Nuclear Materials and Energy 15 (2018) 195–202

Contents lists available at ScienceDirect

Nuclear Materials and Energy

journal homepage: www.elsevier.com/locate/nme

Linear IFMIF Prototype Accelerator (LIPAc): Installation activities for Phase-B beam commissioning in Rokkasho

Keitaro Kondo[a,*], Juan Marcos Ayala[c], Benoit Bolzon[d], Philippe Cara[b], Hervé Dzitko[b], Takashi Ebisawa[a], Enrico Fagotti[e], Dominique Gex[b], Roland Heidinger[b], Yosuke Hirata[a], Ryo Ichimiya[a], Yukiharu Ikeda[a], David Jimenez[f], Antti Jokinen[b], Atsushi Kasugai[a], Takayuki Kikuchi[a], Juan Knaster[c], Masao Komata[a], Sunao Maebara[a], Alvaro Marqueta[b], Ivan Moya[b], Shinobu Nishimura[a], Shigeru O'hira[a], Yoshikazu Okumura[c], Mario Perez[c], Guy Phillips[b], Ivan Podadera[f], Giuseppe Pruneri[e], Keishi Sakamoto[a], Francesco Scantamburlo[e], Takahiro Shinya[a], Masayoshi Sugimoto[a], Moises Weber[f]

[a] *National Institutes for Quantum and Radiological Science and Technology (QST), 2-166 Omotedate, Obuchi, Rokkasho-mura, Kamikita-gun, Aomori 039-3212, Japan*
[b] *Fusion For Energy, Boltzmannstr. 2 85748, Garching, Germany*
[c] *IFMIF/EVEDA Project Team, 2-166 Omotedate, Obuchi, Rokkasho-mura, Kamikita-gun, Aomori 039-3212, Japan*
[d] *CEA Saclay, Gif-sur-Yvette 91191, France*
[e] *INFN-LNL, Viale dell'Università, 2, Legnaro 35020, Italy*
[f] *CIEMAT, Av. Complutense, 40, Madrid 28040, Spain*

ARTICLE INFO

Keywords:
IFMIF
LIPAc
RFQ
Accelerator
Deuteron
Neutron source

ABSTRACT

The construction of the Linear IFMIF Prototype Accelerator (LIPAc) is in progress in order to demonstrate the feasibility of the low energy section of an IFMIF deuteron accelerator up to 9 MeV with a beam current of 125 mA in CW. The next milestone of the project is the so-called Phase-B beam commissioning, and one of the missions is to demonstrate the acceleration of the proton beam up to 2.5 MeV or the deuteron beam up to 5.0 MeV in pulsed mode with a low duty cycle of 0.1% through RFQ. Most of the components and subsystems necessary for Phase-B were delivered by 2016 under the responsibility of Fusion for Energy (F4E) as in-kind contributions of several European institutes, namely CEA (France), CIEMAT (Spain), INFN (Italy), and SCK-CEN (Belgium), and QST is in charge of the installation of the delivered equipment. The installation and check-out of the RFQ subsystem and the RF power system was completed by July 2017, and the RF conditioning of the RFQ cavity started. Also, the installation and the check-out of the important sub-systems for Phase-B, namely MEBT and beam diagnostics, have been completed.

1. Introduction

In a future nuclear fusion reactor, structural materials and functional materials used will be exposed to quite intense flux of 14 MeV neutrons produced by the deuterium-tritium (d-t) reaction. As a neutron source enabling irradiation test of such candidate materials, it was concluded in the early 1970's that an accelerator-based neutron source utilizing deuteron-lithium nuclear reaction was the most suitable, and research and development based on international cooperation has been conducted [1]. The concept of International Fusion Material Irradiation Facility (IFMIF) was established in the Comprehensive Design Report (CDR) compiled in December 2003 under the IEA (International Energy Agency) collaboration. According to that, IFMIF consists of two of 40 MeV, 125 mA high-intensity steady-state deuteron accelerator, a liquid lithium target and an irradiation test facility. The aim of IFMIF is to perform the neutron irradiation at 50 dpa (displacement per atom) per year at maximum, which enables to make an accelerated test of the first wall of a fusion power plant. In order to realize this goal, the accelerator requires CW (continuous wave) operation with the extremely high current mentioned above and high reliability. The IFMIF project is now in the Engineering Validation and Engineering Design Activities (EVEDA) phase under the Broader Approach Agreement between Japan and EU [2]. The purpose of the EVEDA phase is to produce an integrated engineering design of the IFMIF and the data necessary for

* Corresponding author.
E-mail address: kondo.keitaro@qst.go.jp (K. Kondo).

https://doi.org/10.1016/j.nme.2018.04.011
Received 14 December 2017; Received in revised form 13 March 2018; Accepted 23 April 2018
Available online 04 May 2018

future decisions about the construction, operation, exploitation and decommissioning of the IFMIF, and also to validate the continuous and stable operation of each IFMIF subsystem. As a part of the activities, the construction of the Linear IFMIF Prototype Accelerator (LIPAc), which is the prototype of the IFMIF deuteron accelerator projected to validate the acceleration of deuterons up to 9 MeV with a beam current of 125 mA in CW, is progressing at Rokkasho, Aomori, Japan. The commissioning of LIPAc is conducted in 4 phases to aim its full specification step by step. The injector commissioning (up to 100 keV) started in 2014 and the designed performance was confirmed in the experimental campaigns in 2015–2017 [3,4], which is so-called ‘Phase-A’ . The next milestone of the project is to perform ‘Phase-B’ beam commissioning, which includes an important task to demonstrate the deuteron beam acceleration up to 5.0 MeV through the Radio Frequency Quadrupole (RFQ) Linac, to characterize the beam in pulsed mode at low duty cycle and its characteristic as an interface to the Superconducting Radio-frequency (SRF) Linac. Also, the commissioning of Medium Beam Transport (MEBT) section and the functionality test of beam diagnostics are indispensable in order to proceed to the commissioning of the entire accelerator, which is called ‘Phase-C’ (pulsed beam) and ‘Phase-D’ (CW). The nuclear licensing process is also divided into 3 or 4 steps as the beam energy increases to make it easier.

Fig. 1 shows the configuration of LIPAc in the Phase-B commissioning, in which one can see the accelerator in the middle of the figure arranged in the accelerator vault (surrounded by walls displayed in brown), the RF power system equipped in the RF area in the north of the vault, and utilities in the south. Most of components and subsystems necessary for the Phase-B commissioning were delivered in 2014–2016 under the responsibility of Fusion for Energy (F4E) as in-kind contributions of several European institutes, namely CEA (France), CIEMAT (Spain), INFN (Italy), and SCK-CEN (Belgium), and QST has been in charge of the installation of the delivered equipment. In the present paper, the progress of the installation and the check out activities performed in Rokkasho for the accelerator components, namely RFQ, MEBT, beam diagnostics and the RF power system, is described in detail. Some lessons we learnt from the installation, the on-going activities and the prospect of the beam commissioning are explained.

Table 1
RF power system component delivery to Rokkasho.

No.	Components	Date arrived at Rokkasho
1	HV breaker Board (FBR01-10), 10 Transformers (FTR01-10)	14/Jul/2014
2	Common electrical board (APB02)	09/Oct/2014
3	RF module #1&2, 7 HVPSs (FHS01-07), LV distribution board (FCU03-05)	31/Aug/2015
4	2 transformers (FTR11,12)	12/Jan/2016
5	RF module #3	22/Feb/2016
6	RF cooling system #1	04/Apr/2016
7	UPS and White Rabbit board (FCU01,02), Solid state amplifier for MEBT buncher	28/Apr/2016
8	RF cooling system #2	27/Jun/2016
9	RF Module #4, HVPS (FHS08), RF cooling system #3	14/Aug/2016
10	RF cooling system #4	08/Oct/2016

2. RF power system

2.1. Delivery and installation

The radio frequency (RF) power system of LIPAc requires to supply the big RF power of 1.6 MW, continuous wave (CW) to the RFQ cavity, which is a key component in accelerating deuteron CW beam at the huge current of 125 mA. For this purpose, 8 chains of the RF power source with two Tetrodes amplifiers producing 175 MHz, 200 kW and CW are employed [5]. The system is complicated and large scale including electric power distribution equipment and the cooling system. The RF power system was provided to Rokkasho under the procurement responsibility of CIEMAT, Spain. The RF power source module (RF module) was manufactured by INDRA, Spain, and the high-voltage power supply (HVPS) for Anode of the final amplifier Tetrode were manufactured by JEMA, Spain. A part of the equipment was transported first time in the summer of 2014 to Rokkasho, starting from the outdoor components of the power distribution equipment procured by JEMA, and nine different sea transportations followed to complete the system. Table 1 summarizes the date of the arrival for different RF system

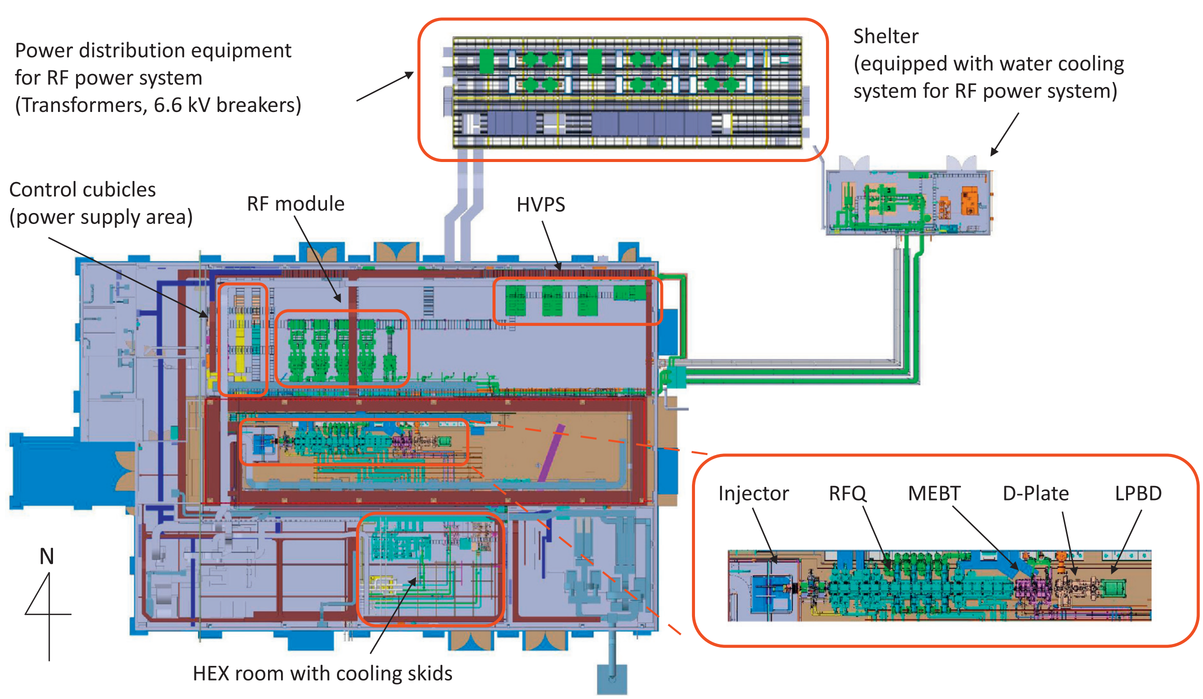

Fig. 1. Phase-B installation of LIPAc to demonstrate the deuteron beam acceleration up to 5.0 MeV.

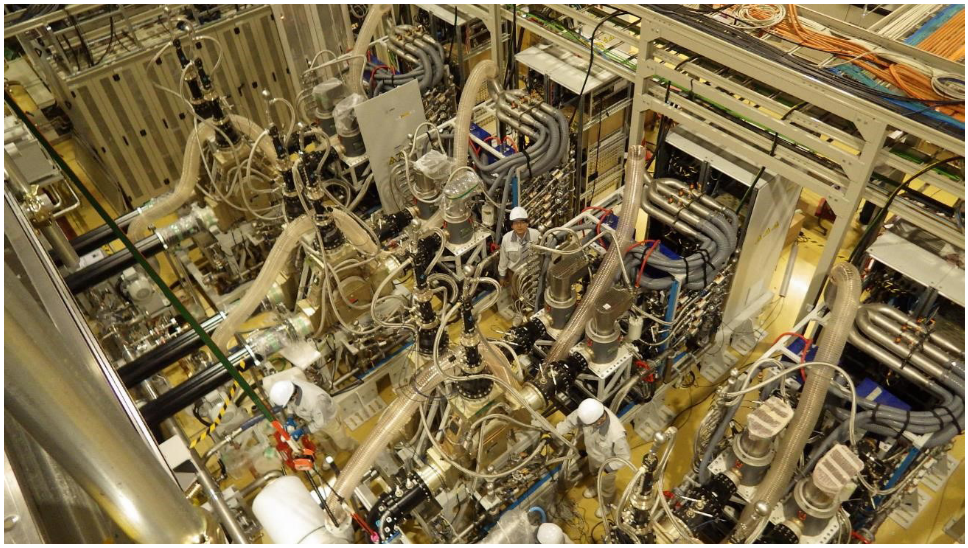

Fig. 2. RF modules for LIPAc RFQ installed in the RF area.

components at Rokkasho.

The installation of the system, including the power distribution system, and all the wiring works are the responsibility of QST. By the end of September 2016 all the installation (except the cooling system) was completed and approximately 500 cables were laid for the RF power system, with a total extension of about 15 km. Fig. 2 shows the RF modules installed for LIPAc RFQ and other components in the RF area, where one can see there are four modules with the same shape, and each module has two amplifiers.

The in-kind contribution is a major feature of the LIPAc project, and most accelerator equipment is procured in Europe. Thus, it is made by conforming to international standards such as IEC, EN and DIN. Especially as all electrical wiring is in accordance with the IEC standard, cable size and crimp terminal size are completely different from the JIS standard commonly used in Japan (for example, 10-16-25-35-50-95 mm^2 defined in IEC vs 8-14-22-38-60-100 mm^2 in JIS) and local contractors had to deal with unexperienced cable sizes and terminals. Power cables require high reliability, in particular in thick cables like 50 or 95 mm^2 transmitting high current, thus QST decided to supply all the necessary tools made in EU to suitably terminate the European standard cables to contractors.

For the same reason, the electrical network (grounding) system utilized is not the TT system commonly used in Japan but the TN-S system (partly IT system). 400 V, five-wire circuit (3 phases, neutral and ground) is used for 3-phase AC, while 200 V, three-wire circuit is common in Japan. The new JIS standard incorporating the IEC standard was already established, but the TN-S system has hardly spread, and usually workers have little experience on its installation. Therefore, it was important to give sufficient explanation about the concept of the power distribution system and the idea of equipotential bonding in prior to start the wiring work.

The 500 V AC supplied to HVPS of the RF module is formed with a transformer by stepping down 6.6 kV, which is the standard potential of the high voltage system in Japan but categorized as medium voltage in Europe. A small 6.6 kV breaker system made by ABB was supplied from Europe as part of the distribution system. Such a breaker is widely used for wind power generation in Europe, and the quick cable connection is standardized as a high voltage connector (24 kV–630 A) conforming to DIN 47,636 / EN 50,180. Meanwhile, wind power generation is not yet so popular in Japan, although windmills made in Europe have been introduced in recent years, and few experiences have been accumulated with this type of connector. In this installation, based on the recommendation from ABB Japan, we procured connectors made by Nkt, Germany through a distributor and received a lecture on the termination method on site to ensure the safe and proper installation. In Fig. 3 one can see the HV terminal and the connectors utilized in the 6.6 kV breaker system.

Fig. 3. HV terminal and connectors connected to 6.6 kV breaker system.

The 13 kV high voltage is supplied from HVPS to the Tetrode in the RF module with a thick RG218/U coaxial cable. A special HV terminal kit made by 3 M (QT II J4 SI-5601 I) withstanding up to 36 kV is used at the HVPS side. The problem is the terminal for the center conductor. Although crimp terminals for stranded wire are available, we didn't find any commercial one suitable for single wire center conductor of the coaxial cable in Japan. Since the steady current of 400 kW flows through this terminal, this is a place where extremely high reliability is required. After some investigations, we finally consulted with Furukawa Electric Power Systems Co., Ltd., a company specialized for terminals for high voltage and ultra-high voltage, and we asked them to prepare a custom-made crimp terminal that fits exactly the core wire of this coaxial cable.

2.2. Cooling system

The RF power system requires a dedicated water cooling system for removing the heat load of high power RF components [6]. It was designed and produced by ENGIE, Spain and supplied to Rokkasho. The requirements of the system are as follows:

- Dissipates the total thermal load of 3.15 MW from the RF system used for RFQ, MEBT and SRF in the future,
- Control the water supply temperature at 25° to stabilize the behavior of the RF circulator and Tetrodes,
- Equipped with de-ionized system to supply pure water with conductivity lower than 1 µS/cm to work with high voltage equipment and Tetrodes,
- Equipped with anti-freeze system with heaters to maintain the water temperature in winter.

The overall configuration of the system is visualized in Fig. 4. The amount of retained water is 16 m^3. The system has two circulation pumps and a small pump prepared for the anti-freeze operation. The heat exchanger, the pumps and the de-ionized system are located in a separate outdoor building, which is called as 'Shelter', and the outdoor buried piping connects to the RF area of the IFMIF/EVEDA accelerator building. The original installation plan was to complete it by the end of 2016, but due to some difficulties, e.g. unavoidable refurbishing due to mismatches in prefabricated piping dimensions, interface flange mismatches, outdoor construction delay, and control system delay. The installation was finally completed by the end of February 2017. After filling the system with pure water, the commissioning of the system was carried out by an engineer of ENGIE visiting Rokkasho. The system started to work on 16th March 2017, and it became possible to carry out the high-power test of the RF system with cooling.

2.3. High-power test

The high-power test of HVPS applying up to 8.3 kV, 400 kW output to a dummy load started on 24th March 2017 and subsequently the high-power test of RF module using water-cooled dummy load began on 13th April. For this test, a CIEMAT scientist permanently stays at Rokkasho, and technical experts of JEMA and INDRA visited Rokkasho repeatedly to support the test. The RF output was increased up to 200 kW, CW and continuous RF production of more than 1 h was confirmed for each RF chain. We reached 200 kW in the first chain on 14th April, and then the power test, the power calibration, the check of circulator and the short pulse test were repeated for the 8 chains. All the tests were successfully completed on 3rd July.

The RF area of the accelerator building does not have any overhead crane. On the other hand, due to constraints of the building space, the arrangement of equipment in the RF area is quite dense by designing on 3-dimensional CAD. The components did not arrive in an ideal order for the installation, thus their installations and the rearrangement of large RF equipment during the power test such as RF modules, dummy loads, waveguides often encountered difficulties. We had to deal with that by using various ways, e.g. using portable trolleys, disassembling a portable crane for transportation and reassembling it near the component, assembling a temporary tower with pipes for a chain hoist, installing a temporary support on the wall, and so on.

2.4. Wave guide installation

The coaxial waveguide (9 3/16″) for transmitting microwave from the RF module to the RFQ cavity is designed to pass through the underground pit between the RF area and the accelerator vault as shown in Fig. 5, which is a vertical cut of the accelerator vault and the RF area. One can see the structure of the underground pit in the bottom of the figure and a big U-shape arranged to prevent the straight penetration from the radiation safety point of view [7]. The installation was carried out by first installing it in the underground pit and then in the RF area between July and December 2016. Since the waveguide in the accelerator vault side needs to start from RFQ RF couplers, it was able to be installed only after February 2017. After the RF module has been unitarily tested in July, the U-shape in the pit was raised up, and the RFQ

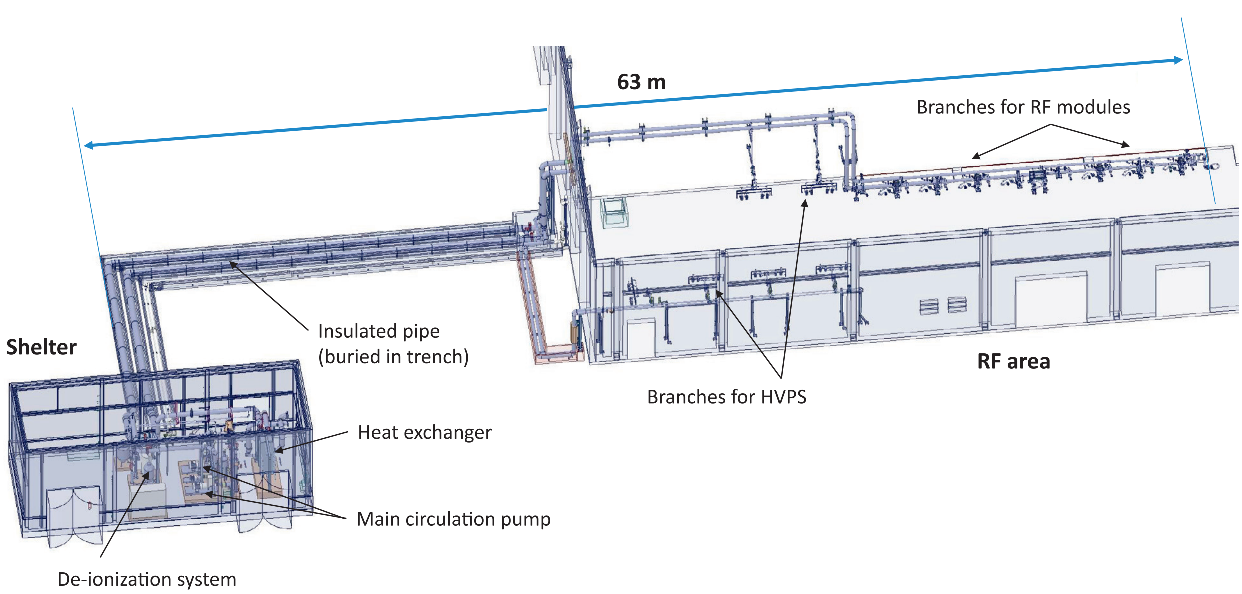

Fig. 4. Water cooling system for the LIPAc RF power system.

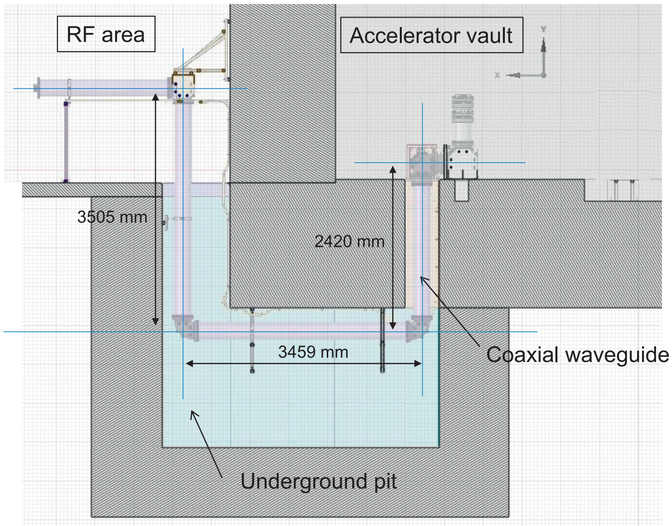

Fig. 5. Structure of the coaxial waveguide used for LIPAc RFQ and the underground pit.

cavity side and the RF module side were connected for the RF injection to the cavity. The left panel of Fig. 6 shows the installation of the waveguide in the RF area where one can see the horizontal waveguides are connected to the RF module, and the right panel show the work connecting the U-shape in the pit and the waveguide in the accelerator vault.

3. Accelerator components

3.1. RFQ

The LIPAc RFQ is the longest one in the world and has 9.8 m length in total [8]. It was manufactured in INFN, Italy and assembled up to tripartition of the whole cavity, which is called as 'super module'. The three super modules were transported to Japan at the end of February 2016, first arrived at Narita Airport and then brought to Rokkasho by ground transportation [9]. After combining them to a single cavity in a temporary position in the accelerator vault, the field and frequency tuning (the low power test) was conducted by means of the bead perturbation method. 110 adjustable tuners were replaced with final tuners in 3 steps and all the test was completed on 8th September 2016 [10]. Processing of the final tuners was carried out in Italy under the responsibility of INFN, while some emergency processing due to inconsistent of some interfaces found during the test campaigns was performed at a local machine shop near the institute.

The main piping that supplies cooling water to RFQ consists of six different primary loops, and a total of 12 pipes are connected to a water cooling skid placed in the HEX room. After some prefabrication work of cutting and welding outside the institute, the on-site installation was carried out under the responsibility of QST in August and September 2016 using days when the low power test was not carried out. Fig. 7 shows the photos taken during the work performed in the vault (left: in the beginning, right: at the end). After the completion of the low power test, the RFQ was again split into three super modules, moved to the final position, and combined. Then, the vacuum equipment was assembled, and the baking of the cavity was conducted in December 2016 [11,12]. From January 2017 the cooling water distribution on the cavity was installed. The vacuum system check-out started in spring 2017, and finally the cavity was pumped down by the cryopumps on 1st June for the first time. The coaxial waveguides were connected to RFQ in July 2017 after the completion of the high-power test of the RF modules.

All the works of the super module connection, the alignment of cavity, the vacuum and cooling system installation on the cavity, and the RF coupler installation were performed by INFN with some supports of QST, e.g. on the crane operation. Many experts, engineers and technicians of INFN frequently visited Rokkasho to conduct these work on site.

3.2. MEBT

The MEBT consists of five magnets, two bunchers and two scrapers, and it plays a role of shaping a beam pulse and transferring the beam to the succeeding SRF Linac in a very short length [13]. MEBT was delivered at Rokkasho on 25th March 2016 from CIEMAT. The MEBT was first installed at a temporary position. From July, CIEMAT scientist and

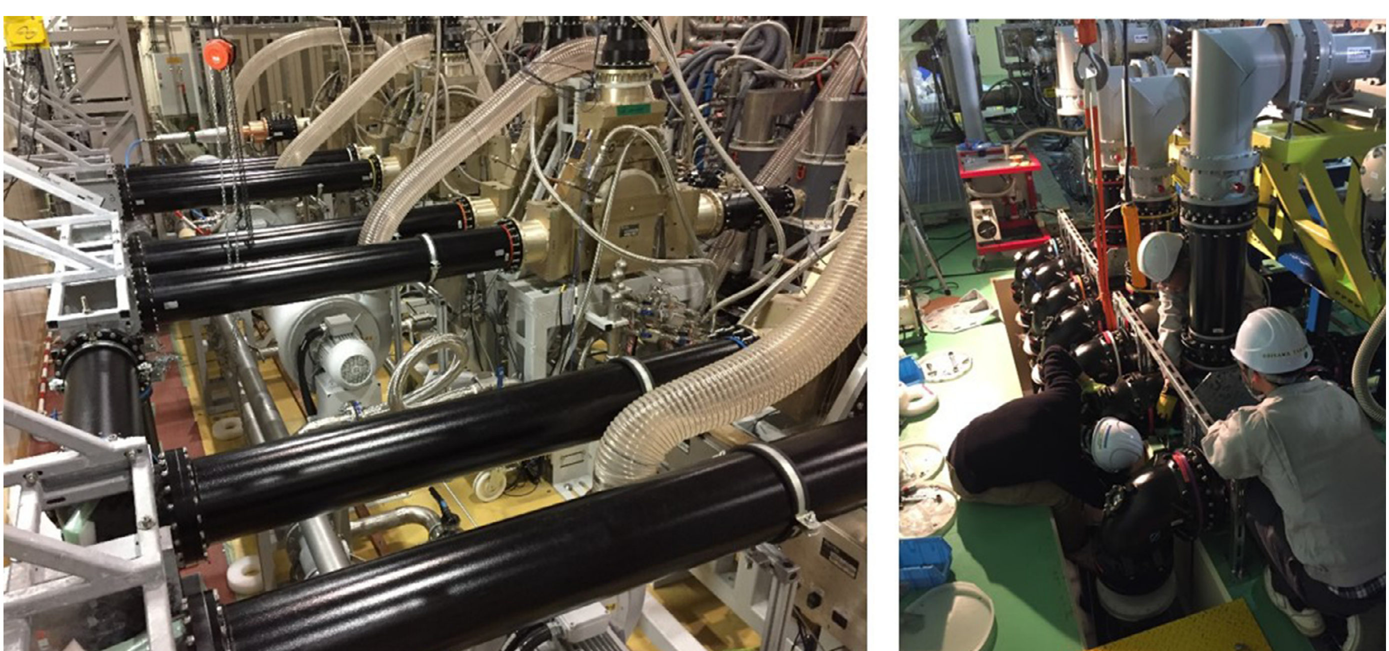

Fig. 6. Coaxial waveguides installed and connected between RFQ and the RF modules.

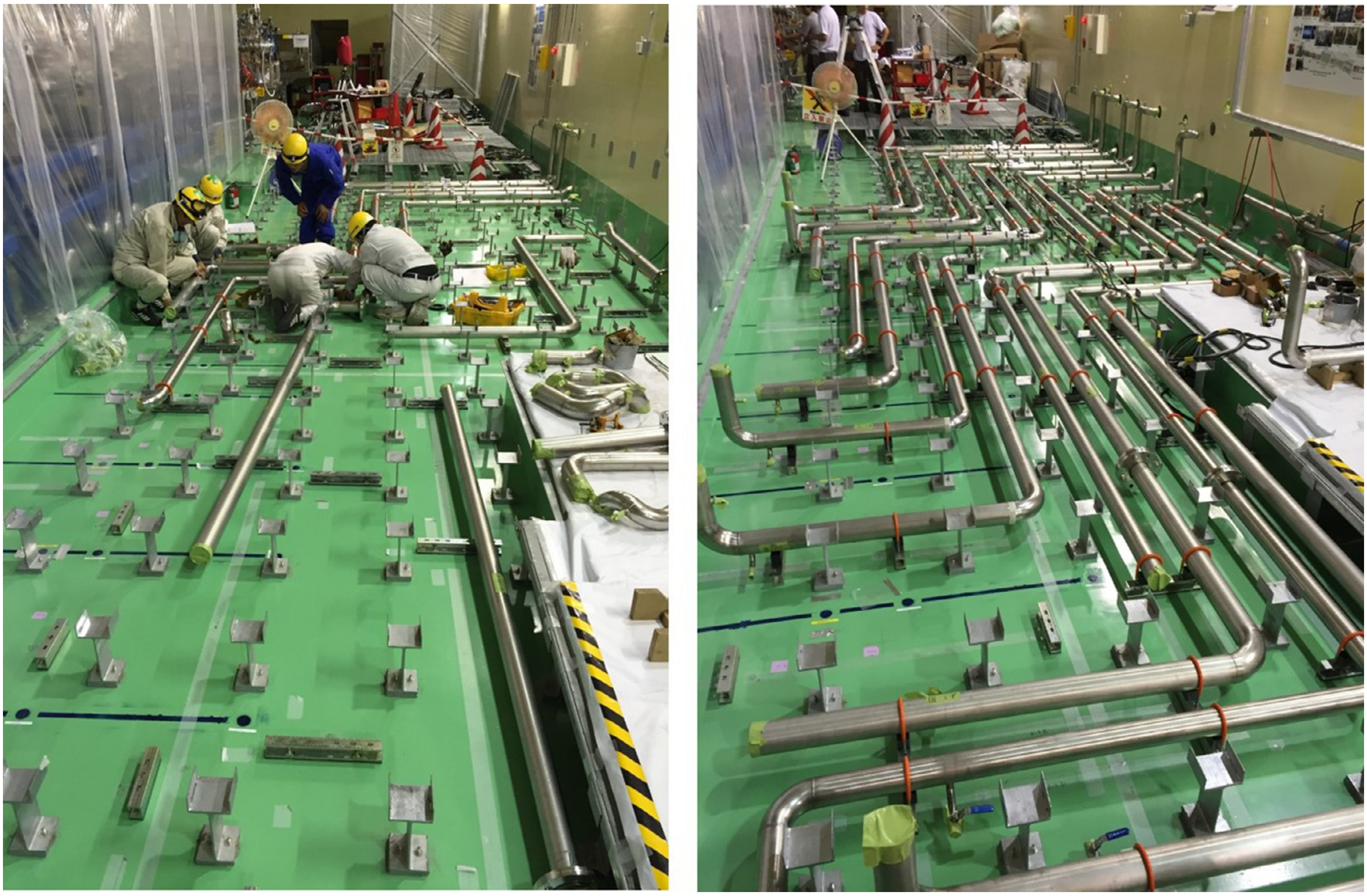

Fig. 7. Installation of primary cooling pipes for RFQ performed in the vault.

engineers stayed in Rokkasho and conducted the inter-wiring, the control system check-out, the installation and operation test of the vacuum equipment, the alignment of the main components, the connection of the cooling water pipe, and so on. After that, in January 2017 we moved MEBT to the final position and tried to connect the beam line between RFQ and MEBT, but a vacuum leak was found during the connection work in a special current transformer (CT) constituting a part of the beamline interface between both subsystems. The beam line connection was hence postponed for the repair of the CT. Thereafter, the cable wiring between MEBT and the control cubicles including power supplies for magnet and steerers, the operation test of the magnet, the movable scrapers and the cooling system, and the pumping down of the complete beamline down to nominal pressure were carried out. After CT repair was completed, the beam line was connected in September 2017 successfully.

The RF source for the MEBT bunchers is solid state type producing 16 kW RF for each and manufactured by BTESA, Spain under the procurement responsibility of CIEMAT [5]. QST performed the installation, wiring and piping. Then technicians of BTESA visited Rokkasho in May 2017 and installed the coaxial waveguide (3 1/8″) and conducted the power test up to the full power, CW. In January 2018 the conditioning of the buncher cavity was performed and the system became ready for the beam commissioning.

3.3. Beam diagnostics

The beam diagnostic instruments have been prepared vigorously for Phase B. Various diagnostics for the beam position, beam profile, beam current, beam emittance, etc. were prepared by CEA, CIEMAT, and INFN [14]. Many of these devices are installed together on a common platform called ‘D-Plate’, which stands for ‘diagnostic plate’ . D-Plate integrated measuring instruments of all the contributing institutes on the flame prepared by CIEMAT [15], then it was transported to Rokkasho and delivered on 15th April 2016. From July, CIEMAT scientist and engineers stayed in Rokkasho, and the inter-wiring for the instruments, the wiring of the control cubicles, the connection / operation test of the vacuum equipment, the alignment of the measuring equipment, etc. were sequentially carried out at a temporary position in the vault. In January 2017, it was moved to the final position, and the beam line between MEBT and D-Plate was connected. After that, cable wiring between D-Plate and the control cubicles and operation test of various instruments were carried out.

3.4. Low power beam dump

In the Phase-B commissioning, the duty cycle will be limited to 0.1% and the average beam power of 650 W will be received by the low power beam dump (LPBD), which can withstand only low duty cycle operations. LPBD consists of Al6082 alloy cone water-cooled, lead gamma shields and high-density polyethylene neutron shields surrounding the cone. LPBD was provided by INFN and arrived at Rokkasho in May 2017. The beam line between D-Plate and LPBD was connected in August and started to be pumped down together.

3.5. Cabling

The installation of cables connected to these accelerator components, namely RFQ, MEBT and beam diagnostics, is the responsibility of QST. The wiring work was conducted intensively from November 2016 to February 2017, laying cables of about 600, about 26 km total extension. All the cables leading to the accelerator components pass through underground pits between the power supply area and the accelerator vault. There is a cable pit dedicated for cables in the north west of the vault, but also a shorter path to the RF area is prepared for some diagnostic cables so as to minimize the distance between instrument and front-end electronics place on the south wall of the RF area.

3.6. Control system

The control system of LIPAc consists of six subsystems: Personnel Protection System (PPS), Machine Protection System (MPS), Central Control System (CCS), Local Area Network (LAN), Timing System (TS) and Local Control System (LCS). The PPS, MPS, CCS, LAN and TS have been developed by QST, and the LCS has been in charge of EU. The development and installation of the MPS, PPS and TS hardware necessary for Phase-B was completed. The interface test and the functionality test has been carried out between MPS/TS and each accelerator subsystem [16].

4. RFQ conditioning and beam commissioning

The individual preparation of RF and RFQ subsystem was completed in the beginning of July 2017 and the integration phase aiming the beam commissioning began on 11th July. The first step is the RF conditioning (the high power test) of the RFQ cavity. In the conditioning, we put the RF power into the cavity, starting from a very low power with a low duty cycle, and increasing step by step up to the nominal field level to enable the deuteron acceleration in CW. The first RF injection into the RFQ cavity succeeded on 13th July [12]. There is a technological challenge to use 8 chains of RF amplifiers to inject RF into a sole cavity. To this end, a precise synchronization of the amplifiers to equalize the phase and amplitude with an active feedback loop is realized by a modern fully-digitalized LLRF (low level RF) unit combined with White Rabbit technology [17]. The RF injection with 8 chains synchronized succeeded on 31st July first time and the RF conditioning activity started in earnest. From October 2017, the operational time has been extended to 24 h by three-shift system with 10 external operation support staffs.

Installation of all the accelerator components necessary for Phase-B was completed and the beam line is connected from the ion source to LPBD as seen in Fig. 8, in which one can see the RFQ cavity with 4 waveguides connected in the middle, the ion source cage in the left side, and MEBT and D-Plate in the right side. Once the RF conditioning is completed, the beam commissioning will start with proton beam. The operation permission necessary for the beam commissioning was already obtained from the Nuclear Regulatory Authority of Japan on 31st March 2016. After the beam acceleration test using the proton beam, we will be subjected to the facility inspection by the authority, and after acceptance the real deuteron beam commissioning will start.

5. Summary

In order to start the Phase B beam commissioning of LIPAc for the demonstration of the deuteron beam acceleration up to 5.0 MeV through the novel RFQ, the installation of the accelerator components and the check-out activities have been significantly progressed in Rokkasho. In this installation and check-out phase, two important technological achievements were obtained:

- The installation of the large-scale and complicated RF power system, including the dedicated cooling system, was successfully completed, and the system began operation safely without any major troubles. All the 8 RF power chains demonstrated operation at the full power of 200 kW, CW as designed, and now the system enables to produce 1.6 MW RF power at CW.
- The longest RFQ cavity in the world was transported from Italy to Japan without damage, and the installation and the tuning of the cavity requiring a very precise alignment process was successfully conducted on site. The result of the low power test proves that the performance designed was achieved perfectly.

All the individual testing of the RFQ and RF subsystems were completed by July 2017 and the RF conditioning of the RFQ cavity has been progressed. In the RF conditioning, with the state-of-the-art digital LLRF technology, we have successfully achieved the injection of RF generated from 8 amplifiers synchronized into a single cavity for the first time in the world.

The check-out of other important components, i.e. MEBT and beam diagnostics, has been also progressed and completed. The beam commissioning will begin with proton beam when the conditioning of the RFQ cavity is completed and then proceed to deuteron beam.

In this installation, we faced various difficulties peculiar to international projects. The difference in standards which we tend to think that are commonplace, such as cable size, piping standards, and anchor bolts used, has a great influence on the progress of work. Confirmation, dissemination and thoroughness of rules is important to ensure the quality of work. Interface problems are a specific issue in such a project based on the in-kind contribution and difficult to eliminate completely. Once it happens, it has a big impact on the schedule. A thorough confirmation prior to manufacture is necessary, but also it is desirable to leave room for adjustment appropriately so that it can be corrected promptly on site. It may also be worth to select a part that is easy to obtain locally as much as possible.

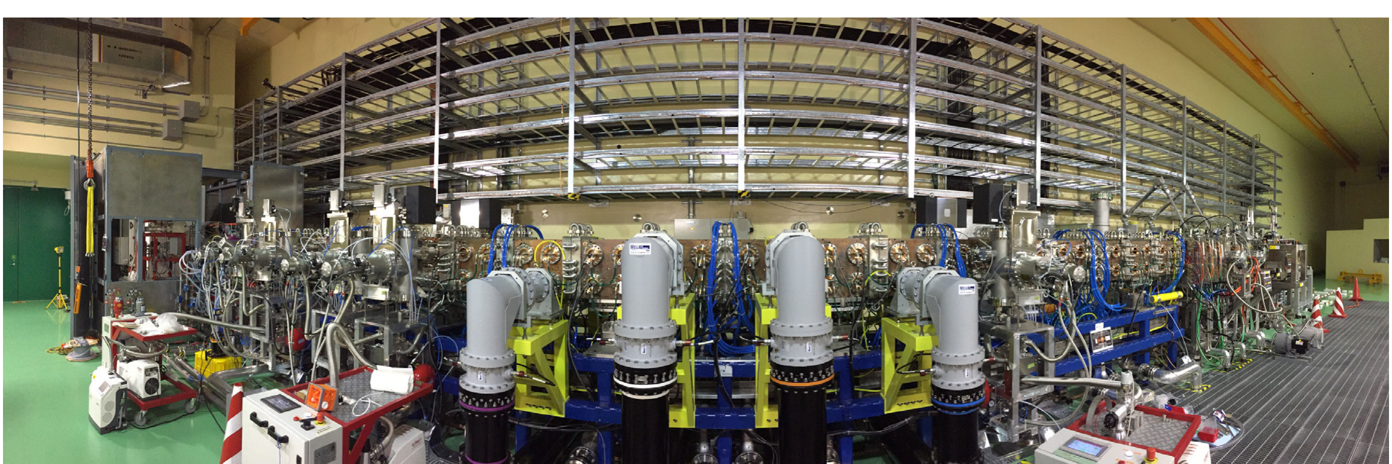

Fig. 8. LIPAc components installed in the accelerator vault for the Phase-B beam commissioning.

Acknowledgements

The present work was performed in the framework of the Broader Approach Agreement. The authors gratefully acknowledge the support of their home institutions and research funders for this work. Views and opinions expressed herein do not necessarily reflect those of QST, Fusion for Energy, or of the authors' home institutions or research funders.

References

[1] J. Knaster, et al., Overview of the IFMIF/EVEDA project, Nucl. Fusion 57 (10) (2017) 102016.
[2] P. Garin, M. Sugimoto, Main baseline of IFMIF/EVEDA project, Fusion Eng. Des. 84 (2009) 259–264.
[3] R. Gobin, Installation and first operation of the international fusion materials irradiation facility injector at the Rokkasho site, Rev. Sci. Instrum. 87 (2016) 02A726 http://dx.doi.org/10.1063/1.4932977.
[4] B. Bolzon et al., Beam diagnostics of the required 140 mA/100 keV CW D+ ECR injector of LIPAc, IFMIF's accelerator prototype, to be presented in ISFNT-13, to be published in Fusion Engineering and Design, 2018.
[5] D. Regidor, et al., IFMIF-EVEDA RF power system, Proceedings of IPAC2011, MOPC135, San Sebastián, Spain, 2011.
[6] G. Pruneri, et al., Conventional facilities of the linear IFMIF prototype accelerator (LIPAc), Fusion Eng. Des. 124 (2017) 1101–1107.
[7] K. Kondo, et al., Radiation safety study for the beam commissioning of IFMIF/EVEDA LIPAc RFQ in rokkasho, Fusion Eng. Des. (2018), http://dx.doi.org/10.1016/j.fusengdes.2018.02.001 (in press).
[8] A. Pisent et al., "IFMIF-EVEDA RFQ design", Proc. of EPAC08, Genoa, Italy.
[9] E. Fagotti, et al., Preparation and installation of IFMIF-EVEDA RFQ at Rokkasho Site, Proceedings of LINAC2016, East Lansing, MI, USA, THPLR066, 2016.
[10] A. Palmieri, et al., Tuning the IFMIF 5MeV RFQ Accelerator, Proceedings of LINAC2016, East Lansing, MI, USA, THPLR049, 2016.
[11] E. Fagotti, et al., Installation and low power test of IFMIF-EVEDA RFQ at Rokkasho site, Proceedings of IPAC2017, Copenhagen, Denmark, THPIK032, 2017.
[12] T. Shinya, et al., Status of RFQ linac installation and conditioning in Rokkasho for the Linear IFMIF Prototype Accelerator, (2018), http://dx.doi.org/10.1016/j.nme.2018.04.001 in this issue.
[13] I. Podadera, Manufacturing, assembly and tests of the LIPAC medium energy beam transport line (MEBT), Proceedings of LINAC2016, East Lansing, MI, USA, TUPLR041, 2016.
[14] J. Marroncle et al., IFMIF-LIPAc diagnostics and its challenges, Proceedings of IBIC2012, Tsukuba, Japan, WECC01 (2012).
[15] J. Calvo et al., MEBT and dd-plate control system status of the linear IFMIF prototype accelerator, Proceedings of ICALEPCS2015, Melbourne, Australia, MOPGF045 (2015).
[16] Y. Hirata, et al., Development Status of Control System Toward RFQ Commissioning of IFMIF/EVEDA Prototype Accelerator, (2018) in this issue.
[17] C. de la Morena, et al., Fully digital and white rabbit synchronized low level rf system for LIPAc, IEEE Trans. Nucl. Sci. 1 (2017) 99.