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# Cyclotron laboratory of the Institute for Nuclear Research and Nuclear Energy

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# Cyclotron laboratory of the Institute for Nuclear Research and Nuclear Energy

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**Abstract.** An accelerator laboratory is presently under construction in Sofia at the Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences. The laboratory will use a TR24 type of cyclotron, which provides a possibility to accelerate a proton beam with an energy of 15 to 24 MeV and current of up to 0.4 mA. An accelerator with such parameters allows to produce a large variety of radioisotopes for development of radiopharmaceuticals. The most common radioisotopes that could be produced with such a cyclotron are PET isotopes like: $^{11}$C, $^{13}$N, $^{15}$O, $^{18}$F, $^{124}$I, $^{64}$Cu, $^{68}$Ge/$^{68}$Ga, and SPECT isotopes like: $^{123}$I, $^{111}$In, $^{67}$Ga, $^{57}$Co, $^{99m}$Tc. Our aim is to use the cyclotron facility for research in the fields of radiopharmacy, radiochemistry, radiobiology, nuclear physics, solid state physics, applied research, new materials and for education in all these fields including nuclear energy. The building of the laboratory will be constructed nearby the Institute for Nuclear Research and Nuclear Energy and the cyclotron together with all the equipment needed will be installed there.

## 1. Introduction

The Institute for Nuclear Research and Nuclear Energy (INRNE) at the Bulgarian Academy of Sciences (BAS) has been working since 2012 on the project "Cyclotron laboratory of INRNE-BAS". The project was launched in 2012 at the initiative of the Council of Ministers of the Republic of Bulgaria and the management of INRNE-BAS to solve a very old problem of the country - the lack of domestic production of short lived medical cyclotron radioisotopes. This problem has existed for decades despite repeated efforts of several generations of researchers from INRNE-BAS and the medical community to persuade the Government that such a center should be built in Bulgaria as was done a long time ago in the other Eastern European countries.

It would have been practically impossible to start-up the project without the generous contributions of our first financial donors. For the purchase of the cyclotron and construction of the laboratory 3,000,000 USD were donated from the United States Department of Energy (DOE) and 2,000,000 USD from Kozloduy Nuclear Power Plant.

In 2014 the project for a new cyclotron center was included in the updated "National Roadmap for Scientific Infrastructure" of Bulgaria. At the beginning of 2015 the project was identified as a priority of the Bulgarian-American relations in the field of science and education. For several years the management of INRNE-BAS has been actively working to insure further state support for the construction of the building of the cyclotron laboratory.

The project envisions a new cyclotron laboratory as a part of INRNE-BAS consisting of: a specialized building that meets the regulatory requirements in the field of radiation safety

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and GMP (good manufacturing practices) in the pharmaceutical industry; a bunker with a TR-24 cyclotron; a sector for applied research and development in radiopharmacy with enhanced educational functions; a sector for the production of 18F-FDG, called Fluorodeoxyglucose, and in future, of other radiopharmaceuticals.

The laboratory of INRNE-BAS is the novel nuclear research infrastructure in the country. Presently Bulgaria has no research nuclear facility, neither a research reactor, nor an accelerator. With the new facility we will restart our experimental research program not only in the field of nuclear physics, but also in many interdisciplinary fields related to nuclear physics. An excellent presentation of the accelerator physics is present in the work [1].

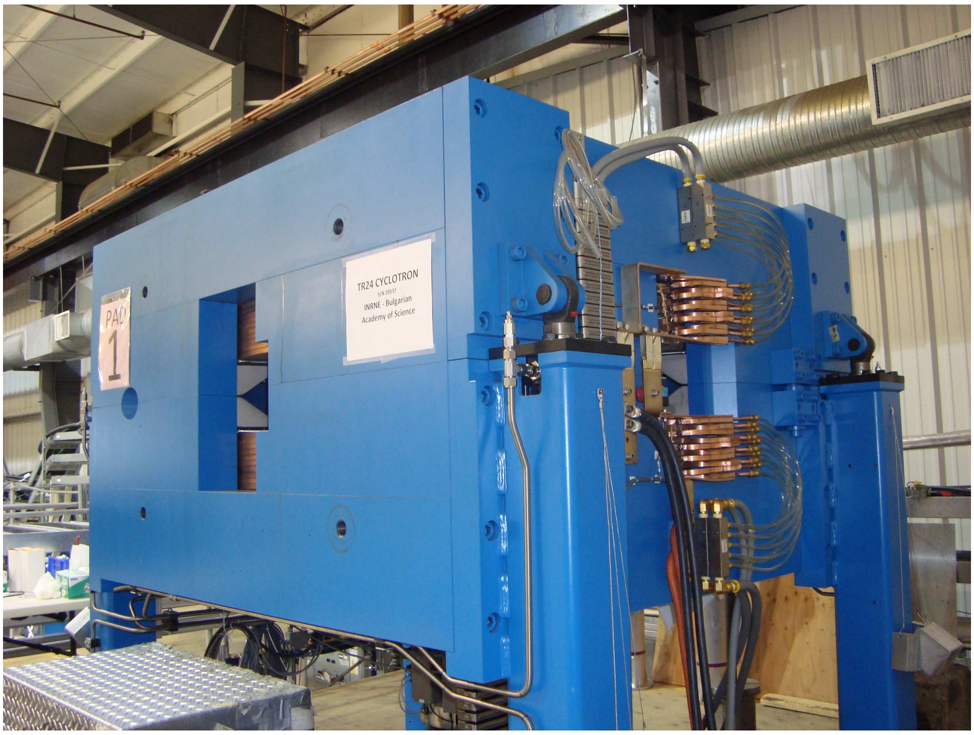


**Figure 1.** A picture of INRNE-BAS cyclotron TR24 during the test in Vancouver in August 2015.

In Europe there are many academic institutions where novel accelerator centers are under development. The TR24 cyclotron is an accelerator which has recently been installed at CYclotron pour la ReCherche et lEnseignement (Cyrce‘) of the Institut Pluridisciplinaire Hubert Curien (IPHC) in Strasbourg, France or will be operated soon at at the Institute of Radiopharmaceutical Cancer Research of Helmholtz-Zentrum Dresden  Rossendorf (HZDR), Germany; Rzez, Czech Republic etc. The Laboratori Nazionali di Legnaro at INFN, using a 70 MeV cyclotron, plans to perform similar to our activities [2].

## 2. Challenges of the INRNE-BAS cyclotron project

One of the main objectives of the project is within five years to allow for regular supply of 18F-FDG to 8 regional PET/CT center at a low price, providing ”full cost recovery”, with a small profit margin used to sustain the laboratory. This will enable more hospitals in Bulgaria to purchase new PET/CT equipment as well as to increase the throughput of the existing scanners. This will allow the examination of 16,000 patients a year in the regional PET/CT centers. The wider access to PET/CT will improve the health and extend the life of the patients suffering from cancer. The revenue from the sale of radioisotopes and radiopharmaceuticals will be fully reinvested in the research program and in the development of the laboratory. The availability of a production sector, meeting all modern regulatory GMP requirements will ensure high quality training of nuclear pharmacists and will close the chain from research through R&D to end products with applications in medicine.

The parameters of the TR24 cyclotron (shown in Figure 1) have been selected in such a way that in the next twenty years INRNE-BAS will be able to produce a wide range of radioisotopes with applications in medicine with a relatively low initial investment and moderate maintenance costs. At these proton energies and beam current it is possible to produce commercial quantities of radioisotopes with traditional and expected future applications in medicine as: PET radioisotopes - 18F, 124I, 64Cu, 68Ge/68Ga; SPECT radioisotopes - 123I, 111In, 67Ga, 99mTc; therapeutic alpha-emitters - 225Ac/213Bi, 230U/226Th. Some part of the equipment for the production of radioisotopes will be designed and constructed in INRNE-BAS with the help of the Design and Production Workshop - Physics and will be sold on the international market subsequently.

The radioisotopes produced by the cyclotron will be used for the development of new radiolabelled molecules for diagnostics [3] and therapy purposes [4].

**Figure 2.** A Y-line belonging to the Sofia cyclotron.

The aim of the INRNE-BAS cyclotron laboratory is to provide a high intensity and a high quality proton beam to perform forefront research in interdisciplinary fields like medical, chemical, biological and material sciences, nuclear physics and applied research. The cyclotron can also produce very low currents (10nA) for radiobiology applications. A longer term goal of the laboratory is to become involved in preclinical studies and clinical trials through collaborations and research projects with academic partners and private companies.

The laboratory in Sofia will open a new possibility for experimental nuclear structure research in Bulgaria. We plan to investigate level-schemes of excited nuclei as well as to measure lifetimes of excited nuclear states. A proton beam will be used to bombard a target and with a multidetector system to investigate the nuclear structure. Lifetimes in the femtosecond region can be measured using Doppler-shift attenuation method (DSAM) following the inelastic proton scattering reaction. Such an approach is presented in details in the work of Hennig et al. [5]. In the setup used in Cologne University, the proton in the exit channel of the (p, p'$\gamma$) reaction is detected with charged-particle detectors placed close to the target. This approach uses the centroid-shift version of the DSAM method and profits from the coincident detection of scattered protons and de-exciting $\gamma$-rays.

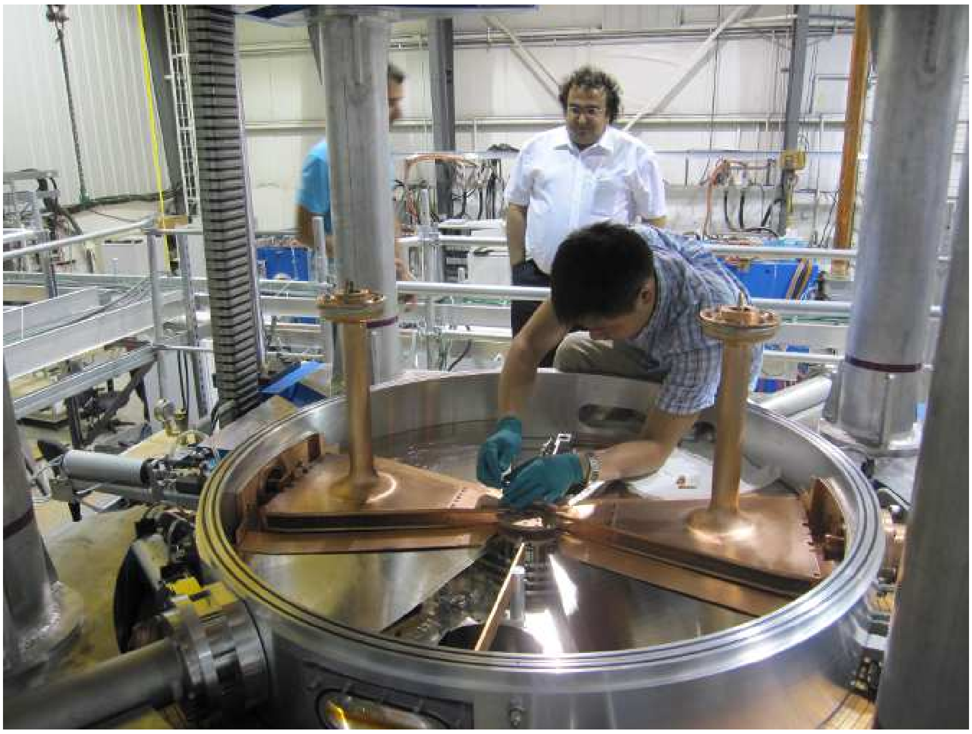

**Figure 3.** Factory acceptance tests in Vancouver, Canada in 2015.

Utilizing this approach thirty lifetimes in $^{96}$Ru are determined in the work of Hennig et al. [6].

An approach using a similar setup we plan to mount at INRNE laboratory in order to measure lifetimes for low-lying states in nuclei which could be approached by (p, p'$\gamma$) reaction.

We would like to continue our research in the fileds of investigation of phase transitions in nuclear physics [7], chirality in nuclei [8, 9] and nuclear structure of light nuclei [10].

A parallel activity of INRNE laboratory includes education and training of physicists, chemists, pharmacists and biologists for radioisotopes production, radiochemistry, quality control of radiopharmaceuticals and their uses in medical imaging, as well as training of specialist for nuclear energy. More general practical topics like radiation protection and dosimetry will also be covered by the training and education program of the laboratory. Most of the training and education activities will be carried out by involving the students in the ongoing research projects of the laboratory. Special attention will be paid to the traning of students which plan to work in the field of nuclear energy. The education of these students will guarantee the high level of nuclear safety of the Bulgarian nuclear power plant.

## 3. The accelerator TR24

The TR24 cyclotron is produced and commercialized by Advanced Cyclotron Systems Incorporation, located in Vancouver, Canada. The TR-24 cyclotron of INRNE-BAS, Figure 2, has the following characteristics: accelerates negatively charged hydrogen ions; variable energy of the proton beam; minimum energy of the proton beam of 15 MeV; maximum energy of the proton beam of 24 MeV; proton beam current of 400 $\mu$A, upgradeable to 1000 $\mu$A; simultaneous extraction of two proton beams; external CUSP ion source. With a very high current of up to 400 $\mu$A upgradeable to 1 mA and proton energy ranging from 15 to 24 MeV, the cyclotron can produce commercial quantities of more than 15 isotopes by irradiating simultaneously two high current targets placed at the exit ports or along high current beam lines. At the beginning one Y-like beam line, shown in Figure 2, will be mounted at one of the exit ports of our cyclotron for greater flexibility. Presently we have two target stations and three targets for the production of 18F-FDG.

## 4. Status of the Bulgarian National Cyclotron Center

In 2014 INRNE-BAS completed successfully the public procurement tender for the cyclotron and signed a contract for the delivery of a TR-24 cyclotron, manufactured by the Canadian company ACSI. The cyclotron passed low energy tests in the factory in August 2015. All the design parameters of the cyclotron were successfully demonstrated during the tests. An illustration for the tests is shown in Figure 3. All the components of the cyclotron were delivered and stored at INRNE-BAS on January 12-th 2016 (Figure 4).

The building for the cyclotron and the hot cells will be constructed nearby the Institute.

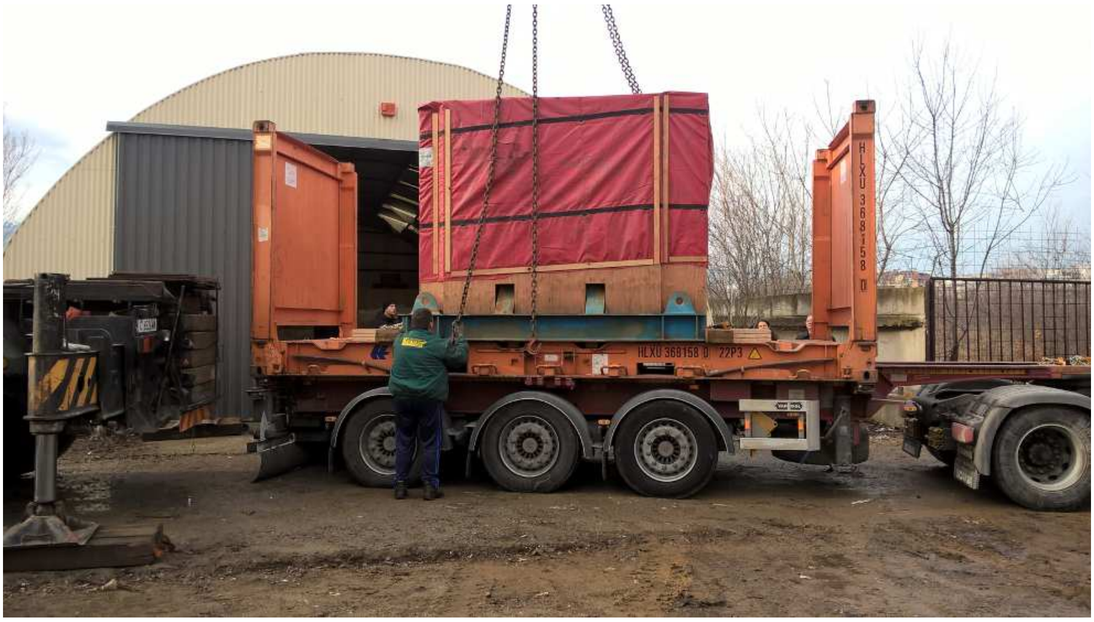

**Figure 4.** Delivery and storage of the cyclotron in INRNE-BAS.

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