Conceptual Design of Internet Accelerator Laboratory (IAL) for DECY-13 Cyclotron

Frida Iswinning Diah[1], Idrus Abdul Kudus[2], Suharni[3], Fajar Sidik Permana[4], Taxwim[5]

***Abstract*—Research and Technology Center for Accelerator of Research Organization for Nuclear Energy of National Research and Innovation Agency (PRTA-ORTN – BRIN) has become the Center for Excellence in Science and Technology (PUI), especially in the particle accelerator field. One of the studies is the DECY-13 cyclotron for radioisotopes production used in the medical field for cancer diagnostics. Currently, the DECY-13 cyclotron R&D is in the final stages of the design process. A Cyclotron internet laboratory facility will be implemented to expand the benefits of this R&D. This facility will support the cyclotron training to be more widely accessible and increase capacity building and human resources programs in the nuclear field. Therefore, a preliminary study for DECY-13 cyclotron Internet Accelerator Laboratory (IAL) is needed, which includes the preparation of long-term concepts and the design of IAL. The formulation of the long-term idea follows the established cyclotron road map. In the conceptual design, the users at the early stages are students and cyclotron operators in hospitals. In order to determine the design requirement, the next step is a literature study on online laboratories and the accelerator learning concept that has been applied in other countries. The IAL apparatus identification is based on a review of the DECY-13 cyclotron laboratory's current conditions and future research plans. The conceptual design that has been successfully developed consists of a research roadmap on IAL for long-term research planning and a material syllabus for two target users, namely students and cyclotron operators in hospitals. While the employed IAL component identification is CompactRIO as the primary controller on the cyclotron operating system and as a liaison with the network system. Supporting the network includes database systems, servers, LAN, internet, webcams, and websites or an application to be accessed by users.**

***Keywords*—Cyclotron, Internet Accelerator Laboratory, Education, Distance Learning.**

I. INTRODUCTION

One of the nuclear technology applications in the health sector is positron emission tomography (PET) for cancer diagnosis. The production of radionuclides and radiopharmaceuticals must accompany the use of PET technology by nuclear devices, one of which is the cyclotron. Currently, cyclotrons in Indonesia are only available in four hospitals, i.e., Gading Pluit Hospital, MRCCC Siloam Hospital, Dharmais Cancer Hospital [1], which are located in Jakarta, and Abdul Wahab Sjahranie Hospital in Samarinda. This condition shows that health services are not evenly distributed in all regions in Indonesia. Based on Riskesdas data, cancer has increased from year to year, from 1.4 per 1,000 population in 2013 to 1.79 per 1,000 population in 2018. The highest cancer prevalence was in D.I. Yogyakarta province with 4.86 per 1,000 population, followed by West Sumatra 2.47 per 1,000 population and Gorontalo 2.44 per 1,000 population [2].

Accelerator Research and Technology Center (PRTA) Nuclear Energy Research Organization - National Research and Innovation Agency (ORTN-BRIN) has conducted studies, R&D, and cyclotron design since 2009 and named them Design Experimental of Cyclotron in Yogyakarta - 13 MeV (DECY - 13). Basically, the purpose of this R&D is to support independence in the cyclotron design for radioisotope production, which will eventually be used as a radiopharmaceutical raw material. By conducting cyclotron R&D, it is hoped that there will be the emergence of human resources (HR) with the expertise and skills on the fundamentals of cyclotron technology, design, installation, and maintenance. In addition, in the long term, the existence of a cyclotron laboratory also provides benefits and opportunities to continuously produce new human resources, which are later expected to add experts able to operate and carry out cyclotron maintenance in hospitals. Therefore, it is necessary to conduct a study so that the cyclotron technology that has been made at the Accelerator Science and Technology Center (PSTA) has a significant research output or contribution. One of them is how to use the existing cyclotron laboratory for the learning or training process aiming to support competent human resources in the nuclear field.

Training on the DECY-13 cyclotron has been carried out in 2019 and 2020 with internal participants from the National Nuclear Energy Agency (BATAN), which has now changed to ORTN-BRIN. After that, there was a request for cyclotron training by inviting BATAN external parties, including from universities, hospitals, industry, and other relevant ministries/institutions, both at home and abroad. Therefore, a method or concept different from the previous one that still provides better training output with a wider range of users is needed. One of them is using online concepts or distance-learning concepts. The distance learning concept begins with a study or research to identify and list the training needs on cyclotron technology and the facilities and infrastructure supporting it. It includes determining methods to directly address practical needs in the field so that training materials can be comprehensively delivered.

One of the distance-learning methods that can be used as a reference is the Internet Reactor Laboratory (IRL) implemented at PSTA-BATAN to learn about nuclear reactors [3]. The IRL

[1,2,3,4,5] *Accelerator Research and Technology Center – Nuclear Energy Research Organization – National Research and Innovation Agency, Jl. Babarsari Postal COde 6101 ykbb, Yogyakarta 55281 Indonesia Phone (0274) 488435, 464436; e-mail: [1]frid002@brin.go.id, [2]idru002@brin.go.id, [3]suharni@batan.go.id, [4]fajar.sidik@batan.go.id, [5]taxwim@batan.go.id)*

[Received: 19 November 2021, Revision: 1 January 2022]

program, which was launched in 2014, demonstrated the effectiveness and ease of conducting training and education on reactor technology because it can be done online without being present in the laboratory. It is an opportunity to be applied to other laboratories, one of which is the DECY-13 cyclotron laboratory. This study aims to develop a conceptual design of the Internet Accelerator Laboratory (IAL) for the DECY-13 cyclotron based on literature studies and recent field studies. With this conceptual design, the process of designing, procuring components, and installing IAL in the next research will be easier. In addition, it is also necessary to determine a long-term road map for the implementation of IAL until it can be used by users; hence, future research steps are more measurable and on target.

II. Internet Laboratory Conceptual Overview

The preparation of the conceptual design begins with determining the design requirements learned from the latest literature on the internet laboratory and DECY-13 cyclotron laboratory conditions.

A. Internet Laboratory as an Alternative Distance Learning Method

Basically, there are three types of laboratories for an engineering process, i.e., the development, research, and education. In the development type, the laboratory is used to direct a product design and development and answer specific problems related to a theory so that the engineering process can continue. Furthermore, the research laboratory is used to make more extensive observations about knowledge that can be generalized and made systematic and often without a specific purpose. The output is in the form of everyday knowledge that humans have used or run naturally. The third type, i.e., educational laboratories, is usually used by students in studying already existing or known sciences [4].

Several overseas training programs have used remote or virtual laboratories for various purposes, including increasing the number of laboratory users, flexibility in the time and place of experimentation, expanding the scope of activities in experiments, sharing knowledge and equipment between laboratories or between universities, as well as collaboration between students in different universities [5]. In addition, the use of a remote laboratory can also save human resources in a laboratory [6].

Fundamentally, the remote laboratory serves to bridge real experiments in the laboratory using the internet as a means of communication accessible from anywhere. A remote laboratory is suitable for use in experiments without being directly in front of the experimental set-up while maintaining quality and experience during experimentation [7]. This concept has been widely used in many institutions for online laboratory purposes. A remote laboratory is made in such a way to experiment in a real way over the internet. In addition to the remote method, there is also a virtual laboratory method using certain software to simulate an experiment [8], [9].

In addition to the terms remote and virtual laboratory, the term internet laboratory is often used, or some call it an e-lab. For internet laboratories, such as those used by IRL, the emphasis is on broadcasting a training course via the internet combined with an interaction between instructors and participants through a teleconference and a special website. Bidirectional responses can be enhanced by the involvement of participants in conducting an experiment [3]. In addition to teleconference, a combination of learning methods can also be used by showing demonstration video clips in the laboratory and computer simulation or modeling [10].

B. Particle Accelerator Learning Concept in Various Countries

The European continent already has a very advanced and modern accelerator laboratory, one of which is CERN, located on the border of France and Switzerland. In recent years, CERN with the Large Hadron Collider (LHC) has begun to focus on teaching particle physics, or high energy accelerator physics, for a more extensive community, one of which is for high school students through classes or specially-trained physics teachers. The introduction of the LHC in classes begins with conducting an in-depth study of each fundamental component of the LHC, which can be learned easily and the media to be used. It is expected to increase the attractiveness of prospective students to choose particle physics science [11].

Besides CERN, in Europe, there is also an Accelerator Research and Innovation for European Science and Society (ARIES) with a Massive Open Online Course (MOOC) program. The MOOC was held after an in-depth study of the accelerator training carried out on the European continent so far. From this study, several recommendations were obtained, including e-learning courses to introduce accelerator science and technology, especially for physics or engineering students at the undergraduate level, and open possibilities for anyone interested in this technology [12]. In addition, on the American continent, there is Fermilab with the US Particle Accelerator School (USPAS), which has regularly held accelerator schools every year since 1987, and many other universities or accelerator laboratories are organizing similar accelerator school activities [13].

In general, in some countries organizing Accelerator School, activities are held classically, and not many carry out online learning. Online services are mostly carried out on free access to fundamental accelerator materials, such as those available on the CERN website and the Joint Accelerator Conferences Website (JACoW). In contrast, online training with a new structured curriculum is carried out by ARIES with MOOC. The target audience for MOOC is students currently undergoing higher education at the Bachelor's level. After receiving lectures on physics in general, students can take online training before continuing to postgraduate or doctoral levels [12].

C. The Current Condition of DECY-13 Cyclotron Laboratory to Support Accelerator Learning Process

The DECY-13 cyclotron cyclic accelerator is made for PET applications in nuclear medicine with proton energy of about 13 MeV. The study, design, and plan processes have been started since 2009. The main components of the DECY-13 cyclotron consist of seven main components and two

(a) (b)

Fig. 1 DECY-13 cyclotron laboratory in PSTA-BATAN Yogyakarta, (a) cyclotron room (outside), (b) DECY-13 cyclotron.

TABLE I
RESULT OF DECY-13 CYCLOTRON SUB SYSTEM TESTING

No.	Component Name	Testing Result
1	Magnet system: strong magnetic field at the center	The testing process was carried out by flowing a current to the cyclotron magnet with a fixed value of 133 A with the temperature of the cooling flow entering the magnet system at 23ºC, the room temperature of the cyclotron magnet was at 25ºC with 60% humidity. The greatest magnetic field value was measured during the alignment process for y at position x = 120 mm with a maximum magnetic field of 1.962 T.
2	RF generator system	The testing process of RF generator system at the frecuency of 77.76 MHz resulted in final power output of 7 kW.
3	Ion source system	The testing was conducted in the vacuum condition of approximately 7-8 × 10^{-6} Torr and a gas supply of 5 sccm. The magnet operated in a magnetic field strength of between 0.4 and 0.88 T. With a cathode voltage of 1.250 V, a cathode current of 45 mA, and a puller voltage (Vpul) = 2 kV, the beam current was approximately (Iion) = 140 A.
4	Vacuum system	2.3 × 10^{-6} Torr (the best condition without adding hydrogen gas).

supporting components. The main components are the ion source system [14], [15], the magnetic system [16], [17], the vacuum system, the radio frequency generator (RF) system, the speeding RF system, the beam measuring system, and the extractor system. Meanwhile, the two supporting components consist of an instrumentation and control system (ICS) [18], as well as a utility system (electricity and cooling).

Some components have been installed and tested, such as electromagnetic systems, ion source systems, RF generators, vacuum systems, and cooling systems [19]. Early-stage cyclotron testing with direct current (DC) voltage was conducted on a vacuum of 7-8 × 10^{-6} Torr, a 5 sccm flow of hydrogen gas for ion source system trials. In this trial, a DC voltage of 35 kV was used as a beam pulling voltage and produced a beam current of 35 μA [15], [20]

The current cyclotron laboratory building condition is shown in Fig. 1. As of this year, of the seven major components, four components have passed several tests and have generated test data, as shown in Table I [16], [19]-[22]. Of the four components, there is a hardware variety used to generate test data or parameters. For internet laboratory needs, data collection of operating data acquisition devices needs to be done to precisely determine the internet laboratory device to be used.

A detailed description of the installed device and the current status is described in Table II [15], [21]-[25]. The process of the four cyclotron components testing is done manually following the operating manual of each component. The testing process that has been done several times produces standard operating procedure (SOP) components used as a reference for later operations.

III. RESULTS AND DISCUSSION

A. *Concept of DECY-13 Cyclotron Internet Laboratory*

Based on references from IRL [3], [4], the IAL road map can be described in the chart in Fig. 2, adapted to current laboratory conditions and plans to complete future cyclotron designs. In 2021, the IAL concept was completed so that in 2022 the digitization and system integration processes on cyclotron is gradually completed. It includes the preparation of internet devices to be used, such as servers, providers, and supporting components. After that, integration with the system and internet

TABLE II
LIST OF CURRENT COMPONENTS OF DECY-13 CYCLOTRON

No.	Component Name	Instruments/Testing Devices	Operating Methods and Status of Data Acquisition Systems
1	Magnetic system	1. Electromagnetic system 2. Magnetic power supply (MPS) 3. Electromagnetic and MPS cooling systems	All components are not yet integrated with the computer and manual operating methods.
2	The RF generator system	1. Direct digital synthesizer (DDS) 2. Amplifier driver 3. Final amplifier 4. Watt meter panel 5. Digital watt meter 6. Analog watt meter	Most of the components have been integrated with the computer and manual operating methods.
3	Ion source system	1. Magnetic system 2. Hydrogen gas flow system 3. Drive motor system 4. Ion source cathode power supply system 5. Beam current measuring system 6. Ion source cooling system	All components are not yet integrated with the computer and manual operating methods.
4	Vacuum System	1. Rotary pump 2. Diffusion pump 3. Vacuum sensor 4. Vacuum meter 5. Vacuum cooling system	All components have been integrated with the computer and manual and automatic operating methods.

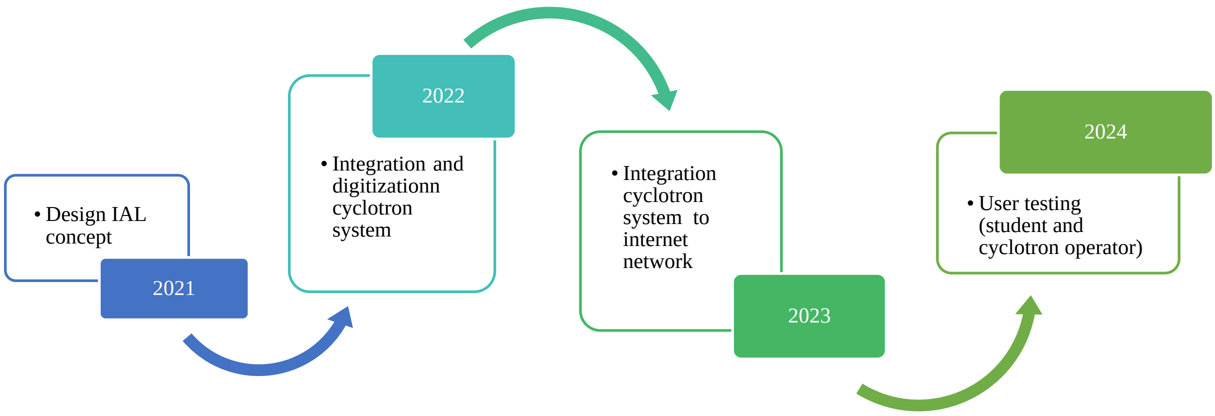

Fig. 2 2021-2024 IAL road map of DECY-13 cyclotron.

network can be done in the following year. Hence, in early 2024 it can be tested to users, and IAL products can be extensively launched to the public.

DECY-13 cyclotron laboratories can be categorized as research and also engineering laboratories because there are devices designed and engineered in such a way as to meet certain specifications. The design and engineering processes first begin with in-depth study and research to produce an optimal design.

Concerning the application of IAL to the DECY-13 cyclotron, the results of literature and field studies resulted in a design concept based on the research process of each component. DECY-13 cyclotron components were divided into two groups, i.e., the component design group, and the operating device group. This division is based on the design up to the testing processes which have been done to date.

The first group is the component design group. The seven components described earlier fall into this group. Components are designed according to the requirements required for cyclotron use, accelerating proton particles up to 13 MeV for radioisotope production.

The second group, the operating device, consists of a vacuum system, ion source system, electromagnetic system, RF generator system, RF speeding system, extractor system, and supporting components. In this group, what is studied is the working principle of the tool and the SOP of each component. The component grouping in the DECY-13 cyclotron device shows the need for materials to support the utilization of IAL facilities. Therefore, it is necessary to determine the details of the material or syllabus supporting learning about the system and design, operation implementation, and maintenance of each cyclotron component.

Syllabus details were determined based on the target user of this IAL. In this study, users focused on two groups, i.e., students and cyclotron operators. For students who took advantage of this IAL, the final output was expected to be

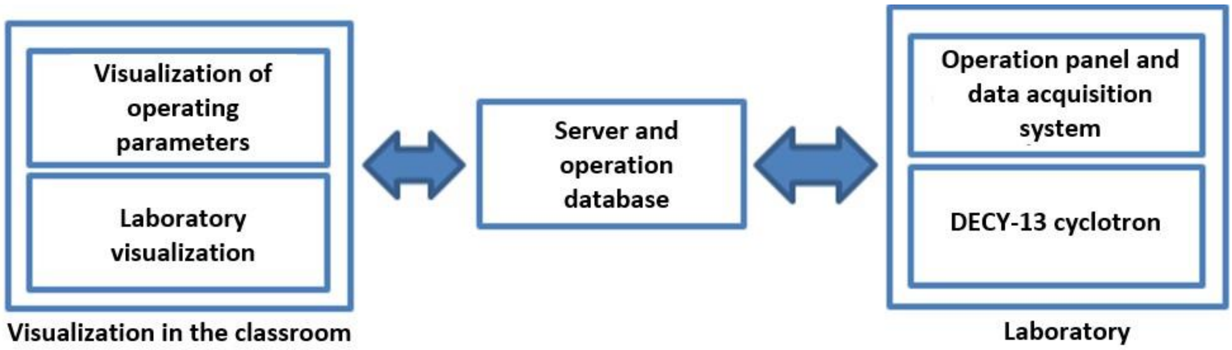

Fig. 3 IAL concept of DECY-13 cyclotron.

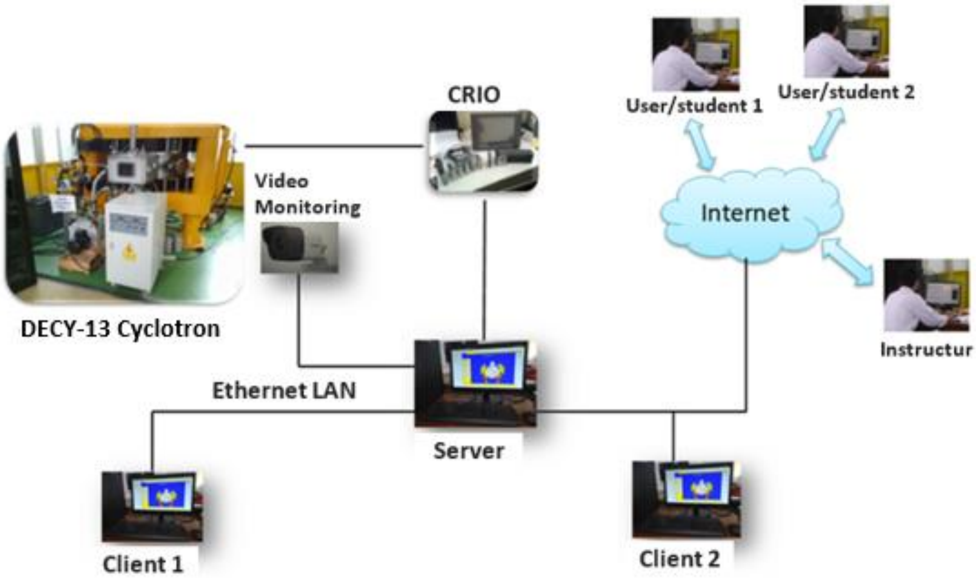

Fig. 4 Foundamentals of DECY-13 cyclotron online laboratory architecture.

expertise in the cyclotron field, especially technology and its application in the medical field. In the meantime, operators were expected to acquire operating and maintenance skills. The syllabus was developed based on the experience of organizing accelerator-related training, both national and regional, carried out in PRTA. Details of the syllabus are presented in Table III at the end of the paper [26].

Furthermore, this syllabus was used as an initial guide to determine learning methods in more detail by utilizing the IAL facilities to be created and also to determine learning methods tailored to the target user. In general, there were two employed learning methods, namely the classical delivery of material and practicum. Teleconference media such as Zoom, Skype, or homemade applications were used for classical material delivery. In the classical method, it is possible to use video recording of material that can be accessed repeatedly or by directly presenting speakers in the digital learning space. Meanwhile, the practicum can be divided into two stages, i.e., the introduction stage, which can be done online, and the experimental stage, carried out in a blended manner, i.e., online and direct practice in the field. For instance, the online laboratory facilitates users to access a laboratory remotely via the internet. After the syllabus and methods have been determined, the next step is to determine the IAL tools supporting each title in the syllabus.

B. Device Design of IAL DECY-13 Cyclotron Internet Laboratory

Conceptually, the online laboratory of DECY-13 cyclotron can be described at an early stage, as shown in the diagram in Fig. 3 [27]. More detailed architecture can be illustrated as in Fig. 4 [28]. The main equipment needed is used to visualize operating parameters and devices available in the cyclotron laboratory via the internet. For the visualization process via the internet network, a server was required for operating data storage and web processing or applications that would be used later. The system in Fig. 3 consists of CompactRIO as controller, server, LAN, internet, webcam, and website or an application to be accessed by users. Operating parameters can also be visualized through the provided website or application.

With the current conditions (as presented in Tables I and II), what needs to be prepared in detail in advance is the digitization of all cyclotron components within, including the preparation of a system for laboratory-scale user interfaces and the process of creating an operating database. After that, the information technology (IT) equipment that will be used, such as servers, internet networks, and all supporting devices, will be determined. Creating a lab-scale user interface also considers that important operating parameters can be accessed via the internet network, and IAL users can easily understand the interface.

Regarding visualization to users, a webcam can be used to directly know the conditions in the laboratory, hoping that the process of understanding the material can be obtained as a whole. Based on references and practices that IRL has applied for interactive processes, users can provide input operating parameters through an application to be subsequently executed by cyclotron operators in the field [3].

IV. Conclusions

From the conceptual design successfully compiled in this study, several things were obtained, including the road map for making internet laboratory facilities, the status of the components on the DECY-13, cyclotron, the syllabus for two student users and the cyclotron operator, and identification of the utilized IAL components. In the long term, the scope of users can be expanded to several cyclotron-related research areas. Basically, this IAL technology was created to keep up with the times, especially concerning increasing the capacity of human resources in the nuclear field in Indonesia.

Conflict of Interest

The authors declare that there is no conflict of interest in the writing of this paper.

Author Contributions

Fundamental concepts and major literature studies, Frida Iswinning Diah, Idrus Abdul Kudus; road map and study of supporting literature, Fajar Sidik Permana; an in-depth study of the current condition of the DECY-13, cyclotron, Suharni; deepening of internet laboratory, Taxwim.

Acknowledgments

Gratitudes are expressed to Emy Mulyani, who has guided the writing of this KTI and also to the entire DECY-13 cyclotron team of PRTA ORTN-BRIN.

References

[1] NS. Risdianto, J. Purwanto, and F.A. Rahmadi, "The Use of Cyclotron for PET/CT Scan in Indonesian Hospitals and Future Collaboration," *Proc. IPAC2016*, 2016, pp. 1911-1913.

[2] (2019) "Penyakit Kanker di Indonesia Berada pada Urutan 8 di Asia Tenggara dan Urutan 23 di Asia." [Online], http://p2p.kemkes.go.id/penyakit-kanker-di-indonesia-berada-pada-urutan-8-di-asia-tenggara-dan-urutan-23-di-asia/, access date: 21-May-2021.

[3] S. Syarip, *et al.*, "Development of Internet Reactor Laboratory Using Kartini Reactor for Training and Education," *Electr. Power, Electron. Commun. Control. Inform. Semin. (EECCIS 2018)*, 2018, pp. 411–414.

[4] Taxwim, *et al.*, "Strengthening Scientific Literacy on Nuclear Reactor and Its Application Through Nuclear School," *J. Phys.: Conf. Ser.*, Vol. 1175, No. 1, pp. 1–7, 2019.

[5] LD. Feisel and A.J. Rosa, "The Role of the Laboratory in Undergraduate Engineering Education," *J. Eng. Educ.*, Vol. 94, No. 1, pp. 121–130, 2005.

[6] A. Chevalier, *et al*., "Development and Student Evaluation of an Internet-based Control Engineering Laboratory," *IFAC-Papers OnLine*, Vol. 48, No. 29, pp. 1–6, 2015.

[7] J.A. Alamo, *et al.*, "An Online Microelectronics Device Characterization Laboratory with a Circuit-like User Interface," *Int. Conf. Eng. Educ.*, 2003, pp. 1–7.

[8] A. Ballu, *et al.*, "Virtual Metrology Laboratory for e-Learning," *Procedia CIRP*, Vol. 43, pp. 148–153, 2016.

[9] A. Cestaprabha, A. Abimanyu, J. Sunardi, and A.D. Atmaja, "Pengembangan Virtual Akselerator Sistem Magnet Development of Experimental Cyclotron Yogyakarta-13 (DECY-13) Berbasis Android," *Pros. Pertemuan Presentasi Ilm. Penelit. Dasar Ilmu Pengetahuan Teknol. Nuklir*, 2018, pp. 245–250.

[10] H. Chowdhury, F. Alam, and I. Mustary, "Development of an Innovative Technique for Teaching and Learning of Laboratory Experiments for Engineering Courses," *Energy Procedia*, Vol. 160, pp. 806–811, 2019.

[11] G.J. Wiener, J. Woithe, A. Brown, and K. Jende, "Introducing The LHC in the Classroom: An Overview of Education Resources Available," *Phys. Educ.*, Vol. 51, No. 3, pp. 1-7, 2016.

[12] N. Delerue, *et al.*, "A Massive Open Online Course on Particle Accelerators," *J. Phys.: Conf. Ser.*, Vol. 1067, No. 9, pp. 512–515, 2018.

[13] (2021) "Courses, Materials & Instructors." [Online], https://uspas.fnal.gov/materials/materials-table.shtml, access date: 9-Nov-2021.

[14] F.I. Diah, *et al.*, "Evaluation of Hydrogen Gas Flow System in DECY - 13 Cyclotron," *J. Phys.: Conf. Series*, Vol. 1825, pp. 1–7, 2021.

[15] S. Silakhuddin, *et al.*, "Ion Beam Preliminary Testing of DECY-13 Cyclotron at the Central Region Using DC Extraction Voltage," *IOP Conf. Ser. Mater. Sci. Eng.*, Vol. 432, No. 1, pp. 1–7, 2018.

[16] I.A. Kudus, Taufik, and K. Wibowo, "Alignment Sistem Mapping untuk Magnet Siklotron DECY-13," *Pros. Pertemuan Presentasi Ilm. Penelit. Dasar Ilmu Pengetahuan Teknol. Nuklir*, 2016, pp. 198–203.

[17] Taufik, K. Wibowo, I.A. Kudus, and F.S. Permana, "Magnetic Field Analysis of Shimmed DECY-13 Cyclotron Magnet," *AIP Conference Proceedings*, Vol. 2381, No. 1, Nov. 2021, paper 020102.

[18] F.S. Permana, N. Effendy, and A.N.I. Wardhana, "Perancangan dan Identifikasi Kendali PID pada Aliran Hidrogen Sumber Ion Siklotron DECY-13," *J. Iptek Nuklir Ganendra*, Vol. 21, No. 2, pp. 59–66, Jul. 2021.

[19] K. Wibowo and Silakhuddin, "Pengujian Awal Perangkat-Perangkat Siklotron DECY - 13," *Pros. Pertemuan Presentasi Ilm. Penelit. Dasar Ilmu Pengetahuan Teknol. Nuklir*, 2018, pp. 355–358.

[20] S. Silakhuddin, R.S. Darmawan, S. Suharni, and IA Kudus, "Characterization on DECY-13 Cyclotron Components," *Phys. J.*, Vol. 3, pp. 64–72, 2019.

[21] A. Dwiatmaja, T. Atmono, and Saminto, "The Behaviour of RF Generator for Power Supply of Dee in the Cyclotron DECY-13," *Proc. Int. Conf. Nuclear Capacity Building, Educ., Res. Appl. (I-Concern'19)*, 2019, pp. 552–557.

[22] F.S. Permana, Saminto, K. Wibowo, and V.A.F. Sari, "Human Machine Interface Berbasis Labview untuk Operasi Sistem Vakum Siklotron Proton DECY-13 MeV," *Pros. Pertemuan Presentasi Ilm. Penelit. Dasar Ilmu Pengetahuan Teknol. Nuklir*, 2016, pp. 186–192.

[23] F.S. Permana and Suharni, "Sistem Akuisisi Data Sumber Daya Magnet MPS 8500 dan Karakterisasinya untuk Pengoperasian Siklotron DECY-13," *Pros. Pertemuan Presentasi Ilm. Penelit. Dasar Ilmu Pengetahuan Teknol. Nuklir*, 2018, pp. 197–202.

[24] F.S. Permana, A.D. Atmojo, and A. Wijayanto, "Perancangan Sistem Akuisisi dan Kendali Generator RF Siklotron DECY-13," *Pros. Pertemuan Presentasi Ilm. Penelit. Dasar Ilmu Pengetahuan Teknol. Nuklir*, 2018, pp. 115–118.

[25] Saefurrachman, Saminto, and A. Susanto, "Analisis Perancangan Sistem Instrumentasi Perangkat Pengatur Posisi Sumber Ion DECY-13," *Pros. Pertemuan Presentasi Ilm. Penelit. Dasar Ilmu Pengetahuan Teknol. Nuklir*, 2018, pp. 369–376.

[26] CAS Team (2016) "Syllabus and Conventions for General COurses Organized by the CERN Accelerator School," [Online], https://cas.web.cern.ch/sites/default/files/CASSyllabus.pdf, access date: 9-Nov-2021.

[27] A. Leleve, H. Benmohamed, P. Prevot, and C. Meyer, “Remote Laboratory Towards an Integrated Training System,” *4th Int. Conf. Inf. Technol. Based Higher Educ. and Training (ITHET 2003)*, 2003, pp. 1-6.

[28] A. Salihbegovic and S. Ribic, “Development of Online Internet Laboratory (Online I-Lab),” in *Innovative Techniques in Instruction Technology, E-learning, E-assessment, and Education*, M. Iskander, Ed., Dordrecht, Belanda: Springer, 2008, pp. 1-6.

TABLE III
IAL SYLLABUS OF CYCLOTRON 13 MEV

<table>
<tr><th>User / Description</th><th>University Student</th><th>Operator</th></tr>
<tr><td colspan="3">***Introduction***</td></tr>
<tr><td>Basic</td><td colspan="2">1. Accelerator fundamental
2. Accelerator app
3. Accelerator physics
4. Cyclotron technology
5. Applications of cyclotrons in the medical field</td></tr>
<tr><td>Advanced [26]</td><td>1. Mathematics for accelerators
2. Electromagnetic theory
3. Particle motion in EM fields
4. Relativity and kinematics of particle beams</td><td></td></tr>
<tr><td colspan="3">***Ion Source System***</td></tr>
<tr><td>Basic</td><td colspan="2">1. Ion source system working principle
2. Types of ion sources
3. Components of the ion source system
4. SOP for operation and maintenance of ion sources</td></tr>
<tr><td>Advanced</td><td>Fundamentals of ion source component design</td><td>Operation and ion sources maintenance practicum</td></tr>
<tr><td colspan="3">***Magnetic System***</td></tr>
<tr><td>Basic</td><td colspan="2">1. Magnetic system working principle
2. Components of the magnetic system
3. SOP for magnetic system operation and maintenance</td></tr>
<tr><td>Advanced</td><td>Magnetic system design fundamentals</td><td>Magnetic system operation and maintenance practicum</td></tr>
<tr><td colspan="3">***Vacuum System***</td></tr>
<tr><td>Basic</td><td colspan="2">1. Vacuum system working principles
2. Components of a vacuum system
3. SOP for magnetic system operation and maintenance</td></tr>
<tr><td>Advanced</td><td>Vacuum system design fundamentals</td><td>Vacuum system operation and maintenance practicum</td></tr>
<tr><td colspan="3">***Radio Frequency (RF) Generator System***</td></tr>
<tr><td>Basic</td><td colspan="2">1. The working principle of the RF generator system
2. Components of a RF generator system
3. SOP for operation and maintenance of RF generator system</td></tr>
<tr><td>Advanced</td><td>Fundamentals of RF generator system design</td><td>RF operation and system maintenance practicum</td></tr>
<tr><td colspan="3">***RF System Accelerator***</td></tr>
<tr><td>Basic</td><td colspan="2">1. RF System accelerator working principle
2. Components of an RF system accelerator
3. SOP for RF system accelerator operation and maintenance</td></tr>
<tr><td>Advanced</td><td>Fundamentals of RF system accelerator design</td><td>RF system accelerator operation and maintenance practicum</td></tr>
<tr><td colspan="3">***Beam Measuring System***</td></tr>
<tr><td>Basic</td><td colspan="2">1. Beam measuring system working principle
2. Components of the beam measuring system
3. SOP for beam measuring system operation and maintenance</td></tr>
<tr><td>Advanced</td><td>Beam instrumentation and diagnostics</td><td>Beam measuring system maintenance and operation practicum</td></tr>
</table>

TABLE III (CONTINUED)
SYLLABUS OF IAL CYCLOTRON 13 MEV

User / Description	**University Student**	**Operator**
	Extractor System	
Basic	1. Extractor system working principle 2. Components of the extractor system 3. SOP for extractor system operation and maintenance	
Advanced	Fundamentals of extractor system design	Extractor system operation and maintenance practicum
	Instrumentation and Control System (ICS)	
Basic	1. ICS on the DECY-13 cyclotron 2. Working principles of ICS in each component	
Advanced	Fundamentals of cyclotronic ICS design	ICS operation and maintenance practicum
	Utility System	
Basic	1. Utility system on the DECY-13 cyclotron 2. DECY-13 utility system working principles	
Advanced	Fundamentals of utility system design	System utility operation and maintenance practicum

 p-ISSN 2301 – 4156 | e-ISSN 2460 – 5719