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中国原子能科学研究院
CHINA INSTITUTE OF ATOMIC ENERGY

成都东部新区
Chengdu Eastern New Area

CYC 2025

24th International Conference on Cyclotrons and their Applications

Oct.27 - 31, 2025 · Chengdu, China

Abstract Manual

Organizer **主办单位**	China Institute of Atomic Energy 中国原子能科学研究院
Co-organizer **协办单位**	National Atomic Energy Industry Metrology and Testing Center 国家原子能产业计量测试中心 Accelerator Engineering Discipline and Technology Research Center 加速器工程学科与技术研究中心 Beijing Nuclear Society 北京核学会 Chinese Particle Accelerator Society 中国核学会粒子加速器分会 CNNC Engineering Research Center of Accelerators 中核集团加速器工程技术研究中心
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Chengdu, China

Oct.27-31, 202

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Monday 27th October	
9:00	Conference Opening, Chair: Tianjue Zhang (CIAE)
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10:10	Take Group Photo & Coffee break
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11:40	**MOAO02**: Ken Fong - Frequency generation and multiple frequency synchronizations in accelerator systems
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14:40	**MOBO03**: Yong Zhang - Operation and Upgrades of Beam Diagnostics for Cyclotron Accelerators at HIRFL in Lanzhou
15:00	Coffee break
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9:40	**TUAO03**: Xin Zhang - Design of an RF Cavity for 30 MeV Alpha Particle Cyclotron
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9:00	**THAI02**: Gaëlle Gerard - The NHA C400 cyclotron facility for Hadron Therapy becomes a reality
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Session MOA

MOAI01: Perspective and design study of a high intensity heavy ion and proton compact superconducting cyclotron

Hongwei Zhao, *on behalf of SK1000 team (IMP)*

Targeted α-therapy with α-particle-emitting isotopes such as ^{225}Ac, ^{223}Ra, ^{213}Bi, ^{212}Pb, has demonstrated a successful clinic trial effect. However, the major bottleneck for conducting translational research and future extensive clinical treatments is the limited availability of those α-emitting isotopes. Meanwhile, radioactive ion beam physics research, material irradiation and nuclear micro-porous membrane production demand high intensity heavy ion beams. A compact superconducting cyclotron for high intensity ion beam with a mass-to-charge ratio of 3 is being designed and developed by Institute of Modern Physics (IMP). The first such compact superconducting cyclotron is being designed which is dedicated to high intensity proton beam for ^{225}Ac and ^{223}Ra medical isotope production with extracted proton beam energy 120 MeV and proton beam intensity 0.5-1.0 mA by acceleration of H_3^+ beam through stripping extraction. The second one will be dedicated to high intensity heavy ion beams with a mass-to-charge ratio of 3 and extracted beam energy 120 MeV/A and typical beam intensity 5 pμA. Perspective and design studies of such high-intensity compact superconducting cyclotrons will be presented in the talk.

MOAI02: Status of the IsoDAR Project

Andreas Adelmann *(PSI)*

I will present an overview of the current status of IsoDAR Cyclotron research and development, as well as the associated physics program.

Originally conceived to meet the requirements of the IsoDAR (Isotope Decay-At-Rest) neutrino experiment, the modular design of the HCHC (High-Current H_2^+ Cyclotron) family enables the fabrication of cost-effective and compact cyclotrons covering an energy range from 1.5 MeV/amu up to 60 MeV/amu. These machines are expected to deliver a continuous-wave (cw) beam current of 10 mA, representing a tenfold increase over commercially available cyclotrons. This performance gain is enabled by accelerating H_2^+ ions, injecting them through an RFQ embedded axially in the cyclotron yoke, and exploiting vortex motion, a collective beam-dynamics effect.

We have validated our design concepts through high-fidelity particle-in-cell (PIC) simulations, optimized the RFQ with machine-learning techniques, and are currently constructing the first 1.5 MeV/amu prototype. Beyond neutrino physics, the HCHC cyclotrons also hold significant potential for medical isotope production and fusion-relevant material testing.

MOAO01: Challenges for new Cyclotron Projects

L. Calabretta *(INFN)*

Some of the new cyclotron projects currently under study or construction address new challenges. In particular, the START project of the company TRANSMUTEX to drive a subcritical reactor with a 4 MW proton beam, the 6 MW CYCIAE-2000 project, the IsoDar cyclotron of MIT, the new 230 MeV superconducting cyclotron for proton therapy and flash therapy in Dubna, and the upgrading of the Catania superconducting cyclotron to reach the 5-10 kW, along with their specific challenges, will be discussed. The procedure and tools to achieve high beam power, high reliability, setting optimization and automatic restart will be analyzed.

MOAO02: Frequency generation and multiple frequency synchronizations in accelerator systems

Ken Fong*; Thomas Au; Fu Xiaoliang (TRIUMF)*

An accelerator system employing RF cavities requires the use of a stable RF source, and some require multiple frequencies, either for acceleration or for bunching. These frequencies must be synchronized in phase in order to work properly. These are usually derived from a single low phase noise master reference frequency source. A fixed frequency oscillator or a variable frequency oscillator such as a frequency synthesizer are commonly used as the master frequency oscillator. Other frequencies are generated using this master source either through frequency multipliers or phase-locked loops. Phase noise is a crucial performance index of these sources, because once generated, phase noise will be persistant and cannot be corrected. Other active devices such as RF amplifiers, frequency up/down converters will contribute to the additive phase noise. The various aspects including merits and limitations of a master source, frequency multipliers and PLLs, together with the effect on beam quality on different types of resonant cavities, are investigated.

Session MOB

MOBI01: New Injection for TRIUMF 500 MeV Cyclotron

Yu. Bylinskii*; Keerthi Jayamanna; Marco Marchetto; Suresh Saminathan; Vladimir Zvyagintsev (TRIUMF)*

A new electrostatic injection for the 500 MeV cyclotron has been designed, constructed, and commissioned. Approximately 40 meters of electrostatic transport now replace the previous injection system, extending from the H^- ion source to the vertical injection section. The upgrade includes the integration of a second H^- ion source, connected through additional electrostatic beam transport, providing operational flexibility and redundancy. A novel suppression scheme for stray magnetic fields from the cyclotron has been implemented using a continuous, in-vacuum passive mu-metal shield along the full beam transport. Beam bunching is performed with a new three-harmonic buncher, whose amplitude has been calibrated through beam-based techniques. Additional diagnostics were introduced to enable non-interceptive monitoring of beam position.

The injection system operates under ultra-high vacuum (low 10^{-8} Torr), achieved through the use of stainless steel and ceramics materials and all-metal seals. The upgrade also incorporates a next-generation multi-cusp H^- ion source, developed at TRIUMF, which delivers higher brightness and improved stability. During commissioning, new high-level software applications for online tuning were deployed. These tools are now integrated into routine operation, providing enhanced automation and reproducibility of tuning procedures. Overall, the new injection system significantly improves the robustness, flexibility, and performance of cyclotron operations.

MOBO01: Upgrade of the INFN-LNS Superconducting Cyclotron: towards its Reassembling and Commissioning

Danilo Rifuggiato *(INFN); Antonio Domenico Russo (INFN-LNS);*

The upgrade of the Superconducting Cyclotron at INFN Laboratori Nazionali del Sud in Catania is aimed at improving its performance in terms of intensity of light ions, as well as in terms of reliability. The project was financed in 2019 by the Italian Ministry of University and Research. The Cyclotron was kept operative until the end of 2020, then in 2021 it was dismantled, so as to proceed with the upgrade. To get the expected improved performance as a result of the upgrade, a new extraction system will be installed to allow for extraction by stripping. The main components to be replaced are the super-conducting magnet, the liners, the dee cones, the trim coils power supplies.

The status of all the components of the Cyclotron is here described with particular emphasis on the design, construction and tests of the new superconducting magnet, which is the main and most challenging device in this upgrade operation.

MOBO02: Recent Upgrade of RCNP AVF Cyclotron

Tetsuhiko Yorita; *Yohei Matsuda; Hiroki Kanda; Mitsuhiro Fukuda; Yuusuke Yasuda; Takane Saito; Hitoshi Tamura; Tsun Him Chong; Hang Zhao; Ahsani Hafizhu Shali; Shotaro Matsui (Osaka University)*

The upgrade project of the RCNP K140 AVF cyclotron was initiated in 2019 to provide intense light-ion beams for the production of short-lived radioisotopes and high-quality, high-intensity beams for precision nuclear physics experiments. Except for the main coil, pole pieces, and yoke of the cyclotron magnet, most components were replaced with newly fabricated systems. In particular, the radio-frequency, injection, and extraction systems were redesigned to accommodate higher beam currents.

A new coaxial-type resonator was developed to cover 16 – 36 MHz, enabling the acceleration of standard ion species under harmonic modes of h = 2, 3, 6. The ion source acceleration voltage increased from 15 kV to 50 kV to enhance beam intensity and reduce emittance, improving injection efficiency. The central region was reconfigured to optimize beam transmission from the LEBT system. Beam commissioning commenced in 2022. A 28.5 MeV helium beam was successfully accelerated and is used to produce At-211 for targeted alpha-particle therapy. Light-ion beams have also been injected into the K400 ring cyclotron and extracted for nuclear structure studies. A 392 MeV proton beam is used to generate white neutron and muon beams. In 2024, heavy-ion acceleration resumed, and a variety of ion beams became available for research and applications. Efforts have also been made to improve operational stability and reliability.

MOBO03: Operation and Upgrades of Beam Diagnostics for Cyclotron Accelerators at HIRFL in Lanzhou

Yong Zhang; *Yongliang Yang; Jia yin; Lili Li; Jiajian Ding; Yuan Wei; ZhiXue Li; Ze Du (IMP)*

Although the cyclotron accelerators at HIRFL, namely the Sector-Focused Cyclotron (SFC) and the Separated Sector Cyclotron (SSC), are over sixty years old, beam commissioning continues to run successfully. The SFC, installed in 1962, can accelerate heavy ions to 17 MeV per nucleon or protons to 37 MeV, with an average current of 10 μA. The SSC (Sector-Separated Cyclotron), commissioned in 1975, serves as our primary accelerator. It is capable of accelerating ions to energies of up to 100 MeV per nucleon or protons to 110 MeV. We will present advancements in beam diagnostics designed to enhance machine operation efficiency and convenience, as well as to enable more precise and comprehensive measurements of beam parameters. The primary focus includes the development of key sensors and electronics tailored to meet the requirements for low-intensity current and transverse emittance measurements. Additionally, it presents the design and implementation of a beam diagnostics control system based on a cloud architecture, operating on a highly reliable server cluster. Native device control and data processing software run within virtual computers on the cloud platform, enabling comprehensive beam measurements including beam current, position， transverse profile, emittance, energy, and longitudinal bunch length. The system apples the EPICS communication protocol and features an integrated user control interface.

Session MOC

MOCI01: The Low-temperature and High-temperature Superconducting Cyclotrons Developed by CIAE in the Last Ten Years

***Tianjue Zhang**; Zhiguo Yin; Chuan Wang; the Project Team (CIAE)*

The cyclotron, which has been around for over 80 years, experienced a period of vigorous development in the last ten years due to urgent needs in multiple application fields, especially for ultra-compact, ultra-lightweight, and high-power cyclotrons.

Since 2013, a low-temperature 230MeV superconducting cyclotron CYCIAE-230 has been developed and successfully obtained the first beam at 231MeV in 2020, which is the first SC cyclotron in China. Currently, CYCIAE-230 has commenced industrialization in Chengdu, China, for proton therapy of cancer and proton irradiation of aerospace chips. Since 2019, a 100MeV high-temperature SC cyclotron CYCIAE-100B has been designed and is under construction now, which is the first try for iron-less, ultra-lightweight cyclotron development. In addition, CIAE started recently an ultra-compact, multi-particle (charge-to-mass ratio of 1:2) SC cyclotron project CYCIAE-36A, for accelerating α and H2+ beam. It will be used for production of 211At, the study of the effects of α irradiation on new materials and aerospace biological effects, and the large-scale production and stable supply of commonly used PET isotopes. Finally, we have been continuously optimizing the design of a 2GeV high-power, high-energy efficiency isochronous FFA proton accelerator CYCIAE-2000, and have been conducting necessary key technical research and engineering design verification, including the 1:4 FDF magnet based on high-temperature superconducting technology.

MOCO01: Design of the EcoCyclone Permanent Magnet Medical Cyclotron

***Alexander Herrod**; Eric Gravier; Frédéric Stichelbaut; Yves Claereboudt (IBA)*

We present the magnet design of an adjustable-field isochronous permanent magnet cyclotron concept, capable of accelerating protons to 18 MeV. Within the cyclotron, the permanent magnet is distributed about the cyclotron return yoke above and below the midplane in rotatable cones. With an outer radius of 1.36 m and height of 1.22 m, the design can replicate the field strength (up to 2.3 T peak) and pole gap of the IBA Cyclone(R) Kiube. We consider efficient application of permanent magnet material, and report the resulting, simulated magnetic field, RF frequency, rough estimate of total power and other properties of the machine. For use as a radio-pharmaceutical cyclotron, we find an 18F production target would cause much less activation in neodymium permanent magnets than in samarium-cobalt permanent magnets, resulting in a strong preference for using the former in such a cyclotron. The torque required to turn the permanent magnet cones to adjust the field is found to be below 2800 Nm, and no demagnetization due to applied magnetic field is expected for the case of neodymium magnets.

MOCO02: Enhanced Ion Beam Delivery Through AECR-U Upgrades at UMCG-PARTREC

Herman Kremers; *Alexander Gerbershagen; M.F. Lindemulder; H.A.J. Smit; Michel Hevinga (PARTREC)*

A series of upgrades were implemented at the AECR ion source at UMCG-PARTREC to improve ion beam performance. The focus was on increasing beam intensity, enhancing long-term stability, optimizing ion species control in cocktail beams, and identifying optimal RF injection frequencies for plasma heating. A key enhancement was the installation of an Einzel lens. This increased the transmission efficiency through the analyzing magnet from 50% to 76% for 23 kV helium beams. As part of the EUROLABS ERIBS collaboration, a novel ion beam monitoring system was developed. It visualizes and records beam intensity and stability in real time. The system uses a semi-automated feedback loop that exploits defects in ion-optical imaging to parasitically monitor the analyzed beam. The gas mixing system was upgraded with a third gas valve and improved control mechanisms. This allows precise and rapid tuning of the ion fraction in xenon-krypton-oxygen cocktail beams. A frequency scanning device was introduced to evaluate beam performance across RF injection frequencies from 12.75 to 14.2 GHz. It successfully identified regions of high intensity and stability. Together, these upgrades enable more reliable and tunable ion beam delivery for experimental applications.

Session MOP

MOP01: Conceptual Design of Central Region of PSC250 Superconducting Synchrocyclotron

Jingxia Gong *(IPP)*

PSC250 is a superconducting synchrocyclotron used for producing 250MeV protons for cancer therapy. It's the first superconducting synchrocyclotron developed by CIM (Hefei CAS Ion Medical and Technical Devices Co., Ltd.) for its advantages in small size and low cost. A new program named CIMSC has been developed especially for beam dynamics calculation in synchrocyclotrons from ion source to extraction region. Some detailed results have been introduced in this article, such as the central region electrodes configuration with a closed ion source, the ratios of captured and lost protons, good centering of protons, the profiles of RF frequencies vs time and magnetic field vs radius, and so on. Optimal central region for protons with the largest capture ratio and good centering has been designed which will be shown in below text.

MOP02: Design and commissioning of a 10 MeV cyclotron accelerator cooling system

Mohammad Yousefi Moghadam*; Hossein Afarideh; Masoumeh mohamadian; R Solhju (AUT)*
Mitra Ghergherehchi (Sungkyunkwan University)

The proposed cooling system is designed with a high reliability factor and considering the economic issues and costs based on the use of a 40 ton chiller for temperature changes of 4.5 to 10 degrees Celsius, which is able to continuously control the water temperature in this range. In this system, the parts of magnet coil, cavity, power transmission line, ion spring and radiofrequency current amplifier with an inlet water flow of 195 L/min are fed from an air-cooled chiller at a height of 40 m on the roof of the building along with a vertical industrial water pump of 4 KW and has been done in ANSYS software.

And using CST software, we showed the distribution of surface flow on the cavity and determined the hottest point of the cavity and used Solid Works software to geometrically model it. The magnet system was made up of hollow layer coils with a square outer cross-sectional area to the side of 10 mm and an inner cross-sectional area of a circle with a diameter of 5.7 mm, and for the power transmission line due to a change in the drampedance of 50 ohms when the temperature increased, the cooling system was used. In the PIG ion spring with a power consumption of 500 watt and the amplifier part of the water pressure limit lamp is set at 3.5 bar pressure for optimal cooling. In this study, practical solutions are presented in the optimal design and commissioning of the cyclotron accelerator cooling system.

MOP03: Preliminary Design of a Cyclotron Measurement and Control System with Distributed Acquisition/Control and Centralized Storage

Yong Zhang; *Xiao Dan (HIPS)*

To address the requirements of modern cyclotrons for high-precision, high-reliability, and high-scalability operation and experimentation, as well as to overcome the limitations of traditional centralized measurement and control systems—such as high single-point failure risks, poor scalability, and bottlenecks in mass data processing and storage—this paper proposes and preliminarily designs a hierarchical system architecture based on "Distributed Acquisition/Control + Centralized Data Management."

The system employs a unified underlying database framework, a unified timing system, and a unified time series as its software core. At the hardware level, a distributed network consisting of multiple acquisition and control nodes is constructed. These nodes are responsible for locally collecting real-time data from subsystems (e.g., magnetic field, RF, vacuum, beam diagnostics) and executing efficient local closed-loop control, with communication facilitated via high-speed Ethernet. At the software level, channel access protocols enable efficient and reliable data communication and interaction among distributed nodes.

MOP04: Uniformity design of large spot and high uniformity beam line

Jing Hu; *Xiaobo Li; Sumin Wei (CIAE)*

The 50 MeV medium-energy proton cyclotron device developed by China Institute of Atomic Energy provides important test conditions for space radiation environment simulation, space radiation protection design and application research. This accelerator fills the gap of proton and neutron irradiation test conditions in the energy range of 30 MeV to 50 MeV in China.

To provide a large-area and high-uniformity proton beam spot of 300 x 300 mm for irradiation tests, it is necessary to perform beam homogenization treatment to meet the requirements of irradiation area and uniformity simultaneously. To achieve both large beam spot and high uniformity, this paper compares schemes such as scanning magnets, beam expansion and scattering, and nonlinear high-order magnets. The design and beam dynamics simulation of the proton target station transmission system in the simulation experimental device are carried out. Through multiple beam transmission simulations with random errors, the uniformity of the beam reaches 90% under the condition of obtaining a 300 x 300 mm large beam spot. Finally, the scanning magnet scheme is selected as the most suitable beam homogenization scheme for this simulation device, and the overall design results of the beam transmission system are presented.

MOP05: Simulation Study on Beam Extraction Efficiency of HIRFL-SSC

MeiTang Tang *(IMP)*

The HIRFL-SSC employs a resonance free extraction method. In the h=4 mode, the larger turn separation allows for single-turn extraction and the extraction efficiency is high, whereas in the h=2 mode, the smaller turn separation results in lower extraction efficiency. To improve the SSC transmission efficiency, simulations were conducted to analyze the extraction efficiency and acceptance under two typical modes (h=2 and h=4). The calculations reveal that the beam size growth caused by the injection phase width is a critical factor limiting the SSC extraction efficiency. To enhance the extraction efficiency in h=2 mode, a simulation study was performed on off-equilibrium orbit injection to achieve “radial focusing” of large-phase-width ions. The simulation results demonstrate that this method can significantly improves the SSC extraction efficiency compared to the old extraction approach.

MOP06: The Extraction of Positively Charged Proton Beam from Cyclotron due to Energy Loss at the Degrader

Georgy Gulbekyan*; Ivan Ivanenko (JINR)*

For modern medical cyclotrons the acceleration of beams of negatively or positively charged protons is most widespread. As a rule, negatively charged ions are extracted from cyclotron by recharging on a thin carbon foil. It is a easy realization method. However, to produce negatively charged protons, a complex system of external injection is usually used. Besides, the effect of electromagnetic dissociation of an electron during acceleration limits the level of cyclotron magnetic field. Positively charged ions are produced by simple internal Penning type ion source and there are no limits in a magnetic field level. However, the extraction of such a beam from a cyclotron is possible only by a complex extraction system with an electrostatic deflector and passive or active focusing elements.

At the paper the extraction of positively charged proton beam by means of partial decreasing of energy at degrader are considered. The proposed method combines the positive features of described above schemes, such as easy of ions production, unlimitation of the magnetic field level and easy technical realization of extraction system. The obvious disadvantage of this method is the increasing of the beam emittance after passing through the degrader.

As an example, a three-sector cyclotron with a magnetic field level of 1 T to accelerate of positively charged protons to an energy of 15 MeV is proposed. The beam extraction is carried out due to 5 - 10% energy loss on a graphite degrader.

MOP07: The Feature of Magnetic Field Formation of Multipurpose U400R Cyclotron

Ivan Ivanenko; *Georgy Gulbekyan; Jozef Franko (JINR); Vladimir Kukhtin (D.V.Efremov Institute of Electrophysical Apparatus)*

At the present time, the activities on reconstruction of U400 to U400R cyclotron are carried out at the FLNR, JINR. The new multipurpose U400R cyclotron is intended for production of high intensity, up to 2.5 pmkA, beams of heavy ions from Helium to Uranium with mass to charge ratio A/Z= 4 - 12. The magnetic structure of the new cyclotron will provide a wide range of the magnetic field level from 0.82T till 1.82T what gives the smooth variation of accelerated beams energy 0.8 – 27 MeV/nucleon. For operational optimization of the magnetic field, the 11 radial and 2 pairs of harmonic correcting coils are used. The numerical formation of the magnetic field is carried out. The problems and solutions of U400R magnetic field design are described.

MOP08: Plasma-Assisted Neutralization in Axial Injection for High-Current Compact Cyclotrons

Chong Shik Park*(Korea University Sejong Campus)*

High-current compact cyclotrons face strong space-charge limitations during axial injection, where the low-energy proton beam expands before reaching the inflector. We present a novel plasma-assisted neutralization module designed as a drop-in element between the final solenoid and the inflector entrance. The device consists of a short solenoid surrounding a beamline cell operated at controlled pressure. Residual hydrogen gas (H_2) or an injected noble gas (Kr) is ionized by the high-current proton beam to form a self-sustaining plasma column. Biased end-electrodes confine electrons and accelerate neutralization, achieving effective space-charge compensation. Krypton seeding provides a faster build-up of neutralization relative to H_2, enabling rapid stabilization for pulsed or ramped operation. Simulations and analytic estimates indicate that neutralization substantially reduces transverse beam blow-up while introducing only modest multiple scattering over the short transport distance. The concept offers a compact, plasma-based method to increase capture efficiency for milliampere-class proton beams and provides a tunable platform to investigate plasma–beam interaction effects in cyclotron injection lines. Initial design parameters, integration strategy, and predicted performance are presented.

MOP09: Results and Developments of PEPITES, a Transparent Profiler based on Secondary Electrons Emission for Charged Particle Beams.

Christophe Thiebaux*; Alexandre Esper (LLR) Lorenzo Bernardi; Rémi Duhamel; Franck Gastaldi; Rémi Guillaumat; Marc Verderi (LLR, CNRS-Institut Polytechnique de Paris) Marco Donetti; Alessio Mereghetti; Marco Pullia; Claudio Viviani (NCOH) Olivier Gevin (CEA Paris-Saclay - Etablissement de Saclay) Charbel Koumeir (GIP Arronax);*

The PEPITES profiler was originally designed for continuous operation on medium-energy (O(100 MeV)) charged particle accelerators. Its ultra-thin structure relies on secondary electron emission (SEE) to generate signals. It has successfully measured the positions and profiles of various hadron beams across a wide dynamic range. This innovative device consists of 50 nm gold strips deposited on a radiation-resistant polyimide substate. Secondary electrons emitted from the strips gold surface form the signal. Thanks to the high linearity of the SEE, the profiler enables accurate characterization of continuous beams as well as pulsed beams across a wide dynamic range, without the saturation effects commonly observed in other detectors. Additionally, the design minimizes beam perturbation while ensuring excellent durability, even under demanding operating conditions.

A first PEPITES prototype was installed and has been routinely used at ARRONAX to measure beam profiles of 70 MeV proton beams in both continuous and pulsed delivery modes. Furthermore, preliminary tests conducted at the CNAO** hadron therapy center with therapeutic-energy protons and carbon ions have produced promising results, confirming the device's compatibility with a broad range of beam types, energies and intensities. These results position PEPITES as a promising and transformative solution for beam monitoring in both current and next-generation hadron beam facilities.

MOP10: A new high current power supply for the main cyclotron magnet at NHS

Miguel Pretelli *(OCEM Energy Technology) Filippo Burini; Marco Farioli (ENERGY TECHNOLOGY Srl) Peter Corlett; Riccardo Casalini; Stephen. R. Elmer (The National Eye Proton Therapy Centre Clatterbridge Cancer Centre NHS Foundation Trust)*

This study presents the design and development of a new power supply intended to provide a highly stabilized current, serving as a replacement for an existing linear converter used in the main magnet of the NHS cyclotron. The power supply is capable of operating in DC mode with currents reaching up to 900 A. It employs a proven modular design approach, previously implemented in other cyclotron facilities, featuring a 12-pulse input rectifier and a single DC link that powers a DC/DC chopper module. This paper outlines the design phases and simulations conducted, along with a comparison to field tests performed since its installation in the third quarter of 2024.

MOP11: Reaccelerating Muons at PSI

Andreas Adelmann*(PSI) Daniel Winklehner (MIT) Pedro Calvo (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas)*

Muon beams are powerful research tools with applications in both particle physics and condensed matter physics. However, surface muon beams suffer from high emittance. Several facilities (PSI, RAL, J-PARC) are developing cooling devices to mitigate this issue, but these devices inevitably reduce the beam's kinetic energy. To address this challenge, the project explores a compact muon cyclotron design, adapted from the IsoDAR project, to reaccelerate muons emerging from the Mu-Cool device. Preliminary OPAL simulations show promising results.

MOP12: Injection And Central Region Design of LB-30TP Cyclotron

Chen Zhang*; Gang Zhang; Guojian Su; Hua Yuan; Jie Li; Jinshui Shi; Ruili Ma; Yang Du; Yuhang Chen; ZHEN SHEN (Sichuan Longevous Beamtech Co., Ltd) Xiaozhong He (IFP)*

Sichuan Longevous Beamtech is currently developing a new tri-particle cyclotron LB-30TP. The LB-30TP cyclotron is designed to be able to accelerate protons(H-) between 13 and 35MeV, deuterons(D-) between 6.5 and 17.5MeV, and alpha particles (He2+) up to 30MeV.

The proton and deuteron beams are generated by a multi-cusp ion source, while the alpha particle beams are generated by an ECR ion source. These two ion sources are located on two sides above (or below) the cyclotron, and the ion beams extracted from them are both transported through a primary focusing solenoid and combined by a dipole before entering the injection beam line. The injection beam line consists of a quadrupole triplet, a steering magnet, a solenoid and a quadrupole doublet, and the matching between the beam emittance and the acceptance at the entrance of the spiral inflector is achieved by optimizing the parameters of these magnetic components. The spiral inflector and the central region electrodes are optimized to achieve high injection efficiency and good orbit centering.

MOP13: Design of Magnetic Field Measurement Device and Research on Magnetic Field Shimming for 50MeV Proton Cyclotron

Fei Wang ***(****China Institute of Atomic Energy****)***

In order to achieve the magnetic field measurement work for the 50MeV proton cyclotron irradiation device, a fully automatic magnetic field measurement device based on the Hall effect method is designed, using non-magnetic materials G10 and PEEK with high strength and wear resistance, optimizing the gear ratio, reducing the weight of the device, and adjusting the magnetic field measurement process to shorten the measurement cycle. The installation accuracy of the magnetic field measurement device reaches ±0.03mm, and the installation accuracy of the shims after adjustment is as high as ±0.02mm. By using a specific shim positioning tool, the shim adjustment accuracy reaches ±0.02mm. Ultimately, through the use of this new magnetic field measurement device, five magnetic field measurements and four high-precision shimming operations have been carried out, successfully completing the magnetic field measurement work of the 50MeV proton cyclotron and achieving good results. The isochronism goal of integral slip phase not exceeding ±10° was achieved, meeting the physical design requirements of the 50MeV proton cyclotron. From the facility commissioning to the customer's experiment, it only took 15 days. During the 12-hour performance test, all systems operated stably without errors, demonstrating the excellent magnetic field performance of the accelerator and proving the importance and accuracy of the magnetic field measurement device and shimming.

MOP14: A General-Purpose, Parameterized Magnetic-Field Measurement and Control System for Cyclotrons

Haoran Fu*; Zhiyu Wang; Huina Meng; Gangjia Zhai; Xiaotong Lu (SPIC Nucreation Technology Company Limited)*

To address the demands for extensive customization, high measurement throughput, and stringent control accuracy in cyclotron magnetic-field measurement and control, this paper presents a general-purpose, parameterized system. The hardware platform is centered on a Beckhoff PLC, integrating I/O, encoder, and serial-communication modules, and supporting both EtherCAT-based stepper and servo motor drives. On the software side, a C# host application communicates with the PLC in real time via the ADS protocol, and is compatible with magnetic-field mapping apparatuses in both Cartesian and polar coordinate frames, providing real-time monitoring and visualization of all motion-control and field-related parameters. The system offers flexible, parameter-driven configuration that covers core settings for measurement and motion control. The proposed solution has been thoroughly validated on cyclotrons of multiple energy classes at China's State Power Investment Corporation (SPIC), demonstrating stable and reliable operation. In particular, under servo-drive mode, fully closed-loop control delivers rapid response, significantly improving positioning speed and control accuracy and substantially reducing magnetic-field measurement time.

MOP15: An 85MHz-133.5MHz broadband radio frequency power source for synchrocyclotrons

Zhiyu Wang; *Yusong Chen; Gangjia Zhai; Yalong Wu (SPIC Nucreation Technology Company Limited)*

In the operation system of a synchronous cyclotron, a broadband high-power RF power source plays an extremely important role. The RF power source is responsible for generating and providing high-frequency alternating electric fields, continuously injecting energy for particle acceleration. Its performance directly determines the acceleration efficiency, beam quality, and operational stability of the accelerator. This article introduces a broadband RF power amplifier with a frequency range of 85-133.5MHz. It has a 15kW RF power output capability and good in band flatness. It has complete functions for incident and reverse power detection, as well as standing wave ratio protection, over reflection protection, and over excitation protection. The human-machine interface is friendly, making it a mature power amplifier.

MOP16: Parameter Analysis and Optimization for Ion Source of Accelerator

Guangzhao Huang; *Xuebao Chen (Shandong University; IANS) Qi Yang; Wen Wang; Consortium FDS(IANS)*

Ion source is an important subsystem in accelerators, which employ electromagnetic fields to accelerate charged particles to generate ion beams. Accelerators are essential facilities for advancing multidisciplinary research and developing technological applications, such as production of medically relevant radioisotopes and ion beam irradiation of cyclotrons. Among the various ion source technologies, the 2.45 GHz ECR (Electron Cyclotron Resonance) ion source demonstrates significant potential due to its ability to generate dense plasma and deliver high beam current. To systematically investigate and optimize its performance, coupled numerical simulations were used to analyze the key parameters of both the plasma chamber and the extraction system, and get the results of plasma density, ion fraction, beam current and quality. With the optimized design, the current increases by 42.4%, the emittance decreases by 21%, and the beam spot decreases by 32.9%, meeting the requirements of accelerating structure, and providing important theoretical data for the beam commissioning. This work also offers some critical insights for the development of high current, low emittance, and high stability ECR ion sources.

MOP17: Secondary Electron Suppression Analysis in Accelerator Based Neutron Source

Xuebao Chen*; Guangzhao Huang (Shandong University; IANS) Wen Wang; Qi Yang (IANS)*
FDS Consortium

Accelerator based neutron sources generate a large number of secondary electrons during operation. For example, secondary electrons generated by cyclotrons will change the spatial distribution of the beam and reduce the stability of the beam. Secondary electrons generated by neutron generators will flow back to the ion source, increase the load of the high-voltage power supply, and affect the safety and stability of the equipment. For neutron generators, this paper uses numerical simulation methods to study the impact of different electric field parameters on secondary electron suppression. The results indicate that when the target voltage is fixed at 120 kV and the bias voltage changes from 600 V to 900 V, the target current decreases from 41.6 mA to 30 mA, indicating that the secondary electrons are completely suppressed. Meanwhile, when the bias voltage is set to 600 V, the target current increased from 30 mA to 41.5 mA as the target voltage was raised. Additionally, a greater inclination angle of the acceleration electrode and a closer baffle to the target can be also effective for the suppression of secondary electrons, the target current decreased from 41.6 mA to 38.2 mA when the inclination angle increased from 84º to 96º, furthermore, the lowest target current could be obtained at the inner baffle distance of 20 mm. This work provides theoretical guidance for the optimization of accelerator neutron sources.

MOP18: Thorium-based Molten Salt Fast Energy Amplifier Reactor-accelerator Coupling and Beam Window Design

Hao Li*; Tianyu Ma; Yuchen Liu; yu zhang; zijian zhang; ziyuan lin; zuokang lin (SINAP) Weishi Wan (QSC of GBA)*

As a fourth-generation nuclear reactor concept, molten salt reactors (MSRs) have unique advantages in safety, economy, and nonproliferation, but online fuel salt treatment remains immature. To avoid complex online fuel treatment, the Thorium-Based Molten Salt Fast Energy Amplifier (TMSFEA) concept was proposed. Compared with traditional Accelerator-Driven Subcritical (ADS) systems, the TMSFEA reactor operates at a higher temperature (over 600 ℃), which enables higher thermal efficiency but also imposes stricter requirements on reactor-accelerator coupling design. Thus, a study on TMSFEA's reactor–accelerator coupling design was conducted: the beam window was isolated from liquid molten salt, with a 2-meter-long helium column inserted between them for protection at standard atmospheric pressure. A beam window structure was designed, featuring single-layer films on both sides and a double-layer film with cooling water flow in the middle, and the effects of parameters like film radius and thickness on the proton beam window's temperature rise and thermal stress were analyzed. After optimization, the beam window film's maximum temperature and thermal stress were 42.5 ℃ and 66.4 MPa, respectively. FLUKA was used to analyze the beam window's radiation damage. Under 1 GeV/4 mA beam current and one-year continuous operation, the calculated value of DPA per year is 0.008 DPA. The safe operating life of the beam window exceeds the 39-year safe operating life of the TMSFEA.

MOP19: Magnetic Field Design and Uniformity Control for Isochronous Multi-Plane Cyclotron Orbits under a Common Magnet System

Zi-Feng He *(SINAP)Wei-Shi Wan (QSC of GBA)*

In pursuit of enhanced beam current and spatial efficiency in high-intensity cyclotrons, this study investigates a novel accelerator concept: the use of multiple axially separated orbits (multi-plane) operating under a common magnet system. A key challenge in such a configuration is maintaining isochronism across distinct axial planes, which critically depends on the uniformity of the magnetic field in the vertical z direction. This work presents a theoretical framework and numerical modeling approach to quantify the magnetic field uniformity requirements necessary to preserve isochronous conditions for multi-plane orbits.

Using COMSOL Multiphysics, we construct a parametric 3D static magnetic field model of a symmetric dipole magnet, incorporating realistic pole shapes and excitation coils. Field distributions are evaluated on three parallel orbit planes (z = −Δz, 0, +Δz), and the deviation of magnetic induction δB(z)=(Bz−B0)/B0 is analyzed as a function of radius. Based on classical isochronous criteria, a quantitative threshold for the vertical field gradient ∂B/∂z is derived to ensure phase stability within $\pm 10^{-3}$ relative deviation. This study provides design guidelines and performance limits for implementing synchronized multi-plane orbit systems within a single magnet, offering a pathway toward compact, high-current cyclotron architectures.

MOP20: Development of a 100 MeV Proton Cyclotron for Multi-disciplinary Research at Harbin Institute of Technology

Bowen Bai*; Tao Yu; Yifan Huang; Lin Zhao; Xuesong Leng (SGC,HIT) Liangchao Zhao (HIT);*

Recently, the Special Environmental Science and Application Infrastructure for Materials and Devices (SEMD), proposed by Harbin Institute of Technology (Shenzhen), has commenced construction. It is dedicated to investigating the mechanisms governing the influence of special service environments on materials/devices. Within the SEMD facility, a medium-to-high-energy Proton Irradiation Research System has been initiated. It aims at creating a multi-disciplinary R&D platform and bringing together various scientific communities around a high-intensity isochronous cyclotron with beam energies up to 100 MeV (upgradable to 150 MeV). A compact cyclotron scheme for accelerating H- ions with four straight sectors has been adopted. Its magnet is designed to have a height of approximately 2 meters and a radius of around 3 meters, with a maximum magnetic field of 1.4T. Two half-wave RF cavities are installed in the valley regions of the magnet, and its working frequency is around 45.7 MHz. H- beams will be accelerated and then extracted via carbon stripping foils. By optimizing their positions, we hope to obtain proton beams with energies varying from 30 MeV to 100 MeV. A multi-cusp ion source has been selected in order to get a high beam current at the experimental terminals. The output intensity is designed to be 500 μA in maximum and the intensity required for stable operation is about 150 μA. In the main text, we will introduce the preliminary design work completed so far.

MOP21: Impact and Mitigation of Fringe Field Effects in Magnetic Lens Systems for Proton Radiography

Shuangxin Li*; Kuanjun Fan (HUST) JinRong Lu; Shizhong An; Xiaobo Li (CIAE)*

The fringe field effect is a critical factor limiting the imaging accuracy of proton radiography magnetic lens systems. The nonlinear magnetic fields it introduces cause the actual transfer matrix to deviate from the ideal model, leading to discrepancies between beam optics designs based on traditional hard-edge models and real beam behavior. Based on the 18 MeV proton radiography experimental platform, this work investigates precise characterization and suppression methods for edge field effects in magnetic lenses. First, pole-face shimming and end-shaping techniques are employed in magnet design to effectively reduce higher-order harmonic components and enhance magnetic field uniformity. Second, a three-dimensional Enge coefficient fitting method is applied to accurately describe the edge field distribution, which is then incorporated into beam-matching software. Based on this, with point-to-point imaging as the optimization objective, the structural parameters and gradient settings of the quadrupole magnets were systematically optimized. Finally, full-scale particle-tracking simulations verify the effectiveness of the proposed design, achieving high-precision proton radiography magnetic lens systems under realistic fringe field conditions. This study provides essential technical support for enhancing the performance of proton radiography systems.

MOP22: Design and optimization of scanning magnets for BNCT facility

Yiping Liu*; Qushan Chen; Qin Bin; Xu Liu (HUST) Liucheng Wang; Wei Wu (Centuray Technology Co., Ltd.)*

Boron Neutron Capture Therapy (BNCT) is a cell-level precision-targeted therapeutic modality. Huazhong University of Science and Technology is currently developing a cyclotron-based BNCT facility in collaboration with partners. This paper reports the design of a scanning magnet system for beam spreading of protons extracted from the cyclotron. By employing two scanning magnets to continuously scan the beam in the horizontal and vertical directions, a flat-topped square scanned beam intensity distribution of 70mm×70mm with uniformity exceeding 90% is achieved on the target, thereby mitigating excessive thermal loading. Following the completion of the lattice layout and physics design of the scanning magnet system, particle tracking simulations are carried out to validate the effective beam deflection on the target under various magnetic field strengths. In addition, the alternating excitation frequency of the horizontal scanning magnet reaches up to 200Hz. Transient electromagnetic analysis is employed to evaluate the integral field error induced by eddy current as well as the variation of integral field homogeneity within the good-field region. Furthermore, steady-state thermal analysis is performed to investigate the temperature distribution caused by eddy current losses and to devise an appropriate cooling scheme. The design and optimization of slits are conducted according to the maximum temperature of the magnet yoke.

MOP23: Effects of Low to Medium Dose Proton Irradiation on Gut Microbiota in BALB/c Mice

Zirui Chen*; Wangcai Ren; Li Sui [1]; Qiaojuan Wang [1]; Yue Wang [1]; Jiancheng Liu (CIAE)*

Proton radiation dominates space radiation (~90%) and threatens deep space missions, yet its effects on gut microbiota at mission-relevant doses (0.1-1 Gy) are unclear. This study assessed impacts in BALB/c mice exposed to whole-body proton irradiation (0, 0.1, or 1 Gy; 100 MeV cyclotron). Fecal samples (day 3 post-irradiation) underwent 16S rRNA sequencing. Results revealed a dose threshold: 1 Gy induced significant structural remodeling, marked by increased Firmicutes (56.93% vs. control 32.23%), decreased Bacteroidetes (3.95% vs. 27.95%), a 116% higher Firmicutes/Bacteroidetes ratio, and enrichment of biomarkers Lachnospiraceae NK4A136 (LDA=4.2) and denitrifiers (LDA=3.8). Conversely, 0.1 Gy caused minor changes (Rikenellaceae, LDA=3.5; Odoribacter, LDA=3.3). Critically, 1 Gy enhanced alpha diversity (Chao1 +15-20%, Shannon +11.3%; $p<0.05$) and altered beta diversity ($R^2=0.251$-0.361, $p<0.05$) versus controls. Functional prediction (PICRUSt2) identified disruptions in cellular processes/signaling ($p=0.0133$), poorly characterized pathways ($p=0.0298$), ABC transporters (K03088, $p=0.021$), and fatty acid metabolism (K02003, $p=0.045$). These findings demonstrate that gut microbiota exhibits differential dose-response patterns to proton radiation, which provide both reference biomarkers and mechanistic insights for evaluating astronaut intestinal health risks and developing microbiota-targeted countermeasures during deep space missions.

MOP24: The performance research of the Beam Shaping Assembly (BSA) materials used for BNCT based on the cyclotron

Lu Lu*; Shizhong An; Fengping Guan; zhe wang (CIAE)*

Cancer has become one of the important factors threatening human life and health, and methods for treating cancer are constantly being studied and explored. It is an urgent demand in the healthcare to treat cancer by rays. Boron Neutron Capture Therapy (BNCT) is given increasing amount of attention due to its ability of selective cancer cell killing. The BNCT neutron source based on the 18 MeV/1 mA cyclotron is researched. To improve the flux of the epithermal neutrons, simultaneously reducing fast neutron dose as much as possible, this paper studies the generation and transport of neutrons in the Beam Shaping Assembly (BSA) of the BNCT. By comparing reaction cross sections (including neutron multiplied reaction, neutron inelastic scattering and neutron elastic scattering) of different materials, the materials of neutron multiplier and neutron moderator are researched. In this study, Be is chosen as the target to produce neutron by 9Be(p,n)9B reaction. Pb is chosen as neutron multiplier. LiF or MgF2 is chosen as neutron moderator. Ni is chosen as fast neutron filtration material. The neutron yield can achieve 5.25×10ˆ13 n/s. The epithermal neutron flux is 2.92×10ˆ9 n/cm2/s, with the fast neutron dose of 5.87×10ˆ-13 Gy • cm2 per epithermal neutron.

MOP25: The effect of different doses of proton radiation on the transcriptomic profiling of vascular endothelial cells

*Li Sui; Qiaojuan Wang; **Zhihao Huang**; Jiancheng Liu; Yue Wang (CIAE)*

With the development of the aerospace industry, the duration of astronauts' stay in space has significantly increased, and space radiation has become one of the major threats to their health. Vascular endothelial cells are relatively sensitive to ionizing radiation, and their dysfunction is closely associated with the occurrence of cardiovascular diseases. Currently, the damage mechanism of proton radiation to organisms, especially to the cardiovascular system, remains unclear. In this study, human umbilical vein endothelial cells (HUVEC) were used as the research object. Relying on the 100 MeV proton cyclotron at the China Institute of Atomic Energy, HUVEC were irradiated with protons at four doses of 0.25, 0.5, 0.75, and 1 Gy. The effects on the results of cell transcriptional sequencing in each dose - group were detected and analyzed. Differential gene expression analysis showed that the number of differentially expressed genes increases with the rise in dose. GO and KEGG enrichment analysis results indicate that at the 0.25 Gy dose, cells exhibit a pro-inflammatory and anti-inflammatory balance. At the 0.5 Gy dose, inflammatory responses remain enriched while the necrotic apoptosis pathway is activated. At the 0.75 Gy dose, immune-inflammatory dysregulation occurs. At the 1 Gy dose, immune-inflammatory dysregulation intensifies alongside DNA damage enrichment.

MOP26: FLUKA based Monte Carlo Simulation of the South African Isotope Facility

***Hugo Barnard**; Philip Beukes (iThemba LABS)*

The South African Isotope Facility (SAIF) is a recently commissioned radioisotope production facility located at iThemba LABS in Cape Town. It is based around a C70 cyclotron from IBA, and contains four beam lines with target stations, of which two can be bombarded simultaneously. This article describes and discusses the radiation shielding simulations performed with FLUKA in the design of SAIF, and compares the predictions to actual measured values obtained during commissioning of the facility. This includes the effect of multi-layered target stations, temporary stacked brick shielding, concrete walls and vaults, access labyrinths, air ducting labyrinths and interlocking concrete roof beams.

MOP27: Feasibility Study on the Further Miniaturization of AVF Cyclotrons

Hiroshi Tsutsui; *Yuta Ebara (SHI)*

The use of AVF cyclotrons for proton therapy in hospitals has been on the rise in recent years. However, further miniaturization is essential for wider adoption. Our company has previously succeeded in reducing the size of conventional AVF cyclotrons for proton therapy to approximately 60% of their original dimensions by implementing superconducting technology. While synchrocyclotrons are relatively easy to miniaturize, AVF cyclotrons offer the advantage of continuous beams with high average beam current. This contributes to shorter treatment times, enabling less burdensome therapy for patients.

In this report, we present the results of a physical study on further miniaturization of superconducting AVF cyclotrons, focusing on aspects such as isochronism and beam extraction.

MOP28: Design of a Metamaterial-Based Cavity Beam Detector for Cyclotron-Based Proton Therapy System

Yuexin Lu; *Jun Yang; Kuanjun Fan (HUST)*

Cyclotron-based proton therapy systems have become the mainstream equipment in modern radiation oncology. Their therapeutic efficacy critically depends on the precise control of key beam parameters such as intensity and energy. In clinical applications, energy modulation is typically achieved by a degrader. However, it inevitably induces large dynamic fluctuations in beam intensity. In addition, long-term operation of the accelerator often introduces thermal drifts, which lead to undesired energy instabilities. Thus, high-precision, real-time beam diagnostics and feedback control technologies are essential for accurate dose delivery in proton therapy.

To address this, we propose a re-entrant resonant cavity detector based on metamaterials. This design enables flexible electromagnetic parameter engineering and internal field reconstruction. It reduces operating frequency, enhances field confinement and achieves miniaturization while maintaining a high-quality factor. Theoretical and simulation results confirm a uniform central electric field distribution with superior amplitude resolution over conventional cavities. The detector supports high-precision diagnostics under large beam variations and enables synchronous, real-time monitoring of bunch phase, intensity and energy. This work demonstrates the feasibility of metamaterial-based compact cavity detectors for medical accelerators, promising enhanced robustness in clinical proton therapy through accurate beam monitoring.

MOP29: Advances in Simulation Tools and Cyclotron Projects at Lanzhou University

Yongquan Wang; *Guan Wang; Jinbiao Zhang; Jing Qiu; Long Gu; Meilou Liu; Qijian Chen; Xin Huang; Xingkang Su (Lanzhou University)*

This paper summarizes recent progress in cyclotron research and development at Lanzhou University. In computational physics, a comprehensive time-domain beam dynamics code, RAYS, has been developed that solves the Newton-Lorentz equation using 4th or 5th order Runge-Kutta integrators to simulate particles from injection to extraction. RAYS supports synchrocyclotron modeling with a time-varying RF frequency module and facilitates automated design workflows via both GUI and console modes. Additionally, a high-stability closed-orbit analysis program RSCYC has been created. It employs a multi-scale coarse scanning method combined with the Adam optimization algorithm and symmetry constraints to ensure rapid, stable convergence to physical solutions. The numerical accuracy of these codes has been validated through cross-verification with mainstream programs.

Leveraging these in-house dynamics programs, several cyclotron projects are under development. For hadron therapy, the 230 MeV superconducting isochronous cyclotron (SC230) has entered the full production phase, with some systems already mechanically fabricated. Meanwhile, the comprehensive physics design and dynamics analysis for the 210 MeV superconducting synchrocyclotron (S2C210) have been completed. For isotope production, the 8 MeV proton cyclotron (Smart8) is also in full production, while the physics design for the 30 MeV alpha cyclotron (Smart30α) has been finalized.

MOP30: Electron Accelerator-Based Co-Production Method for Multiple Medical Isotopes via Molten Salt Targets

Junze Lin; *Xiaoxiao Li; Deyang Cui; Chenggang Yu; Jianhui Wu; Jingen Chen (SINAP) Ruidi Yuan (Henan Normal University)*

Medical radioactive isotopes play an increasingly critical role in nuclear medicine. Accelerator-based production of medical isotopes offers advantages including simplified regulatory approvals, operational flexibility, system safety, and lower costs, making it an important production method. This study proposes a multi-isotope co-production system utilizing electron accelerators. The methodology employs direct electron beam irradiation of molten salt targets, obviating the use of conversion targets, thereby improving beam utilization efficiency. The unique flow characteristics of liquid molten salt targets provide superior thermal management capabilities, effectively addressing heat dissipation limitations of solid targets while enabling continuous online extraction potential. Compared to solid target systems, the liquid target system significantly simplifies target fabrication procedures. Additionally, this methodology allows simultaneous production of multiple medical isotopes through compositional adjustment of the molten salt, improving production efficiency. This study employed FLUKA Monte Carlo simulations to optimize the structural parameters of the molten salt target and evaluate the yields of medical isotopes. The results revealed that the saturation yields of the target medical isotopes reached: Tc-99m (48.77 Ci), Mo-99 (55.77 Ci), I-131 (17.41 Ci), and Sr-89 (8.35 Ci). This method provides a new approach and reference for the production of medical isotopes.

MOP31: INFN-LNS Superconducting Cyclotron upgrade: Magnetic field mapping results

Antonio Domenico Russo; *Carmelo Manna; Danilo Rifuggiato (INFN-LNS) Giorgio Mauro; Mario Maggiore (INFN) Pasquale Fabbricatore (INFN-SG)*

The upgrade of the Superconducting Cyclotron at INFN Laboratori Nazionali del Sud in Catania is aimed at improving its performance in terms of intensity of light ions, as well as in terms of reliability. In the framework of the upgrade, a key milestone has been the magnetic field measurements of the new superconducting magnet, with the following goals: a) to implement a measurement procedure able to quantify and correct errors due to coils misalignment; b) to validate the field quality in the symmetry plane evaluating the differences between the measured and theoretical values.

The measurement procedure started in February 2023 at ASG Superconductors company. The first measurement campaign was performed with coils at room temperature: it was necessary to align them with respect to the ideal symmetry plane minimizing the undesired field harmonics contents. Moreover, a post-processing tool has been developed to obtain the best coils centering. The second phase has been performed considering the same measurements set with the coils operating inside the cryostat filled with liquid helium at 4.2 K. The magnetic measurements mapping data are here presented.

MOP32: Collimator design in the injection line of the ARRONAX C70XP cyclotron

Teddy Durand; *Xavier Goiziou (GIP Arronax) Freddy Poirier (Cyclotron ARRONAX) Basile Madiot; Meriadeg Guillamet; Théo Bigourdan (LPSTA)*

A low energy collimator is being designed for the injection line of the C70XP cyclotron at Arronax. The context of its conception follows the studies that were performed with an Allison emittance-meter and several simple collimators*. The studies show the presence of offset beams, beamlets and hollow beams inside the injection line. The new dedicated collimator, based on four independent and adjustable slits, is planned to allow selection of the transverse geometry of the beam. The design of the collimator is constrained by a number of considerations, including spatial limitations, beam power, electronic perturbation, and radiation. These considerations are taken into account to ensure that the collimator does not cause any disruption to other nearby systems.

The primary objective of the collimator is to be robust and to allow for electric measurements. The collimator will be used to conduct a study on the potential optimization of the transmission from the injection line to the target, as well as the beam shape. In order to achieve these objectives, it is imperative that the collimator performs precise displacement and precise electrical measurements. The motor control and electrical measurement functions will be integrated into the EPICS environment. The paper presents the advancement of the project and also the initial results of the bench prototype control system.

MOP33: Compact Beam Energy Monitor for Cyclotrons

Zoltán Kormány *(HUN-REN)*

Determining the energy of cyclotron beams is challenging. Calculating it from the machine settings typically results in an error of several percent. Higher accuracy requires measurement, but each developed measurement system has disadvantages: either the space requirement is large, the unit is destructive, or the signal evaluation is complicated. The Beam Energy Monitor (BEM) was designed to provide an ideal solution: compact size, non-destructive sensors, low energy consumption and user-friendly operation. This was achieved by developing an innovative sensor unit*, which enables accurate time-of-flight measurements on an extremely short flight path. The unit's signal is acquired and processed digitally. Various digital signal processing methods were evaluated using simulated probe signals to determine the most effective method of measuring time difference between pulses. The signal processing was tested using pulses from a generator. The results show that time measurements with an absolute error of less than 1 ps were achieved. The accuracy of the complete system during practical operation was also investigated. Neutron threshold reactions showed that the measurement accuracy is at least one order of magnitude better than the calculated energy value accuracy. The prototype unit was developed for the cyclotron at the HUN-REN Institute for Nuclear Research. Installed in the main beamline, it can monitor the beam energy continuouslyand independently from the beamline in use.

MOP34: Upgrade of RF Control System for the K-800 Superconducting Cyclotron al INFN-LNS

Alberto Longhitano*; Antonino Sparta'; Luca Platania (INFN-LNS)*

The INFN-LNS is proceeding with the upgrade of the Superconducting Cyclotron, the final goal is the increasing of extraction efficiency to reach a beam power up to 10 kW. RF systems are also undergoing significant changes through several upgrades. The new control system architecture presented will be able to manage the LLRF system, HLRF devices, and beam pulsing systems on a single hardware platform. The new software allows for a more accurate management of all the RF parameters and a centralized control of the peripheral devices. This structure will be capable of enabling at the same time: control of cavity phase/amplitude/tuning loops, monitoring of power amplifier parameters, protection and fault diagnosis, and integration with various acquisition and measurement systems. A new Reference Master Clock Oscillator and RF Signal Distribution are almost completed. The Power Amplifiers and the drive systems involved in the tuning and coupling of the resonant cavities have undergone substantial refurbishment. All these changes will be detailed and compared to the previous systems.

MOP35: Digital Soft Square Wave Generator

Sepehr Farid; *Christian Wolf; Jasmin Walk (HS Coburg)*

This research focuses on making compact cyclotrons genuinely reconfigurable without hardware changes (matchbox) with digitally timed, wide-range RF/voltage source.

We propose a concept that introduces a digitally agile acceleration-voltage source that replaces an analogue sinusoidal RF drive with a programmable, soft-edged square-pulse waveform. The Digital Soft Square Wave Generator (DISWAG) approach utilizes an FPGA-driven logic unit and a high-frequency Class-D power stage to generate precisely timed voltage pulses, leveraging Zero-Voltage Switching (ZVS) to minimize switching losses alongside a custom-made transformer. This concept allows for the generation of a nearby rectangular signal which further optimizes the performance.

Key design targets include operation in the low MHz range (around 2-4 MHz acceleration frequency) and kilovolt-level output to match the needs of multi-keV compact cyclotrons. Initial simulations and GaN transistor tests have affirmed the feasibility of this approach, demonstrating stable MHz switching with lower thermal losses. The digital waveform can be retuned during functionality to accommodate different isotopes and beam conditions.

MOP36: RF Cavity Design of a High-current H2+ Small Cyclotron

Yaqing Wang; *Bin Ji (CIAE)*

A new technology research of a high-current H2+ small cyclotron is in progress at China Institute of Atomic Energy. The cyclotron is designed based on a RFQ injection line, which is expected to break through the current limit of the small cyclotron and bring the current of the small cyclotron to above 3mA. This project is designed to achieve a particle energy of 10MeV, and the theoretical design of each system has been completed, preparing to enter the manufacturing stage. This paper mainly introduces the design and research work of the radio-frequency cavity. In order to increase the energy gain per circle to reduce the beam loss, we choose the fourth harmonic, four cavities scheme. Each cavity is a half-wave coaxial resonator, and the four cavities are in the same phase. In order to reduce the complexity of the system, we use a single transmitter to drive the four cavities, and the four cavities are connected together through the head of the Dee-plate. This paper expounds the simulation process of the electromagnetic field of the cavity, the optimization process, and the multi-physics coupling analysis of the cavity. The final resonant frequency of the cavity is designed as 36.5MHz, and the quality factor is 5000. The acceleration voltage of the cavity gap is 40kV on average， and the total power loss of the four cavities is 18kW. The design results of the cavity meet the technical requirements， laying the foundation for the construction of project.

MOP37: ZycloSim 2000 – A Simulation Program for Ion Dynamics in a Classical Cyclotrons

Christian Wolf; *Jasmin Walk (HS Coburg)*

We present ZycloSim 2000, a software package developed to simulate the motion of ions in a classical, non-relativistic cyclotron. The program is primarily designed for educational purposes and is employed in workshops and laboratory courses to illustrate cyclotron dynamics and to investigate the resonance condition in detail. The code allows the user to adjust a wide range of parameters, including ion species, magnetic flux density, and the frequency and amplitude of the accelerating voltage, thereby enabling systematic studies of their influence on particle trajectories. Key trajectory data (e.g. radius, velocity, path length) are calculated and can be visualized through five different types of plots. In addition, data export facilitates further analysis with external software such as Excel, MATLAB, or Octave.

MOP38: Artificial isochronous magnetic field maps

Willem Kleeven *(IBA)*

A software tool has been designed which allows us to make isochronous cyclotron field maps. The rotational symmetry number, the center field, the particle properties, the maximum radius and the sector spiraling angle as function of radius can be freely chosen. Out of four radius-dependent parameters (flutter, hill-field, valley-field and sector azimuthal extent), the user can define two of them freely and the tool will then calculate the complementary two; from that the full isochronous map is calculated. The azimuthal field profiles are defined by the hill field and the valley field which are connected by user defined transition zones. These zones may have a double-quadratic or cubic form factor. For the average isochronous field, a precise theoretical formula is used. The tool, in combination with a closed orbit code, may be used for exploring the parameter space of new cyclotrons to be designed. This may predict optical properties such as tunes and structural resonances. The author designed the tool in order to validate a theoretical model that predicts the energy limit of isochronous cyclotrons (as presented in the previous cyclotron conference). Equations are derived and the fundamentals of the tool are explained. Good precision of isochronism is confirmed by closed-orbit integrations for a wide range of the field map parameters introduced above.

MOP39: Research on parameter optimization of uniforming transport lines based on deep reinforcement learning

Yuzhuo Huang*; Tianjian Bian; Shizhong An; Sumin Wei (CIAE)*

Beam transport line of uniformization is an essential step before beam shooting and plays a critical role in applications such as neutron imaging and isotope production. In practical experiments, particle beams generated by cyclotrons typically exhibit an approximately Gaussian intensity distribution. Local bright spots on the targets for high-power Gaussian beams create difficult cooling problems and shorten the lifetime of the target. To address this issue, a beam transport line with multiple beam elements is designed. Considering the complexity of multi-parameter optimization process, an automatic optimization method based on deep reinforcement learning is investigated. In the simulation environment, the Soft Actor-Critic (SAC) algorithm is employed to adjust multiple beam elements for optimizing the uniformity of the beam. Results indicate that the SAC algorithm based on the maximum entropy principle achieves over 85% uniformity on the target. Compared with manually optimizing parameters, the proposed method demonstrates higher efficiency and superior uniformization performance.

MOP40: Optimization of Isochronous Magnetic Fields and Beam-Dynamics Simulations for a High-Intensity Superconducting H3+ Cyclotron

Guoliang Dou*; Xi Chen; Qinggao Yao; Bing Wang; Xianwu Wang; Yao Yang; Liangting Sun;*

Hongwei Zhao (IMP) Yi-Nong Rao (TRIUMF)

High-intensity proton cyclotrons have widespread applications in scientific research, medical treatments, and industrial processes. As cyclotron technology continues to evolve, the trend leans toward more compact designs with increased beam intensity. Our proposed design involves a 120 MeV/u superconducting H3+ cyclotron named SK1000, capable of achieving 3 times the operational beam intensity through foil stripping. This configuration meets the demand for compact and high-intensity cyclotrons in practical applications. However, the intense space charge effects have significant impact on proton beams during injection, acceleration, and extraction, imposing stricter requirements on magnet design, RF systems, and beam extraction system. Particularly in the magnetic system, we aim to achieve a magnetic field with high precision(±10Gs), strong focusing capability, and excellent isochronism (±0.3‰), while simultaneously meeting the stringent requirement for a large axial acceptance in the central region, as well as realizing a single-turn extraction orbit using a stripping foil. Throughout the design and optimization of the magnetic system, continuous efforts are devoted to exploring and implementing effective methods for enhancing magnetic field performance and efficiency. And We simulated the baseline model of SK1000 by OPAL during acceleration and extraction.

MOP41: Impact of Magnetic Field Imperfections on Beam Dynamics in a High-Intensity Compact Cyclotron

Xi Chen; *Guoliang Dou; Liangting Sun; Bing Wang; Xianwu Wang; Qinggao Yao; Yao Yang; Hongwei Zhao (IMP) Yi-Nong Rao (TRIUMF)*

Compact high-intensity cyclotrons are increasingly important for isotope production worldwide. The SK1000 is a proposed superconducting cyclotron designed to accelerate H_3^+ ions to 120 MeV/u. It features a large main magnet with a height of 2.99 m, a diameter of 7.58 m, and an outer sector radius of 2.25 m. The manufacturing and installation of a magnet of this scale inevitably introduce field imperfections. This study investigates the effects of such magnetic field errors on beam dynamics to inform magnet mapping and shimming strategies. Through combined analytical and numerical simulations, we establish tolerance limits for magnetic field errors. Special attention is given to the resonances $\nu_r = 1$ and $2\nu_r = 2$, driven by first- and second-harmonic field errors, which lead to radial emittance growth. Resonances contributing to vertical emittance growth are also examined. Finally, we present the maximum allowable magnetic field errors that ensure stable beam operation in the SK1000 cyclotron.

MOP42: Beam dynamics modeling in the superconducting cyclotron MSC-230

Simeon Gurskiy; Oleg Karamyshev; ***Galina Karamysheva****; Taisia Karamysheva; Ivan Lyapin; Vladimir Malinin; Aleksandra Sinitsa (JINR)*

The dynamics of a proton beam in the MSC230 cyclotron were simulated. Since the maximum beam current is limited by extraction efficiency, an approach was employed, in which the beam trajectory started at the deflector with an emittance equal to its acceptance and ended at the entrance of the ion source. This method allows for a detailed characterization of the phase space boundaries for the beam originating from the cyclotron's central region. In the particle tracking simulations, the results of computer modeling of the accelerating and magnetic systems were used, obtained from 3D electromagnetic field maps in CST Studio Suite.

MOP43: Hybrid Autoencoder and Isolation Forest Approach for Time Series Anomaly Detection on ARRONAX Cyclotron Operation Data

Fatima Basbous *(Nantes Université) Diana Mateus (ÉCN, Nantes Université) Ferid haddad (LPSTA, Nantes Université); Freddy Poirier (Cyclotron ARRONAX)*

The Interest Public Group ARRONAX's C70XP cyclotron, used for radioisotope production for medical and research applications, relies on complex and costly systems that are prone to failures, leading to operational disruptions. In this context, research is being conducted to develop an active machine learning method for early anomaly detection to enhance system performance. One of the most widely recognized methods for anomaly detection is Isolation Forest (IF), known for its effectiveness and scalability. However, its reliance on axis-parallel splits limits its ability to detect complex anomalies, especially those occurring near the mean of normal data. This study proposes a hybrid approach that combines a Multi-Layer Perceptron Autoencoder (MLP-AE) with Isolation Forest to enhance the detection of complex anomalies. The Mean Squared Error (MSE) of the data reconstructed by the MLP-AE is used as input to the IF model. Validated on beam intensity time series data, the proposed method demonstrates a significant performance improvement, as indicated by the evaluation metrics, specifically the Area Under the Precision-Recall Curve (AUC-PR) and the F1 score.

MOP44: Design and Optimization of the Central Region of a Compact Superconducting Cyclotron

Panpan Zheng *(ShanghaiTech University)*

The intensity and quality of the extracted beam are critically influenced by the central region structure. Variations in the central region design can lead to difference in beam transmission efficiency, largely attributable to divergent acceleration dynamics during the initial few turns. In cyclotrons employing internal ion sources, the very low beam energy at the source outlet makes the beam highly sensitive to changes in the central region design. Therefore, optimizing the central region is necessary to ensure high transmission efficiency and better beam quality. This study presents a conceptual design simulation for the central region of a compact superconducting cyclotron designed for radioisotope production. Beam trajectory and centering are optimized through adjustments of the ion source position, the direction of the opening slit, and puller electrode geometry.

MOP45: Magnet System Design and Static Analysis of a Superconducting Ring Cyclotron for Thorium Molten-Salt Energy Amplifiers

Minggao Xia *(SINAP) Weishi Wan (QSC, GBA)*

Superconducting ring cyclotrons (SRCs) are widely studied as drivers in accelerator-driven systems (ADS) for thorium-based molten-salt energy amplifiers, owing to their capability of delivering high-energy and high-intensity beams. This poster presents the magnet system design of an H_2^+ superconducting separated-sector cyclotron with an extracted beam energy of 800 MeV/amu for ADS applications.

The required beam quality for this cyclotron is defined according to the operational criteria of the Thorium-Based Molten Salt Reactor System as outlined in a recent study on thorium-based energy amplifiers at the Shanghai Institute of Applied Physics. The main tasks include modeling the magnet system, optimizing the isochronous magnetic field, and performing equilibrium orbit analysis to verify stable beam dynamics.

The results demonstrate that the optimized field configuration can achieve the required isochronous condition with tolerances compatible with ADS operation, providing a solid foundation for further beam dynamics and engineering studies.

MOP46: Upgrades On The Cyclotron Injection Line at SPES Facility at LNL

Piergiorgio Antonini*; Mario Maggiore; Lorenzo Pranovi; Alberto Ruzzon (INFN) Arturo Abbondanza (INFN-LNL; University of Ferrara)*

The 70 MeV cyclotron in use at Laboratori Nazionali di Legnaro at INFN was designed to deliver proton current up to 0.75 mA. Being designed as a relatively high current cyclotron, little attention was dedicated to the possibility to operate at low currents in the order of few tens of nA. On the other side, it is very interesting to try to increase the deliverable current near or above the 1 mA range. Experiments planned at the SPES facility require operation at low currents. To be able to operate at such currents in a fail-safe mode, a chopper is being designed for the injection line. To increase the current, on the other hand, a beam buncher is being designed for the injection line. Beam dynamics simulations and both mechanical and electronic design will be discussed.

MOP47: Applications of AI/ML in Virtual Cyclotron Prototyping: Challenges and Opportunities

Oleg Karamyshev; *Ivan Lyapin* ***(****JINR****)***

Cyclotron design involves extensive computations for both individual accelerator systems and particle dynamics, requiring careful optimization of numerous interdependent parameters. The integration of artificial intelligence (AI) and machine learning (ML) into cyclotron design and operation is already demonstrating significant benefits, accelerating development, enhancing control, and improving system reliability. AI-driven approaches have the potential to revolutionize cyclotron optimization, enabling researchers to streamline design processes, explore a broader parameter space, and ultimately enhance device performance. This presentation discusses initial results from applying ML to magnetic field shaping and analyzes the broader opportunities and challenges in leveraging AI/ML for virtual cyclotron prototyping. The use of AI in the development of software for beam dynamics, particularly for seamless integration between 3D models, electromagnetic field simulation programs, and particle tracking, has significantly simplified the process and taken it to a new level.

MOP48: Research on Separation Technology for the Production of Ga-68 by Cyclotron

Pengfei Zhao*; Guoying Guan; Shizhong An; Yu Wang; Yunlong Zhao; Yong Li(CIAE)*

This study describes the production of ^{68}Ga by irradiating an enriched $^{68}ZnCl_2$ liquid target with a 12 MeV, 50 μA proton beam in a cyclotron. The post-irradiation products were first simulated, and a simulated solution was prepared based on the computational results. This solution was adjusted to approximately pH 5.0 and subsequently loaded onto a pre-conditioned ZR resin. The subsequent purification involved a two-step process on the ZR resin: first, washing with HCl (pH = 4) effectively removed 99.99% of the ^{68}Zn substrate; second, ^{68}Ga was efficiently eluted using 5 mol/L HCl.

The resulting ^{68}Ga-containing eluate was then loaded onto a pre-conditioned anion exchange resin for further purification. Residual impurity ions were removed by washing the resin with 5 mol/L HCl, followed by the elution of purified ^{68}Ga using ultrapure water. The chemical purity of the final ^{68}Ga sample was confirmed to comply with the quality specifications for accelerator-produced ^{68}Ga as defined in the European Pharmacopoeia.

MOP49: Research on design of neutron beamlines based on the 50 MeV proton cyclotron

***Xiaobo Li**; Shizhong An; Fengping Guan (CIAE)*

With the growing demand for neutrons in applications such as detector calibration, device irradiation, and cross-section measurements, neutron sources are advancing toward higher energy and higher flux. In Beijing, China, two neutron beamlines, a quasi-monoenergetic one and a white light one, based on a proton cyclotron with a maximum energy of 50 MeV is under construction and preparation. We designed a quasi-monoenergetic neutron beamline, focusing on the target chamber and collimator. Lithium was selected over beryllium as the target material due to its superior quasi-monoenergetic peak performance. Parametric studies on lithium thickness revealed its impact on the neutron peak characteristics. Energy loss of protons through titanium films and argon gas was evaluated to guide chamber design. Neutron spectra and fluxes were simulated at various positions, leading to an optimal collimator length of 2 m based on flux and peak ratio. Regarding the white light beamline, detailed simulations and discussions were conducted on the composition of the shielding and collimation structure, leading to the determination of the final design. This approach significantly reduced the amount of cast iron required, resulting in a notable decrease in overall weight. These above-mentioned works provide key data for the beamline's construction and operation.

MOP50: Simulation and experimental study on the production of actinium-225 radionuclide based on a 100MeV cyclotron

***Yunlong Zhao**; Lei Cao; Shizhong An; Zhe Wang; Fei Wang; Sumin Wei; Jia Zhou; Pengfei Zhao; Yong Li; Yu Wang (CIAE)*

Actinium-225 is a radionuclide of significant interest in the field of Targeted Alpha Particle Radiotherapy (TAT), with its targeted drugs showing promising applications for prostate cancer, brain tumors, neuroendocrine tumors, and more. One of the primary approaches being explored by major international laboratories for the commercial production of ^{225}Ac involves the spallation reaction induced by high-energy proton accelerators (>70 MeV) irradiating a ^{232}Th target. This study conducted detailed simulations using the Monte Carlo program FLUKA to analyze the production yield of ^{225}Ac, reaction products, variations in impurity radionuclide yields with cooling time, and the ^{227}Ac/^{225}Ac ratio at different energies in the context of irradiating a thorium target with the 100 MeV proton cyclotron at the China institute of atomic energy (CIAE) in China. The findings provide a reference for subsequent engineering experiments on producing ^{225}Ac via irradiation of thorium targets with medium and high-energy proton accelerators. CIAE conducted irradiation experiments on metallic thorium targets using the 100 MeV cyclotron, achieving an experimental production yield of 0.02 mCi/μAh.

MOP51: Research on the Production of 68Ge through Proton Irradiation of Electroplated Gallium-Nickel Alloy Solid Targets and Niobium-Encapsulated Natural Gallium Targets in Accelerators

Yong Li *(CIAE, Tsinghua University); Guoying Guan; Shizhong An; Yu Wang; Yunlong Zhao; Pengfei Zhao; Lifeng Zhang (CIAE) Jing Chen (Tsinghua University)*

This study compares the production of ^{68}Ge using proton irradiation on two types of targets: an electroplated gallium-nickel alloy solid target and a niobium-encapsulated capsule with natural gallium. The alloy target was prepared on copper via electroplating, while the capsule was designed and fabricated to be irradiated in a cyclotron. The generated ^{68}Ge was then separated and purified using resin columns. Results show the electroplated target had a smooth surface and good adhesion, but its low loading capacity and vulnerability to thermal damage limit its use for large-scale production. The niobium-encapsulated target, with its higher loading capacity, improved stability and safety under irradiation, though it requires precise welding and sealing due to gallium's low melting point. For the separation and purification of ^{68}Ge, the dissolution of the electroplated target is an open operation that introduces significant impurities, necessitating a combined purification process using both chelating and gel resins. In contrast, the niobium-encapsulated target allows for a closed operation, resulting in lower impurity levels and offering distinct advantages for subsequent purification.

MOP52: Stability Improvement of Genetic Algorithm and Study of Surrogate Model for CSNS-FFAG Lattice Optimization

Yan Cui *(IHEP)*

In accelerator physics, lattice optimization is a foundational step for subsequent work. Traditional optimization methods face problems that balancing several input parameters with conflicting optimization objectives and the prohibitive computational cost of key physics simulations, particularly for Dynamic Aperture (DA). As a part of the China Spallation Neutron Source (CSNS) FFAG project, this study aims to enhance the efficiency and reliability of its multi-objective lattice optimization workflow.

This study focuses on improvements to two critical components of this process. First, we refine the elite clustering process to increase the stability of the genetic algorithm (GA), leading to more robust optimization results. Second, for the time-consuming physics simulations, we have verified the unique suitability of a Transformer-architecture surrogate model for this application. Compared to conventional neural networks, its prediction accuracy is higher.

The combination of the stability-improved genetic algorithm and the high-precision Transformer surrogate model provides a fast set of optimization tools for lattice. It can provide guidance for the choose of lattice parameters in FFAG and significantly accelerate the design and optimization time for the actual engineering project.

MOP53: A powder target preparation technology for producing the 44Sc radionuclide

Haomiao Chu; *Ma Chengwei; FEI DUAN; Zhao Ziyu; Wen Kai (High-Tech Atomic Co., Ltd.)*

1. Introduction: 44Sc is a novel radionuclide with a high branching ratio (Eβ+av=632 KeV, I = 94.3%), which is highly suitable for positron emission tomography (PET) imaging, endowing it with broad application prospects in the field of nuclear medicine. The preparation of 44Sc by 44Ca (p, n) 44Sc nuclear reaction in a cyclotron is the most widely used preparation method. In this study, calcium oxide powder was used as the target material and the pressing experiments were carried out.
2. Material and Methods: The influence of different pressures and different target material quantities on target sheet formation was investigated. A certain amount of calcium oxide was weighed, and pressing experiments were conducted under different pressure conditions to observe the formation of the target sheet.
3. Results and Conclusion: The results of different pressure and target material quantities are shown in Table 1. When the pressure reaches 49 KN and the amount of target material reaches 250 mg, target sheets that meet the requirements can be obtained. Simulation calculations of the target pieces were carried out, and the results are shown in Figure 1. The maximum surface temperature of the target piece is 615℃, which can meet the production requirements of 44Sc.

MOP54: Cooling optimization design of ultra-compact 9.5MeV cyclotron—18F liquid targets

Xue Ran; *Yi Yang; Jiansheng Xing (CIAE)*

For the treatment of major diseases such as cancer, Positron Emission Tomography (PET) nuclear medicine imaging technology has irreplaceable advantages over traditional imaging technology. At present, 18F-2-deoxyglucose (18F-FDG) is a widely used positron electron drug in clinical practice in China. Therefore, the Chinese Academy of Atomic Energy has carried out the research and development of the "ultra-compact 9.5MeV cyclotron — 18F liquid target" for medical PET isotope production. By using a 60A proton beam obtained by a 9.5MeV cyclotron, a liquid target filled with oxygen-rich water is bombarded to produce 18F on the order of 1.5 Curie (Ci). The 30Ti window is used as the vacuum membrane window, and the 25 Havar membrane window is used to seal the liquid target cavity. The purpose of this paper is to reduce the damage of the beam to the titanium window and the Havar membrane window, and the helium cooling chamber innovatively adopts a cyclic helium cooling design to reduce the temperature on the membrane window. Simulating the cyclic helium cooling process through finite source software, the flow rate of helium is introduced with a flow rate of 2.5m/s. So, the feasibility of the cooling design for reducing the temperature of the membrane window is analyzed and verified.

Session TUA

TUAI01: New Generation High Intensity Proton Cyclotron using H3+ Ions

Yi-Nong Rao; *Hui Wen Koay; Iouri Bylinskii; Lige Zhang; Rick Baartman; Thomas Planche (TRIUMF) Guoliang Dou;Xi Chen (IMP)*

We propose a new class of compact superconducting cyclotrons based on the stripping of H3+ ions. In this method, H3+ ions are accelerated and pass through a thin carbon foil, where the electrons are removed to produce three protons per ion. Compact cyclotrons require high magnetic fields, which makes H- acceleration impractical; H3+ ions, however, can possibly tolerate much higher fields and are therefore suitable for this approach. The stripping technique offers very high extraction efficiency, enables variable-energy proton beams, and allows simultaneous delivery to multiple production targets. These features make such machines highly attractive for producing protons in the 70-120 MeV energy domain, which remains largely undeveloped worldwide. Our study focuses on beam dynamics, particularly the large acceptance required for high-intensity beam and feasibility of single-turn extraction to minimize beam losses. A baseline design and preliminary results are presented.

TUAO01: Steps towards a 1.6μA extracted beam of the CYCIAE230 superconducting cyclotron for proton therapy

Zhiguo Yin; *Tianjue Zhang; Chuan Wang; Tianyi Jiang; Ziyi Cheng; Aolai He; Aoxuan Ding; Yang Wang; Qiqi Song; Bohan Zhao; Xinyu Li; Zeyuan Xia (CIAE)*

A superconducting cyclotron, the CYCIAE230, has been developed by CIAE of CNNC for proton therapy applications over the past few years. The beam commissioning of this machine was completed previously, in 2023. A series of improvements were carried out in the early part of this year to increase the stability and beam intensity of the cyclotron for potential FLASH usage. It includes optimizing the ion source to achieve higher intensity, optimizing the phase selection in the central region, and aligning the primary coil, as well as adjusting the location of the electrostatic deflector, among other factors. In the meantime, several measures have also been taken to improve cyclotron subsystem stability, including enhancements to the RF system and improvements in beam diagnostics, such as the time structure and beam phase. A dedicated beam tuning software has been developed to adapt to the needs of cyclotron beam fine-tuning. It provides a feature that displays all parameters on a single page, which facilitates beam tuning activity. All these technical adjustments combined led to an overall extraction beam current of up to 1.6 μA. Afterward, the radiation distribution analysis and relocation of the cyclotron accessory device were performed according to the configuration of the short-term runs. The optimization measures, improvements to the subsystems, and beam tuning results will be reported in this paper, along with the dedicated beam tuning software.

TUAO02: Gyrating Ion Beam Driven Whistler Wave Instability in a Dusty Plasma

Amit Kumar; *Twinkle Pahuja (Amity University)*

This manuscript examines the non-linear interaction between the negative energy beam cyclotron mode and high-frequency whistler waves. The negative energy beam mode is supported in the vicinity of the beam gyro-frequency harmonics by a gyrating ion beam with ring shaped velocity distribution. Using a gyrating ion beam, we have examined how dust charge variations affect the parametric up-conversion of high frequency whistler waves (WW) into an side band wave and a low-frequency mode. For the linked modes, a non-linear dispersion relation is obtained. It is demonstrated that whistler waves divided by beam gyro-frequency harmonics are upconverted by a gyrating ion-beam frequency. A formula for the ion cyclotron mode wave growth rate has been obtained. The estimation of the turbulence growth rate takes into account for the typical parameters of an existing dusty plasma. It is detected that an increased growth rate appears with a rise in the pump wave amplitude, beam gyro-frequency, number density of dust grains, and the relative density of dust grains. However, a decline in the growth rate has been detected with increasing gyrating ion beam density and dust grains size.

TUAO03: Design of an RF Cavity for 30 MeV Alpha Particle Cyclotron

Xin Zhang *(USTC); Gen Chen; Yuzhou Mao; Kaizhong Ding; Yonghua Chen (IPP); Chujie Chao; Xiangtian Kong (HFCIM)*

Alpha particle accelerators hold significant potential for applications in the production of medical radioisotopes, particularly demonstrating unique advantages in obtaining At-211 medical radioisotope, which is difficult to produce via traditional neutron reactions, such as reactor neutron irradiation. In this paper, a high-frequency resonant cavity operating at 36.8 MHz was designed for a 30 MeV alpha particle cyclotron and multi-physics simulations were employed to analyze the electromagnetic characteristics, thermal distribution, mechanical deformation and frequency deviation of the cavity. Through the implementation of a deep-valley and stepped-impedance coaxial cavity, 36.8 MHz frequency resonance was achieved within a relatively compact volume while maintaining high Q-factor and low power consumption at 90 kV accelerating voltage. Furthermore, an inductive power coupler was placed near the short-circuit wall that was avoided in the constrained engineering environment. The reflection coefficient of RF coupler can be adjusted to below -35dB by rotating power coupler, which indicates excellent matching. The maximum electric field strength and thermal stress of water-cooled RF window during high-power operation have been analyzed. The engineering design will be informed by the physical analysis of RF cavity, which will be finished before 2026.

Session TUB

TUBI01: Reinforcement Learning for Real-Time Cyclotron Tuning: Results from the Injector 2 Experiment at PSI

Malek Haj Tahar*; Antonio Barchetti; Christian Baumgarten; Joachim Grillenberger; Jochem Snuverink; Markus Schneider (PSI) Evgeny Solodko (TRANSMUTEX); Marco Busch (BEVATECH GmbH);*

Achieving reliable, fast, and reproducible cyclotron tuning remains a key operational challenge as accelerators move towards increasingly complex beam configurations and higher intensities. To address this, we conducted a two-week experimental campaign at PSI Injector 2 to evaluate the feasibility of applying reinforcement learning (RL) for real-time beam optimization. These experiments represent an important first step towards automated and reliable cyclotron control, demonstrating the potential of RL-based approaches to improve tuning efficiency and operational stability. We will present the experimental setup, methodology, and safety strategies, highlight key results, and discuss lessons learned for future deployment at high-current HIPA operations.

TUBI02: FETS-FFA Project at RAL, UK

Jean-Baptiste Lagrange *(STFC)*

A Fixed Field Alternating gradient (FFA) accelerator is an option as a proton driver for the next generation spallation neutron source (ISIS-II) in the UK. To demonstrate FFA suitability for high intensity operation, a prototype 3-12 MeV proton ring is proposed at RAL using as injector the ISIS Front End Test Stand (FETS). The lattice of this ring, called FETS-FFA, is more similar to a synchrotron than a cyclotron since it uses FD spiral focusing unit and has a super-period structure to accommodate long straight sections for injection and extraction. Beam stacking is a key technique to increase the peak intensity in an FFA. The design and experimental validation will be shown. The main lattice magnet is the crucial component of an FFA, with necessary operational flexibility of the working point as a function of beam intensity. A wide range of diagnostics were investigated to measure the beam parameters. This talk will review key results of the 2025 Conceptual Design Report (CDR), as well as other aspects of the FETS-FFA project.

TUBO01: Design of q/A=1/2 K100 compact cyclotron system for heavy-ion space radiation effects and radiobiology studies

Jong-Won Kim *(IBS)*

We have designed a q/A=1/2 K100 cyclotron for various applications including the production of medical isotopes and neutrons using high-intensity H2+, D+, He2+ ions at the maximum energy of 25 MeV/u. In addition, with acceleration of fully charge-stripped light heavy ions such as 14N7+, 36Ar18+, we plan to study space radiation effects on semiconductor chips and precision radiobiology by using microbeam as a high-energy microprobe. Both horizontal and vertical microbeam lines have been designed to conveniently accommodate solid and liquid targets, respectively. The beam optics for microbeam was carried out using TRACE-3D, TRANSPORT in linear optics and TURTLE for particle tracking including up to 3rd order. To produce different ion species in wide range of beam currents, ion sources for H2+, D+, He2+ are placed on top of the cyclotron while a high-performing superconducting ECR ion source needs to located on the upper floor with a beam line for charge selection and axial injection. I will present the design of microbeam lines along with the progress on the cyclotron system design.

TUBO02: Machine Learning Applications in Large-Scale Accelerators

Xiaolong Chen; Zhijun Wang; Yuan He; ***Xunye Cai****; Chunguang Su; Yaxin Hu; Lijuan Yang; Penghui Shao (IMP)*

Improvements in beam power and current for large-scale accelerators place increasingly strict demands on operational stability. Traditional operation-and-maintenance strategies are becoming insufficient to meet these high-availability requirements. Rapid advances in artificial intelligence offer a new technical paradigm for delivering efficient, reliable accelerator operation. In this study, we combine nonlinear dynamics with modern machine-learning algorithms to develop a robust beam-tuning method. The method is trained in simulation and has been successfully transferred to a real accelerator system. Building on this result, we developed a flexible, AI-driven beam-tuning platform that significantly improves tuning efficiency and operational flexibility. Future work will focus on enhancing algorithm generalization and on advancing an intelligent operation-and-maintenance framework for accelerators.

Session TUC

TUCI01: Development of high intense heavy ion beams from ECR ion source for RIBF

Takashi Nagatomo; *Glynnis Mae Saquilayan; Junichi Ohnishi; Osamu Kamigaito; Takahide Nakagawa; Yasuyuki Morita; Yoshihide Higurashi (RIKEN)*

At RIKEN RIBF, the development of 28-GHz superconducting electron cyclotron resonance ion sources (SC-ECRIS) 1 is crucial for advancing high-intensity beams of various ion species for scientific, industrial and medical applications. To achieve the RIBF upgrade's core goal of extracting a 2-particle μA uranium (U) beam from the superconducting ring cyclotron (SRC), it is essential to develop a novel Charge Stripper Ring (CSR) to significantly enhance charge stripping efficiency, and to generate 300-μA U^{35+} beam from the SC-ECRIS. To achieve this goal, we are developing several technologies to confine high-electron-temperature, high-density ECR plasma. This includes the introduction of GM-JT cryocoolers exceeding 8W capable of withstanding X-ray heat loads on the SC mirror coils, the development of a gyrotron for ECR plasma heating, and the design of an oven as a solid sample evaporator in the SC-ECRIS. Especially, the oven heated by high current of around 600 A, was designed with careful consideration of stresses caused by the mirror field exceeding 2 T. These advances aim to significantly enhance intensity and stability across a wide range of ion species. Furthermore, to enhance beam quality, a new analysis method using Pepper Pot Emittance Meter (PPEM) was developed for advanced beam diagnostics. This approach facilitates further improvements in the quality of non-Gaussian beams influenced by the complex fringe field of the ECRIS mirror.

TUCO01: Resume of Cyclotron operation of SPES Facility at LNL

Mario Maggiore; *Alberto Ruzzon; Lorenzo Pranovi; Piergiorgio Antonini (INFN-LNL)*

In 2024 the SPES project entered in the commissioning phase and the cyclotron has restarted the operation by providing the primary proton beam for the ISOL target. During the shutdown, many ancillary systems of the cyclotron have been upgraded in order to improve the reliability of the machine in view of the full operation mode expected in next years. The upgrades and the status of recent achievements will be presented and discussed in the presentation.

TUCO02: JULIC – Half a Century of Reliable Operation

Olaf Felden *(FZJ) Ralf Gebel (GSI Helmholtz Centre for Heavy Ion Research)*

The cyclotron JULIC at Forschungszentrum Jülich (FZJ), has been operating for over 56 years. It is a remarkable example of innovation, long-lasting technology and reliability. With its high performance and versatility it was an essential part of the FZJ research program in the field of nuclear physics, irradiation experiments for medical, technical and space application and radiation effects in materials and electronics. During JULICs long life many changes and improvements widened its working spectrum. With the superconducting ECR ion source ISIS, JULIC has accelerated highly charged heavy ions up to Ne, enabling nuclear physics research with light towards heavy ions. Since 1993 and with its colliding beams source CBS, JULIC has delivered unpolarized and polarized proton and deuteron beams to the Cooler Synchrotron COSY and its hadron physics research program and for the JULIC-Neutron Platform with pulsed beams of cold to fast neutrons. Even with operation of proton and deuteron beams mainly, JULIC hasn't lost its ability to run with other species as shown with acceleration of He-3-beams lastly. The technical improvements made to the JULIC systems over the years, like the adaptation of the diagnostic and timing system to meet different experimental needs or transition to an oil-free vacuum system are just a few of the many, led to its high reliability and operational efficiency. Thus all is a testimonial to the ingenuity and dedication of the FZJ staff who made it possible.

TUCO03: Recent Developments of the TRIUMF 520 MeV Cyclotron

Lige Zhang*; Huiwen Koay; Marco Marchetto; Olivier Shelbaya; Paul Jung; Rick Baartman; Suresh Saminathan; Thomas Planche; Yi-Nong Rao; Yu. Bylinskii (TRIUMF)*

The TRIUMF 520 MeV cyclotron continues to serve as a reliable driver for high-intensity proton beams, supporting a broad range of applications. To sustain and enhance high intensity operation, recent developments have focused on reducing beam losses and improving overall reliability. This talk will highlight progress in several key areas: upgrades to the new injection beamlines; cyclotron tune optimization and the avoidance of linear coupling resonances to suppress beam spills and reduce component activation; and the implementation of a refined degaussing procedure for the main magnet to improve reproducibility and ensure accurate restoration of the isochronous field.

Session TUD

TUDI01: Solid state VS tube power amplifiers as one of the problematics of a wide band Cyclotron RF system

Antonio Caruso; *Luigi Celona; Santo Gammino (INFN) Fulvio Perri (BrEx Broadcasting Experience Ltd)*

In the large family of particle accelerators and in the relatively small environment of the wideband cyclic accelerators, the high-power RF Systems were mostly based on the vacuum tube technologies up to a couple of decades ago. Unfortunately, some alarm bells about the tube market prospective, relative to the low bandwidth of the cyclotron radiofrequencies, appeared quite clearly about ten years ago. The cost of some specific tetrodes increased, and their availability decreased. The two phenomena were counterbalanced by the parallel growth of a very efficient families of power semiconductors in the low frequency range. Frequency range large enough to easily cover the cyclotron RF bandwidth. For example, one tetrode, first stage of our RF power amplifier was considered obsolete, and we successfully replaced it with an SSA stage (1-2 kW 15-50 MHz) developed in-house. The undeniable advantages of this choice convinced us to develop a new broadband SSA. A prototype is under study, and a first preliminary conceptual design is in progress. The architecture is developed as a "mosaic", a series of blocks, called tèssere. A single tèssera* should produce a power of about 5 kW. The composition of several blocks can increase the final power a lot, making the system scalable. The prototype under study is a sort of demonstrator of this scaling model. A final power of 20 kW CW in the range of 10-90 MHz in a space of 10-12 Unit Rack (RF part + power supply) will be our goal.

TUDO01: Status Update on Cyclotron Development and RFQ-Based Injection for the IsoDAR Experiment

Samuel Engebretson; Jarrett Moon; Daniel Winklehner (MIT) Denis Joassin; Alexander Herrod; ***Erik van der Kraaij****; Gil Wery (IBA)*

The IsoDAR experiment aims to deliver a high-intensity neutrino source for precision measurements in neutrino physics. Central to this effort is the development of a compact, high-current cyclotron capable of accelerating H_2^+ ions to 60 MeV/amu. This presentation provides a status update on the cyclotron's development, covering key aspects of its radiofrequency (RF) systems, magnetic configuration and mechanical design.

A major innovation in the IsoDAR injector is the implementation of a novel Radio Frequency Quadrupole (RFQ) inserted into the cyclotron for direct axial injection. We also present the latest details on a smaller cyclotron, designed to match as closely as possible the magnetic and electric fields of the larger cyclotron, up to 1.5 MeV/amu. This smaller cyclotron will be used to test and validate the injection system and first turns of acceleration. The presentation will conclude with an outlook on upcoming integration tests and commissioning plans.

TUDO02: Development of a α-beam for ^{211}At production at iThemba LABS

Moenir Sakieldien; *Deidre Prince; Elton Van Oordt; Gideon Steyn; Jacobus Conradie; Joele Mira; Philip Beukes; Shadley Baard (iThemba LABS)*

South Africa has a proud history of radionuclide production dating back to the 1960s. Since those pioneering years, several improvements and additions have been made to the accelerator infrastructure in the country to exploit this advantage. In recent years an isotope, astatine-211, has emerged as a promising candidate for α-particle therapy of cancers. As a result of this interest, 211At has been identified as one of the radionuclides for development. iThemba LABS is one of about 30 cyclotrons in the world that have the beam characteristics required to produce this isotope. Despite the potential advantages of 211At for targeted α-particle therapy, its application for this purpose is constrained by its limited availability. The most commonly used production method is via the 209Bi(α,2n)211At reaction which utilizes bismuth as the target and straightforward cyclotron irradiation methodology. The most significant impediment to the availability of 211At availability is the need for an accelerator capable of generating ≥28 MeV α-particles with sufficient beam intensities to make clinically significant levels of 211At. To this end the biggest challenge faced thus far at iThemba LABS has been extracting enough beam intensity out of the injector cyclotron. With this contribution we will report on the preliminary results of the development to produce α-beam. This discussion will focus on challenges with beam transmission, target development and chemistry.

Session TUP

TUP01: High Resolution Electronics for Radial Probe of Superconducting Cyclotron for Proton Therapy

Fu Zheng*; Qingwei Han (CIAE;* Chengdu Cyclotron Science and Technology Co., LTD*) Zhiguo Yin; Tianyi Jiang; Yang Wang; Chuan Wang (CIAE)*

It is inevitable to carry out beam diagnostics inside the superconducting cyclotron used for proton therapy at the application site. Radial probe plays an essential role in the field of beam diagnostics for SC cyclotrons. Years of efforts have been put forward by a group in the China Institute of Atomic Energy, focusing on advancing the beam diagnostics probe and readout electronics for the R-Probe system of the CYCIAE230 SC cyclotron. The EM interference inside the compact cyclotron poses a significant challenge for precise beam diagnostics. For example, when the R-Probe is moving along the radial path, the alternating high voltage from the RF system and the strong magnetic field generate greater noise than the signal itself. Care has been taken with the shielding and grounding design of the new radial probe used in the large radius. A replaceable scintillator-based probe head is also included for the beam diagnostics in the center region. The electronics design utilizes a logarithmic amplifier, which yields a dynamic range of 140dBV, providing greater flexibility compared to the feedback IV ammeter. Fast ADC, as well as ZYNQ SOC, is used to reduce the noise to an acceptable level further. Besides, a magnetically friendly, lens group and a CMOS camera are developed and integrated for the scintillator-based probe head. The design of the new R-Probe for CYCIAE230 S.C. cyclotron will be reviewed in this paper, together with the preliminary test results.

TUP03: Simulation Study of Beam Dynamics and Extraction in an 18MeV Compact Cyclotron

Ruijin Liu[1]*; Sumin Wei; Tianjian Bian (CIAE)*

An 18MeV/1mA High-Current Cyclotron has been designed and construction at CIAE (China Institute of Atomic Energy). H- ion will be accelerated in this cyclotron and proton beam will be extracted by carbon strippers. To analyze the beam loss in the high-current cyclotron, this paper conducts a beam dynamics simulation study on the cyclotron. Based on actual magnetic field measurement, beam oscillation, phase slip and axial oscillation of the non-ideal beam are simulated to determine the beam alignment condition and the effect of Walkinshaw resonance in the cyclotron. Calculate beam variations during acceleration and extraction of single and multiple bunches under different alignment conditions. Emphasize the analysis of particle optical properties of the beam after stripping extraction—including beam energy spread, beam envelope variations and beam loss conditions. The results show that the beam loss for well-aligned beam is significantly lower than that for poorly-aligned beam. Additionally, a beam dynamics study was conducted on multi-bunch beams with intensities of 1mA, 3mA, and 5mA, and the simulations show no appreciable difference in beam loss.

TUP02: Structural Design and Machining Process Research on RF Cavity for Ultra-compact Multi-particle SC Cyclotron

Zhan Liu; *Jun Lin; Yunlong Chai (CIAE;* Chengdu Cyclotron Science and Technology Co., LTD*)*
Pengzhan Li; Tianjue Zhang; Wei Fu; Ling Qin; Hongji Zhou; Jingyuan Liu; Xi Wang; Chuan Wang; Zhiguo Yin (CIAE)

Ultra-compact multi-particle SC cyclotron being developed by CIAE is intended to be a high intensity cyclotron, especially for $H2^{+}$ particle and 冈 particle acceleration. Two half-wavelength RF cavities are installed in the valleys of the main magnet independently. The high dynamic beam loading requires high reliability and robust for RF cavity. The structural design and machining process for the two RF Cavities are dedicated investigated. Four kinds of electrical contact technologies such as welding, crimping, spring finger contact and metal wire mesh contact are applied in the structural design of RF cavity to provide flexible and efficient contact, ensure the continuity of surface current path, and then improve the quality factor, Q-value. Based on the analysis of structural deformation and tolerance control, support structure with adjustment function for stems is designed to enhance cavity structure stability under operational conditions as well as the positioning fixtures developed to eliminate the possible errors in the cavity assemble process. The machining process related with water-cooling channel machining, surface treatment, quality verification is also presented in this paper. The RF cavity mechanical design and research show that it provides fundamental basis for the realization of high-performance RF cavities in this ultra-compact multi-particle SC

TUP04: A Spatio-Temporal and Management-Based Multi-Dimensional Integrated Safety Management System for Cyclotron Operation and Experiments

Yong Zhang; *Dan Xiao (HIPS)*

Traditional safety management models for cyclotron operation and experiments, which address potential risks such as radiation safety, personal safety, and equipment safety, suffer from issues like information silos, insufficient dynamic response, and regulatory blind spots. This paper proposes and preliminarily designs a safety management system architecture based on “spatio-temporal full coverage and multi-dimensional collaborative management.” It aims to establish a proactive and humanized safety management system that achieves comprehensive multi-dimensional coverage through three aspects: temporal processization, spatial zonation, and management systematization, thereby comprehensively enhancing safety assurance levels and emergency response capabilities. This design achieves seamless safety monitoring of the cyclotron facility across both time and physical space. It enables dynamic perception of the safety situation, facilitating a shift from reliance on “human defense” and “technical defense” towards a comprehensive, systematic, and ecological approach.

TUP05: Control System Development for Ultra-compact Multi-particle SC Cyclotron

***Dongxu Ran**; Yunlong Chai (CIAE; Chengdu Cyclotron Science and Technology Co., LTD)*
Tianjue Zhang; Zhiguo Yin; Hongji Zhou; Chuan Wang; (CIAE)

The China Institute of Atomic Energy is developing an ultra-compact multi-particle superconducting cyclotron, which can provide two different ions, including a particle and H_2^+ with corresponding energies. To ensure convenient operation and stabilize the beam current, a PLC-based control system with comprehensive interlock protection has been developed. This paper presents the design of a PLC-based control system. The system utilizes a distributed industrial network architecture, enabling supervisory control of key subsystems, including the superconducting magnet, radio frequency system, and ion source. It allows real-time monitoring and precise control, integrating functions such as interlock protection, data acquisition, remote operation, and fault diagnosis to ensure stable and reliable cyclotron operation. An innovative PLC-based automated protection system for low-temperature superconducting coils has been developed to prevent quenching. It's believed that such a system will significantly improve reliability and maintainability of the superconducting cyclotron. In this paper, a multi-mode operation design will be reported, which combines automation with manual intervention, offering high scalability and fault tolerance. The development of a generalized, intelligent PLC control program will also be reported, which can provide reliable control of the ultra-compact multi-particle cyclotron for various applications, including research on biological effects.

TUP06: Design and analysis of a compact single-stage cavity combiner for the 20kW solid state amplifier under vacuum

***Zhuoheng Liu** (CIAE; Chengdu Cyclotron Science and Technology Co., LTD); Tianjue Zhang; Zheyuan Zhang; Ziyi Cheng; Zhiguo Yin (CIAE)*

Focusing on high-power radio-frequency systems for ultra-lightweight high-temperature superconducting cyclotrons in special environments, we aim to make breakthroughs in key technologies that restrict the improvement of radio-frequency system reliability for highly automated cyclotrons. Research has been conducted on direct power combining technology and dynamic matching adjustment for solid-state power amplifiers at the 20-kW level. A dynamically tunable single-stage cavity direct power combiner based on a TEM cavity has been designed. Radio-frequency power signal flow analysis has been performed for a system with 24 inputs and one output. Research has also been conducted on the impact of up to three module failures at arbitrary positions on the total production of the power source under different power combining circuit topologies, as well as corresponding compensation methods. It is expected to achieve iterative breakthroughs in key technologies such as ultra-lightweight high-power radio-frequency cavity direct synthesis and adaptive power amplification circuit topology reconfiguration for solid-state power sources. This paper reports an adaptive, highly redundant, and lightweight solid-state radio-frequency power amplifier system designed for space applications.

TUP07: Alternative method and practice to evaluate cyclotron RF control performance during commissioning

Zeyuan Xia*; Zhuoheng Liu; Lingyun Xia (CIAE;* Chengdu Cyclotron Science and Technology Co., LTD*) Zhiguo Yin; Zheyuan Zhang; Ziyi Cheng; Tianjue Zhang (CIAE)*

Low-level radio frequency (LLRF) systems play an essential role in cyclotron control, and the beam quality is closely tied to the overall performance of the RF system. Efforts have been carried out by the individuals of the China Institute of Atomic Energy (CIAE), focusing on the design of a self-excited digital LLRF system for ultra-lightweight high-temperature superconducting cyclotrons in special environment applications. In CIAE, a self-excited digital LLRF controller has recently been developed and tested for the cyclotron RF control. In practice, for this special cyclotron, however, it is uneconomical to construct a dedicated vacuum tank just for the hot test of the RF system. Since the Q value and thermal drift of the cavity can be made identical under atmospheric or vacuum conditions, an alternative testing method has been developed to evaluate the performance of the LLRF control system, along with the cavity and the high-power RF amplifier. The cavity is excited by a 20kW solid-state power amplifier using a directional coupler, with a Q value of 2500, at a frequency of 77 MHz. Two dedicated digital signal processors, together with the ADCs, are included in the reported LLRF to achieve amplitude-phase control. Communication between DSPs is achieved through dual-port SRAM. A fast PID algorithm for IQ modulation was designed, achieving a group delay of less than 800 ns. This paper reviews the design of the self-excited digital LLRF, along with preliminary test results.

TUP08: Implementation of Tuning Loop for High-Frequency System of Cyclotron Based on FPGA and FFT/Cordic Algorithm

Jiayi Zhang (CIAE)

The LLRF system is the key to stable particle acceleration in a cyclotron, and demodulating the amplitude and phase is an important step in LLRF system. In this paper, the signal is directly sampled from the cavity, and FFT & Cordic algorithm is used to demodulate the high-frequency signal in FPGA. Based on the demodulation result, the stepper motor is driven to make the cavity in a resonant state. Simulation results show that the algorithm can demodulate amplitude and phase and accurately drive stepper motors to achieve tuning closed-loop control. The scheme was tested on a 9.5mev accelerator and achieved the expected results.

TUP09: Research on Electric Focusing in Central Region of Ultra Compact Cyclotron

Yunlong Chai (*CIAE;* Chengdu Cyclotron Science and Technology Co., LTD***)*** *Tianjue Zhang; Wei Fu; Chuan Wang; Pengzhan Li; Bohan Zhao; Hongji Zhou; Zhiguo Yin (CIAE)*

Ultra-compact SC cyclotrons for high-intensity medical isotope production pose unprecedented central region design challenges. Strong magnetic fields, compact geometry, and intense space charge effects generate complex focusing conditions where conventional design approaches prove inadequate. In the central region, magnetic focusing is negligible due to minimal azimuthal field variation, while low-energy ions are dominated by electric forces from RF acceleration gaps. High current beam requirements impose stringent electrode design constraints, as poor vertical acceptance directly compromises beam quality. This study investigates electric focusing mechanisms in the central region of an ultra-compact SC cyclotron under development at CIAE for ☒ and $H2^+$ dual-beam acceleration. Through mathematical modeling and Hilbert transform-based numerical fitting of simulation data, we quantitatively determine the vertical betatron tune ν_z and systematically compare electric and magnetic focusing contributions. The methodology combines analytical derivations with numerical techniques to determine focusing parameters from particle tracking simulations. Results reveal the relative importance of electric versus magnetic focusing under intense space charge and strong magnetic field conditions. The findings provide critical insights for optimizing electrode geometry and maximizing vertical acceptance, offering design guidance for improved extracted beam quality in medical isotope production.

TUP12: Extraction and magnet design of LB-30TP cyclotron

Chen Zhang; Gang Zhang; Haitao Bai; Hua Yuan; Jinshui Shi; Peng Zhang; Ruili Ma; Xiaozhong He; Yang Du; Yuhang Chen; ***Zhen Shen*** *(Sichuan Longevous Beamtech Co., Ltd)*

Sichuan Longevous Beamtech is currently developing a tri-particle cyclotron LB-30TP. The LB-30TP cyclotron is designed to be able to accelerate protons(H-) between 13 and 35MeV, deuterons(D-) between 6.5 and 17.5MeV, and alpha particles (He2+) up to 30MeV.

To compensate the difference of relativistic effects between H- and D- beams, two sets of tuning coils are winded around each pole base, while the isochronization of H- beams is achieved by machining of a removable pole edge on one side of each pole. The magnetic pole is designed to be slightly spiral to enhance the axial focusing force, and it also will alleviate the influence of fringe field on the ions that are extracted from different radii on the other side of the pole. The proton and deuteron beams are extracted from the cyclotron by stripping foils, while the alpha particle beams are obstructed by a bismuth target inside the cyclotron for producing At-211.

TUP10: Thermal Deformation Simulation for Ironless High-temperature Superconducting Magnet of Cyclotron CYCIAE-100B

Lingyun Xia*; Zhenguo Niu; Zeting Ou (CIAE; Chengdu Cyclotron Science and Technology Co., LTD) Hongji Zhou; Wei Fu; Jingyuan Liu; Xiaofeng Zhu; Suping Zhang; Chuan Wang; Tianjue Zhang (CIAE)*

Ironless superconducting cyclotrons, with their advantages of strong magnetic field, compact size, ultralight weight and less sensitive to ambient temperature, show broad application prospects in many areas, such avs isotope production, proton irradiation, etc. However, compared to conventional room temperature cyclotron with iron yokes, using superconducting coils as magnet poles and operating at low temperatures to maintain superconductivity necessitates considering thermal deformation of the cold mass during the design of the ironless superconducting magnet. An ironless superconducting cyclotron with 100MeV final energy is under development at China Institute of Atomic Energy. The cooling process within the cryogenic environment induces non-uniform thermal contraction deformation in multi-material components. To avoid concentrated residual stresses, geometric distortion, magnetic field distortion, and the possible quench risk, a three-dimensional finite element model has been established to simulate the thermal structural deformation behavior of the ironless superconducting magnet under several working conditions during the cooling process from room temperature to the operating temperature. The displacement and stress distributions of key components, and their impact on magnetic field homogeneity have been evaluated and an optimized ironless superconducting magnet design has been obtained for the 100 MeV ironless high-temperature superconducting cyclotron.

TUP11: Research and Development of a Control System for a Domestically Produced 14MeV Medical Cyclotron

Yuanhao Liu; ShiGang Hou; Tianjian Bian; Fengping Guan (CIAE)

Medical cyclotrons are widely used in cancer treatment, nuclear medicine imaging, biophysical research, and other fields, all of which require stable and safe operation. To meet the long-term stable operational requirements of a 14MeV medical cyclotron, a control system for the cyclotron was designed and implemented. This paper first introduces the overall architecture of the control system, followed by detailed descriptions of the hardware structure and software development of each subsystem. Industrially programmable logic controllers were employed for the hardware, while TIA Portal automation software was used for programming. The system has been deployed at Peking University for the production of medical isotopes such as ^{18}F and ^{64}Cu. Validation has shown that the system achieves millisecond-level response times, enables rapid equipment monitoring, exhibits strong anti-interference capabilities, and demonstrates excellent stability and safety, meeting the requirements for the long-term stable operation of medical cyclotrons.

TUP13: Design of the Vacuum System for the RFQ Injector of a Small-Scale High-Intensity Cyclotron

Cong Wu*; Shizhong An; Tianjian Bian; Sumin Wei; Jing Fang; Jiansheng Xing (CIAE) Kun Zhu; Zhi Wang (Peking University)*

Using a split coaxial radio frequency quadrupole accelerator (RFQ) as the injector for a small-scale high-intensity cyclotron and adopting a bottom-to-top injection method, the aim is to fundamentally break through the flow intensity limit of the small-scale high-intensity cyclotron. Improving the vacuum level of the RFQ injector can effectively reduce the risk of micro-spark discharge, ensuring stable operation of the accelerator and thereby enhancing overall performance. To ensure stable operation, the vacuum level is set to 10ˆ-6 Pa. Due to the large size of the RFQ electrode head and the relatively small flow conductance between each quadrant, achieving high vacuum and uniformity presents significant challenges. The lateral mechanical dimensions of the RFQ injector have a diameter of 271 mm, and the longitudinal mechanical dimensions are 1616.6 mm. To address these challenges, a molecular pump with a pumping speed of 1200 L/s is selected, and a symmetric double vacuum exhaust window layout is adopted. By positioning the exhaust windows in symmetric locations, each exhaust port can simultaneously act on two adjacent quadrants, establishing a full-space synchronous exhaust mechanism to effectively maintain the high vacuum environment of the RFQ injector, ensuring its stable operation, and thereby enhancing the overall performance and reliability of the entire small-scale high-intensity cyclotron.

TUP15: Parameterization of a Cylindrically Symmetric Magnetic Inflector

Lige Zhang*; Rick Baartman; Thomas Planche; Yi-Nong Rao; Yu. Bylinskii (TRIUMF)*

A cylindrically symmetric magnetic inflector is a promising approach for high energy axial beam injection into cyclotrons. In our previous study, a conceptual design for an H2+ cyclotron demonstrated the feasibility of such an inflector. In this work, we derive parameterization formulas to optimize the inflector field and discuss the injection conditions under different field configurations. Furthermore, we propose a 2-stage magnetic inflector for cyclotron injection. The required magnetic field of the 2-stage inflector can be naturally generated within the injection hole of the main magnet.

TUP14: Conceptual Design of a 70 MeV/u Variable-Energy Superconducting Cyclotron for Multipurpose High-Intensity Applications

Chuan Wang; Hongji Zhou; Pengzhan Li; Tianjue Zhang; ***Wei Fu****; Yunlong Chai; Zhiguo Yin; Ling Qin; Lingyun Xia (CIAE)*

Conventional superconducting H_2^+cyclotrons are inherently limited in variable energy extraction, as the stripped particles spiral inward, constraining both trajectory control and beam quality. To meet the increasing demand for high-intensity, variable-energy beams across a wide range—particularly for applications in medical isotope production and proton FLASH therapy—this study presents the physics design and magnet simulation of a novel 15 – 70 MeV/u variable-energy, multi-particle superconducting cyclotron. The proposed cyclotron is capable of accelerating particles with a charge-to-mass ratio of 1:2, such as H_2^+ and He^{2+}, with intense proton beams obtained via H_2^+ stripping. To address the long-standing challenge of multi-turn extraction for H_2^+ at low energies, an alternating-sign field configuration was introduced to enable rapid extraction. Based on a detailed particle orbit model, the key magnetic parameters were optimized, yielding a hill field of 3.6 T, a valley reverse field of 0.6 T, and a sector angle of 36 – 40°, which also provides sufficient space for RF cavity installation. Finite-element simulations further demonstrated the feasibility of a compact superconducting magnet system, where coils are wound directly around the pole structure. This design enhances axial focusing while maintaining compactness. Static beam dynamics calculations confirm that the transverse oscillation frequency remains below 1.9, effectively avoiding low-order resonance risks.

TUP16: Design and Test of the Phase Probe for CYCIAE230 superconducting cyclotron

Tianyi Jiang*; Zhiguo Yin; Yang Wang; Ziyi Cheng (CIAE) Zeyuan Xia (CIAE;* Chengdu Cyclotron Science and Technology Co., LTD*)*

Ever since the first non-classical isochronous cyclotron was invented in 1956, the stability of the isochronism of this kind of accelerator has been pursued for decades. For the CYCIAE-230 superconducting cyclotron, the matching between the RF frequency and the magnet field is even more challenging. A dedicated 2nd harmonic resonator has been designed, manufactured, and installed on the beamline to track the phase drift of the cyclotron-extracted beam. Front-end electronics and embedded software have been implemented to detect and broadcast the beam phase via a local ethernet connection. A dedicated software has been developed to trace the phase error and constantly regulate the frequency of the master oscillator of the cyclotron in a predefined frequency range. The same software also takes supervisory control of the excitation current of the superconducting coil and the temperature of the magnet. Online tests have been conducted using the cyclotron beam and the phase probe system. Preliminary results indicate that the resonator has a good signal-to-noise ratio and can detect magnetic field drift in the order of 10ˆ-7. In the meantime, the system can also be used as a non-invasive beam current detector, providing valuable information to the beam current regulation system. This paper reviews the design of the phase probe, electronics, and software, along with preliminary test results.

TUP17: Design of the Desktop Hard X-ray Source Measurement and Control System

***Zhengyu Wei**; Lin Wang; Zeran Zhou (NSRL, USTC) Ziqiang Dong; ZhuoXia Shao (USTC) HaoHu Li (Shanghai APACTRON Particle Equipment Co. Ltd)*

To bridge the gap between conventional X-ray tubes and large-scale X-ray generation facilities, we have developed a Desktop Hard X-ray Source. This device provides higher X-ray intensity compared with traditional X-ray tubes while maintaining advantages of compactness, low cost, and ease of operation. The device consists of three main components: an injector, a beam transport line, and a storage ring. In this system, the electron beam generated by the injector is resonantly injected into the storage ring, where it circulates at high speed. During circulation, the electron beam repeatedly collides with a metallic micro-target installed inside the vacuum chamber, thereby generating X-rays. To achieve a more compact configuration while ensuring improved beam quality, an electron cyclotron accelerator is employed as the injector. This accelerator offers benefits such as small size and high microwave power efficiency. To ensure precise and stable operation of the device, a dedicated measurement and control system has been designed. The software framework of this system is built on Debian 12 and EPICS 7, integrating all device control and data processing into EPICS IOCs and establishing interconnections among relevant PVs. An OPI has been developed based on Phoebus to support system operation. In addition, machine learning techniques have been explored for integration into the control system to further enhance the intelligence and accuracy of control strategies.

TUP18: Development of a Distributed Intelligent Control System for compact Cyclotron Accelerators

***YunLong Li**; YunTao Liu; Shigang Hou; Fengping Guan; ChuYun Ma; Peng Huang; Yaozhu Chen; Xianping Li; Fei Wang (CIAE)*

Modern compact cyclotrons have multiple system components and are used for a variety of applications such as radioisotope drug development and production, neutron imaging, BNCT, etc., which require high stability and safety of the accelerator equipment. Aiming at the series of compact strong-flow cyclotron accelerators of the China Institute of Atomic Energy, a high-speed control system architecture is constructed in this paper, which effectively improves the scalability and efficiency of the control architecture. A multi-threaded parallel data acquisition database based on MySQL is designed and implemented for multiple subsystems of the accelerator. Based on these operational data, a neural network and other machine learning algorithms are used to implement a beam current prediction model and a fault diagnosis model, which can assist the operator in judging the state of the beam current and then debugging. This research provides a stable and scalable distributed control solution for the small cyclotron, which provides a reliable guarantee for improving the operation of the accelerator, and more intelligent control technology will be completed based on this system in the future.

TUP19: A Cyclotron-based BNCT-TPS design

***Yaozhu Chen**; Fengping Guan; Yunlong Li; Xianping Li (CIAE)*

Boron neutron capture therapy (BNCT) is a binary targeted radiotherapy technique that exploits the high neutron-capture cross-section of Boron-10. The treatment planning system (TPS) is the essential component of the BNCT system used to make treatment plans for patients, which can simulate the treatment process, adjust the parameters in the irradiation process and calculate the dose in the patient. With the development of accelerator technology, accelerator-based BNCT has entered the stage of rapid development around the world. However, cyclotron-based BNCT and its TPS in China exist flaws, significantly impeding the progress of BNCT clinical applications. To address this issue, an independently developed BNCT-TPS has been designed based on 18 MeV high-intensity proton cyclotron in CIAE. The system developed a range of tools and features including medical image processing, 3D data reconstruction, tumor target delineation, particle transport simulation (using MCNP as Monte Carlo engine), dose distribution output and optimization. It has been built to be a user-friendly interface and expected to be updated for clinical practice.

TUP20: The design of the neutron exit of the neutron source based on the cyclotron by simulation to improve the thermal neutron flux

***Ye Zhu**; Lu lu; Shizhong An; Fengping Guan; Sumin Wei; Xiaobo Li; Tianqi Lv (CIAE)*

A neutron source based on the 18 MeV cyclotron is designed for thermal neutron imagine. A groove is usually designed at the thermal neutron exit to improve the thermal neutron flux. To further improve the thermal neutron flux and decrease the gamma in the neutron beam, some cerium sticks are placed in the neutron port. Because the thermal neutron reaction cross-section in cerium is smaller than this in the moderator, and the gamma reaction cross-section in cerium is larger than this in the moderator. Neutrons tend to propagate preferentially along the cerium sticks, thereby enhancing the collimation of the emitted thermal neutron beam. Simultaneously, the gamma in the thermal neutron beam is effectively reduced.

A thermal neutron exit is designed as a circle with the 10 cm-diameter, incorporating cerium sticks with a radius of 0.2 mm spaced at 1 cm intervals. By simulation, when the cerium sticks placed in the exit, the thermal neutron flux at 10 meters from the source increased from 5.12×10-11 n/cm2/proton to 5.81×10-11 n/cm2/proton, while the gamma flux decreased from 8.03×10-11 n/cm2/proton to 6.99×10-11 n/cm2/proton.

TUP21: The design of the irradiation terminal for the CYCIAE-230 cyclotron beamline

Qiqi Song*; Bohan Zhao; Zhiguo Yin; Yang Wang (CIAE)*

The study of radiation effects and radiation-hardening technology has become increasingly demanding for modern proton cyclotrons in the middle energy range. To meet this requirement, the China Institute of Atomic Energy (CIAE) has designed and constructed a dedicated irradiation terminal downstream of the beamline, following the telescope section, for the CYCIAE-230 superconducting cyclotron complex. The irradiation station uses the double scattering technique to generate a uniformly distributed dose field. The setup incorporates a primary scattering target made of Lexan material and a secondary scattering target composed of lead/Lexan material, functioning as a double scattering beam expansion and uniformization device to form a 3cm × 3cm irradiation field. The Siebers profile is adopted for the secondary scatter. Energy calibration has been studied, yielding a beam energy of 223 MeV at the terminal position when the first scatter is set to a minimal length. The proton particle distribution reveals a dose distribution uniformity of better than 85%. The fluence of the desired field with a measured fluence in the range of 1 × 108 P × sec-1 × cm-2 to 5 × 1011 P × sec-1 × cm-2. The typical irradiation period is adjusted to be in the range of 10 to 1000 seconds, accordingly to facilitate beam gating. The design, geometry, and test results of the beamline and irradiation terminal will be reported in this paper, along with the calibration and online beam diagnostics results.

TUP22: Design of the Dose Monitoring and Safety Interlock System for the Huludao Base Cyclotron Accelerator Facility

Meirao Sun*; Shigang Hou; Fengping Guan; Xianping Li; Xueyun Bai (CIAE)*

To meet the research and manufacturing needs of a new type of cyclotron, there is an urgent need to establish a new cyclotron research and development center. The Huludao base has been selected as the site for constructing this new cyclotron R&D center. During the operation of the cyclotron, a dose monitoring and safety interlock system is required to monitor the radioactivity generated throughout the process in order to protect the operating personnel and the public from additional ionizing damage. To meet safety protection requirements, a dose monitoring and safety interlock system based on a programmable logic controller (PLC) has been designed. This system can ensure that no personnel enter the accelerator area during its operation and that there is no beam in areas where personnel are present, thus protecting personnel safety. The PLC can handle information control for on-site radiation monitoring, protective door positions, emergency stop buttons, inspection switches, emergency open buttons, and other related functions. This paper provides a detailed description of the system's design structure and the control logic between each component and generally describes the expected operational outcomes of the system at the Huludao base cyclotron R&D center.

TUP23: Production of high-intensity titanium ion beams by plasma sputtering

Andrei Bondarchenko; *Dmitriy Pugachev; Vladimir Loginov; Vladimir Mironov (JINR)*

The research program of Flerov Laboratory of Nuclear Reactions (JINR) in the synthesis of Super Heavy Elements and in applied research requires the production of intense accelerated beams of solid materials. Constant developments are being made to broaden the range of available beams for physics. In this paper we report the results of production Ti ion beams by plasma sputtering. The experiments were performed with DECRIS-5M ion source at the Flerov Laboratory of Nuclear Reactions at ECR test bench.

TUP24: R&D of Multichannel Readout Electronics for Compact Ion Chambers of Nozzle for Proton Therapy

Qingwei Han *(CIAE, Chengdu Cyclotron Science and Technology Co., LTD) Zhiguo Yin; Tianyi Jiang; Qiqi Song; Chuanye Liu; Yang Wang (CIAE)*

A superconducting cyclotron-based proton therapy system has been developed at the Chengdu Cyclotron Science and Technology Co., Ltd. (CCST). For a cyclotron-based proton therapy system, the ion chamber at the nozzle is crucial for both the therapy system and the adaptation of the planning system. In practice, to achieve low noise measurement, the existing system is equipped with 256 triaxial cables from the ion chambers to the readout electronics, which brings an extremely high cost and is space-consuming. Distributed multi-channel readout electronics are designed and partially integrated into the ion chamber of the nozzle, thereby increasing the signal-to-noise ratio in detecting the scanning beam spot position. For this purpose, multiple 128-channel Current-to-Digital ADCs are integrated into the ion chamber to digitize the charge and enhance electronic electromagnetic compatibility. The digital readout electronics are based on the ZYNQ 7020 and transmit data via the AXI GPIO bus and the UDP protocol, which meet real-time requirements. Besides that, a low-overhead beam center localization algorithm is designed, which is suitable for embedded electronics. This paper reviews the design of the multichannel readout electronics for compact ion chambers, along with preliminary test results.

TUP25: Design and Principle Analysis of Pneumatic Rabbit System for Zr-89 Isotope Production Using Solid Targets in Medical Cyclotron

Jiajing Bao*; Zhan Liu (CIAE; Chengdu Cyclotron Science and Technology Co., LTD) Jingyuan Liu; Pengzhan Li; Chuanye Liu; Tianjue Zhang (CIAE)*

The medical isotope Zr-89, with its short half-life and excellent positron emission characteristics, shows significant promise for PET imaging applications. China Institute of Atomic Energy is developing a novel Zr-89 solid target pneumatic transport system. To address the challenge of rapidly delivering the "rabbit" capsule to designated locations, this study employs computational fluid dynamics and 6DOF dynamic mesh techniques to investigate how supply pressure, transport tube geometry, and capsule mass affect the transport process, thereby determining optimal capsule structure and tube configuration. Based on simulation results, the pneumatic transport system design was finalized and equipment specifications determined, enabling reliable isotope target delivery to specified positions.

TUP26: Design and fabrication of a large area multi-strip ionization chamber for proton therapy

Xiaoqing Ren*; Zhan Liu (CIAE;* Chengdu Cyclotron Science and Technology Co., LTD*); Zhiguo Yin; Qiqi Song; Tianyi Jiang (CIAE)*

Focusing on the high precision dose distribution monitoring in the spot scan beam delivery system of proton therapy, we design and fabricate a high-precision ionization chamber with multiple strip electrodes, ensuring a stable gain from the ionized pair. Based on advanced laser etching technology, using aluminum-plated polyimide film as the electrode material, we investigated multiple fabrication parameters to produce high-precision, flexible strip PCBs. Using these flexible PCBs as central detection parts, we designed a large-area parallel plate ionization chamber with integrated dose and position monitoring. The reported ionization chamber has a sensitive area of 250 mm by 250 mm, comprising 256 channels in the X-direction and 256 channels in the Y-direction, along with two mutually verifiable integral plane electrodes. The ultra-thin film electrodes and window materials allow for virtually non-invasive ion beam measurements with a water-equivalent thickness of less than 0.3 mm. This ionizing chamber can be integrated into the nozzle of a proton therapy system to measure beam spot position in real-time. It also provides precise dose distribution information and can be integrated into quality assurance systems to make diagnostics at the iso-center. The design, fabrication results, and calibration of the large-area domestic ionization chamber will be reported in this paper.

TUP27: Design and Implementation of a Wire Scanning System Based on BNCT

Xianping Li; *Fengping Guan; Lipeng Wen; Shigang Hou; Peng Huang; Hao Sun; Yunlong Li; Wu Jiming; Tianhao Cui; Zhengcan Zhang; Jiayi Zhang; Yaozhu Chen; Yaoyang Tang (CIAE)*

China Institute of Atomic Energy (CIAE) has developed a beam diagnostic wire scanning system for an 18 MeV, 1 mA BNCT prototype. The system is centered around a Python-based upper computer interface for re-mote control of the double-wire scanning device. It employs pneumatic-driven scanning wires to avoid the drawbacks of electric drives in high-radiation environments. The system integrates an NI6259 acquisition card, pneumatic electronic ruler, and weak current preamplifier to synchronously and accurately collect position and induced current data. Based on a modular design, each unit is integrated into a compact chassis, enhancing maintainability and expandability. This paper describes the software architecture, the collaborative mode of pneumatic and acquisition systems, and the chassis integration scheme, and analyzes the stability of the pneumatic system and the material characteristics of molybdenum wires. The system provides key diagnostic tools for beam commissioning, optimization, and operation of the BNCT device, and also supports beam profile measurement.

TUP28: Preliminary Study of Beam Orbit Correction and Betatron Tune Characterization in CSNS-FFAG Accelerator

Yuwen An *(IHEP)*

This paper presents beam dynamics studies for the CSNS-FFAG accelerator, designed for 50kW proton beams at 25Hz repetition rate. We report on orbit correction and betatron tune measurement methods developed for this fixed-field alternating gradient machine.

TUP29: Optimizing Magnetic Flux Distribution in MA-Loaded Cavities through Nested Core Architecture for Scaling FFAG Accelerators

Bin Wu*; Jian Wu; Xiao Li (IHEP)*

Magnetic alloy-loaded RF cavities are critical components in scaling Fixed-Field Alternating Gradient (FFAG) accelerators, enabling ultra-high acceleration gradients and broad frequency operation without tuning. As FFAG accelerators advance toward higher power applications, enhanced cavity performance through improved magnetic core design becomes essential. Current large-scale magnetic cores fabricated from 18-micrometer nanocrystalline ribbons face limitations in shunt impedance for high-power operation. While ultra-thin ribbons (13-micrometer) theoretically offer superior performance through increased permeability and reduced eddy current losses, practical implementation encounters significant challenges including high costs, manufacturing difficulties, and stress sensitivity in large cores. This study proposes a novel nested core architecture utilizing selective ultra-thin ribbon placement in specific radial regions while maintaining conventional thickness materials elsewhere. Through theoretical analysis and simulation, we demonstrate that this approach not only provides cost-effective impedance enhancement but also redistributes magnetic flux density to improve temperature uniformity—critical for high-power FFAG applications. The nested design addresses power scaling challenges while maintaining economic viability, offering a promising solution for next-generation FFAG accelerator systems.

TUP30: Optimizing Magnet of IRANCYC-10 Cyclotron: Matrix Modeling vs. Experimental Shimming

R Solhju; ***Hossein Afarideh*** *(Amirkabir University of Technology) Mitra Ghergherehchi (Sungkyunkwan University)*

This paper presents preliminary steps for the shimming of IRANCYC-10 cyclotron magnet. Shimming, as a crucial step in magnet fabrication, significantly contributes to improving particle acceleration quality, beam stability, and the precision of output energy. Since some shimming procedures—such as pole edge trimming—are irreversible, they require a high degree of accuracy. In this study, the required adjustments for magnetic field corrections are predicted using a matrix method based on mathematical modeling, alongside an experimental approach. A comprehensive comparison of these two methods is provided, highlighting their respective limitations and advantages. The findings of this research offer valuable guidance for optimizing and designing future AVF cyclotron magnets, contributing to their improved performance.

TUP31: Investigation of Negative Hydrogen Ion Beam Profile in the Karaj C30 Cyclotron Using Mylar Foil

Keyvan Tabaei; *Iraj Jabbari (University of Isfahan) Zafar Riazi; Hamidreza Mirzaei; Abolfazl Abbasi (Nuclear Science and Technology Research Institute)*

The 30 MeV Karaj-C30 cyclotron, developed for medical and industrial radioisotope production at the Karaj Research Institute for Agricultural, Medical, and Industrial Studies, accelerates H- ions to 15 – 30 MeV and D- ions below 15 MeV. The system features a filament-based negative hydrogen multicusp ion source providing 1 – 2 mA, an injection line with optical elements, a two-sector electromagnet, and an RF resonator. It was observed that after a period of cyclotron operation, the beam current on the target gradually decreased. Examination revealed beam impingement on optical elements, indicating misalignment. A Mylar foil was used to investigate the beam profile. The recorded beam profile on the foil was analyzed through image processing. It was found that the beam was misaligned with respect to the beam transport line. Further investigation revealed that the ground electrode had undergone corrosion, as the magnets within the puller electrode caused deflection of the ion beam, leading to its collision with the ground electrode. Erosion of the ground electrode generated a radial electric field deflecting the beam. After replacing the ground electrode with an identical, non-corroded electrode, the beam profile was re-evaluated under the same operating conditions, and it was observed that the beam had been successfully realigned with the beam transport line.

TUP32: Extension of COLUMBUS Cyclotron Experiments to Helium Ions

Christian Wolf; *Jasmin Walk (HS Coburg)*

In this study, we investigated the feasibility of accelerating helium ions with the COLUMBUS educational cyclotron, which until now had been operated exclusively with hydrogen ions. The primary questions addressed were whether helium ions can be successfully accelerated under the existing experimental conditions, and whether He-3 ions can be detected in the beam. These questions were first analyzed theoretically, and the resulting insights guided a series of dedicated experiments. The measurements confirmed the acceleration of all four ion species, including the rare He-3 isotope. This achievement demonstrates both the technical feasibility and the pedagogical potential of extending the COLUMBUS program to helium, thereby broadening the scope of student experiments and future workshops.

TUP33: Structural Design and Magnetic Field Optimization of a Combined-Function Quadrupole-Sextupole Magnet

Jialian Zhang; *Kuanjun Fan (HUST)*

Achieving the design goal of a collision luminosity of 10^{35} $cm^{-2}s^{-1}$ for the Super Tau-Charm Facility (STCF) poses a critical challenge in optimizing the performance of the injected positron damping ring. This damping ring must damp a 1 GeV positron beam with a large injected transverse emittance (>1400 nm • rad) to an extracted transverse emittance below 11 nm • rad within the 166.7 ms storage time. This imposes stringent requirements on the magnetic field distribution accuracy, damping efficiency, and dynamic aperture of the magnet system. This paper proposes a damping ring design based on combined-function quadrupole-sextupole(QS) magnets. This design achieves an effective balance among key parameters such as emittance control, damping time, and dynamic aperture. Based on this concept, two types of QS magnets with adjustable sextupole to quadrupole field ratios are designed. The paper elaborates on their design and multi-objective optimization methods, with a particular focus on the application of the pole shaping method and asymmetric excitation method. By optimizing the pole face, the impact of higher-order harmonic fields is effectively suppressed. Multiple iterations demonstrate that the major higher-order harmonics in QS magnets are suppressed to the order of 2×10⁻⁴, meeting the damping ring’s tolerance for magnetic field errors. This provides a reliable technical foundation for high-luminosity positron beam injection.

TUP34: High-Frequency Air-Core Transformer Design

Sepehr Farid; *Christian Wolf; Jasmin Walk (HS Coburg)*

Compact cyclotrons need kilovolt Radiofrequency in the MHz range, yet product changeovers increasingly demand drives that can retune frequency, amplitude, and duty cycle. We report the design and experimental validation of a high-voltage, low-MHz transformer/matching network tailored for a digitally synthesized, soft-square Class-D driver. The method co-optimizes magnetizing inductance, leakage inductance, and winding capacitance to preserve Zero Voltage Switching and constrain dv/dt under variable frequency (2-4 MHz) and duty cycle. In this paper we provide a CAD layout and calculation and simulations and adjusting properties, resulting in an optimal geometry of the transformer.

These calculations adjusted the range of each property of the transformer in order to work within required range of frequency and voltage. These are material choice, quantification of the coupling k, spacing trade-off, and production of parameters suitable for 2-4 MHz operation and the design of the secondary circuit. This establishes a reproducible path from geometry to circuit model for a high-voltage RF transformer supporting agile RF drives.

TUP35: Design Study of the Main Magnet for a 100 MeV Spiral-Sector Cyclotron at CIAE

JinRong Lu; *Shizhong An; Tianjian Bian; Sumin Wei (CIAE)*

The development of a 100 MeV Spiral-Sector cyclotron, which is capable of extracting a beam with a rated power exceeding 50 kW, is in progress at The China Institute of Atomic Energy. Such a machine is designed for the production of medical radioisotopes for nuclear medicine. The basic parameters of the isochronous cyclotron magnet and its characteristics are described. An isochronous magnetic field was achieved by adopting the upper surface shimming scheme. The spiral angle was adjusted to control the vertical betatron tunes and avoid potentially harmful resonances during acceleration. We performed iterative magnetic field optimization with OPERA-3D, followed by detailed beam dynamics simulations and Lorentz stripping loss analysis. This process ultimately improved the beam acceleration efficiency. Guided by simulated electromagnetic deformation data, the magnet structure was further optimized for weight reduction through an analysis of its stress distribution and magnetization characteristics.

TUP36: Thermal Simulation of a High-Power Metallic Beryllium Target for a High-Current Cyclotron Neutron Source

JiangLong Xiang; *Sumin Wei (CIAE)*

To enhance the reliability and service life of a metallic beryllium (Be) target used in a cyclotron-based neutron source under high-beam-power conditions, this study presents the design and numerical simulation of a solid Be target with a back-cooling structure. Computational Fluid Dynamics (CFD) simulations were performed to analyze the thermal effects induced by a proton beam with an energy of 30 MeV and a current of 1 mA. The results provide critical technical support for the design and longevity improvement of the target system. The simulations demonstrate that heat exchange through the water-cooling channels in the copper backplate significantly reduces the maximum temperature on the target. Furthermore, the insertion of a vanadium interlayer between the Be target and the copper substrate effectively mitigates the risk of hydrogen embrittlement in beryllium. Under specified cooling conditions with typical water chiller parameters, the maximum temperature of the Be target remains well below its melting point (1287℃), thus ensuring safe operation under high-power proton irradiation.

TUP37: Numerical validation of theoretical isochronous cyclotron energy limits

Willem Kleeven *(IBA)*

In the previous cyclotron conference, an analytical prediction for the energy limit of isochronous cyclotrons was presented. The current paper shows numerical results to validate this model. For this purpose, extensive use is made of a tool that creates artificial isochronous magnetic field maps; a tool that is the subject of another contribution to this conference. A wide range of field maps with varying rotational symmetry numbers, varying flutter profiles and varying sector spiral angles is studied. Besides the energy limits, other optical properties such as the radial and vertical tunes and the stop-band of the 2Nur=N resonance are compared with the analytical predictions. The quality of agreement between theory and simulations is good but, as will be shown in the paper, depends on the amount of flutter in the map.

TUP38: Optimization Design and Performance Study of the Parallel-Plate Ionization Chamber for the Space Radiation Effects Analysis and Testing Platform– HuaiRou (50 MeV) Proton Cyclotron Facility

Zhengcan Zhang*; Fengping Guan; Sumin Wei; Lipeng Wen; Peng Huang; Hao Sun; Xianping Li; Jiayi Zhang (CIAE)*

To characterize the beam energy and transverse profile of the 50 MeV proton cyclotron at HuaiRou, a fixed-pitch strip ionization chamber is being developed. Systematic Monte-Carlo studies with Geant4 and SRIM were performed to quantify energy deposition and particle-transmission probabilities under varying electrode gaps, wall materials and gas compositions. Comparative simulations led to a baseline design in which 50 μm Mylar foils, aluminized on both sides, serve as the 2 kV high-voltage electrodes, while charge is collected on 150 μm flexible printed-circuit strips; the electrode gap is 3 mm and ambient air is adopted as the working gas. The optimized chamber yields a gas gain of 207.45 and exhibits excellent linearity of response versus proton energy, providing a robust foundation for prototype fabrication and further optimization.

TUP39: Simulation Study of an Inductively Heated Ion Source for Electromagnetic Separators

Hongyang Liu *(CIAE)*

High-abundance stable isotopes of nickel possess broad applications and significant demand, which can be prepared using the electromagnetic separation method. The core equipment of an electromagnetic separator for isotope separation is the ion source. To improve the heating efficiency of the traditional Calutron ion source, an electromagnetically induced heating-type ion source is designed. The heating performance of the crucible depends on the configuration of the induction heating power supply and the process design of the inductor. Based on theoretical empirical formulas and electromagnetic field theory, a finite element simulation software, COMSOL Multiphysics, is used to establish a Calutron ion source model. By studying factors affecting heating efficiency, such as the current magnitude, number of turns, spacing of the energized coil, distance between the coil and the crucible, and frequency of the alternating current–electromagnetic-thermal multiphysics coupling simulations are conducted. This helps determine the parameter configuration of the induction heating system power supply. Finally, the inductor design is optimized through orthogonal experiments. The research results can provide practical engineering guidance for the design of electromagnetic induction heating systems in Calutron ion sources.

TUP40: Application of an Inspection Robot in an Accelerator Manufacturing Workshop

Yaoyang Tang*; Huiyuan Liu; Xianping Li (CIAE)*

Abstract: To address dispersed inspection points, space constraints, and the difficulty of close-up human access in accelerator manufacturing workshops, this study develops a low-cost inspection prototype composed of a mobile base and a lightweight robotic arm, together with a manually operated PC-based supervisory interface (HMI). The system uses wired/wireless links to coordinate chassis motion and arm control. The end-effector carries a general-purpose camera and auxiliary lighting to enable WYSIWYG teleoperation, fixed-point framing, and fine pose adjustments. The HMI provides real-time video, joint/velocity sliders, recall of preset poses, and a one-click emergency stop, while logging captured images and operator actions for traceability. Tests in simulated and real workshop aisles and around equipment show the prototype can complete typical inspection tasks (e.g., photographing nameplates, visually checking connectors/ports, and inspecting fasteners), reducing the need for personnel to enter narrow or occluded areas and improving framing consistency and repeatability. The results indicate that a human-in-the-loop approach based on manual HMI control is feasible without complex algorithms or expensive sensors, and it provides an engineering foundation for subsequent extensions such as semi-autonomous waypoint routes, status annotation, and basic anomaly prompts.

TUP41: Particle Cyclotron Remote Monitoring System

Huiyuan Liu *(CIAE)*

As a high-end scientific research device, the stability, reliability, and safe operation of particle cyclotrons are crucial. The traditional on-site control methods limit the flexibility of researchers, especially when timely response to equipment status or long-term experiments are required. This study aims to design and implement a remote monitoring system based on Android mobile terminals, aiming to break through geographical limitations and provide researchers with safe, real-time, and efficient monitoring and intervention capabilities for key parameters of cyclotrons, such as magnetic field strength, vacuum degree, beam flow rate, etc.

TUP42: Development of the Multi-Channel Beam Diagnostics Electronics for Cyclotrons at CIAE

Peng Huang*; Hao Sun; Fengping Guan; Lipeng Wen; Shizhong An; Shigang Hou; ChuYun Ma (CIAE)*

To address the beam diagnostics requirements of multiple cyclotrons at China Institute of Atomic Energy (CIAE), a multi-channel digital beam diagnostics electronics system based on current-to-voltage (IV) conversion was developed. The IV conversion circuit integrates high-precision operational amplifiers with ultra-low bias current and low-temperature-drift resistors. The system implements a hybrid filtering architecture: analog filters and digital filters. The analog filters include the first-order RC filter and the second-order MFB low-pass filter, and the digital filters include the FIR filter, median filter, and MAF filter. Xilinx Artix-7 series FPGA(XC7A100T-2FGG484I) is used as the main controller and an 8-channel 18-bit resolution ADC(AD7606C-18) is used to realize analog-to-digital conversion. UDP protocol is selected as the communication protocol between the electronic system and the host PC or PLCs. Test results show that the max 0.5% relative error can be reached when the beam current ranges from 100 pA to 20 mA, with linearity $R^2 > 0.999999$ for all channels. The system has been validated through long-term operation on CIAE's high-current accelerators (e.g., BNCT and neutron imaging accelerators, with the 16-channel electronics) and low-current accelerators (e.g., 16MeV and 9.5 MeV cyclotrons, with the 8-channel electronics).

TUP43: Design of a set of multi-use field measurement system and its control algorithm for Cyclotron beamline magnets

***Xinyu Chen*[1]** *; JinRong Lu; Shizhong An; Fei Wang (CIAE)*

Beamline magnets are essential parts of an accelerator system in order to ensure final beam quality on the target. Thus, it is necessary to conduct magnetic field measurement and shimming to ensure that ever magnet has sufficient field accuracy. CIAE is vigorously promoting the industrialization of cyclotrons and the promotion of design capabilities for other types of particle accelerator. In order to conform with such tendency, a new set of magnetic field measurement system is designed, which can be easily transferred between point measurement mode and rotation measurement mode. The system consists four axes of motion: 3 translational axis following Cartesian System and 1 rotation axis following axial direction, and the control system is designed to be able to conduct field measurement automatically. For accuracy, field measurement system uses high-precision hall probe and moves in go-stop mode when run in point measurement mode; when it runs in rotation measurement, the system uses induction coil and switch to external trigger mode, allowing users to gain field reading while the probe is rotating.

TUP44: Cyclone® IKON : From commissioning to operation

Erik van der Kraaij*; Michel Abs; Jean-Michel Geets; Jerome Mandrillon; Olivier Michaux; Vincent Nuttens; Patrick Verbruggen(IBA)*

At the CYC2022 conference, IBA presented its new 30 MeV proton accelerator. The first installation of this Cyclone® IKON, with four beam transmission lines and a beam energy of 30 down to 13 MeV, has now successfully been commissioned and is running at a customer site. In this presentation we will go into the details of the accelerator's performance, from its injection to its transmission, plus intensity on targets. With the accelerator fully operational, we will also present a comparison of the latest results with the design and commissioning simulations.

TUP45: Jacobian for the Design of Variable-Gap Dipole Magnets

Thomas Planche; ***Lige Zhang****(TRIUMF)*

When exploring the design of constant-tune (isochronous) cyclotron magnets, we found it useful to employ dipole magnets with a variable gap height, allowing fine control of the radial field profile. To determine the optimal gap-shape profile that produces a prescribed magnetic field distribution, we employ an iterative search using 3D finite-element simulations (e.g., OPERA). To minimize the number of iterations, we use a Newton – Raphson scheme, which requires knowledge of the Jacobian matrix relating field errors to gap corrections. In this work, we derive exact analytical expressions for this Jacobian in two limiting cases: the non-saturated regime, obtained using conformal mapping, and the fully saturated regime, modeled with current sheets. We then describe a method to interpolate between these two limits to obtain a general Jacobian valid across the full range of magnetization. This approach serves as a practical building block for designing variable-gap magnets with only a few iterations; it can also readily be applied to the design of fixed-field alternating-gradient (FFA) magnets.

TUP46: RF Design, Fabrication, Commissioning, and Testing of a Significant-beam-loading Buncher with Synthesized Fundamental and Third-Harmonic Operation

Xinyu Li*; Zhan Liu (CIAE;* Chengdu Cyclotron Science and Technology Co., LTD*) Tianjue Zhang; Zhiguo Yin; Ziyi Cheng; Bohan Zhao (CIAE)*

China Institute of Atomic Energy is upgrading the injection line of the 100MeV high current compact H- cyclotron (CYCIAE-100) with the aim of extracting mA level beam from the cyclotron to meet growing scientific research and commercial application demands, ultimately aiming to establish the world's highest beam power cyclotron facility. The buncher upgrade represents a critical component of this project. The buncher can effectively enhance the beam current within the acceptance phase of the cyclotron and optimize beam performance parameters. The newly developed buncher system employs a bunching voltage synthesized from the fundamental and third harmonics, for which a compact cavity matching circuit supporting both harmonics was specifically designed. The cavity adopts a λ/4 coaxial transmission line structure, was modeled and optimized for key parameters such as frequency and Q-factor using CST software, and the cavity was folded to accommodate the compact layout of the injection line. The cavity matching circuit and buncher have now completed cold testing and highpower testing, have been successfully installed in the injection line, and have undergone online testing under low-beam-current conditions. The results demonstrate a bunching gain of 2.2 achieved at an ion source extraction current of 1.4 mA, providing preliminary verification of the buncher's proper operation.

TUP47: Study and Survey on the Beam Spot Shape Invariance during Gantry Rotation

Yandong Zhu; *Xinmiao Wan; Deqiang Tau; Zhiqiang Ren; Xuankai Chang; Zhihui Li (Sichuan University)*

Particle therapy gantries are essential for modern radiation therapy, requiring precise beam spot control to ensure dose delivery accuracy during multi-angle irradiation. However, gantry rotation alters the relative positions of optical components, affecting beam spot characteristics. Current solutions each offer distinct advantages under different system conditions. A unified theoretical analysis is imperative to reconcile these approaches, elucidate their intrinsic connections, and ultimately enrich the design paradigm for rotation-invariant systems.

This study not only integrates existing approaches but also introduced A novel constraint (Mx=My) for the gantry transfer matrix. It ensures beam spot invariance without needing symmetric input beams or extra rotators. This constraint offers a versatile and cost-effective solution for gantry design. Simulations validate its effectiveness in maintaining stable beam spots across all rotation angles, even with asymmetric emittances. Importantly, the proposed framework integrates seamlessly with existing techniques, such as sigma matching, thereby enhancing the overall robustness and adaptability of gantry systems.

This work proposes a unified design framework for rotation-invariant beamline systems in particle therapy, providing theoretical foundations for future system optimization.

TUP48: Study on the Injection Line for a 30MeV High-Current Cyclotron

Tianhao Cui; *Shizhong An; Luyu Ji; Xianping Li (CIAE)*

The China Institute of Atomic Energy is developing a 30 MeV high-current cyclotron. To meet the injection requirements of the accelerator, this paper conducts the design of the injection line as well as particle tracking simulation calculations. The beamline elements of the injection line employ electrostatic lenses, bunchers, solenoids, and double quadrupole lenses. The overall layout of the injection line and the relevant parameters of the beamline elements are preliminarily determined using the TRANSPORT software, and subsequently, the parameters of the injection line are further optimized through the particle tracking software OPAL. After completing the design of the injection line, particle tracking simulations are carried out using OPAL to examine the beam's behavior through the injection line under different beam current conditions, and simulations are also performed to study the beam status within the injection line under both single-bunch and multi-bunch conditions.

TUP49: Half-frequency buncher upgrade for SFC cyclotron

Xiaoping Sha *(IMP)*

To increase the beam transmission efficiency, a new buncher has been installed on the injection line of the HIRFL injector cyclotron SFC. This new buncher uses saw-tooth RF waveform with an effective voltage of up to 2.54 kV and operates at half of the SFC cyclotron RF frequency. With this half-frequency matching mode, we achieve 100% theoretical longitudinal matching between the injector SFC (H=1) and the main cyclotron SSC (H=2). As a result, the beam transmission efficiency has doubled compared to the original full-frequency mode.

TUP50: Research on the Preparation Process of Tantalum-Based Electrodeposited Nickel Targets for Accelerator-Based Production of ^{64}Cu

Yu Wang*; Yong Li; Yuxuan Wu; Guoying Guan; Shizhong An; Pengfei Zhao; Yunlong Zhao (CIAE)*

In order to enhance the coating quality of tantalum-based electroplated nickel targets for the production of ^{64}Cu radionuclides, and to address issues such as thin and easily detachable nickel coatings in conventional targets, this study systematically investigated the pretreatment processes of tantalum substrates, the composition of the plating bath, and electroplating parameters. The effects of pretreatment methods, pH of the plating bath, surfactant concentration, current density, temperature, and agitation rate on the quality of the nickel coating were examined. The fabricated targets were subsequently characterized through metallographic examination, drop tests, and thermal shock experiments. Results demonstrated that under ambient temperature conditions, by adjusting the plating bath pH to 9.80 with ammonia, maintaining a sodium dodecyl sulfate concentration of 15 mg/L, applying a current density of 3 mA/cm^2, an agitation rate of 200 r/min, and an electroplating duration of 2 hours, a high-quality tantalum-based electroplated nickel target suitable for accelerator-based

^{64}Cu production was achieved. The resulting coating exhibited a thickness of 20.87 mg/cm^2, with excellent uniformity, adhesion, and thermal stability. Additionally, the utilization efficiency of Ni^{2+} in the plating bath reached 60%.

TUP51: Physics design of a compact cyclotron for isotope production

Guohui Wei *(IHEP)*

Nowadays, there are almost 5 million new patients every year who get cancer in China. However, isotope drugs are not enough according to this large numbers of patients. A compact cyclotron with 16-MeV proton is designed for current tough situation to product isotopes.

The diameter of the core part of this compact cyclotron is less than 60 cm. Physics simulation has been done by the CODE CYCLONE. With adjust extraction, a reasonable current of 100 um can be got by this machine. This paper will report the study in detail.

TUP53: Automated Separation and Purification of 68Ge from Cyclotron-irradiated Ga-Ni Alloy Targets

Fei Duan; *Li Guang; Wen Kai; Ma Chengwei; Wang Xiaoming (High-Tech Atomic Co., Ltd)*

1. Introduction

Germanium-68 (68Ge, T1/2=270.9 d) serves as a crucial precursor for the 68Ge/68Ga generator, which provides radionuclide gallium-68 (68Ga, T1/2=67.7 min). The present study aimed to develop an efficient and automated methodology for the separation and purification of 68Ge from the irradiated Ga-Ni alloy targets.

2. Method

The Ga-Ni alloy targets were dissolved in a mixture of sulfuric acid and hydrogen peroxide at 95℃using an automatic dissolution apparatus. Subsequently, the conditions for purifying germanium via a double-column approach (Hydroxamate and Sephadex G 25 resin) were optimized, and the process validated through radiochemical separation experiments for 68Ge.

3. Results & Conclusion.

As shown in Figure 1, the hydroxamate resin (Column-A) removed impurities including Ga, Ni, and Zn; the Sephadex G-25 resin (Column-B) then eliminated Nb and Au. The radiochemical separation experiments of 68Ge confirmed a separation recovery rate exceeded 90%. The 68Ge product exhibited a radionuclide purity greater than 99.9% with all elemental impurity levels below 1.5 ppm (Table 1). In conclusion, the established automated double-column separation process proves to be stable and efficient, offering a reliable technical foundation for the large-scale production of high-quality 68Ge.

TUP52: Beam Dynamics Analysis of the Axial Injection System for the CIM30 Cyclotron

Xin Zhang (USTC) Zou Wu; Kaizhong Ding; Gen Chen; Yonghua Chen; Yutao Song; ***Feng Jiang****;*

Yue Hu; Chujie Chao; Shiwen Xu; Zhong Wang (HFCIM) N. Morozov; E. Samsonov (JINR)

Anaxial injection system has been developed for the CIM30 cyclotron, which is designed to accelerate α-particles up to 30 MeV for medical isotope production of At-211. This system transports a 50–60 keV α-beam from an external ion source into the cyclotron center. Both transverse and longitudinal focusing are applied to ensure high beam extraction efficiency and quality. The injection line consists of dipole magnets, a buncher system, a beam diagnostics system, a vacuum system, Glaser lens, and a spiral inflector. The buncher and the spiral inflector are identified as key components. Their physical design and beam dynamics characteristics are described in detail. Additionally, mechanical and magnetic tolerances of the injection system are analyzed, providing a basis for engineering design

TUP54: Design of the 18MeV Injection Line System

Yi Yang; *Yuzhuo Huang; Luyu Ji (CIAE)*

This paper presents a comprehensive design study of the H^- injection line system for an 18 MeV compact high-current cyclotron. The injection line system, with a total length of 1310 mm, employs a configuration incorporating dual solenoids for transverse focusing and a buncher for longitudinal bunching. Beam transport design and space charge effect simulations were performed using specialized beam optics calculation software. Comparative analysis of buncher performance at 300 V and 500 V led to the selection of 500 V as the optimal operating voltage for longitudinal bunching. The influence of space charge effects at different beam currents (1mA, 3mA, 6mA) on beam envelope was systematically investigated under fixed solenoid strengths. Results demonstrate that while space charge effects significantly affect beam envelope, the 6mA condition remains within design specifications. Beam envelope matching across different space charge conditions was achieved by adjusting solenoid currents, resulting in a maximum envelope below 40 mm and an exit envelope under 20 mm. The normalized emittance after envelope matching reached maximum values of only 0.27365 mm·mrad and 0.27616 mm·mrad in the x and y directions, respectively, at 6mA operation. The optical system can maintain compact beam envelopes throughout transmission while ensuring proper focusing at the line exit. All results fully comply with initial design requirements, providing a reliable foundation for engineering implementation.

Session WEA

WEAI01: Installation of C70 Cyclotron and the Commissioning of the Sweeper Magnets for SAIF at NRF-iThemba LABS

***Joele Mira**; Hugo Barnard; Izak Strydom; Hein Anderson; Ntuthuzelo Pakade; Johan Broodryk (iThemba LABS) William Duckitt (Stellenbosch University) Justin Abraham (TSN Systems PTY Ltd)*

iThemba LABS is an accelerator-based science research facility administered by National Research Foundation (NRF) and has been in operation since 1986. iThemba operates a K200 separated sector cyclotron for research in nuclear physics, radiation biophysics and the production of medical radioisotopes. iThemba LABS has installed an IBA C70 cyclotron, which is phase one of the South African Isotopes Facility (SAIF). The facility includes a 70 MeV H-minus cyclotron and four beamlines for the production of radioisotopes. Decommissioned proton and neutron therapy vaults have been retrofitted to accommodate the cyclotron and bombardment target stations.

Two high-power bombardment target stations have been installed and commissioned in two opposite vaults for the production of radioisotopes. Due to power dissipation in the vacuum windows and the target, heat spots can form during irradiation, which might cause the window and the target to break. In order to reduce the heat spots, two H-type dipole magnets have been designed, installed and commissioned on the two target stations. The magnets are each powered by 1.6 kHz AC power sources with a 90° phase difference between the vertical and horizontal magnets. These magnets sweep the beam in a circular pattern with a radius of 20 mm on the target surface. The presentation will showcase the installation of the C70 cyclotron, design off sweeper magnets coils, electronic setup and magnets commissioning.

WEAI02: FLNR JINR Accelerator Complex for multipurpose applied research

***Semen Mitrofanov**; Igor Kalagin; Pavel Apel; Vladimir Skuratov(JINR)*

The Flerov Laboratory of Nuclear Reactions (FLNR) conducts fundamental scientific research alongside extensive applied science activities on its accelerator complex. Key applied research areas include the production of heterogeneous micro- and nano-structured materials; radiation hardness testing of electronic components (avionics and space electronics); ion-implantation nanotechnology and radiation materials science; as well as the production of high-purity radioisotopes and radioanalytical researches. The talk will provide an overview of the current state of the FLNR accelerator complex, the ongoing life science research activities based there and outline the Laboratory's evolution trajectory (include both accelerator instrumentation and applied physics) over the next seven years.

WEAO01: Development and Application of the Cyclotrons for the mA level beam current at CIAE

Shizhong An; *Fengping Guan; Sumin Wei; Bin Ji; Jiansheng Xing; Tianjian Bian; Luyu Ji; Lipeng Wen; He Zhang; JinRong Lu (CIAE)*

A great progress on the cyclotron technologies has been achieved and a series of high-intensity cyclotron devices have been developed at China Institute of Atomic Energy (CIAE). The first 14 MeV high-intensity proton cyclotron with an extraction current exceeding 1 mA was independently developed by the department of nuclear technology and application of the CIAE in 2021. The completion of the 14 MeV/1 mA high-intensity proton cyclotron laid the foundation for China's applications of compact high-intensity proton cyclotrons in neutron source technology. CIAE has successively established the China's first prototype of a boron neutron capture therapy (BNCT) treatment device based on 14 MeV/1 mA high-intensity proton cyclotron. A 18 MeV/1 mA high-current proton cyclotron was developed successfully as the upgraded BNCT cyclotrons in 2024. Many kinds of BNCT medicine experiments with mice and cells for the hospitals and Universities have been finished. A new high-intensity cyclotron based on with beam current reaching 3-5 mA is being developed at CIAE. CIAE's high-intensity cyclotrons are playing a crucial role in the development of nuclear science and the nuclear technology applications, as well as in the production of medical radioisotopes in China.

WEAO02: Development of Series Neutron Sources at FDS

Qi Yang; ***Wen Wang*** *(IANS)*

Neutron sources play a key role in advancing nuclear energy systems and expanding nuclear technology applications. The FDS Consortium has developed a series of neutron sources for various uses, such as the Mini Neutron Generator (MINEG), Small Neutron Generator (SNEG), Compact Neutron Source (CONEG), High Intensity Neutron Source (HINEG), and Volumetric Neutron Source (VNEG). MINEG, with a minimum diameter of 26mm, features long service life, heat resistance, and strong anti-vibration performance. Its pulse timing is adjustable and has been widely used in neutron logging, industrial material analysis, and security inspections. SNEG is a DD/DT neutron source featuring high neutron yield, a compact design, and mobility. It is widely used in neutron radiography, elemental analysis, detector calibration, and nuclear physics experiments. CONEG is a cyclotron-based neutron source with an intensity exceeding 1014 n/s. It is primarily designed for neutronics and shielding validation in advanced nuclear energy systems, as well as for neutron therapy and isotope production. HINEG consists of three phases: HINEG-I, HINEG-II, and HINEG-III. HINEG-I is currently operational and serves as a D-T fusion neutron source with a yield of 6.4×10^{12} n/s. HINEG-II is a D-T neutron source with a yield exceeding 10^{13} n/s and is located in Chongqing, where it is currently available for experiments. FDS provides an open platform for global collaboration in neutron source research and applications.

Session WEB

WEBI01: Status of AGOR accelerator facility at Particle Therapy Research Center in Groningen, Netherlands

Brian Jones; *Sytze Brandenburg; Marc-Jan van Goethem; Jan de Jong; Herman Kremers; Alexander Gerbershagen (PARTREC); Jacobus Schippers (PSI)*

Particle Therapy Research Center (PARTREC) operates the AGOR AVF superconducting cyclotron capable of delivering multiple particle types (protons, light and heavy ions) at multiple extraction energies (from 8 to 190 MeV/u, dependent on particle type). Following decades of routine operation of AGOR's cryogenic system, the filling of the cryostat and extraction channels with liquid helium became increasingly unstable. This greatly impeded AGOR's ability to reliably deliver ion beams and eventually resulted in a prolonged technical shutdown of the facility. A comprehensive cryogenic system overhaul has further enhanced operational stability. The many lessons learned during this exercise will be presented.

Recent upgrades have significantly expanded PARTREC's capabilities. The new EMC1 extraction element has demonstrated reliable operation. High-intensity beam development (>1 μA) now supports both FLASH radiotherapy and the production of theranostic radioisotopes, notably Terbium. Dedicated dosimetry monitors have been developed to ensure precise dose delivery at ultra-high dose rates. Advancements in ion source technology now allow fine control of proton beam intensity and the inclusion of xenon in the heavy ion cocktail, contributing to more efficient radiation hardness testing. These developments position PARTREC as a unique multidisciplinary hub for cutting-edge research in particle therapy, radiobiology, and nuclear science.

WEBO01: Probing Ion Transport across Crystalline – Amorphous Interfaces through Synchrotron Spectroscopy and Machine-Learning-Potential Simulations

Wenqian Chen *(Shanghai Institute of Applied Radiation)*

Understanding ion transport across crystalline–amorphous interfaces is essential for advancing next-generation solid-state ionic conductors. In this study, we integrate synchrotron-based spectroscopic and diffraction techniques with large-scale machine learning potential (MLP) simulations to elucidate the microscopic ion transport mechanisms in a partially amorphized natural mineral electrolyte, In situ synchrotron X-ray diffraction and X-ray absorption fine structure (XAFS) analyses confirm the structural stability of the amorphous phase and reveal significant local distortions at the crystalline–amorphous interface. Pair distribution function (PDF) analysis and solid-state NMR further indicate a progressive redistribution of Na coordination environments, with the amorphous fraction reaching nearly 65%. Large-scale molecular dynamics simulations (>50,000 atoms) employing MLPs accurately reproduce the experimental PDFs and uncover a flattened ion-hopping energy landscape at the interface. The combination of surface-sensitive TEY-XAFS and atomistic modeling identifies partially amorphized Na–Na bonding networks as the primary channels facilitating rapid ion migration. This integrated experimental–computational framework—coupling synchrotron characterization with data-driven simulations—offers profound insights into interfacial ion transport and establishes a generalizable strategy for the rational design of high-performance solid electrolytes derived from natural minerals.

WEBO02: The experience of using FLNR JINR cyclotrons for Spacecraft Electronics Radiation Testing

Pavel Chubunov; *Alexander Bakerenkov (ISDE) Georgy Gulbekyan; Igor Kalagin; Semen Mitrofanov (JINR)*

During the flight, spacecraft are constantly exposed to cosmic ionizing radiation. This radiation causes various types of radiation effects in on-board electronics. The most dangerous for modern electronics are single event effects from the impact of individual charged particles of galactic and solar cosmic rays. Charged particles accelerators are used to simulate the impact of heavy ions on electronic devices. Based on the requirements for the active lifetime of spacecraft, orbit and the probability of failure-free operation, the requirements for test facilities were determined and the most suitable type of accelerators are cyclotrons.

The Institute of Space Device Engineering (ISDE) and FLNR JINR have been cooperating for over 15 years in the field of creating single event effects test facilities, developing methodology for conducting tests and their dosimetry. Based on the U-400 and U-400M cyclotrons, FLNR JINR has created an infrastructure for irradiating electronic components with a set of heavy ions from C to Bi with energies from 3 to 40 MeV/A, which, together with the equipment available at the ISDE for setting and measuring the parameters of test objects, as well as their preliminary preparation, allows for a full cycle of testing any electronic components for space applications. The report presents a description of the test facilities and the testing process, the methods and devices used to determine the beam characteristics and metrological support for testing.

WEBO03: Research on Pressure Prediction in Vaccum Systems of Particle Accelerators

Jie Wang *(Xi'an Jiaotong University)*

Particle accelerators, such as cyclotrons, are intricate and extensive installations that demand meticulous maintenance and precise control over their operational conditions. It is inevitable that some minor malfunctions will occur. These malfunctions can lead to an increase in pressure within the vacuum vessel of the facility. Nevertheless, there are situations during the operation of particle accelerators where a gauge malfunctions while the pressure in the vacuum pipeline remains below the pre-estimated critical value. In such instances, it is not necessary to halt the operation, and the faulty gauge can be conveniently replaced during the next scheduled maintenance.

In this Oral Presentation, a novel approach that integrates Monte Carlo pressure simulation with a linear regression model is introduced. This integrated method is designed to forecast the pressure distribution along the axis of the pipeline in particle accelerators similar to cyclotrons. Through this approach, a trained AI model, which is founded on a linear regression algorithm, can accurately predict the maximum pressure within the vacuum pipeline. Moreover, it can determine the pressure value that a malfunctioning gauge would show by referring to the measurements from other gauges. The outcomes of this research offer significant insights that can serve as a valuable reference for the efficient operation of vacuum systems in particle accelerators.

Session THA

THAI01: Proton therapy status and progress

Jinming Yu *(Cancer Hospital of Shandong First Medical University)*

This report will focuse on clinical difficulties, technical transformation paths, and international cooperation possibilities of proton therapy. The construction history, development scale, core technologies, and clinical achievements of China's proton therapy centers, especially the progress of proton therapy in Shandong Cancer Hospital will be introduced systematically. In addition, this report also introduces the latest research progress in the innovation of proton therapy technology, multidisciplinary diagnosis and treatment, and the development planning in the future in the areas of proton, heavy, BNCT and other technology research, discipline construction, and international cooperation.

THAI02: The NHA C400 cyclotron facility for Hadron Therapy becomes a reality

Gaelle Gerard*; Alexandre Duval; Alexis Bonnemains; Arnaud Dumont; Arnaud Duvivier; Arthur Guillon; Batista Nsunda; Benoit Barriaut; Carole Lafitte; Christophe Lefoll; Claire Leconte; Clément Bienvenu; Colin Guillaume; Cosimo L'abbate; Cyprien Vogels; David Germain; Dimitri Degeyter; Dirk Doelling; Eric Van Den Hove; Farid Boulaayoun; Florian Morel; Francois-Louis Laillier; Frédéric Stichelbaut; Geoffrey Lebrun; Gianluca Yernault; Gilles Goosse; Guillaume Despont; Henry Austins; Idris Maubant; Imane Masselis; Jacob Kelly; Jean Festy; Jean-Baptiste Jacquin; Jefferson Sorriaux; Jerome Hanot; Jerome Mandrillon; Jules Detobel ; Julien Beguin; Julien Jourdain; Laurent Koffel; Laurent Maunoury; Louis-Edouard Vallee; Marc De Leenheer; Marc Rouy-Beltran; Mathias Sergio; Maxime Dufour; Mehrdad Mostafavi; Michael De Coninck De Merckem ; Michel Abs; Mihai Baja; Mihaja Andrianarivony; Mikael Laisney; Nicolas Bakon; Oliver Gillessen; Olivier Cosson; Paulin Laronche; Philippe Velten; Pierre Snappe; Richard Borys; Sarah Julien; Sebastien De Neuter; Sebastien Deprez; Sebastien Le Pivert; Thomas Michel; Vincent Engelen; Vincent Nuttens; Virgile Letellier; Willem Kleeven; Xavier Donzel; Yohakim Otu; Yves Jongen; Yves Paradis(IBA & NHA)*

The NHa C400 is an isochronous cyclotron for cancer therapy which can deliver high intensity of alphas to carbons at 400 MeV/amu and protons at 260 MeV. It is the first cyclotron-based clinical carbon therapy solution worldwide characterized by K=1600, this is the strongest compact cyclotron. Most of the part of the cyclotron has been constructed and assembled as well as subsystems such: Super Conducting Coil, Yoke lifting system, Cryogenic System, External Injection System (EIS), etc… In parallel, Control Unit (CU) cabinets are fitted to the power room, cabled and tested to control subsystem hereabove. The EIS system is under trials at IBA / Louvain-la-Neuve, the functionalities of this system will be validated before its settle back to Cyclhad. Similarly, the mapping wheel dedicated to the magnetic field mapping of C400 is ready to leave IBA / Louvain-la-Neuve for be installed inside the C400 cyclotron and perform last final in-situ tests. Beside the construction and installation of subsystems, electrostatic deflector as well as beam probe are in the final stage of design before their production. The paper will present the status of all the components of the SRTH (Systeme de Recherche et Traitement en Hadrontherapy) machine with a focus on the actual assembly of C400 subsystems.

THAO01: Status of Heavy ion cancer treatment machine in China and the perspectives

Jian Shi *(IMP)*

Heavy ion beam therapy has become an important modality in cancer treatment due to its characteristic Bragg peak and high relative biological effectiveness. Currently, there are 18 heavy ion therapy centers in operation worldwide, with 5 located in mainland China. This paper focuses on the current status of heavy ion therapy facilities in China, objectively describes the technical features of domestically developed heavy ion therapy equipment, and provides an perspective on future technological developments.

THAO02: A novel 240MeV superconducting cyclotron SC240 development for proton therapy system in China

Chujie Cao; Yucheng Wu; Suangsong Du (HFCIM) Gen Chen; Jiang Feng; ***Kaizhong Ding****;*
Yonghua Chen; Yuntao Song (IPP) Xin Zhang (USTC)

Five sets of 240 MeV superconducting proton cyclotrons (SC240) have been successfully developed by Hefei CAS Ion Medical and Technical Devices Co., Ltd. (HFCIM) in collaboration with the Institute of Plasma Physics, Chinese Academy of Sciences. Two of these SC240 have been installed and are currently operational at dedicated proton therapy system in Hefei and Wuhan. The SC240 employs superconducting magnet technology capable of generating a maximum coil field of 4.3 T, delivering a 240 MeV proton beam with currents exceeding 500 nA for proton therapy applications. The cyclotron features a yoke with a diameter of 3 meters and a weight of approximately 70 tons. Two dedicated RF cavities, operating at a frequency of 77.8 MHz and providing up to 100 kV of accelerating voltage, are used to accelerate the proton beam. Three magnetic channels guide the beam from the deflector to the external cyclotron. Specific first-harmonic field compensation has been designed for the first and second magnetic channels. Both the deflector and the magnetic channels are equipped with remotely controlled positioning systems. The maximum beam extraction efficiency of the SC240 has been demonstrated to reach 84% in tests. At customer sites, the extracted beam current consistently exceeds 500 nA. This article presents the key design features of the SC240 cyclotron, including its injection and extraction systems, and provides experimental results from the fourth SC240 unit.

Session THB

THBI01: The SPES facility at LNL: status and perspectives

T. Marchi *(INFN)*

The construction and commissioning of the SPES facility is the flagship project of the INFN Legnaro National Laboratories. The goal is to build a state of the art accelerator facility to carry on research in the fields of Fundamental Physics and Interdisciplinary Physics. The core of the project is represented by a high-intensity cyclotron capable of delivering proton beams at 35-70 MeV with a maximum total current of 750 microA on two simultaneously operated exit ports. A wide range of applications is foreseen spanning from the production and re-acceleration of Rare Isotope beams using the ISOL (Isotope Separation On Line) technique to Research and Development of innovative radioisotopes for medical diagnostics and therapies. The production and supply of radioisotopes to industry is also envisaged. In this contribution, the status of the project will be summarized and the recent commissioning achievements will be illustrated.

THBI02: Molecular Imaging Probe: Universality & Specificity, Expansion & Innovation

Xiaoli Lan *(Wuhan Union Hospital)*

Molecular imaging in nuclear medicine, based on radiopharmaceuticals, enables the diagnosis and evaluation of major diseases at the molecular level. The development and translation of radiopharmaceuticals driven by clinical needs represent the essence of nuclear medicine advancement. Existing radiopharmaceuticals, such as 18F-FDG, hailed as the "Molecule of the Century," play a critical role in the precise diagnosis of malignant tumors, cardiovascular, and cerebrovascular diseases. However, there remains a need to develop diverse molecular probes to meet clinical demands and expand the clinical applications of existing probes. Focusing on the development, translation, expansion, and innovation of radiopharmaceuticals is the future path for the advancement of molecular nuclear medicine.

THBO01: Radionuclides production and medical applications thereof at Peking University

Zhibo Liu *(Peking University)*

Peking University has built a fully integrated ecosystem for radiopharmaceutical research that spans radionuclide production, drug discovery, and clinical translation, catalyzing innovation at the interface of nuclear science and precision medicine. At its core is the Radiopharmaceutical Research Center (Cyclotron Platform), anchored by the CIAE-developed CYCIAE-14 cyclotron (14.6-MeV protons), 68Ge/68Ga generators, and dedicated radiopharmaceutical synthesis laboratories. These facilities support the production of a broad radionuclide portfolio—routine isotopes such as 18F and 68Ga as well as novel PET emitters including 64Cu, 86Y, and 89Zr. Peking University has also pioneered domestic production of key therapeutic and generator isotopes, notably 225Ac, 212Pb, and 213Bi, substantially reducing long-standing reliance on imports.

This radionuclide capability underpins extensive screening and preclinical evaluation of radiopharmaceuticals and BNCT agents at Peking University, accelerating the translation of candidates such as BF3-BPA and CTR-FAPI. Beyond clinical applications, isotopes—especially 89Zr and 64Cu—also enable a range of fundamental life-science studies across the university.

THBO02: Alpha Emitter Radioisotope development plan from natural Thorium Target at IRIS

Jae Hong Kim; Yeong Heum Yeon; Vivek Raghunath Chavan; D.S. Ahn; Wongu Youn; H.W. Jung; ***B.S. Park****; Inseok Hong; Heejung Yim; Jinho Lee; Taeksu Shin (IBS) Minho Jung (Newcurem) Yungdoug Suh (Chungnam National University Sejong Hospital)*

Several alpha-emitting radioisotopes, Ac-225, Ra-223, and Th-227, can be produced from natural thorium targets, primarily through nuclear reactions induced by a high-energy proton irradiation. These isotopes are of interest for targeted alpha therapy, a cancer treatment approach that utilizes the high energy of alpha particles to destroy cancer cells selectively. Ac-225 radioisotope decays into Bi-209 by emitting 4 alpha and 2 beta particles with a half-life of 9.9 days, which is appropriate for medical applications. In this work, we have tried to produce Ac-225, which is an alpha particle emitting radioisotope by irradiation of Th-232 target with protons in the energy range of 50-70 MeV with RAON cyclotron. Investigating a practical method helps us identify production routes with increased yields. Therefore the present study will be helpful in identifying more effective production methods including chemical separation. Additionally, simulations and numerical calculations of the beam conditions to maximize production yield will be presented. Corresponding to the target thickness of 3 mm, the 70 MeV proton energy is degraded to 50 MeV, while maintaining energy above the threshold. Beam currents about 100 uA irradiated for two days is theoretically estimated in typical actinium-225 yields of 100 mCi, which will be applied to preclinical evaluation of radiopharmaceuticals. In this talk, a brief research activity of ISOL system with 70 MeV cyclotron at IRIS will be presented.

Session THC

THCI01: Beam stacking experiments at KURNS, Japan and ISIS, UK

Jean-Baptiste Lagrange (Ishi Yoshihiro) *(RRI, Kyoto University)*

A key challenge in particle accelerators is achieving high peak intensity. Space charge effects are strongest at injection and typically limit the achievable peak intensity in a ring. The beam stacking technique can overcome this limitation by accumulating a beam at high energy, where space charge is weaker. It also allows the user cycle and the acceleration cycle to be decoupled. In beam stacking, a bunch of particles is injected and accelerated to high energy. This bunch continues to circulate while a second, and subsequent, bunches are accelerated and merged into the first. Beam stacking with large momentum acceptance is only possible in fixed magnetic field machines with a variable accelerating frequency, such as Fixed Field Alternating Gradient (FFA) accelerators.

This talk presents an experimental demonstration of beam stacking involving two beams at the KURNS FFA facility at Kyoto University, resulting in only a slight increase in the momentum spread of the combined beams. However, the intensity of the first beam was significantly reduced due to RF knockout. This resonance phenomenon has been experimentally confirmed in the ISIS synchrotron at the Rutherford Appleton Laboratory, and two mitigation methods were investigated and will be described here.

THCO01: The start-to-end beam dynamics simulation study and its application in the High-Intensity Cyclotron of CIAE

Tianjian Bian*; JinRong Lu; Peng Huang; Shizhong An; Yuzhuo Huang; Fengping Guan; Lin Dai; Luyu Ji; Ruijin Liu; Sumin Wei (CIAE)*

The neutron yield of the neutron source based on the 18MeV/1mA high-intensity cyclotron developed by the China Institute of Atomic Energy (CIAE) has reached 7×10ˆ13 n/s and has been successfully applied in high-resolution neutron imaging and Boron Neutron Capture Therapy (BNCT) experiments. Precise and quantitative start-to-end beam dynamics simulations facilitate a better understanding of the complex beam dynamics behavior of high-intensity beams, which is one of the key technologies for high-intensity cyclotrons. The beam dynamics simulation technology for cyclotrons is relatively mature. However, it is typically implemented independently in each subsystem. During the simulation process, assumed initial conditions are introduced multiple times, making it difficult to obtain quantitative results and carry out a global optimization design of beam dynamics. Start-to-end beam dynamics simulation is used in the 18MeV/1mA high-intensity cyclotron. It quantitatively simulates the beam dynamics behavior of high-intensity beams in each subsystem, including the injection line, spiral inflector, central region, acceleration region, extraction region, and uniform beam transport line.

THCO02: A novel cyclotron concept for isotope production and proton therapy

Oleg Karamyshev *(JINR)*

Cyclotrons for isotope production and proton therapy are becoming increasingly compact and widely used. The main trend is reducing size by increasing the magnetic field strength through superconductivity. I propose an alternative approach: instead of increasing the magnetic field, switch to a different scheme—raise the RF system frequency, making the system more compact. Additionally, by radically reducing ampere-turns in the coils, the coils can be made more compact and energy-efficient, without the need for superconductivity. As a result, the cyclotron becomes just as compact as superconducting models, but much cheaper and simpler.

As an example, an 18 MeV cyclotron with 3 sectors and 3 RF resonators at a harmonic number of 6 (145 MHz) is presented, along with a 230 MeV cyclotron with 4 sectors and 4 RF resonators at the same harmonic number and frequency. The weight and power consumption of these concepts are half that of conventional cyclotrons. A range of cyclotrons from 18 to 230 MeV is under development, sharing the same RF frequency and common components across the lineup.

Session FRA

FRAI01: A General Approach to Radioprotection and Activation Studies for Proton Therapy Facilities

Frédéric Stichelbaut *(IBA)*

Proton beam therapy has demonstrated over the past 50 years clear advantages compared to conventional radiotherapy. However, the use of high energy protons results in the production of complex mixed secondary neutron and photon fields. The shielding calculations and activation studies require the use of complex computation codes such as the MCNP6 and the FISPACT-2 codes. The use of those codes will be illustrated in the case of the ProteusONE system developed by IBA. Based upon the use of a superconducting synchrocyclotron (S2C2) delivering 230 MeV proton beams, ProteusONE is a compact PT system with a single treatment room equipped with a compact gantry. ProteusONE shielding design is based on a detailed patient case mix including a limited number of representative clinical indications and realistic QA activities. It is entirely performed with MCNP6 Monte Carlo simulations including detailed modellings of the concrete vault, the S2C2 cyclotron and the compact gantry. The MC calculations have been validated with a radiation survey performed with an extended-range WENDI-2 rem meter. Detailed activation studies have also been performed for all aspects of the facility like the cyclotron, the beamline and the concrete walls. A low-activation concrete (LAC) has been developed in collaboration with SCK-CEN in Belgium, reducing considerably the amount of activated concrete generated after 20 years of usage. The LAC has been successfully implemented in several ProteusONE Facilities.

FRAO01: Research and industrialization progress of 2G-HTS based on MOCVD technology

Yulei Chen *(Eastern Superconductor Science& Technology (Suzhou) Co. Ltd)*

The progress of HTS technology has been particularly impressive in the last decade. The progress of commercialization of high-temperature superconducting tapes will depend on the degree of mass production and the price. Eastern Superconductor Science& Technology (Suzhou) Co. Ltd (Eastern Superconductor) has developed a new MOCVD technology to prepare the REBCO film. The stability of the MOCVD equipment has been significantly improved. Based on a new technological roadmap Eastern Superconductor has developed the complete set of production line for the HTS manufacture, and has achieved efficient production of s of the REBCO HTS tapes. Here, we could achieve of critical current (Ic) above 1000A-4mm in magnetic field 10T (B//c) at 4.2 K, 10T in heavily doped (11mol.% Zr-added) $REBa_2Cu_3O_{7-\delta}$ (REBCO, RE:Gd,Y) superconducting tapes. And the critical current densities (Je) could reach above 2500A/mm2 at 4.2 K, 20T (B//c) which has been used in the superconducting magnets of fusion project. By adjusting the elemental ratios (RE:Ba:Cu) the average value of lift-factor between Ic at 77 K in self-field and Ic at 4.2K, 20 T (B//c), can be 4.84 in mass production which is tested by PPMS, and all values are within the + /− 30% corridor.

FRAO02: Physics design of a High-density Alpha Cyclotron CIM30

Shiwen Xu; *Zhong Wang; Xiangtian Kong; Yue Hu (HFCIM) Kaizhong Ding; Yuntao Song; Gen Chen; Yonghua Chen; Zou Wu; Shuangsong Du; Feng Jiang (IPP) Evgeny Samsonov [3]; Nikolay Morozov (JINR) Xin Zhang (USTC)*

A high-intensity cyclotron dedicated to the production of the radiopharmaceutical Astatine-211 (At-211) has been designed. This cyclotron employs an external injection system to introduce alpha particles, utilizing a four straight-sector magnet design and a dual radio-frequency (RF) cavity configuration to accelerate the alpha particles to an energy of 30 MeV. The beam is then extracted from the cyclotron via an electrostatic deflector (ESD). This paper presents an overview of its primary parameters. It subsequently provides a detailed physical design description of two core systems: the magnet and the RF systems. Furthermore, extensive beam dynamics simulations are performed. The particle trajectory is tracked from the exit of the spiral inflector through the entire acceleration process to the final extraction, with evaluation of the extraction efficiency and transverse beam profile, confirming the design's capability to deliver a high-indensity beam suitable for medical isotope production.

Session FRB

FRBI01: Cyclotron Design in an Industrial Environment - Continued Learning, Experience and Optimization

Vincent NUTTENS*; Erik van der Kraaij; Jerome Mandrillon; Willem Kleeven (IBA)*

Over the past decade, IBA has modernized its cyclotron design tools and accelerator portfolio. This presentation shares key lessons learned, illustrated with practical examples. Controlling gas stripping is essential to minimize beam losses and component activation. Tools like SPICE models and Molflow+ help simulate vacuum behavior. Beam dynamics in the central region, particularly phase acceptance and vertical focusing, affect performance. Optimizing the placement of accelerating gaps and implementing effective beam cleaning reduces extraction losses.

While the cyclotron magnet defines the machine's physical footprint, the total system footprint is also influenced by beam line layout and radiation shielding. Using a larger yoke and optimized beamlines can reduce power consumption without increasing system size. High-temperature superconductors may also reshape future magnet design but they must be weighed against cost. Output beam energy remains a key factor, especially with evolving needs in nuclear medicine. Adapting fixed energy cyclotron installed base to new energies is vital to support new radioisotope adoption. Accurate magnetic field mapping is critical for nominal operation and isochronism. FEM analysis allows early correction predictions, reducing mapping time and milling steps. Additional shimming during Smith – Garren beam tests may be required, and new tools help anticipate these, accelerating commissioning.

FRBO01: Comparative study of Ion Bernstein and Ion Cyclotron Wave Generation via Parametric Instability of Whistler Waves in Dusty Plasma

Twinkle Pahuja*; Supreet Kaur (Amity University) Jyotsna Sharma (South Asian University)*

In this manuscript, a comparative study is presented on the generation of ion Bernstein waves and ion cyclotron waves through the parametric instability of whistler waves in dusty plasma. The electron density perturbations associated with the ion Bernstein wave couple with the oscillatory velocity of plasma electrons driven by the whistler pump wave, creating a nonlinear current that drives the whistler sideband wave. Both the whistler pump wave and the whistler sideband wave exert a ponderomotive force on the electrons, which in turn drives the ion Bernstein and ion cyclotron waves. The impact of dust charge fluctuations on this process is investigated, and the growth rate expressions for both the ion Bernstein and ion cyclotron waves are derived. It is observed that the growth rate increases with higher pump wave amplitude, wave number, scattering angle, and dust grain density. However, a decrease in growth rate is seen with increasing dust grain size and electron temperature. Additionally, a comparison reveals that the ion Bernstein wave is more unstable than the ion cyclotron wave, resulting in a higher growth rate for the ion Bernstein wave in dusty plasma.

FRBO02: A Practical Study on Spot and Layer Reduction in Proton Therapy: A Simulation-Based Validation for Liver Cancer Pencil Beam Scanning Proton Therapy

Xianhu Zeng (West China Hospital of Sichuan University) ***Shiyan Shen*** *(Sichuan University)*

The lengthy treatment time of pencil beam scanning proton therapy (PBS-PT) limits its application for mobile tumors like liver cancer. This study aims to combine a high-efficiency beam transport system with spot reduction techniques to significantly shorten treatment time, enabling single breath-hold therapy. We simulated three treatment plans for 12 liver cancer patients: conventional (Plan A), spot reduction only (Plan B), and a combined high-efficiency transport and spot reduction plan (Plan C). Our core innovation involved using BDsim to optimize beam transport, which increased the efficiency of low-energy beams (70 MeV) by 100 times, with parameters validated by TOPAS.

Plan C was significantly superior to Plan A, reducing control points by 69.8% and energy layers by 53.5% ($P<0.001$), shortening the average single-field irradiation time to under 10 seconds. In contrast, Plan B showed no significant improvement. Plan C maintained dosimetric quality and robustness while boosting efficiency.

This study demonstrates that combining a high-efficiency beam transport system with spot reduction effectively addresses the challenge of long treatment times for mobile tumors, providing a crucial solution for the broader clinical adoption of PBS-PT.

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