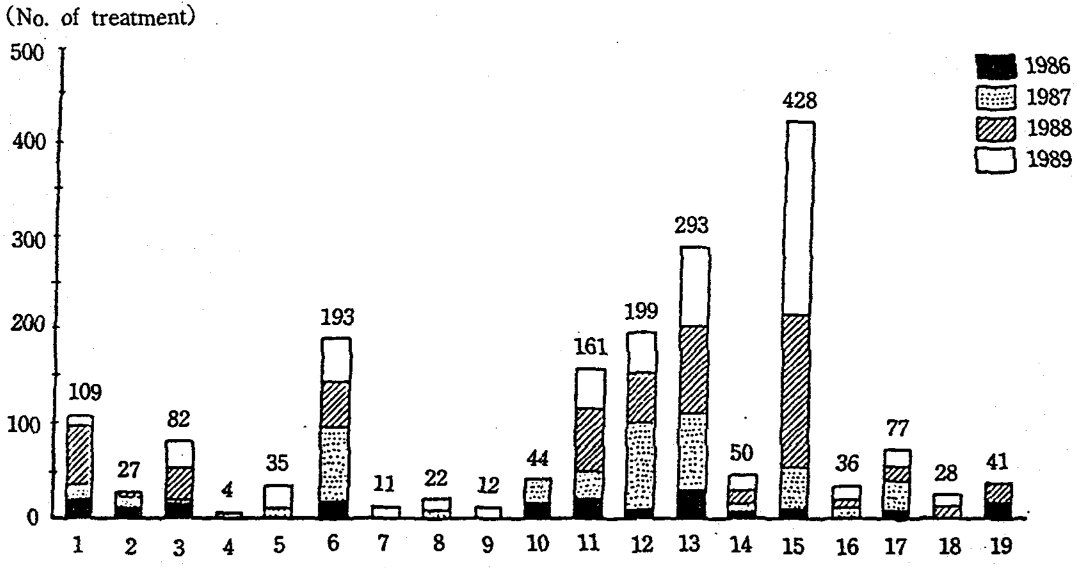


Fig. 2. Neutron Treatment Statistics (1989).

time. FromNovember1986 to December 1989, 179 patients(1852 sessions) have been treated. Figure 3 shows the annual repartition of patients according to the tumor type or localization.



1 : Nasal cavity & maxilla
2 : Larynx
3 : Oropharynx
4 : Nasopharynx
5 : Hypopharynx
6 : Salivary gland
7 : Mandible
8 : Thyroid
9 : Axilla
10 : Breast
11 : Oral cavity
12 : General urinary
13 : Sarcoma
14 : Gynecology
15 : Digestive
16 : Sacrum
17 : Unknown primary
18 : Melanoma
19 : Central nervous system

Fig. 3. Annual repartition of patients accrding to tumor. type or localization.

V. Isotope Production

The target system contains two solid target stations including the target transfer system and one gas target station. The solid target station consists of a vacuum box with one gate valve for beam exit and one for the carrier module port. A remotely controlled external target transfer system known as a "Telelift" system automatically carries a target from a loading station to a irradiation chamber. After irradiation the target will be carried back to the loading station. For irradiation of gases, the gas target is equipped with a water-cooled energy degarder made of aluminum. The aluminum degraders in front of the target reduce the beam energy to 15-20 MeV region best suited for the production of the PET isotopes. An aluminum gasket is used to seal between the foil and the target body. The characteristics of carbon-11 target are summarized in Table 4.

Table 4. Characteristics of Carbon-11 Target.

Material	Aluminum
Length.	465 mm
Volume	0.75 l
Cooling water	1-1.5 l/min
Gasket	Aluminum
Working pressure	4.5-5.5 atm N_2

Nuclides routinely produced for medical use are Ga-67, In-111, I-123 and Tl-201. In order to increase the production yield, the proton beam of 50.5 MeV is often used for isotope production. The operation of the cyclotron for isotope production has to be done between neutron therapy runs for optimal use of beam-on time. The production yields of each nuclides shown in Table 5 are determined from experimental measurements. Table 6 shows the total amount of produced isotopes for eight months.

Table 5. Production Yield of Ga-67, In-111, I-123 and Tl-201.

Isotope	Reaction	Energy (MeV)	Target	Production yield (μCi/μA · hr)
Ga-67	Zn (p, Xn)	50	nat. Zn	500
In-111	Cd (p, Xn)	28	nat. Cd	520
I-123	Te-124(p, 2n)	30	enriched Te-124	4000
Tl-201	Tl (p, Xn)	28	nat. Tl	530

Table 6. Isotope Production in 1989

(Unit : mCi)

Month	Nuclide				Total
	Ga-67	Tl-201	I-123	In-111	
5	85	16			101
6	445			15	460
7	360				360
8	432	33	10	10	485
9	75	6	15	15	111
10	25	21		15	61
11	40	16		20	76
12	16	15		10	41
Total	1.478	107	25	85	1.695

VI. Maintenance

The maintenance can be grouped into two categories. The first is preventive maintenances done in the normal planned maintenance periods for preventing failures of the cyclotron and upgrading the systems. The scheduled maintenance accounted for 18.5% of the cyclotron total working time in 1989. The second is unscheduled ones. Repairs must be done without delay, and a good set of spare parts needs to be on hand. In this way, disabled parts can be quickly replaced and actual repairs on the parts can be done later. The out-of service time due to breakdowns met on the cyclotron and its peripheral units amount to about 12% of the cyclotron total working time. Table 7 shows the breakdowns of the system caused losses of neutron treatment and isotope production in 1989.

Major causes of equipment down-time were associated with the failures in control system, RF system, gantry driving system, primary cooling system or power system. The control computer and I/O system had caused a couple of week of down-time in September. About 20% of system breakdowns were caused from external faults such as primary cooling and power failure. Many failures in several systems were attributed to the failure of packaged low voltage power supplies. Apart from some cases, the supplies failed by ove-

Table 7. Analysis of System Breakdown (1989)

(No.／hr)*

System ╲ Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Magnet	1／0.5		1／1					2／1			2／0.5	1／0.3	7／3.3
RF	4／29	1／8	5／15				3／5	3／1.5	1／6	1／2			18／66.5
Anode PS		2／1.5	5／4					1／0.5					8／6
Ion source			1／1	1／8			1／1					1／0.3	4／10.3
Extraction											1／8		1／8
Arc PS					1／3								1／3
Diagnostic					1／2								1／2
Vacuum					1／4				1／1			1／0.7	3／5.7
I／O								1／2	1／80				2／82
Computer						1／1.5		1／0.5	3／10		1／1	2／6	8／19
Beam line PS				1／1				3／2			1／4	1／2	6／9
DMC	1／8											1／12	2／20
Gantry driving		2／10	2／11								3／3		7／24
UPS		3／0.5	5／1										8／1.5
Target					1／3		1／1				2／3		4／7
Primary cooling				2／4.5			2／10	2／10		3／17	1／8		10／49.5
System cooling						1／1.5		1／2				1／2.5	3／6
Power failure	3／6		1／2	1／8	2／4	4／8	1／2	1／2					13／32
Total	9／43.5	8／20	20／35	5／21.5	6／16	6／11	8／19	15／21.5	6／97	4／19	11／27.5	6／19.8	106／345.8

*(a／b) a : the number of system breakdown.
b : the time taken for repair of recovery of breakdown system (hr).

rtemperature problem. Especially, it is very important to solve the high temperature and humidity problems in summer. This kind of failure was eliminated by installing the auxiliary air conditioning system and de-humidifier. The ion source failed four times because of broken cathode, water leaking, anode wearing and damage to the blocking resistor. Life of the LaB_6 cathode was checked by weekly preventive maintenance. In particular, the down-time of the vacuum and extraction system was remarkably reduced by the preventive maintenance compared with that of 1988. There were some disturbing failure of isotope target system which were finally overcome by improving the design. We at present run routinely at 30-35μA corresponding to a dose rate of 30-35 rad/min for neutron therapy and at 25-30μA for radioisotope production.

VII. Conclusions

The characteristics of the KCCH MC-50 cyclotron facility, operation results, technical aspects and the preventive maintenance in 1989 are presented. The cyclotron has been used for neutron therapy with 599 treatment sessions and radioisotope production of 1695 mCi. The availability is 88.2% in 1989 and it is remarkably improved with 71.0% of the previous year by virtue of the preventive maintenance. The operation experience shows that the cyclotron facility in KCCH runs well to fulfill the everyday requirements of hospital neutron treatment and radioisotope production. The number of systems contributed to long shutdown time must be further reduced by preparing sufficient stock of spare parts and by improving subsystems causing delays. Also the analyses and loggings for system failure will be helpful to shorten the repair time. The present system has a good potential for more advanced techniques in neutron therapy and radioisotope production.

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중성자 치료와 동위원소 생산을 위한
KCCH 의학용 싸이클로트론의 운영 (1989)

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요 약

원자력병원에 설치된 MC-50 의학용 싸이클로트론은 4년간의 장비 도입 계획, 장비 인수 및 설치 그리고 빔 특성조사를 거쳐서 1986년 11월부터 가동을 시작하였다. MC-50 싸이클로트론은 현재 중성자 치료 및 방사성 동위원소 생산에 이용되고 있다. 1989년 12월 현재, 중성자선 치료는 총 179명(1852 sessions)의 환자에서 시행되었다. 핵의학 분야에 이용되는 방사성 동위원소의 생산은 표적운반, 표적용융, 빔 진단 그리고 화학적 처리과정에 관한 문제들을 해결하기 위한 다각적인 연구를 거친 후 1989년 3월부터 시작하였다. 이 논문은 중성자 치료와 동위원소 생산에 이용된 MC-50 싸이클로트론의 운영 현황 및 장비의 특성에 대하여 기술하였으며, 또한 1989년도의 운영결과 및 제반 문제점들을 요약하였다. 1989년도 총 운전시간은 1252.5시간이었으며 이 중 중성자 치료에 400시간을 이용하였다(599 sessions). 동위원소 생산에는 832.5시간을 이용하여 총 1695mCi(Ga-67：1478mCi, Tl-201：107 mCi, I-123： 25mCi, In-111：85mCi)를 생산하였다. 빔 특성실험 및 기타 연구에는 20시간을 이용하였다. 1989년도의 가동율은 88.2%이었으며 전년도의 71.0%에 비하여 현저히 향상되었다.