ACCELERATOR PHYSICS ACTIVITIES IN BULGARIA
- past, current state and future

Ass. Prof. Dr. Dinko Dinev

1. PARTICLE ACCELERATORS IN BULGARIA

In Bulgaria there are only small accelerators for industrial and medical applications.

- **Direct Voltage Electron Accelerators**

  i. Aurora – 4 in the Chemical University in Bourgas.
  Aurora – 4, Fig.1, is a direct voltage electron accelerator produced by Efremov Institute in St. Petersburg, Russia. It produces electron beams with 750 KeV energy and 45 KW beam power. The high-voltage generator is a three-phase cascade generator (Cockroft – Walton generator with voltage multiplication) with inductively connected stages. The generator has more than 90% efficiency. Aurora accelerator is used for radiation modification of rubber, cable insulation treatment etc.

  ii. ELV – 1 in Hrabarsko, near Sofia.
  ELV – 1, Fig. 2, is a direct voltage electron accelerator produced by Budker Institute of Nuclear Physics in Novosibirsk, Russia. This is a DC machine with energy of electrons in the range 0.4 – 1.0 MeV and maximum beam power 20 KW. The high voltage generator is a coreless step-up transformer. The secondary winding is sectionized and the AC voltage of each section is rectified by a voltage – doubling circuit. The accelerating tube is integrated with the column of rectifying sections. All these are placed into a tank filled with pressurized sulfur hexafluoride. The electron beam can be extracted into the atmosphere through a foil with linear scanning of the beam over the extraction window. An alternative feature is extraction of a concentrated beam through a system of diafragms. The accelerator is used for radiation treatment of glass articles.

- **Linear Electron Accelerators**

  i. 4 MeV electron linac for radiography of bulk metal constructions, up to 270 mm. in Heavy Machinery, Radomir.

  ii. 9 MeV electron linac NEPTUN 10p for cancer therapy in Medical University, Pleven, Fig. 3. This kind of accelerators is produced by the Institute of Nuclear Studies, Eexperimental Establishment for Nuclear Equipment in Swerk, Poland. The linac generates high – energy X-rays on tungsten target for radiography of cancer tumours. It uses a standing – wave accelerating structure working at 3,000 MHz. The microwave generator is a 2 MW pulse magnetron. The dose rate is e Gy/min.

- **Microtron MT –16**
  The microtron is made by Flerov Laboratory of JINR, Dubna and is situated in the Plovdiv University. It accelerates electrons up to 16 MeV and can generate

Fig.2. Electron Accelerator ELV – 1   for radiation treatment

Fig.3. Linear Medical Accelerator

10^{14} γ - quanta per second on a beryllium target. It will be used for study of photonuclear reactions and for activation analysis.

- **Fast Neutron Generators**

  i. SAMES in INRNE

  ii. NG – 12 in INRNE.
  NG – 12 is fast neutron generator produced by Efremov Institute in St. Petersburg, Russia. This is a 150 KeV direct voltage accelerator with duoplasmatron as an ion source, which deliver 20 mA deuteron current. It generates 10^{12} neutrons/sec on a 90 mm in diameter tritium target.

2. PARTICLE ACCELERATORS GROUP OF INRNE

In 1978 a group of specialists working on the problems of accelerator physics and technics was organized in INRNE of BAS.

The founder of the group was Ass. Prof. Dr. Ivan Enchevich. He has specialized for many years in JINR, Dubna, working on cyclotrons problems and also for two years in CERN in early seventies.

At that time a project for building a cyclotron center in BAS was approved by the government. The main machine had to be a 2.5 m heavy ion cyclotron, the so-called U – 250. this was a 4 sectors AVF cyclotron with energy parameter K = 200 MeV. The cyclotron had to be built by the Efremov Institute in St. Petersburg. Unfortunately the deep economical crisis and the sweeping political changes in the country that have started since 1990 or even earlier have as a result the suspending of this project.

Few words about the staff of PAG.

1. **Ass. Prof. Dr. Dinko Dinev –** now a group leader; specialized in IHEP in Protvino, Russia, JINR, Dubna, Russia and FZ in Julich, Germany.
2. **Ass. Prof. Dr. Angel Angelov** – specialized in JINR, Dubna, Russia, Nica, France, Sardinia, Italy and CERN. In CERN he has worked on the LHC superconducting cavity.
3. **V**. **Anguelov-** specialized in CERN, working on the SPS – LHC transfer line.
4. **Ass**. **Prof. Dr. Stephan Tzenov** – specialized in JINR, Dubna, Russia, FNAL, SLAC. Now he is Ass. Prof. In PPL, Prinston.
5. **Dr**. **Dobrin Kaltchev** – specialized in JINR, Dubna, Russia. Now he is in TRIUMF, Vancouver, but works on LHC on the problems of halo formation and collimators.
6. **Dr**. **Emil Ivanov** – specialized in JINR, Dubna, Russia. Now is in the private business.
7. **Georgi Radonov** – specialized in JINR, Dubna, Russia. Now is in the private business.

2. PARTICLE ACCELERATORS GROUP ACTIVITIES

A. U – 250 Cyclotron (1978 – 1988)

- Designing of the beam transport system of the cyclotron center.
- Designing of a system for beam monochromatization by means of additional 3rd order harmonic cavity.

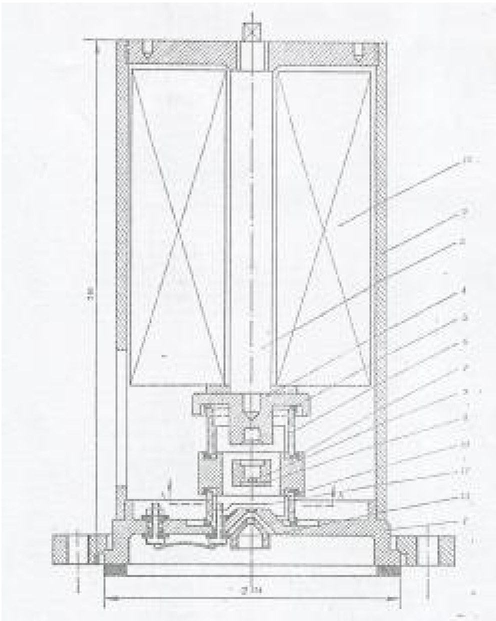

Fig.4. Ion source for Metal Ions

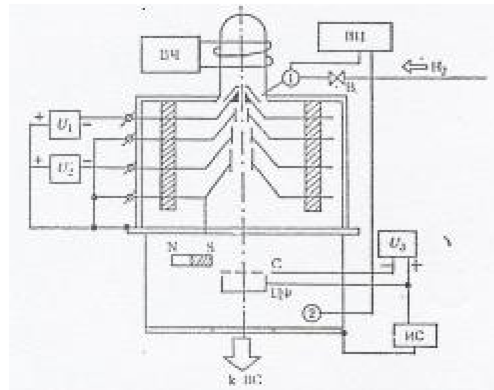

Fig.5. Ion Source for Negative Ions

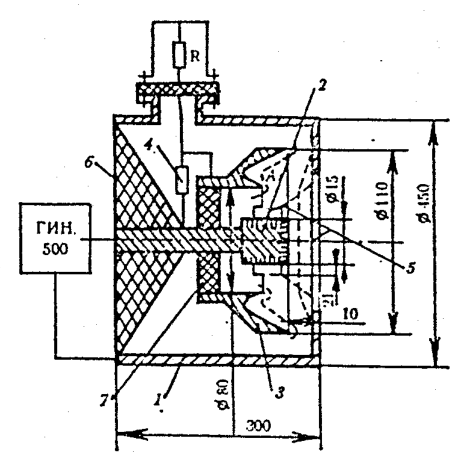

Fig.6. Pulsed High Current Electron Gun with Plasma Cathode

B. Ion and Electron Sources (1978 – 1988)

1. **ION SOURCE FOR METAL IONS**
   The ion source is shown on Fig.4. The main feature of the source is that the evaporation and the ionization of the working material (probe0 happen simultaneously in the discharge chamber. Both the evaporation of the metal probe and the ionization of the evaporated atoms are produced by the oscillation discharge electrons. The source utilizes Penning type of discharge. It uses hot tungsten cathode, two anticathodes, cylindrical anode and longitudinal magnetic field. The source has high efficiency, i.e. high ratio of the extracted ion current to the electric power. The ion current is about few hundreds microamps.

2. **NEGATIVE ION SOURCE**
   The source is depicted on Fig.5. This is charge exchange type negative ion source. It uses high-frequency electrodless discharge exited by a 300W/ 38 MHz generator. The positive ions are converted to negative ones by electron exchange on the walls of a long extracting electrode. The received ion current is of the order of few tens microamps.

3. **INTENSE NANOSECOND ELECTRON GUN**
   The pulsed electron gun is shown on Fig.6. The gun uses a high-vacuum cold-cathode discharge. The physics of this type of electron guns was studied intensively in Russia, foe example by Prof. G. A. Mesyats and co-workers. It consists in exploding of the micro spikes on the cathode due to the intense field emission and the formation of dense cathode plasma. We have constructed a vacuum triode which allowed us to control the electron current. Changing the voltage of a special reflecting electrode from 20 to 70 KV we managed to change the electron current from 1.0 to 2.5 KA. The cathode is of special construction – it is made by dicks of carbon textile with radialy oriented fibers. Such a cathode is highly reliable and gives highly reproducible electron pulses. The applied voltage of 150 KV and 150 nsec pulse duration is generated by a five stages marx high-voltage pulse generator with gap spark chambers

C. Beam Dynamics (1990 -)

The Particle Accelerator Group has always had poor investment but since 1990 the funding for R&D works has stopped completely. This forced us to turn all our efforts to areas that don't need much money. By that time we had some acctivities in the field of accelerator theory, we had good colaboration with High Energy Laboratory of JINR, Dubna on the superconducting heavy ion synchrotron NUCLOTRON, that is why we turn our attention to the area of beam dynamics and to collaboration works with JINR on NUCLOTRON..

1. **NUCLOTRON**

The NUCLOTRON is an accelerator of relativistic nuclei working at the Joint Institute for Nuclear Research in Dubna, Russia, Fig.7-9. This is a superconducting heavy ion synchrotron. It has FODO magnetic structure with 32 periods and 8 superperiods. The main accelerator parameters are:

Circumference	251.52 m
Injection energy per nuclei	5 MeV/ A
Maximum energy per nuclei (Z/A=0.5)	6 GeV/ A

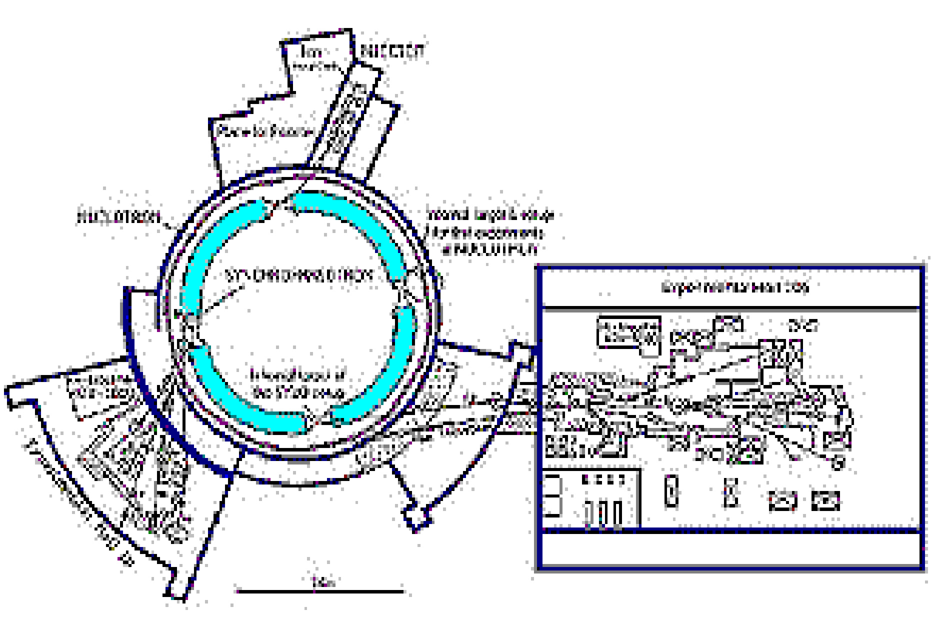

Fig.7. Superconducting Heavy Ion Synchrotron NUCLOTRON

Fig.8. NUCLOTRON superconducting Magnets

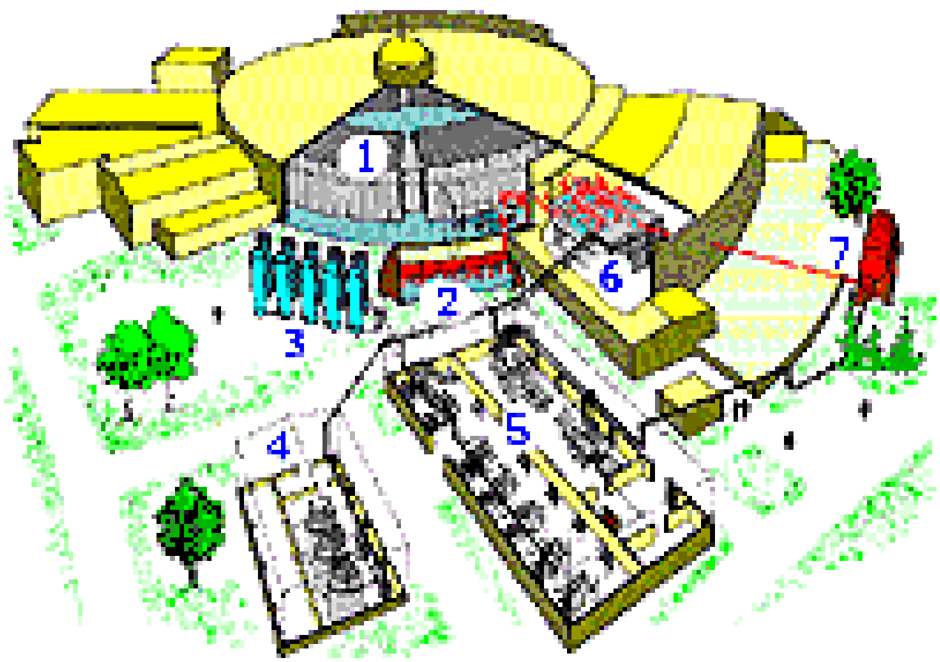

Fig. 9. NUCLOTRON Experimental Setup

Beam intensity 5.10^{11} A/Z^2 particles/cycle

The injector is an Alvaretz type linac which accelerates ions with a charge-to-mass ratio of $0.28 < q/A < 0.5$ up to 5 MeV/u and protons up to 20 MeV. The existing ion sources are: duoplasmatron for protons, deuterons and α - particles, a source of polarized deuterons, a laser ion source and an electron beam ion source (EBIS). This allows to get ions over a wide range of masses.

The bending magnets are of window frame type.The winding is made of hollow superconducting cable fabricated from thirty one filaments wound and soldered on a cupro-nickel pipe and cooled by two-phase hellium. The maximum field of 2.0 T is shaped by an iron yoke. Such a construction is simple, cheap and reliable and allow repetition frequencys up to 1.0 Hz.

2. **LINEAR AND NONLINEAR ORBIT THEORY**
    - Works on magnetic structures – optimization of the magnetic structure of the cooler-synchrotron COSY in FZ – Julich; calculation of the magnetic structure of the Nuclotron booster.
    - Works on corrections – development of DINAM orbit correction algorithm; correction of the closed orbits in COSY and NUCLOTRON; correction of chromaticity and resonances in NUCLOTRON.
    - Development of algorithm for revealing of linear errors on the base of orbit measurements.
    - Works on nonlinear dynamics – DA, smear and resonances in NUCLOTRON.

3. **MAGNET SORTING –** development of algorithms for optimum posisioning of the magnetic elements and application to NUCLOTRON.

4. **INJECTION**

- Analitic treatment of the charge exchange injection of heavy ions.
- Stripping injection of polarized deuterons in NUCLOTRON
- Simulation of multiturn injection, stripping injection and RF stacking in the Nuclotron booster

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5.COMPUTER CODES

- ORBIT –3.0 – simulation and correction of closed orbit and first turn
- MSS – magnet sorting
- LEA – revealing of linear errors on the base of orbit measurements
- BeamLine – beam transport with dialog optimization
- INTRANS – interactive beam transport code

Some examples of PAG activities in the field of beam dynamics are shown on Fig. 10 – 13.

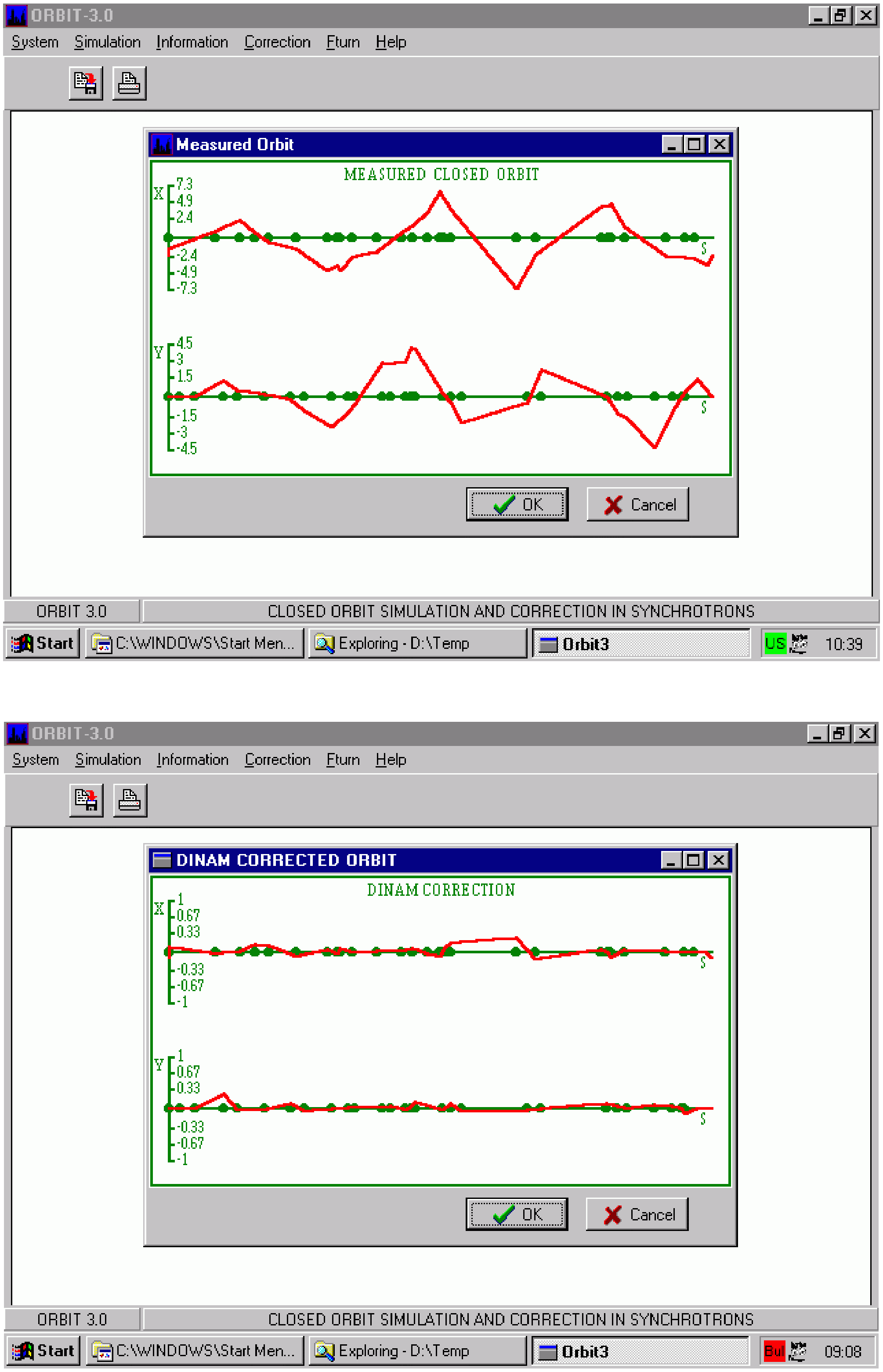

Fig.10. Computer Code ORBIT-3.0 for Simulation and Correction of Closed Orbit and First Turn

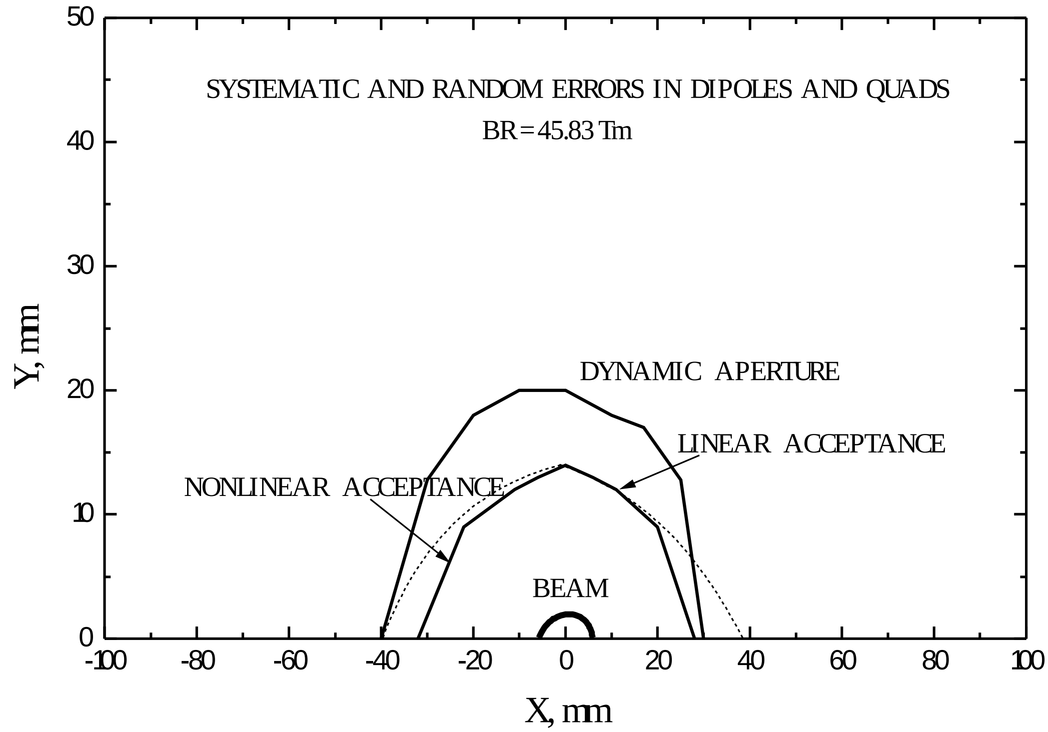

Fig. 11. Dynamic aperture and nonlinear acceptance of NUCLOTRON

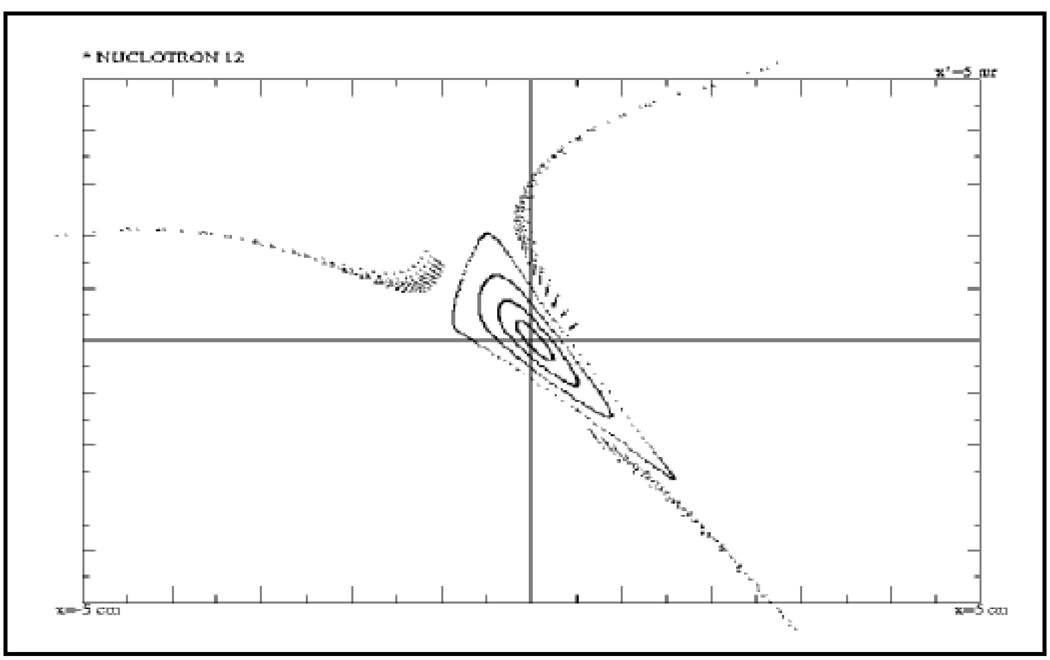

Fig. 12. Resonance Extraction from NUCLOTRON

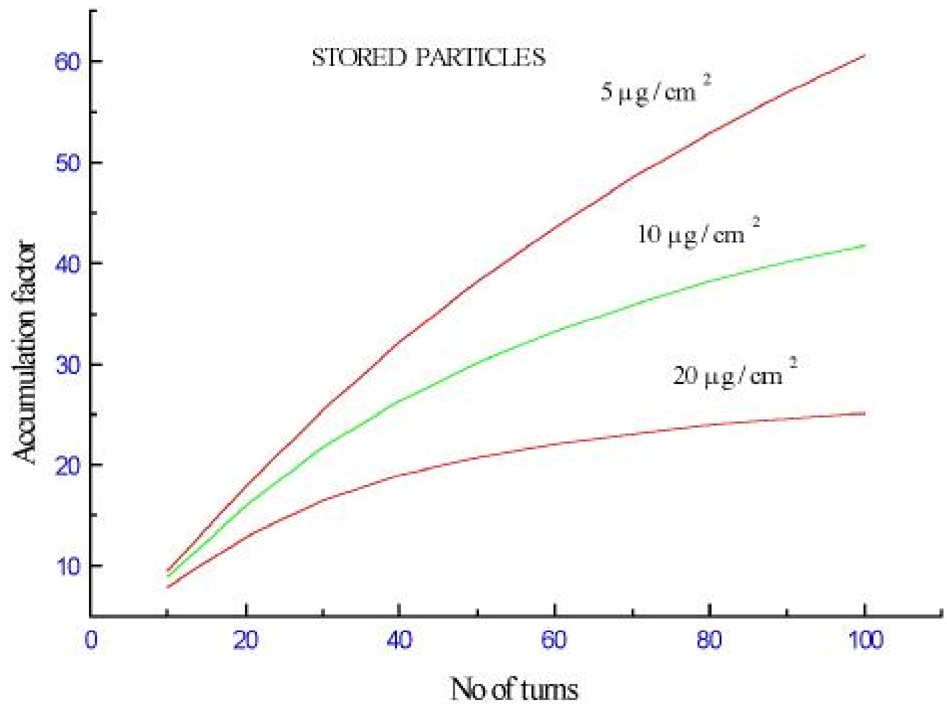

Fig.13. Charge Exchange Injection of Polarized deuterons in NUCLOTRON

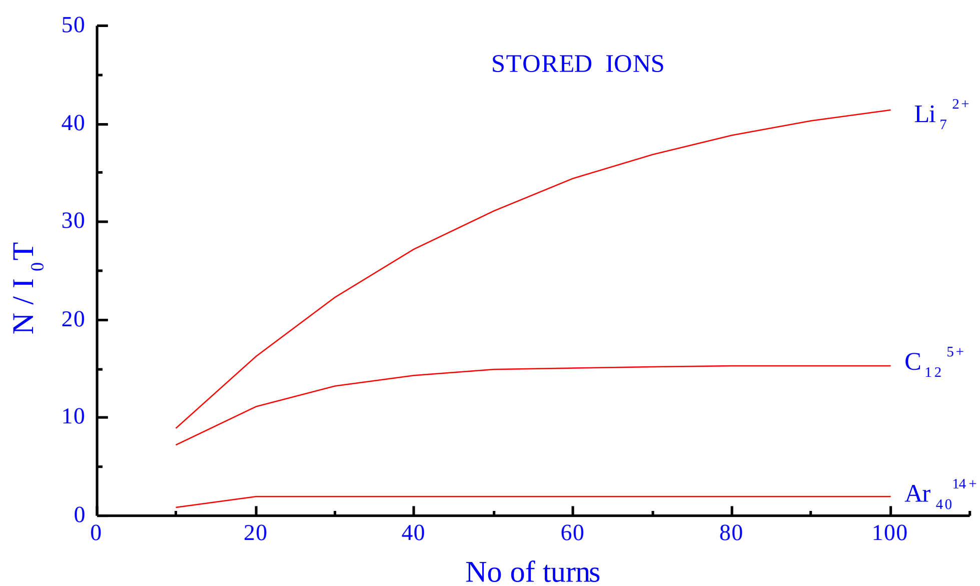

Fig.14. Charge Exchange injection of Heavy ions in Nuclotron Booster