# NIRS HEAVY PARTICLE ACCELERATOR FOR MEDICAL USE

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## ABSTRACT

This report is mainly concerned with the present situation and future schedule of the construction of a dedicated heavy particle accelerator for medical use at the NIRS. The design of this machine will be speciffically optimized to meet the accelerator requirements which are determined from the experience of the particle radiotherapy at the NIRS and from the various physical, biological and clinical heavy particle data of the LBL. The conceptual design of this machine has just started from this year. The fundamental and detailed design will be carried out during the next two fiscal years. The whole accelerator facilities will be completed in 1991 and the clinical trials using heavy particles will start in 1992.

## INTRODUCTION

As a link in the chain of a national project for cancer extermination, the NIRS (National Institute of Radiological Sciences) has a plan to construct a dedicated heavy particle accelerator for medical use, which will contribute to the improvement of cancer treatment. The NIRS Hospital has used high energy radiation, such as photons and electrons, for cancer treatment during more than 20 years. Further, several clinical trials using particle beams, such as fast neutrons and protons, have been also performed at the NIRS during more than 15 years.

The first stage of fast neutron radiotherapy was carried out from May 1967 to Sptember 1975 using a Van de Graaff. Number of treated patient were 36 during this period. Most of cases were far advanced and thought hardly curable by conventional treatment, and 23 patients were malignant melanoma. The results indicated a marked improvement in local control especially for the primary cases.

The second stage of fast neutron radiotherapy has been carried out genuinely since November 1975 using a medical cyclotron which is able to provide a vertical neutron beam for therapy. More than 1200 patients were treated with this neutron radiotherapy system. The results demonstrate that the fast neutron beam could be effectively applied to improve the cure rate for the tumors of selected organs, such as carcinoma of the larynx and the esophagus, Pancost's tumor of the lung and osteosarcoma.

The clinical trial of proton radiotherapy has been done 27 patients since October 1979. This number of patient is rather small because of a limited machine time available, that is a half day per week, and a limited range of 70 MeV protons which can only be applied to the superficial region within 4 cm depth in tissue. However, the results have been showing good local control and cure rate with making good use of the characteristics of definite range of protons.

From these results, it has been found that the use of these particles are highly expected as the effective modalities for cancer treatment.

On the other hands, the heavy particles possess the exquisite dose localization properties of protons and the biological high-LET properties of neutrons. From the above mentioned our experiences, such heavy particles are considered as next trump card in the future radiation therapy. Therefore, we proposed a special research program on the medical use of the heavy particle beams, which includes the construction of a heavy particle accelerator for medical use at the NIRS. A main purpose of this accelerator involves the evaluation of heavy particle beams in the treatment of cancer in humans, and the basic and clinical research, such as physics and biology in medicine. Preliminary research works performed at the LBL (Lawrence Berkeley Laboratory in California) using 185-inch synchrocyclotron and BEVALAC which is a unique combination of two accelerators, the Bevatron and the HILAC. The present data have indicated that the heavy particle beams offer several advantage over conventional photon beams in cancer treatment, or they are at least as long as with the best of other available methods.

## ACCELERATOR REQUIREMENTS

The accelerator requirements of the NIRS machine have been arranged by the planning group of heavy particle accelerator for medical use, based on the ideas of the user's working group. The construction committee of heavy particle accelerator for medical use approved the draft almost in its original form. Further, the draft of the requirements was reported to the research committee of particle radiation therapy which involved the outside specialists and finaly determined by the congress of the NIRS.

The outline of these requirements are listed in the followings.

I. Requirements for particles extracted from main accelerator

1. Particle species:

From He to Si and Ar (He, C, O, Ne, Si and Ar are involved at least).

2. Accelerating energy:

The kinetic energy is continuously variable in the ranges from 100 MeV/amu to 600 MeV/amu for all above mentioned particles in principle. At least, the energy is variable as stepwisely as the steps of 100 MeV/amu within the above energy range. The maximum kinetic energy of 600 MeV/amu was determined from the range-energy relationship of Fig.1 so as to secure the range of 20 cm in soft tissue for silicon.

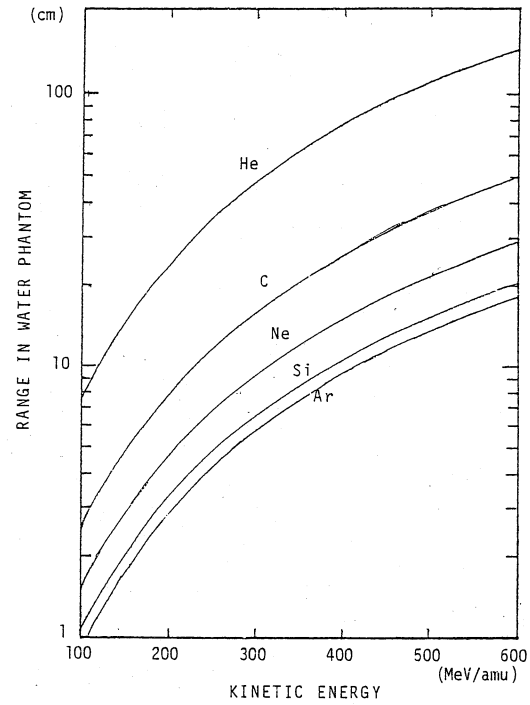


Fig.1 Range in water phantom for heavy particles of interest as a function of their kinetic energy.

3. Beam intensity (particle flux density):
Low intensity for counting experiments (especially for diagnostic purpose) is less than $10^6$ particles/sec (for all particles).
High intensty for therapy is as follows.

| particle | particles/sec |
|---|---|
| He | $2.2 \times 10^{10}$ |
| C | $3.7 \times 10^{9}$ |
| Ne | $1.6 \times 10^{9}$ |
| Si | $8.4 \times 10^{8}$ |
| Ar | $5.0 \times 10^{8}$ |

These beam intensities were determined from considerations of treatment volume and dose rate, which are the dose rate of 500 rad/min and the treatment volume for 10 cm square field and 20 cm depth except silicon and argon. Further the beam losses in the scatterers and in the beam transport system from beam extraction site to treatment site are considered factors of 10 in the above intensities.

4. Momentum spread and emittance:
Momentum spread $\Delta p/p$ : $2 \times 10^{-3}$
Emittance : $2 \times 10^{-5}$ m radians
The above values indicate the guide lines. They are not essential. The values should be within the range in which beams can be used for beam transport and patient treatment with no trouble.

II. Beam requirements at therapeutic site
1. Maximum field size and uniformity:
Maximum field size : 30 x 30 cm
Dose uniformity : $< \pm 2$ %
In order to spread the beam as required field size double scatterer method is certainly available. Either magnetically deforcusing system or spot beam scanning system is also available. Pencil beam irradiation within 5 mm diameter is also provided.

2. Beam waveform:
Beam with long pulse and flat top intensity ($\geq$ 100 ms/pulse) is extracted. Beam duty factor is more than 25 % at the repetition rates of less than 2 Hz.
Short pulse extraction is possible at the repetition rates of 2 Hz, for the special experiments with high dose rate.
The synclotron has two beam extraction channels of fast and slow extractions. Both beams are delivered to each irradiation room with same beam line.

3. Use of radioactive beam:
Radioactive beams which are positron emitter are available for diagnosis and/or traetment planning.

III. Irradiation facilities
1. Irradiation room and beam port:
Treatment room: 4 rooms (A, B, C and D). Each room A and B has two (horizontal and vertical) beam lines. Each room C and D has only a holizontal beam line
Biology cave : one room (has a horizontal beam)
Physics cave : one room (has a horizontal beam)
General use cave : one room (has three or more horizontal beam lines)
Radioactive beam cave : one room (has a horizontal beam)
Radiographic cave : one room (has a horizontal beam line)

2. Control system
Operation of accelerator itself, and operation of therapy and diagnosis facilities should be separated. The control system should be fully automated from the start to the end of operation, so as to operate with as few people as possible.
The system should provide self-diagnosing features to quickly repaire the failing components.
In order to increase the operating efficiency, ion sources should be attached. They can be quickly switched one by one. Accelerating energy in the same ion source should be possible to change easily in short time.

## PROPOSED SCHEDULE

In 1984 (Japanese fiscal year), the conceptual design and developing study of the NIRS heavy particle accelerator for medical use were accepted by Japanese government. They have been ordered to four Japanese major companies which have a volition to join the construction and have potentials enough to make the accelerator design. The reports will be submitted to the NIRS by the end of February 1985.

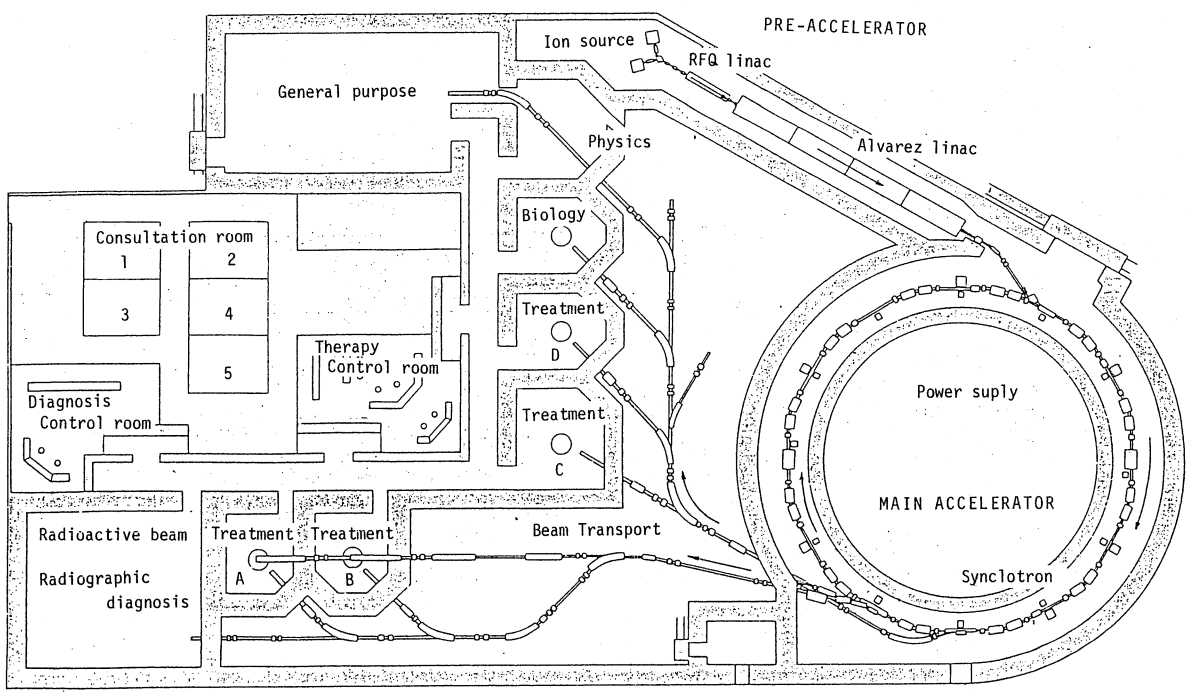


Fig.2 Plan view of a conceptual facility layout.

Before the order of the conceptual design of this machine, the NIRS set up the adviser committee for examination of the accelerator design and study. It is organized by several staff of the NIRS and the experts of accelerator physics, medical physics and radiotherapy of other institutes. The committee will give the careful consideration and suport to promote this project in future.

To realize this long-term project within the 10 years all-around strategy for cancer extermination, the following time schedule has been proposed.

I. Design of technical components and buildings (1984 - 1986)
   1. Conceptual design 1984
   2. Fundamental design 1985
   3. Detailed design 1986

II. Construction of technical components (1987 - 1991)
   1. Pre-accelerator and main accelerator
      Manufacture 1987 - 1989
      Installation 1990
   2. Beam transport and irradiation facilities
      Manufacture 1988 - 1990
      Installation 1990 - 1991

III. Construction of Buildings (1987 - 1990)
   1. Building structure 1987 - 1990
   2. Conventional components 1987 - 1989

IV. Commissioning (1991 - 1992)

V. Research and Clincal trials with new machine (1991 - )
   1. Dosimetry 1991 -
   2. Biological test 1991 -
   3. Clinical trials 1992 -

Some special terminology in the above schedule are defined as follows:

1. Technical components: Accelerator and beam delivery.
2. Building structure: Standard elements of the building.
3. Conventional components: Building components directly related to the accelerator only, e.g., shielding (except stractural walls), cooling tower special power requirements, cranes.
4. Commissioning: Bringing the installed components into a full and reliable operating status; operator training.

From our preliminary investigation on the NIRS heavy particle accelerator for medical use, one of the typical plan view of a conceptual facility layout which will be satisfy the accelerator requirements, is shown in Fig.2. The principal elements of this machine are: a strong focusing synchrotron as a main acclerator; a pre-accelerator, consisting of a Penning ion source, an RFQ and Alvarez linacs; a beam delivery system; and a comprehensive control system. The specification of these elements will be put into concrete shape in the stage of design studies.

This accelerator facility is unique and expensive resource. Therefore, we are fully expecting that the new facilities will also be focus to a variety of external users who will conduct their own experimental research or collaboration on our programs with our staff.