

## THE EULIMA PROJECT

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### Abstract

At the European Organization for Research and Treatment of Cancer (EORTC) - meeting held in Nice, on October 18-19, 1985 the idea of a EUropean high energy LIght Ion Medical Accelerator (EULIMA) has been proposed. On March 14, 1986 a group of potential medical users, radiobiologists, physicists and accelerator engineers from different European countries have met at CERN to define the goals of the project and to examine the possibility to carryout a feasibility study. A request for funding for such a study has been introduced to the European Economic Community.

This paper summarizes the preliminary ideas underlying the project.

### 1. Introduction

The key concept of EULIMA consists in adding a booster accelerator to an operational medical facility :

- the first stage is an existing compact cyclotron used for neutron-and protontherapy (like MEDICYC [1] or CYCLONE [2]) equipped with an external injection system and a source of completely stripped light heavy ions like OCTOPUS e.g.
- the second stage accelerates the particles from the cyclotron (with energies in the range 15 to 25 MeV/nucleon) to a final energy of several hundred MeV/nucleon

Preliminary studies being carried out, show that a cyclotron consisting of 4 separated sectors and a single circular superconducting coil could reach a maximum energy of about 450 MeV/nucleon.

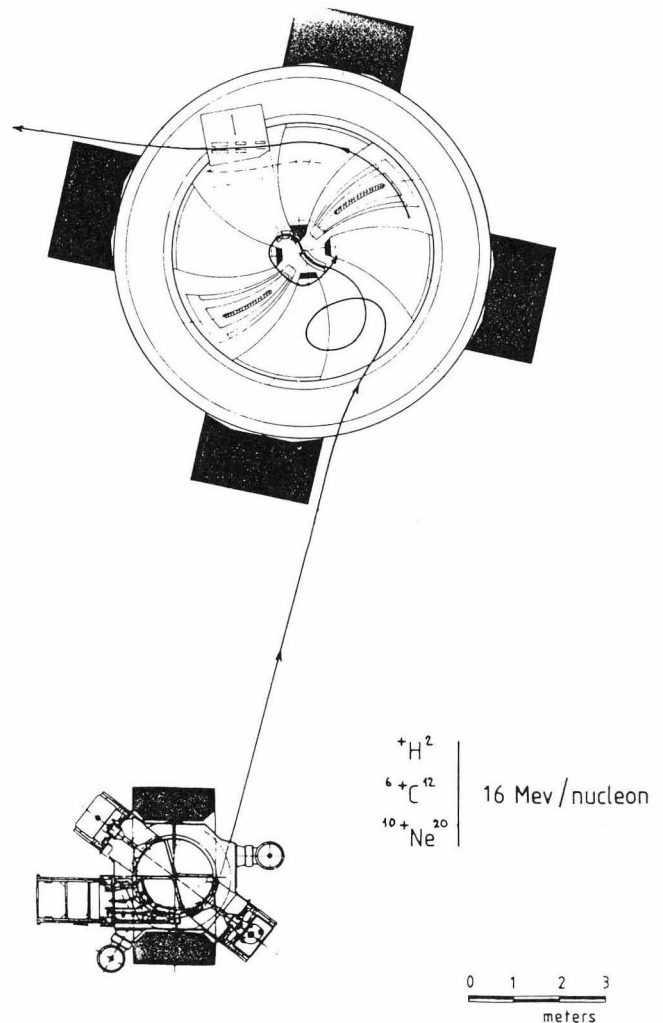


Figure 1  
 The EULIMA cyclotrons.

## 2. Biomedical characteristics

High energy charged particles present a double advantage for therapeutic purposes over the more classical radiations : from the ballistic point of view, the delivered dose can be concentrated accurately in the tumour volume (Bragg's peak) and from the biological point of view, they present the advantages of high LET particles (like the neutrons), compared to the conventional low LET radiations.

These advantages have been recognized earlier and a series of biomedical experiments have been carried out at the BEVALAC [3] in Berkeley. Biomedical accelerators are now proposed by e.g. the National Institute of Radiological Sciences (NIRS) at Shiba, Japan and by the Lawrence Berkeley Laboratory (LBL) in the U.S.A. [4].

The energy of 450 MeV/nucleon for EULIMA yields penetration depths in tissue of resp. 32 cm for Carbon, 27 cm for Oxygen and 20 cm for Neon.

## 3. The injector cyclotron

This cyclotron can be operated in two modes :

- acceleration of protons to 65 MeV e.g. on the fundamental mode to provide beams for neutrontherapy and low energy proton therapy ;
- acceleration of ions with a charge to mass ratio close or equal to 1/2 on the second harmonic mode using an external Electron Cyclotron Resonance (ECR) ion source.

To achieve treatment times of a few minutes, intensities in the order of  $10^7 \rightarrow 10^9$  ions per second are required. Assuming an overall efficiency of 15 percent between injection into and extraction from the booster cyclotron, these intensities can be easily obtained for ions up to Neon by e.g. the CYCLONE-OCTOPUS [5] combination.

## 4. The superconducting cyclotron

A four Separated Sector Cyclotron (SSC) with a single circular superconducting coil, operating at fixed field and fixed frequency has been chosen. The solution reduces both construction and operating cost.

However, the particularity of such a machine compared to a room temperature classical SSC is that the conditions of beam injection are much more strained due to the presence of a non negligible field between the sectors.

With an average field of about 2 Tesla (1 Tesla uniformly given by the coil and 2 Tesla added by the iron in the sectors), the required extraction radius is about 3 meters.

Table 1 gives some preliminary parameters of the booster cyclotron.

### 4.1. The magnetic field.

To examine the general conditions of beam acceleration to 450 MeV per nucleon, a magnetic field has been synthesized with the following assumptions :

- the axial symmetric field of the superconducting coil which produces the required gradient for isochronous acceleration was calculated with the programme POISSON. This

field saturates the iron of the sectors which produce the azimuthally varying component of the field.

- the field due to the iron in the  $(r,\theta)$ -plane was approximated by a single analytical formula which derives from the fact that in saturated sectors only the surface magnetic charges are present. The field form factor  $f(\theta)$  in the vicinity of the sector edges is presented by the formula :

$$f(\theta) = \frac{\cos N(\theta - \alpha)}{\sqrt{1 - k^2 \sin^2 N(\theta - \alpha)}}$$

where N = number of sectors = 4

$\alpha$  =  $\alpha'R$  = spiral angle

k = a suitably chosen factor which takes care of the sector gap.

For vertical stability a constant spiral angle of 25°/metre has been chosen.

An example of a synthetic field is presented in figure 2.

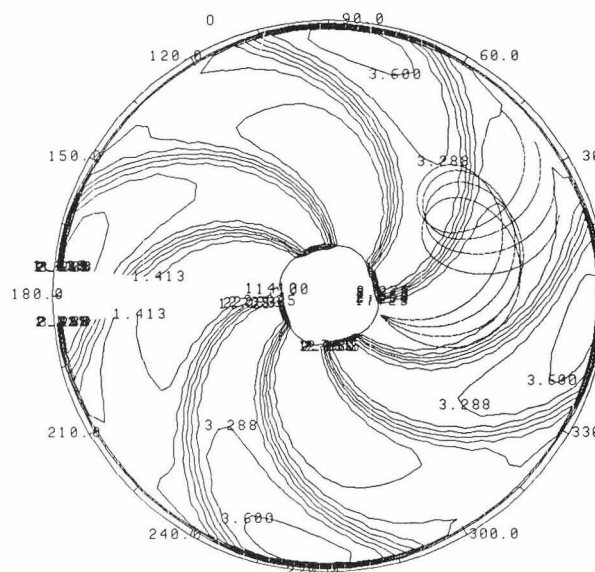


Figure 2

Theoretical magnetic field and injection trajectories.

Maximum energy ( $Z/A = 1/2$ )	450 MeV/nucleon
<b>MAGNET</b>	
Average field at extraction	2.4 Tesla
Number of sectors	4 x 40°
Magnet gap	60 mm
Estimated magnet weight	4 x 400 tons
Main coil inner radius	3.00 m
Main coil outer radius	3.40 m
Spiral angle	25°/m

<b>ACCELERATING CAVITIES</b>	
RF frequency injector	25 MHz
RF frequency booster	125 MHz
Number of cavities	2
Peak energy gain/turn at extraction	800 kV

Table 1 : Parameters of the booster cyclotron for EULIMA.

4.2. Preliminary considerations on beam dynamics.

Using the synthetic field two main questions have been investigated so far :

1. Injection.

The possibility of injecting the ions through the valley at an energy of about 17.5 MeV/nucleon has been looked into using a programme integrating the equations of motion in the horizontal plane. Because of the relatively high field in the valley an injection trajectory forming one loop has been chosen. Different trajectories are shown on figure 2.

2. Equilibrium orbits and stability.

Equilibrium orbits were calculated using the EXODOS programme. Once an equilibrium orbit has been found, the radial and axial betatron frequencies  $\nu_R$  and  $\nu_Z$  are calculated. The result for the selected geometry is shown in figure 3.

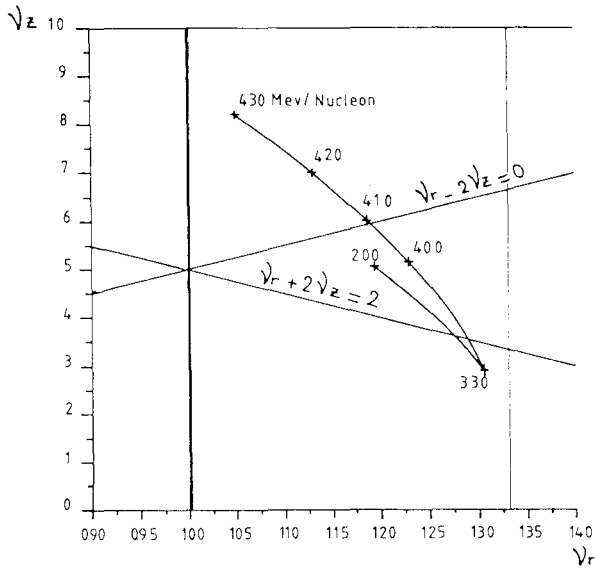


Figure 3

$\nu_R, \nu_Z$  diagram of the EULIMA postaccelerator.

3. Extraction.

To conserve entirely the advantage of the sharp Bragg peak, energy variation can be obtained by moving the extraction system inward. However, this solution has still to be examined in detail.

4.3. The R.F. system.

The R.F. accelerating cavities are located in two opposite valleys. Accelerator matching requirements taking into account the average field of the 2nd machine indicate an harmonic number of 8 as the best compromise, which leads to an operating frequency of 125 MHz.

Taking as reference a 10 mm beam clearance at injection, a phase compression factor of 2 with a phase width of 10° at extraction, then  $V_{inj} = 376$  kV and  $V_{ext} = 2 \times V_{inj}$ . A detailed study of the injection process will indicate the minimum allowed beam clearance and, therefore, the R.F. voltages.

In any case, high Q cavities with very high circulating power will be necessary.

Presently, the most economical ones seem to be 15° H101 cavity sectors, loaded with drift plates to reduce the transit time losses down to about 5 percent. Such a cavity is presented schematically in figure 4.a. With this type of cavities, the losses will be  $P = 2500/2000 \times (V_{ext}/100 \text{ kV})^2$  Watt per cavity, the uncertainty depending on how many conflicting

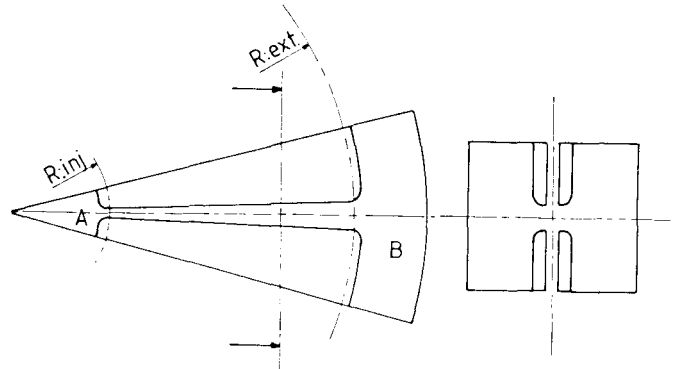


Figure 4.a  
H101 accelerating cavity.

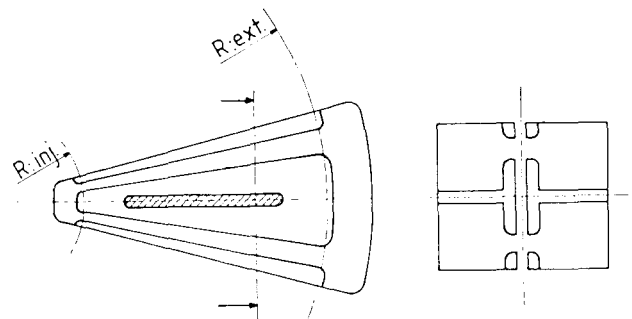
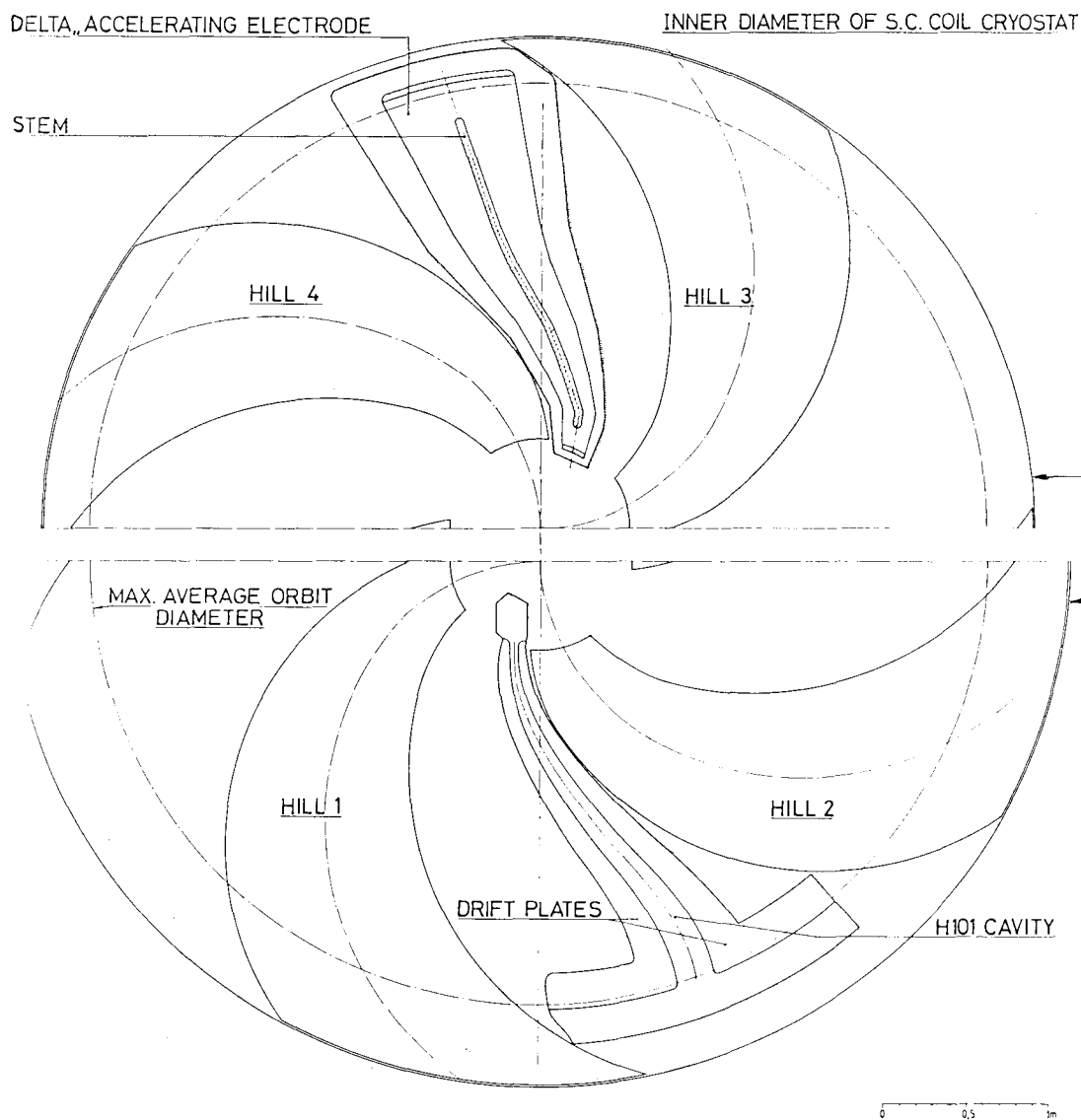


Figure 4.b  
Delta-accelerating cavity.

requirements between the boundary space of such cavities and the other machine items can be solved. One other solution, which calls for more classical deltas is shown in fig. 4.b, which has the advantage of not requiring additional volume, since the flux return occurs around the supporting stems. The current path, however, is increased which causes the losses to be quoted :  $P = 4000/3500 \times (V_{ext}/100 \text{ kV})^2$  Watt per cavity where  $V_{ext}$  is again the total energy-gain when the beam crosses the cavity. Figure 5 shows how the two solutions can be implemented in the machine and it shows in particular that the sector cavity requires more space radially. Extensive wood modelling and measurements will be necessary as long as the mechanical studies are progressing.

Preliminary tests and verification of numerical calculation have been carried out on such a model.



**Figure 5**  
Implementation of H101, resp Delta cavity in the EULIMA postaccelerator.

Conclusion

The solution for EULIMA presented in this paper is a first approach which shows that a 450 MeV/nucleon post accelerator is probably feasible. Its main advantages are compactness and integrability in an existing neutron-and protontherapy facility. Nevertheless, many aspects of the design have to be studied in detail and this solution has to be compared to the solution using a synchrotron in combination with an injector cyclotron.

References

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