MEDICAL CYCLOTRON AND DEVELOPMENT IN CHINA

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Abstract

The first medical cyclotron CYCIAE-30 in China has been designed and constructed by China Institute of Atomic Energy (CIAE), and its construction was finished in 1995. Since then, medical cyclotron got developed in China, several cyclotrons had been constructed, and some medical experiments and practice had been done with those cyclotrons. Now medical cyclotron develops even quickly in China, several medical cyclotrons are under design and construction. Meantime, a compact cyclotron virtual prototyping was developed to help the cyclotron design and reduce cyclotron R & D cost.

INTRODUCTION

Cyclotron, especially medical cyclotron had a slow development in China in the past few decades, up to now ,there are just a few cyclotrons in China which had be designed and constructed by Chinese accelerator groups themselves, the main medical cyclotrons or cyclotrons on which medical research or practice be done are the CYCIAE-30 and the HIFRL, CYCIAE-30 is a high intensity medical cyclotron which affiliate to China Institute of Atomic Energy (CIAE), The HIFRL is the two-cyclotron complex at Institute of Modern Physics, Chinese Academy of Science (IMP). Recent years medical cyclotron has a quick development, a 10MeV high intensity cyclotron synthesis experimental platform be constructed in CIAE in 2009, several medical cyclotrons are been under designing or construction. Also the technology of cyclotron had gotten development in China especially the Virtual Prototyping was adopted and developed at Huazhong University of Science and technology [1].

MEDICAL CYCLOTRONS AT CHINA INSTITUTE OF ATOMIC ENERGY

There are two cyclotrons at CIAE, one is the CYCIAE-30 (fig.1) which was designed and constructed by Chinese and has been operated since 1995, and it is the first high intensity medical cyclotrons used for accelerated mass production of isotope. Fig 2 shows the total yearly beam times at the first several years.

The other one is a compact cyclotron [2] (fig.3), it is the main part of a high intensity cyclotron experimental platform (CYCIAE-CRM), and it is also the first compact cyclotron which China has Independent Intellectual Property Rights. The main beam parameters of the machine are show in table 1:

Figure 1: CYCIAE-30

Table 1: main parameters of CYCIAE-CRM

Parameters	Value
Accelerated particle	H^-
Extraction energy	10Mev
Internal beam intensity	430μA
Accelerate efficiency	94.5%
Extraction efficiency	99.87%

The success of this machine is a significant affair, it can be used for the developing of PET-cyclotrons which be used for diagnose of cancer and other diseases, this region in China was monopolized by foreign companies in the past.

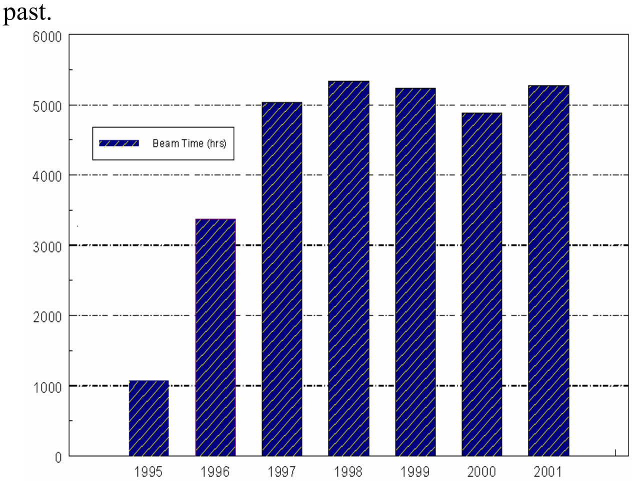

Figure 2: beam time of CYCIAE-30

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Figure 3: CYCIAE-CRM cyclotron

Now a PET cyclotron prototyping CYCIAE-14 (fig.4) is under construction at CIAE [3], it will be finished in the next 2 years, it can product not only the normal PET particles 11C, 15O, 13N, 18F but also the isotopes 64Cu, 124I, 99mTc. The main parameters of the machine are show in table 2.

Table 2: Parameters of CYCIAE-14

Parameter	value
Particle accelerated	H-
Final energy	14.6MeV
Bmin/Bmax	2.0kGs/18.5kGs
Radius of sector magnet	500mm
Sector angle	52o
Hill gap	23-26mm
Valley gap	318mm
Outer radius of magnet	880mm
Height of Magnet	1066mm
Dee Voltage	50kV
RF frequency	73.02MHz
Harmonic mode	4
Extracted particle	Proton

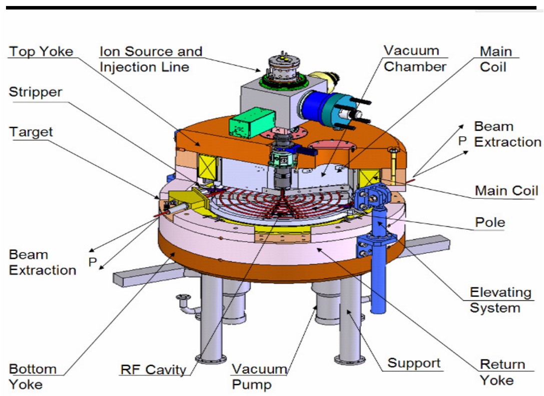

Figure 4: The sketch of CYCIAE-14

MEDICAL RESEARCH AND PRACTICE ON THE CYCLOTRONS AT IMP

Comparison to CIAE cyclotron technology development, IMP did a lot of works on biomedical research and practice using the cyclotron system - HIRFL (fig.5), HIRFL consists of two ECR ion source (one is a normal ECR source, and the other is a superconductive ECR source), two cyclotrons (The injector is a sector focus cyclotron, it is an upgrade of a classical cyclotron, the energy constant is K=69. The main accelerator is a separate sector cyclotron which energy constant is K=450.) , and several beam transport lines.

The biomedical research begun in middle of the 1990's at IMP, the aim is focus on:

(1) Understanding the biological effects induced by heavy ions.

(2) The mechanisms of the action between heavy ions and biological material.

(3) The application of heavy-ion irradiation in medicine and biology.

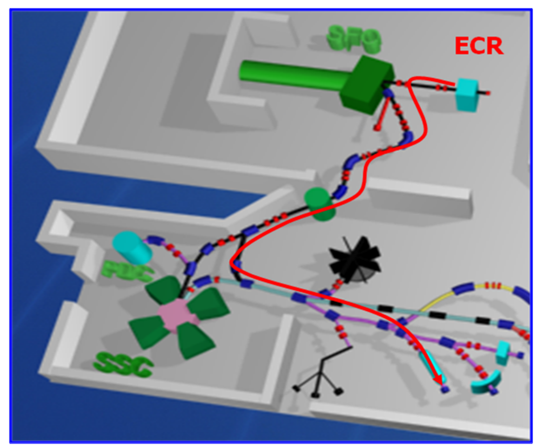

Figure 5: Layout of HIRFL

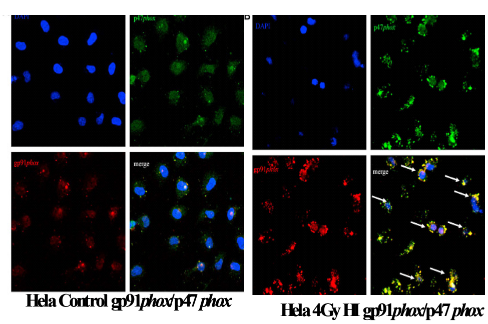

Figure 6: The effect of NADPH oxidise-mediated generation of reactive oxygen species on cancer cell DNA injure induced by heavy-ions

Basic Researches on Biomedical Related to Heavy Ion Irradiation

Biomedical group at IMP have been doing a series researches to understand the biological effects induced by heavy ions and the mechanisms of the action between heavy ions and biological material, fig.6 to fig.10 show some results of those researches and the results.

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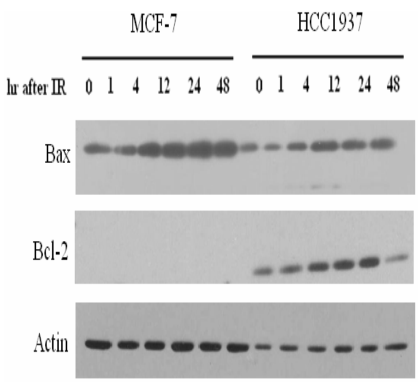

Figure 7: BRCA1 answers for the cancer cell death induced by heavy-ion irradiation by adjusting Bcl-2 protein

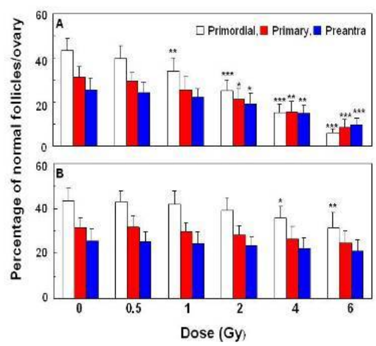

Figure 8: Affections of heavy-ion irradiations on procreating cells and genetics

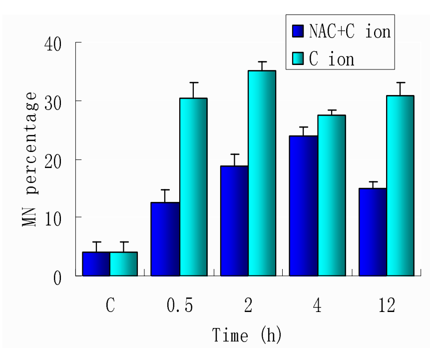

Figure 9: affections of heavy-ion irradiations on the immunity system of mice

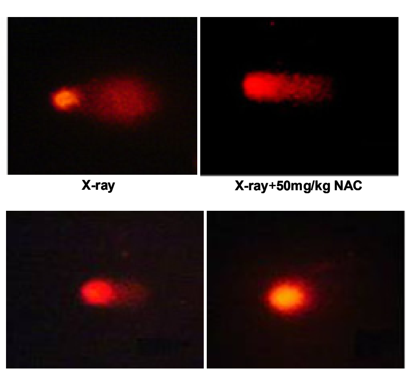

Figure 10: conservation of antioxidant of injure induced by heavy ions

Fig.6 and fig.7 show the cell injure induced by heavy-ions and their corresponding mechanisms. Fig.8 shows the affections of heavy-ion irradiations on procreating cells and genetics. Fig.9 and fig.10 show the affections of heavy-ion irradiations on the immunity system of mice, conservation of antioxidant of injure induced by heavy ions.

Basic Researches on Heavy-Ion Tumour Therapy

Some techniques had been adopted by IMP medical group about heavy-ion tumour therapy researches, such as siRNA and the protein group method, fig.11 to fig.15 show the techniques and the results.

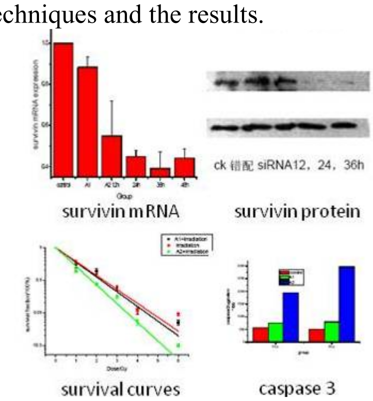

Figure 11: siRNA restraints the answer of surviving protein

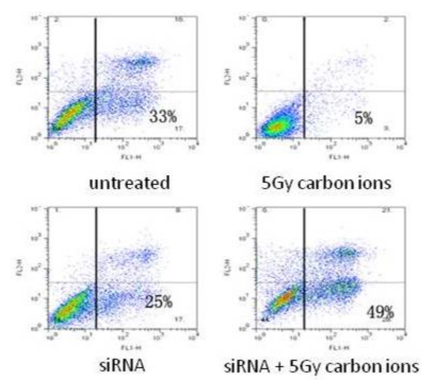

Figure 12: siRNA increase sensitivity of tumor cell to heavy-ion irradiaton

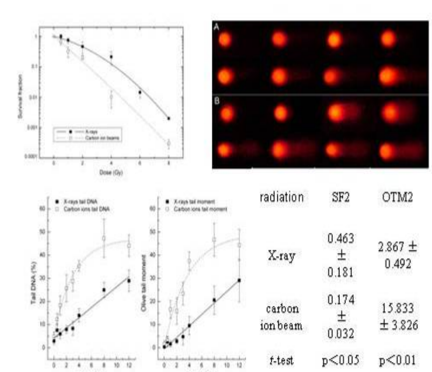

Figure 13: The affection of heavy ion irradiation in mammal cell DNA injure

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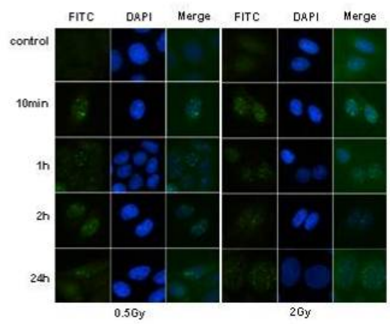

Figure 14: The affection of heavy ion irradiation in mammal cell DNA repair

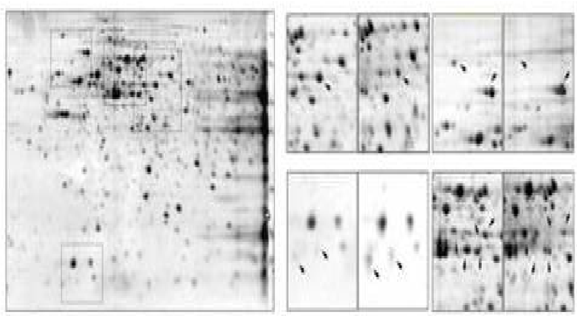

Figure 15: The protein group method in ion irradiation cancer biomedical

Practice of Tumour Therapy at IMP

Up to now, there are 103 patients who has a superficial tumour had been treated at IMP. Fig.16 and fig 17 show some results of the therapy.

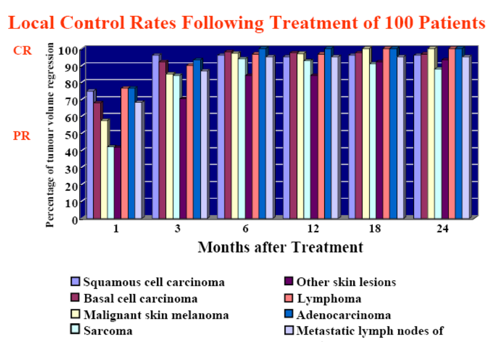

Figure 16: Local control rate

Figure 17: Some typical patient

In these figures the horizontal coordinate is the month after therapy, the bars are squamous cell carcinoma of skin, Basal cell carcinoma of skin, malignant skin melanoma, Sarcoma, Other skin lesions, Lymphoma, Breast cancer and Metastasis lymph nodes of carcinomas

MEDICAL CYCLOTRONS UNDER CONSTRUCTION AT IMP

Now IMP is designing a cancer therapy machine, it consists a injector cyclotron and a main accelerator synchrotron, the sketch (fig.18) and some parameters (table.3) of the injector cyclotron are show below.

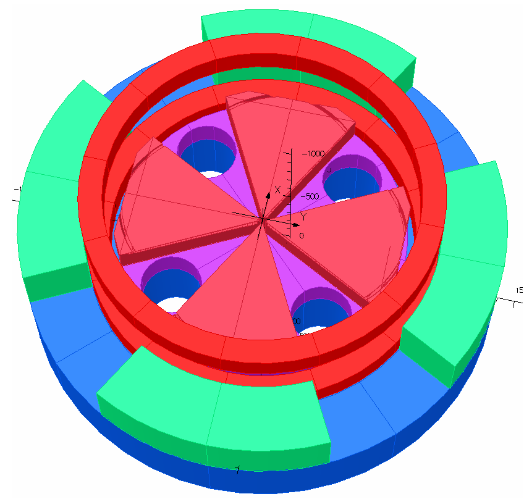

Fig.18: Sketch of the injector cyclotron

Table.2: parameters of the injector cyclotron

Accelerated Ion Species	$^{12}C^{6+}$
Extraction Energy	7Mev/u
Ex-Beam Intensity (C)	10euA
Energy Spread	±1%
Emittance	20-25 π mm.mrad
Frequency	31.02MHz
Accelerating Voltage	70KV
Degree of Dees	30°
Dee Number	2
Stability of Phase	±1°
Stability of Voltage	$\pm 5\times10^{-4}$/24hour
Stability of Frequency	$\pm 1\times10^{-6}$/24hour
Power Source Number	2
Power	50KW

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PROGRESS IN VIRTUAL PROTOTYPING FOR DESIGN OF COMPACT CYCLOTRON

Virtual Prototyping (VP) has been developed since 1990s with the strong demand for products to short R&D period and to reduce cost, the virtual prototyping technology had be adopted and made progress at Huazhong University in China.

CVPP is the development of VP, the primary goal is to provide an integrate environment for multi-domain design or analysis components covering beam dynamics, the cyclotron magnet, the RF cavity etc. In CVPP, the design, theoretical analysis, manufacture, assemble, operation and maintenance could be studied and adjusted by an interactive way, thus the complete machine can be optimized from a top view.

Under the integrate design environment CVPP, a compact cyclotron had been studied at Huazhong University. The pictures from fig.19 to fig.22 are the virtual prototype model and main parts of the 10 MeV internal ion source cyclotron - CYCHU-10.

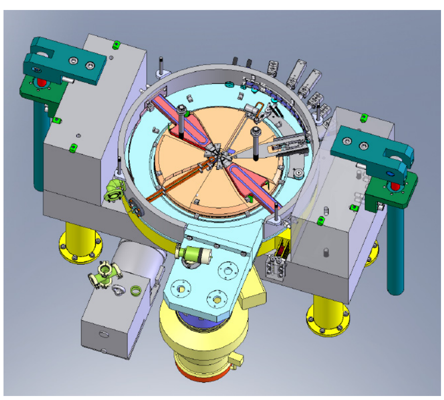

Figure 19: The virtual prototype model of CYCHU-10

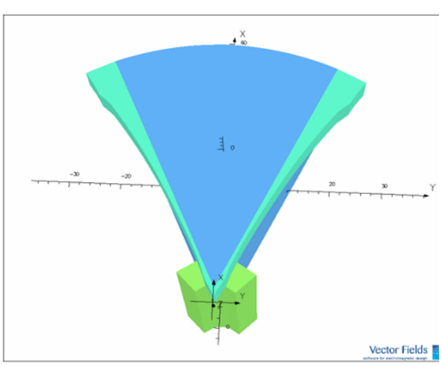

Figure 20: Optimized one sector magnet pole model

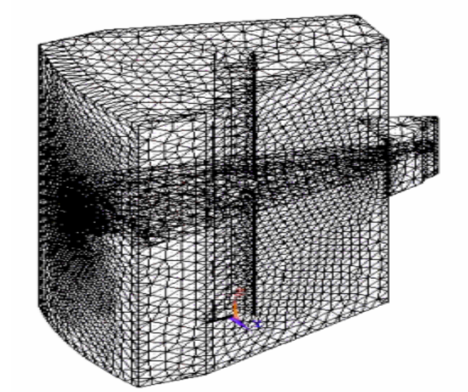

Figure 21: The FEM model of a 65MHz cavity

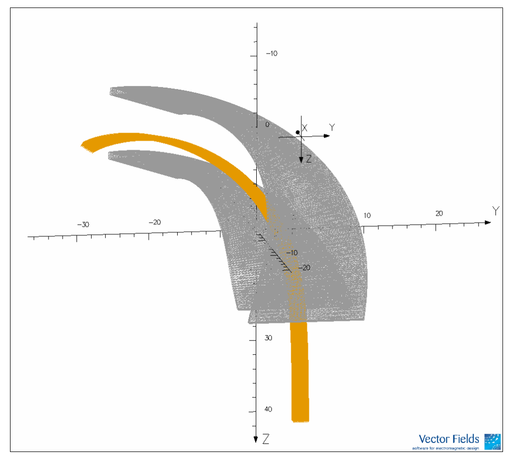

Figure 22: The spiral inflector FEM model and beam trajectories

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