Development of a Tandem-Electrostatic-Quadrupole facility for Accelerator-Based Boron Neutron Capture Therapy

A.J. Kreiner [1,2,3], W. Castell [1], H. Di Paolo [1,2], V. Thatar Vento [1], J. Bergueiro [1], A.A. Burlon [1,2], J.M.Kesque [1], P. Levinas [1], A.A. Valda [1,2], H.R.Somacal [1,2], M. Obligado [1], D. Cartelli [1].

[1] Departamento de Física, Comisión Nacional de Energía Atómica, Av. Gral Paz 1499, 1650, San Martín, Buenos Aires, Argentina.
[2] Escuela de Ciencia y Tecnología. Universidad Nacional de Gral. San Martín, M. De Irigoyen 3100, 1650, San Martín, Buenos Aires, Argentina.
[3] CONICET, Avda. Rivadavia 1917, C1033AAJ, Ciudad Autónoma de Buenos Aires, Argentina.

Email contact of main author: kreiner@tandar.cnea.gov.ar

Abstract. In this work we describe some aspects of the present status of an ongoing project to develop a Tandem-ElectroStatic-Quadrupole (TESQ) accelerator facility for Accelerator-Based (AB)-Boron Neutron Capture Therapy (BNCT) at the Atomic Energy Commission of Argentina. The project final goal is a machine capable of delivering 30mA of 2.4MeV protons to be used in conjunction with a neutron production target based on the ^{7}Li(p,n)^{7}Be reaction slightly beyond its resonance at 2.3MeV. These are the specifications needed to produce sufficiently intense and clean epithermal neutron beams, based on the ^{7}Li(p,n)^{7}Be reaction, to perform BNCT treatment for deep-seated tumors in less than an hour. The machine being designed and constructed is a folded TESQ with a terminal at 0.6MV for a small scale prototype as a first step and 1.2MV for the final accelerator. The general physical layout, the mechanical and electromechanical structures and subsystems, including alternators and high-voltage power supplies, are being designed and constructed. The associated electrostatic fields, and the acceleration and beam transport modules (tubes) are being simulated using 3D finite element procedures. Tests on tube prototypes have also started.

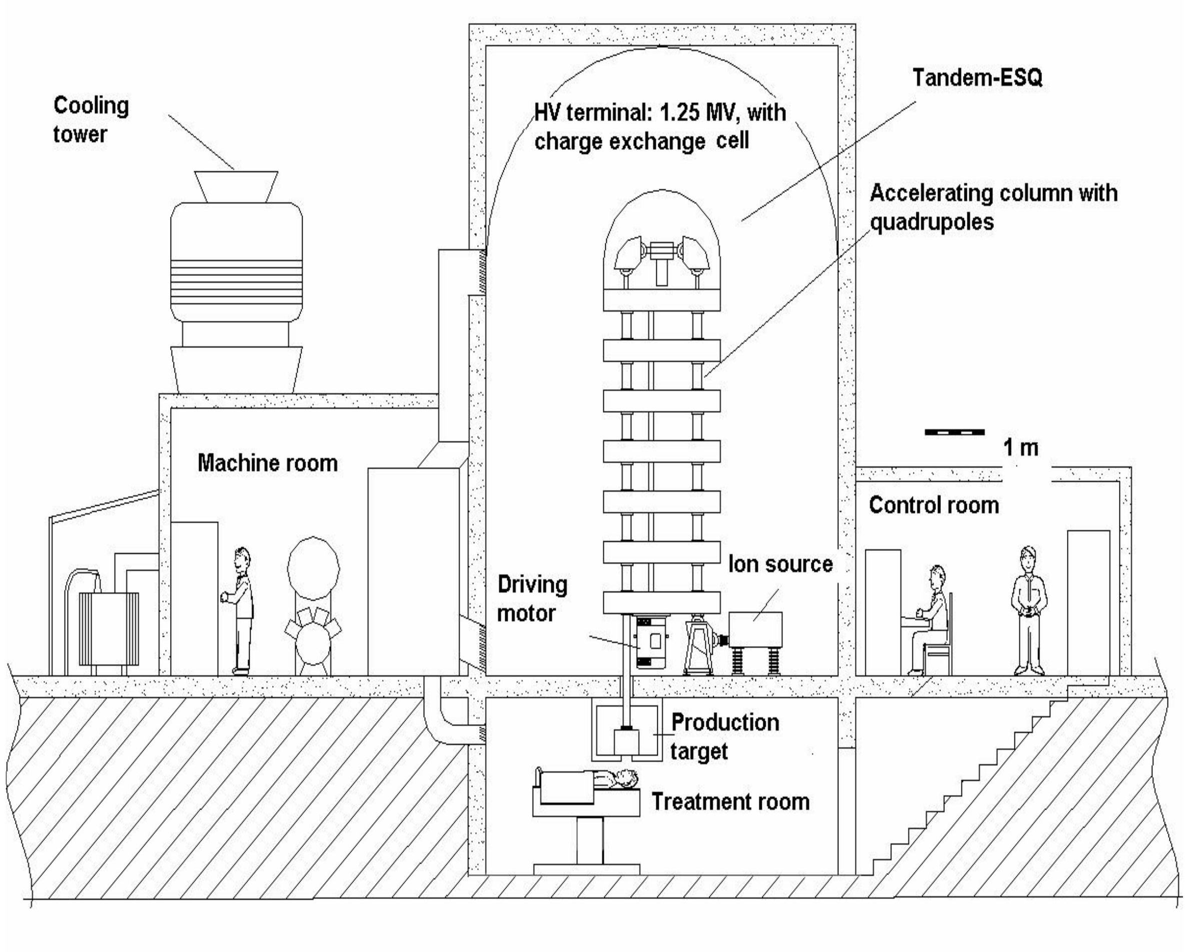
1. Introduction

Within the frame of Accelerator-Based BNCT (AB-BNCT) [1-2], a project to build a **T**andem-**E**lectro**s**tatic-**Q**uadrupole (TESQ) accelerator facility is under development in Argentina [3-5] based on the ^{7}Li(*p,n*)^{7}Be reaction, slightly beyond its resonance, at 2.3MeV. The machine being designed and constructed is a folded TESQ with a terminal at 1.2MV intended to work in air, to avoid the need for a pressure vessel and for an insulating gas installation. The project aims at developing a machine capable of delivering a proton beam of about 2.4MeV and 30mA to irradiate a Li metal (or a refractory Li compound) target in order to produce the therapeutic neutron beam after appropriate beam shaping. We report on the present status of the project and the progress in construction. The general physical layout, the mechanical and electromechanical structures and subsystems, including alternators and high-voltage power supplies, are being designed and constructed. The associated electrostatic fields, and the acceleration and beam transport modules (tubes) are being simulated using 3D finite element procedures. Tests on tube prototypes have also started.

2. General layout of facility

A first version of the TESQ accelerator general layout has already been discussed in previous publications [3-5] and is shown in fig. 1. The accelerating column consists of a series of stacked cylindrical boxes which are separated by 200kV and 40cm air gaps (a total of 7 to reach 1.2MV, the first one being at ground potential). This column houses the up- and down-going acceleration tubes with the quadrupoles inside.

FIG.1. General layout of the installation showing the folded Tandem-ESQ (TESQ) with the 1.2-1.25 MV high voltage terminal in air with stripper cell, the control room, the neutron production target, the treatment room, the machine room and cooling tower.



3. Results

3.1 A prototype of 600kV

A partial view of the current design of this structure is shown in fig. 2, but for a 600kV prototype. It shows the general geometric layout of the high-voltage column. It is being built as a right cylinder of 2.5m diameter crowned at its upper ending by a high voltage dome at 0.6MV. The column consists of a series of stacked cylindrical boxes (35cm in height), surrounded by semi-toroidal surfaces, which are separated by 200kV in voltage and 40cm air gaps. The boxes house 12kVA alternators, driven by vertical insulating rotating shafts which are attached to electric motors placed at ground potential, that provide the necessary power to feed the high-voltage supplies (100kV and 60mA units also housed within the boxes shown as dark cubes to the left of the figure) which will energize the whole installation. The 1.2MV complete facility has three equal boxes more (at 600, 800, and 1000kV) and a larger dome at 1.2MV. These boxes are traversed vertically by the up- and down-going acceleration tubes, which are made of slices of borosilicate glass and stainless steel electrodes. Most of the supporting elements, like base structures, insulating posts and rotating shafts have already been constructed and tested, and the mechanical structure is being assembled to run stability and vibration tests as soon as the alternators are completely developed.

FIG. 2. Vertical cut of the machine for a 600kV prototype showing 3 boxes surrounded by semitoroidal shields (the first one at ground potential with the base plate holding the impulse motors, the two consecutive ones at 200 and 400kV and the high voltage dome at 600kV). The successive boxes are separated by insulating posts.

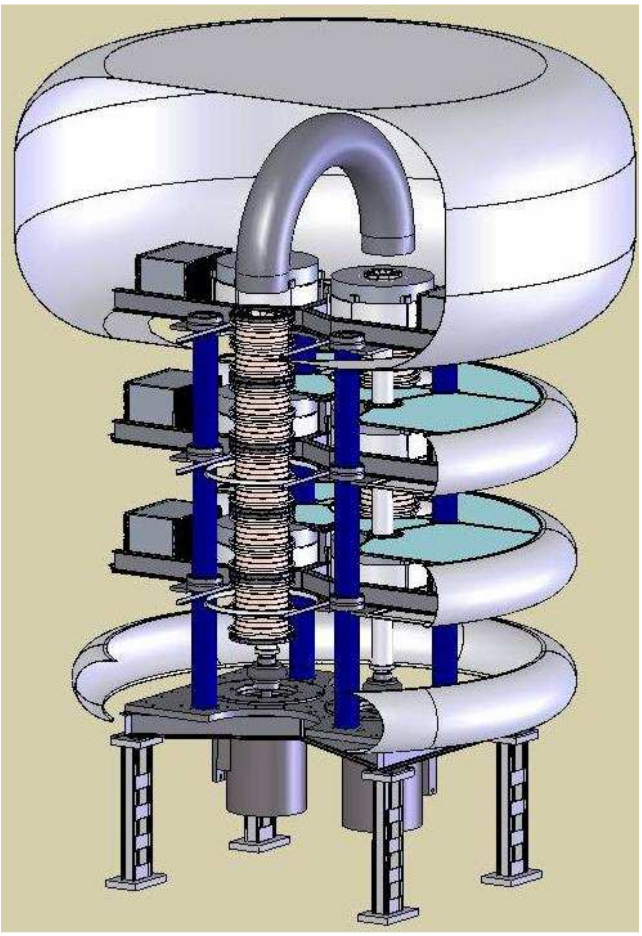


FIG. 3. A more detailed view of one of the boxes, housing two alternators and two high voltage units on opposite sides, mounted on a support structure.

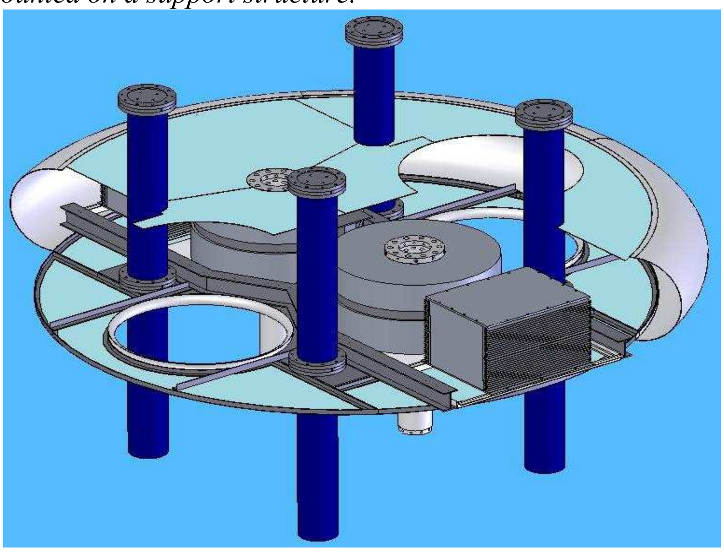
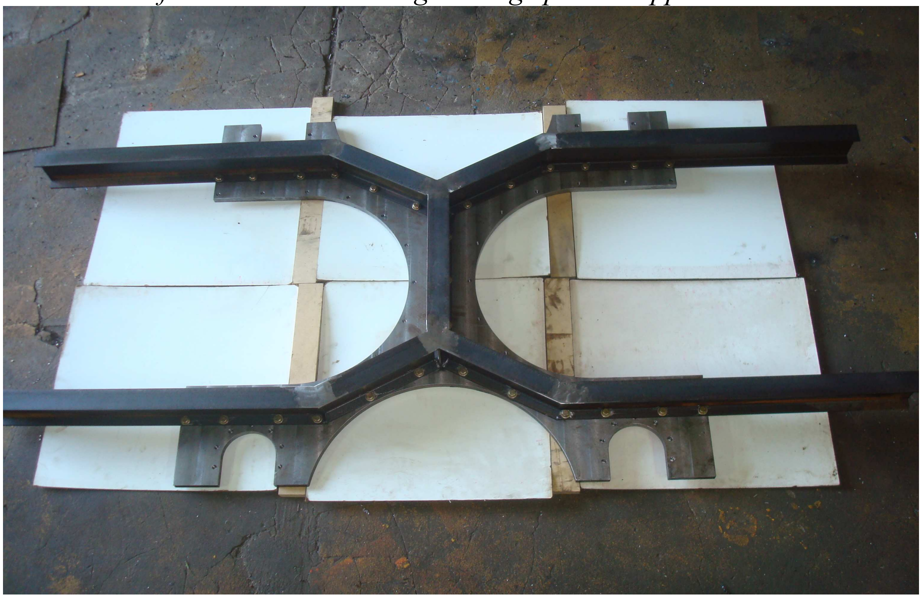


Fig. 4 shows one of the support structures already constructed and ready to be mounted.

FIG. 4 Support structure for alternators and high voltage power supplies.



3.2 Alternators

The machine will be powered by electric motors installed at ground potential which in turn will drive rotating insulated shafts, at 10^3 rpm. These axes will move the rotors of alternators. Since there are no commercially available alternators of the required size the decision was made to develop them in-house. They are 3x380V, 12kVA units. Figs. 5 and 6 show different construction stages of the alternator rotor made up of laminations of silicon steel.

FIG. 5. Partially assembled rotor.

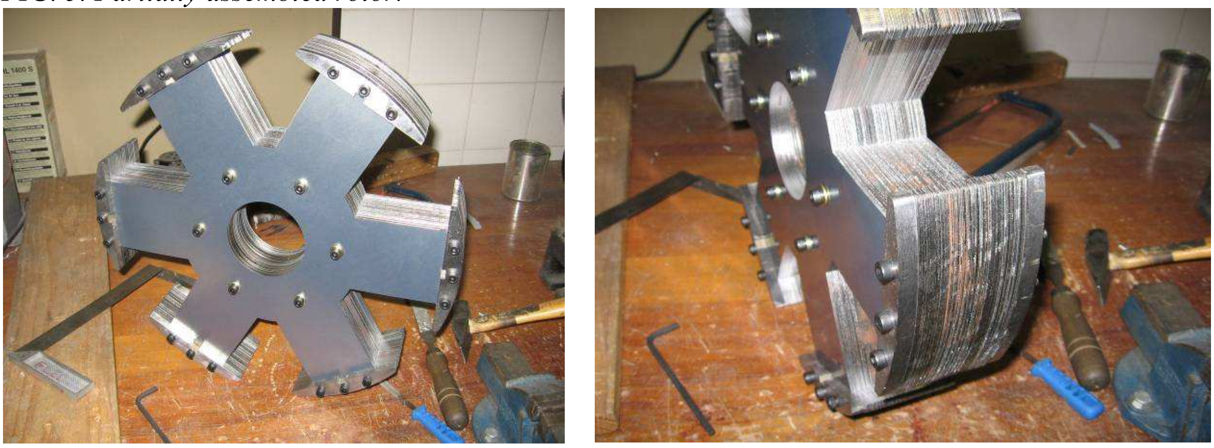
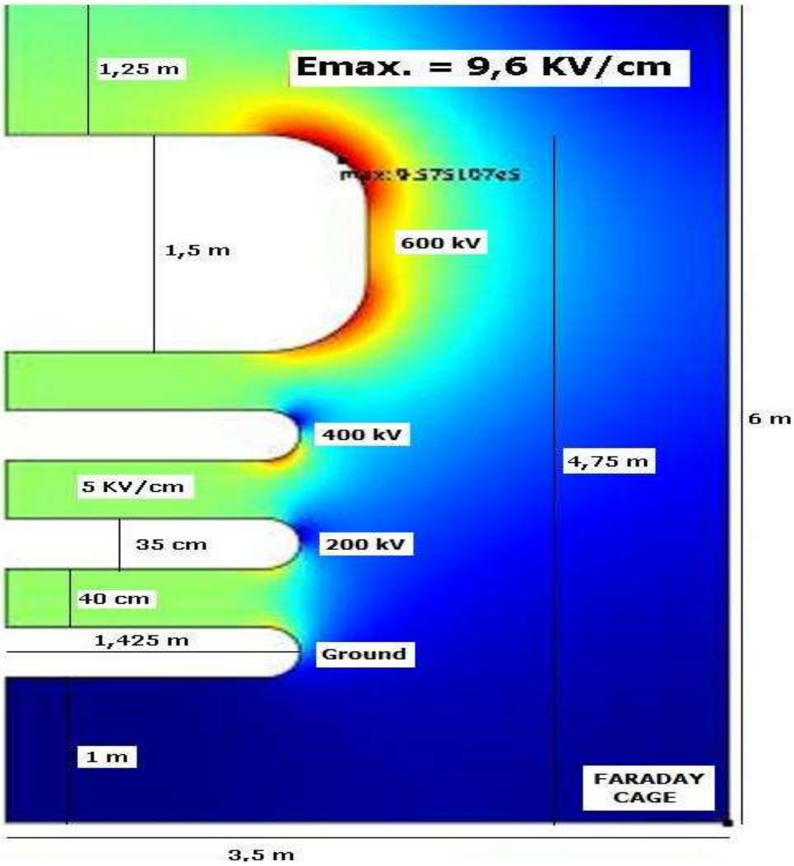


FIG. 6. Winding the rotor.

3.3 Electrostatic fields

The electrostatic fields have been calculated by means of 3D finite element and other numerical codes and a detailed design has been made paying special attention to the avoidance of sharp edges and points to limit the fields to safe values. The criteria have been to limit the fields on metal surfaces in air to values not exceeding 12 kV/cm (for the complete machine), to 5 kV/cm at the interfaces between insulators and air (the room which will house the machine will have controlled temperature and humidity, about 20 ^{0}C and 35% respectively) and to 45 kV/cm on metal surfaces in vacuum. As shown in fig. 7, the maximum electric field for the 600kV prototype is on the dome and reaches 9.6kV/cm.

FIG. 7 Electrostatic fields along the accelerator column. The maximum field at the dome is 9.6kV/cm.



The distance to the wall (a cylindrical grounded Faraday cage) is also optimized in order to keep the electrostatic field at its minimum value. In our case the required distance from the box column central axis is 3.5m. The height from ground to roof turns out to be about 10 m for the 1.2MV accelerator while 6m are sufficient for the 600kV prototype.

3.4 Accelerator tubes

The accelerator tubes are composed of focusing-defocusing quadrupoles and accelerating gaps. Fig. 8 shows details of one tube section or module. Each tube section is about 35 cm long and consists of slices of borosilicate glass (outer diameter of 30 cm and thickness along the tube axis of 3.15 cm) bonded to stainless steel electrodes. The electrodes are protruding to the inside, with a curved geometry, in order to block the direct view of the beam by the insulating glass walls. To the outside they are terminated in rings to limit the maximum field at the sharp edges. In addition, the tubes house a series of quadrupole focusing elements. These are made of semi-cylindrical rounded-edge stainless steel or aluminum pieces which are held in place by conducting supports fixed to the appropriate electrodes. The total voltage across two tube sections, located between the mid-planes of two consecutive boxes, is designed to be 200 kV. The voltage between poles for each quadrupole is typically between 20 to 40 kV, and the voltage between poles of consecutive quadrupoles (accelerating gaps) is of the order of 70 kV for most of the tube. This last voltage is responsible for acceleration along the machine.

FIG. 8. Vertical cut of a tube module, showing partially six quadrupole electrodes out of eight, the protruding shielding electrodes, the grading rings outside and the transparent insulating glass.

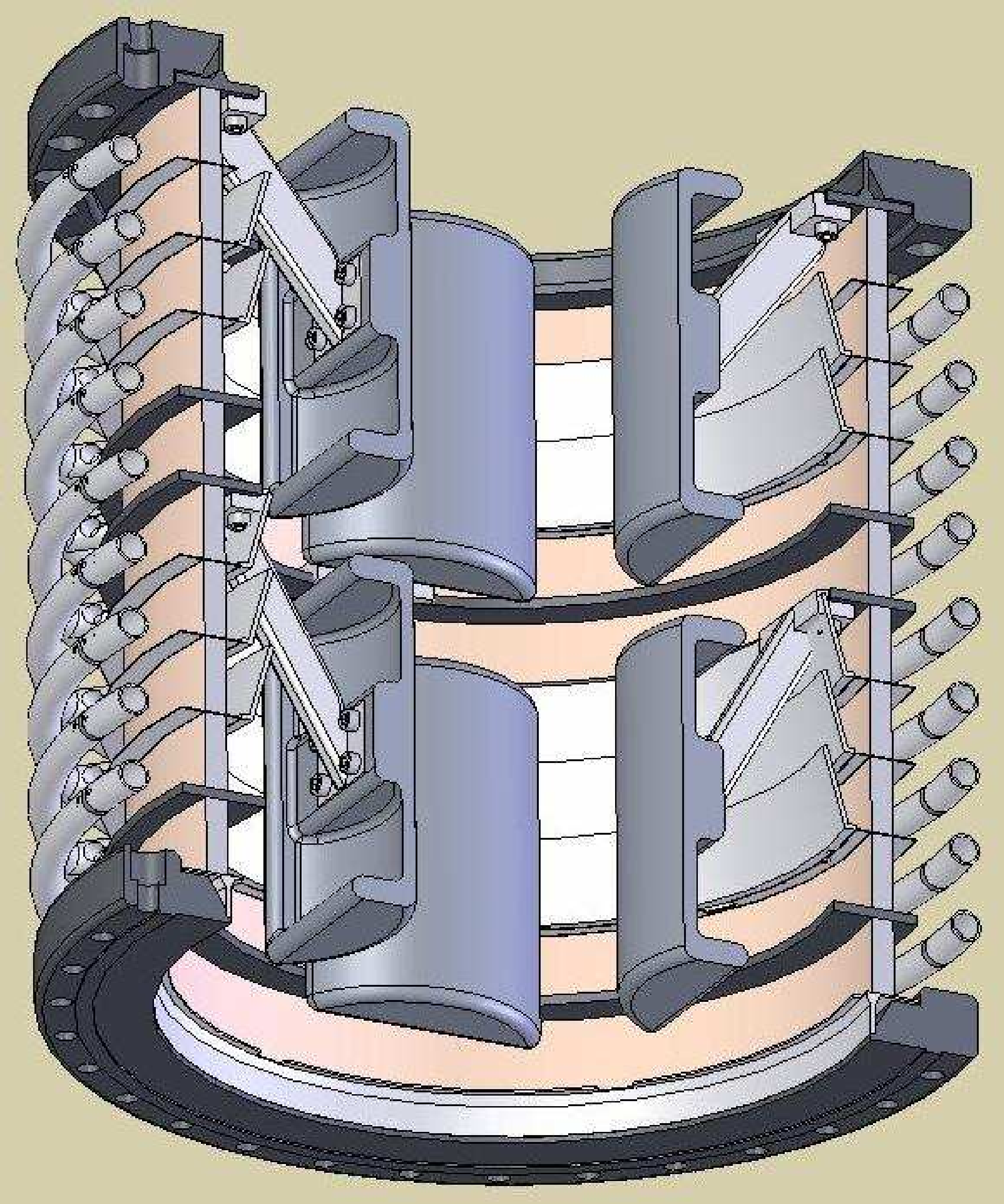
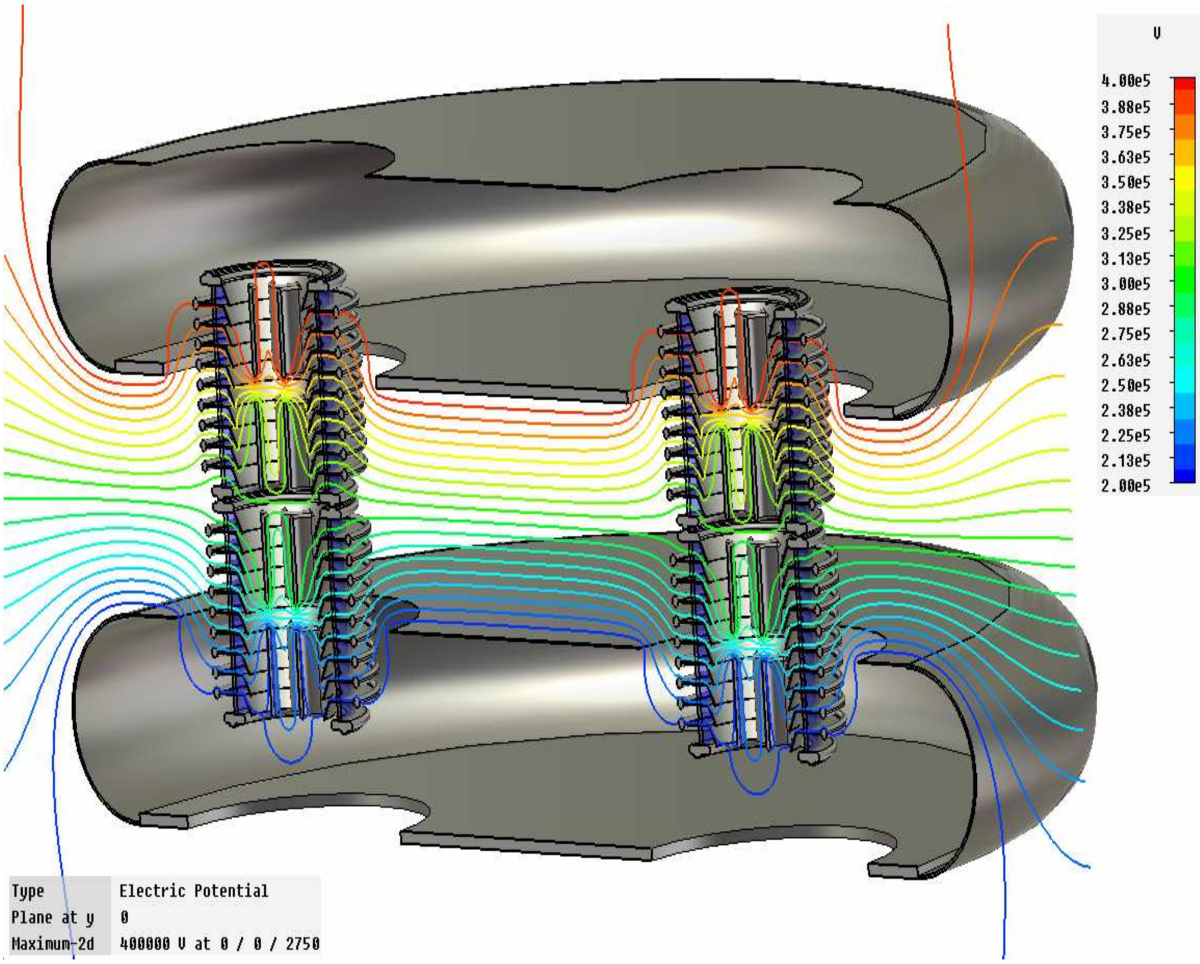


Fig. 9 shows two tube sections, their location in between the mid-planes of two consecutive boxes at 400 and 200kV respectively and the resulting voltage distribution.
Finally it should be mentioned that tests on simple tube prototypes have already started.

FIG. 9. Vertical cut of two sets of two tube modules (upgoing and downgoing), showing partially six quadrupole electrodes out of eight, their location from mid-plane to mid-plane of two boxes and the 3D voltage distribution corresponding to an upper box at 400kV and a lower box at 200kV.



4. Discussion, conclusions and final remarks.

A Tandem-ElectroStatic Quadrupole accelerator facility for AB-BNCT is being designed and constructed at CNEA’s atomic center Constituyentes in Buenos Aires, Argentina. The first step is the development of a 600kV prototype due to building limitations at the present point in time and to gain experience with the different subsystems involved. The general physical layout, the mechanical and electromechanical structures and subsystems, including alternators and high-voltage power supplies, are being designed and constructed. The associated electrostatic fields, and the acceleration and beam transport modules (tubes) are being simulated using 3D finite element procedures. Tests on tube prototypes have also started.
Other important subsystems like strippers, vacuum generation, neutron production targets, beam shaping assembly, treatment room, and ion sources are being defined and built but are not discussed in this presentation.
Since an accelerator can be sited in a hospital environment, is easier and safer to operate and of lower cost than a reactor, our present results provide a strong justification for the ongoing efforts to develop such a machine as a means to achieve further progress in the field of BNCT. Efforts are under way to start construction of an appropriate building al the National Cancer Institute Roffo.

Acknowledgements

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