Progresses of heavy-ion cancer therapy

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Abstract The status of heavy-ion cancer therapy has been reviewed. The existing and constructing heavy-ion beam facilities for cancer therapy in the world are introduced. The first clinical trials of superficially placed tumor therapy at heavy ion research facility in Lanzhou (HIRFL) are presented.

Key words heavy-ion cancer therapy, inversed dose profile, relative biological effectiveness

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1 Introduction

Wilson R first realized the medical therapy function of the inversed dose profiles of ions in 1946[1]. From 1975, the Lawrence Berkeley Laboratory collaborated with the University of California, San Francisco Medical Center started the heavy-ion cancer therapy. According to the favorite performance of heavy-ion beams like carbon such as inversed dose profiles, precise physical dose distribution with lateral and range scattering less than one millimeter in treatment depth, tracing the beam by Positron Emission Tomography (PET) based on positron emitters produced by nuclear reaction fragmentation, as well as high relative biological effectiveness (RBE), the heavy-ion cancer therapy is becoming attractive all over the world[2].

2 International status

In the United States, the heavy-ion therapy with argon, silicon, neon and carbon ions was performed by using the Bevalac (see Fig. 1), the world's first relativistic heavy-ion accelerator, at Berkeley in 1975[3]. In the following 18 years, 433 patients were treated and tolerable side effects for the lighter ions such as neon ions were found. In 1993, the Bevalac was closed because of the construction of new facilities RHIC and CEBAF.

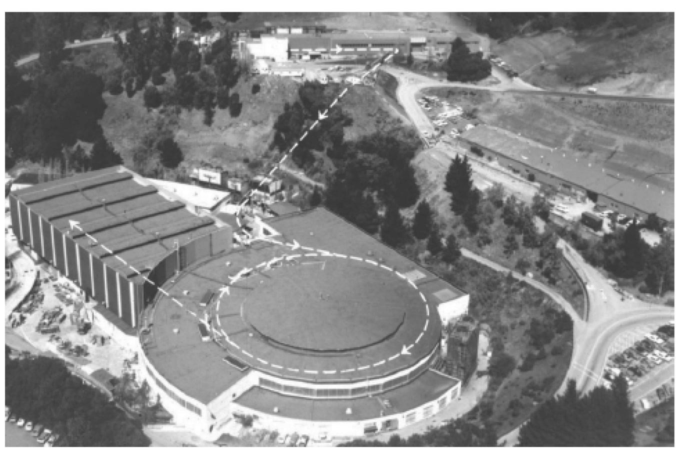

Fig. 1. The Bevalac facility, the world's first relativistic heavy-ion accelerator at Berkeley.

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In Japan, the passive carbon ion therapy started at the National Institute of Radiological Sciences (NIRS) (Fig. 2) in Chiba in 1994[4]. In 2002, a facility for carbon ions and protons was established in Hyogo (Fig. 3). More than 3000 patients have been treated successfully with the local control rates more than 80%. The construction of the third facility in Gunma began in 2006 (Fig. 4). More facilities in Japan were proposed.

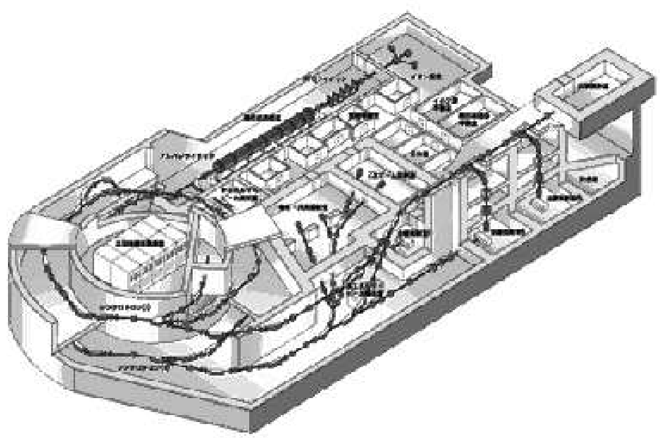

Fig. 2. Layout of the HIMAC facility for heavy-ions in NIRS.

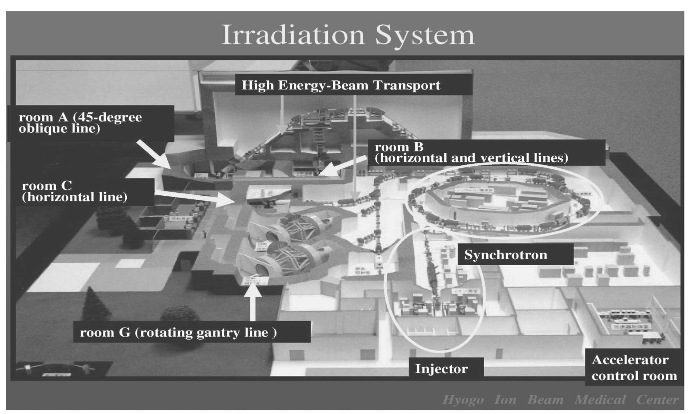

Fig. 3. The layout of the facility for carbon and proton in Hyogo.

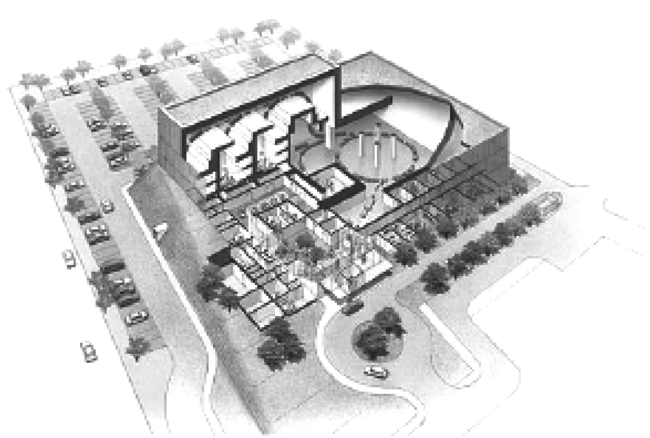

Fig. 4. The heavy-ion cancer therapy facility for Gunma University.

In Germany, the carbon therapy with active particle-beam delivery systems initiated at GSI collaborated with the University of Heidelberg in 1997. More than 400 patients have been treated very successfully with the high local control rates between 83% and 100%. With encouraged by the positive treatment results, the Heidelberg Ion Therapy facility started in 2003 and will be operated in the end of 2008 (Fig. 5). In addition, more new projects, such as the facilities of the Marburg and Kiel Heavy Ion Therapy, began construction in 2007 and 2008, respectively.

In other European countries, a series of new projects for heavy-ion therapy have been also proposed, such as the Med-AUSTRON in Austria and the ETOILE in Lyon. The Italian CNAO heavy-ion therapy facility in Pavia near to Milan was started in 2005 and is expected to treat patients in 2008.

3 Heavy-ion facility and first clinical trials in China

In China, the cancer therapy researches started in 1995. The first beam line for the heavy-ion cancer therapy was constructed at HIRFL in 2005, which can deliver the beam to the underground of the experimental hall of the HIRFL[5]. A passive beam delivery system has been developed and installed in the therapy terminal at HIRFL (Fig. 6) consisting of a pair of orthogonal dipole magnets (scanning magnets), range shifter, range modulator (ridge/ripple filter), a multi-leaf collimator, and a compensator. Two-dimensional

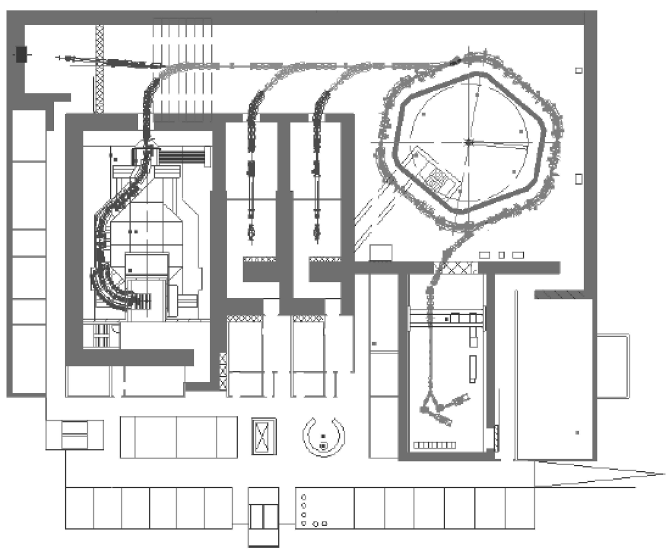

Fig. 5. The construction layout of the HIT facility in Heidelberg.

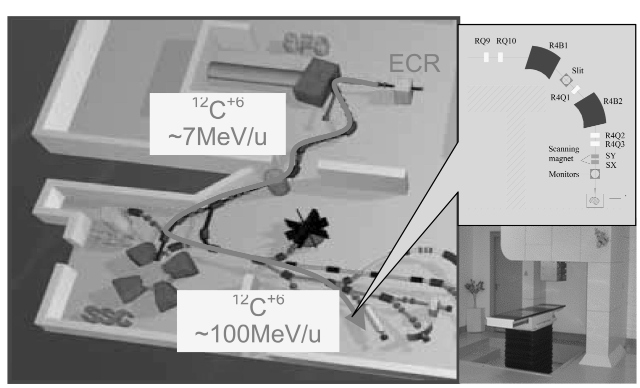

Fig. 6. Vertical treatment terminal at HIRFL.

(2D) and three-dimensional (3D) conformal irradiations can be performed utilizing this passive system[6, 7]. The carbon beams with the maximum energy of ~100 MeV/u were used for the skin tumor therapy. The first clinical trials of superficially-placed tumor therapy were carried out since November 2006[5]. Up to September 2008, totally 82 patients were treated for different kinds of tumors such as squamous cell carcinoma, basal cell carcinoma, malignant skin melanoma, sarcoma, lymphoma, skin breast cancer, metastatic lymph nodes of carcinomas and so on (Table 1). The majority of tumors disappeared completely and the local control rates are more than 90%. No obvious side-effects and no local recurrence have been observed.

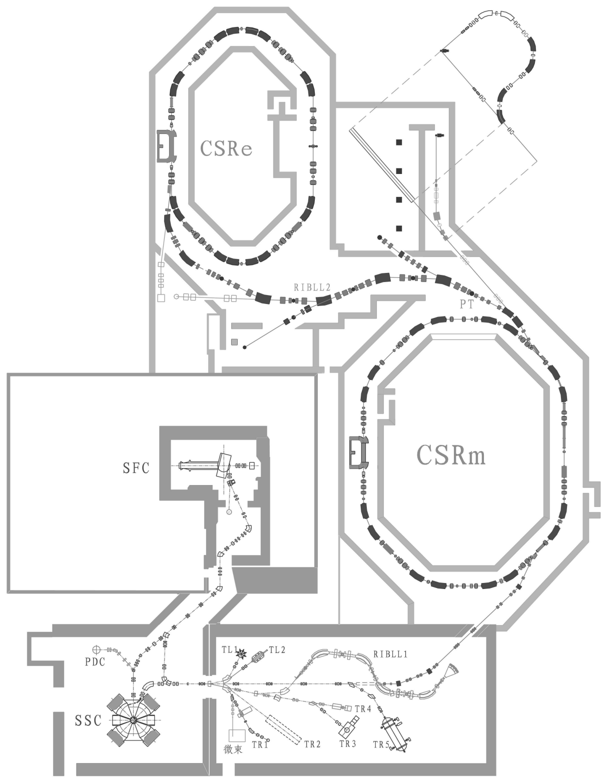

Fig. 7. The layout of cooler storage ring at HIRFL.

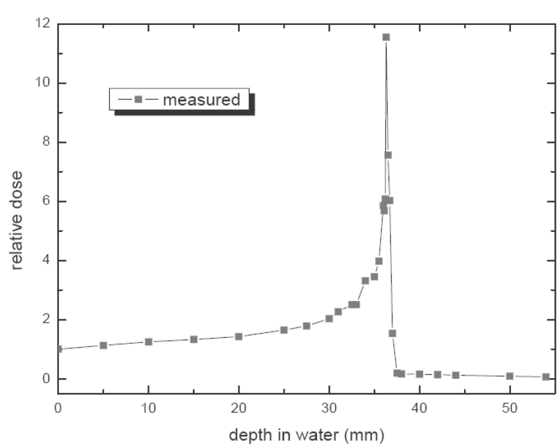

Fig. 8. The depth-dose distribution of carbon ions with energy of 150 MeV/u measured at HIRFL-CSR.

Table 1. 82 clinical trials for carbon therapy at HIRFL.

trial date	patients number	treatment depth
Jan.2007	9	2.1 cm
March 2007	14	2.1 cm
August 2007	9	2.1 cm
Dec. 2007	15	2.1 cm
March 2008	15	2.1 cm
Sept. 2008	16	2.1 cm

In 2000, a new ion cooler-storage-ring system was started at HIRFL[8] (Fig. 7). It consists of a main ring (CSRm) for accumulation and acceleration as well as an experimental ring (CSRe) for high precise measurement. The two existing cyclotrons SFC (K=69) and SSC (K=450) at the HIRFL are used as its combined injector system. In November 2008, the first depth-dose distribution for carbon ions with energy of 150 MeV/u was measured at the treatment terminal for the deep-seated tumor therapy utilizing the beam extracted from the CSRm which can accelerate carbon ions up to 1 GeV/u (Fig. 8).

4 Conclusion

The heavy-ion cancer therapy due to the excellent cure and clinical success is expected to benefit increasing cancer patients. There are more than five heavy-ion facilities used for cancer therapy in hospitals are proposed and are under construction. In future, more such facilities will be started especially in some Asian countries including China.

References

1 Wilson R R. Radiology, 1946, **47**: 487
2 Amaldi U, Kraft G. Europhys News, 2005, **4**: 114
3 Chu W T et al. Rev. Sci. Instrum., 1993, **64**: 2055
4 Kanai T et al. Int. J. Radiat. Oncol. Biol. Phys., 1999, **44**: 201
5 LI Q. Med. Bio. Eng. Comput., 2007, **45**: 1037
6 DAI Z Y et al. HEP & NP, 2006, **30**: 920 (in Chinese)
7 DAI Z Y et al. HEP & NP, 2007, **31**: 831 (in Chinese)
8 XIA J W et al. Nucl. Instrum. Methods A, 2002, **488**: 11