Neutrino Facility at J-PARC: Construction Status and Future Prospects

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Abstract

To carry out the T2K, a next-generation long-baseline neutrino oscillation experiment connecting Tokai and Kamioka spanning 295 *km*, has inspired the construction of J-PARC. It employs a 50-GeV proton synchrotron as a neutrino super-beam source and Super-Kamiokande (SK) as a far neutrino detector. At the Tokai campus, commissioning of the accelerators commenced as scheduled, and a neutrino beamline is under construction as one of the last public works of the facilities. In this speech I present the characteristic features of the beamline and apparatus therein in detail, together with the current status of construction/production and commissioning plan scheduled in April 2009. I also brief the future prospects for the intensity upgrade of the J-PARC main ring, requested by the future projects such as T2K phase-II and the T2KK.

1. Introduction

Recently, the rapid progress in neutrino oscillation experiments has uncovered finite but tiny neutrino masses and mixing between the flavors. After an announcement[1], a three-neutrino-flavor model has almost been established. The Maki-Nakagawa-Sakata (MNS) matrix, the mixing matrix between the neutrino flavor eigenstates and the mass eigenstates[2], has six observables through neutrino oscillation experiments: two mass-squared differences (Δm^2_{12}, Δm^2_{23}), three mixing angles (θ_{12}, θ_{23}, θ_{13}), and a CP phase (δ_{CP}). Through past and present experiments in the last ten years, the order of the magnitude difference Δm^2_{12} and Δm^2_{23} have been obtained, and the mixings between two successive eigenstates (1-2 and 2-3) are found to be nearly maximum[3, 4, 5]. Meanwhile, a mixing between the 1st and the 3rd eigenstates is known to be small, and only the upper limit for $\sin^2 2\theta_{13}$ is obtained so far by reactor experiments[6]. Through accelerator long-baseline experiments, we can investigate this 1-3 mixing by studying the ν_μ-to-ν_e appearance mode. K2K, the first long-baseline experiment connecting 250 *km* between KEK PS and Super-Kamiokande (SK) (running through 1999 to 2004) collected approximately 100 accelerator-made neutrino events[7]. By using the μ/e identification of the SK detector and applying tighter cuts to reduce the electron-like background, a ν_e-like event was obtained[8]. This could be compared to the background, estimated to be 1.7. These mostly result from the intrinsic beam ν_e and π^0 produced by neutral-current inelastic interactions. Not only an improvement in the statistics, but also a reduction in these backgrounds are required for future projects.

The T2K is the first super-beam neutrino oscillation experiment[9]. It connects a distance of 295 *km* between the J-PARC 50-GeV main ring (MR) at Tokai, which acts as a neutrino super-beam source, and SK, which acts as a far neutrino detector, to explore the mass and mixing of the neutrinos with unprecedented

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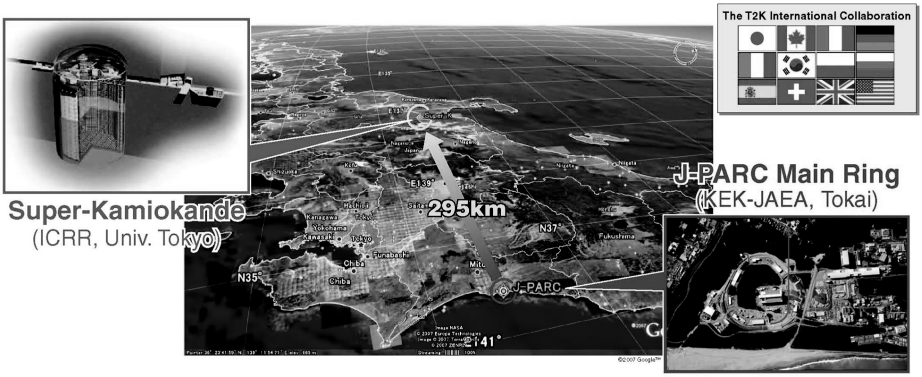

Fig. 1 Layout of the T2K experiment.

precision. The design value of the proton beam power of the MR at the phase-I operation (750 kW) is 100 times larger than that of KEK-PS.

We are currently constructing a neutrino secondary beamline and developing the apparatus therein towards completion in March 2009. The beamline is particularly designed to observe the first signal of the tiny ν_μ-to-ν_e appearance and also to measure the CP phase in the lepton sector[10].

2. J-PARC Accelerators and Facilities

J-PARC, Japan Proton Accelerator Research Complex, is a joint facility of High Energy Accelerator Research Organization (KEK) and Japan Atomic Energy Agency (JAEA). It comprises high-intensity proton accelerators to produce Megawatt-class primary proton beams and surrounding experimental facilities[3]. Through the proton and fixed-target interactions, a variety of secondary particles (neutrons, pions, kaons, hyperons, antiprotons) and daughter particles (muons and neutrinos) are to be produced. These high-intensity secondary beams provide unique opportunities to explore frontiers both in particle and nuclear physics, material and life sciences, and nuclear transmutation technology.

J-PARC accelerator cascade

J-PARC accelerator complex comprises the following:

- 400-MeV Normal-conducting Linac. It is an injection system for the entire accelerator complex. From upstream to downstream, it comprises an ion source, 3-MeV Radio-frequency Quadrupole (RFQ), 50-MeV Drift-tube Linac (DTL), 181-MeV Separate-type DTL (SDTL), and 400-MeV Annular-ring Coupled Structure Linac (ACS)[*]. The repetition rate is 25 Hz with a pulse width of 500 μs. The nominal peak current is 50 mA at 400-MeV beam energy. After future upgrading to 600 MeV by adding another superconducting system, it will supply a proton beam to the Transmutation Experimental Facility (TEF)[12].
- A 3-GeV Rapid Cycling Synchrotron (RCS), which provides proton beams at 333 μA (1 MW) to the Material and Life Science Facility (MLF). It will also act as a booster synchrotron of the MR. The repetition rate is 25 Hz, and the harmonic number is 2.

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[*] The ACS is not installed on the first day. It will cause the reduction of the peak current of the Linac to 30 mA. It will also limit the nominal current of the MR to 9 μA.

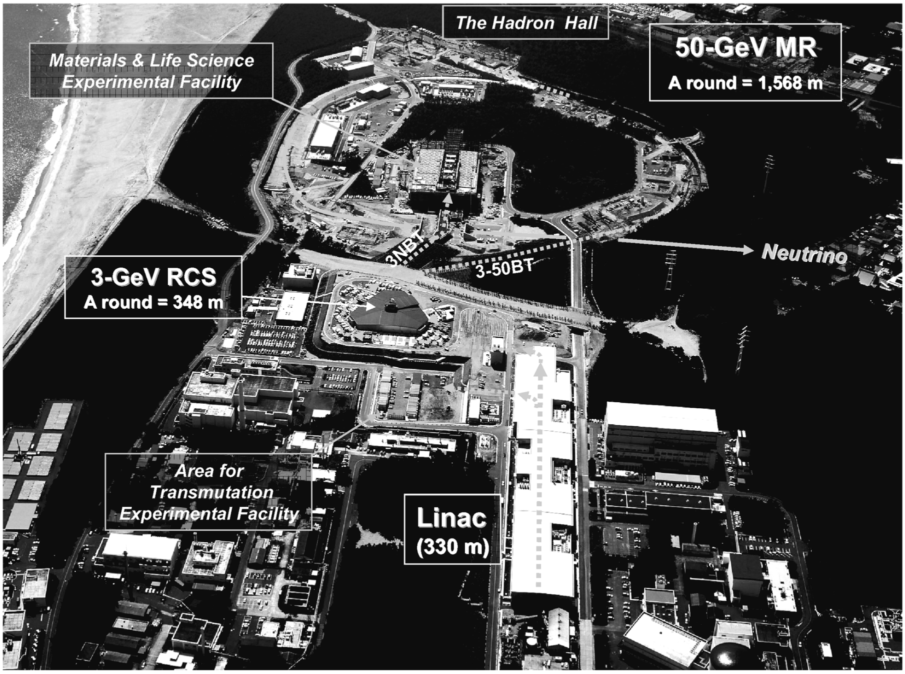

Fig. 2 Bird's-eye view of J-PARC (as on Feb. 2006).

- A 50-GeV MR, which provides proton beams at 15 μA (750 kW) to nuclear and particle physics facilities at the Hadron Hall and also to a neutrino beamline. The repetition rate is ~0.3 Hz, and the number of beam bunches is 8 with a harmonic number of 9.

A bird's-eye view photograph of the J-PARC site from north to south is shown in Fig. 2. The construction, installation, and beam commissioning plan of the accelerators and facilities are summarized in Fig. 3. The construction was started in April 2001, and most of the public works are now being completed, except for the neutrino beamline. The installation of the apparatus is almost complete for the Linac and RCS, and is in progress for the MR.

In the Linac, the commissioning has been started from November 2006, and acceleration to 181 MeV has been achieved successfully in January 2007 without any notable beam loss[13]. In the RCS, off-beam commissioning was started last April and the beam run is scheduled for September 2007[†].

In the MR, the initial beam commissioning will take place in early FY2008 for establishing a closed orbit. After the installation of slow extraction devices, beam acceleration and slow extraction will take place at the end of CY2008[15]. On the first day, the beam energy is determined to be 30 GeV. The fast extraction of the beam to the neutrino beamline is scheduled for April 2009. The repetition cycle will be 3.04 s with a 0.1-s flat top. The beam structure has 6 bunches instead of the nominal number of 8; further improvement is required for the rise time of the fast extraction kickers.

[†] Accelerating the beam to 3 GeV has been successful in the end of October 2007[14].

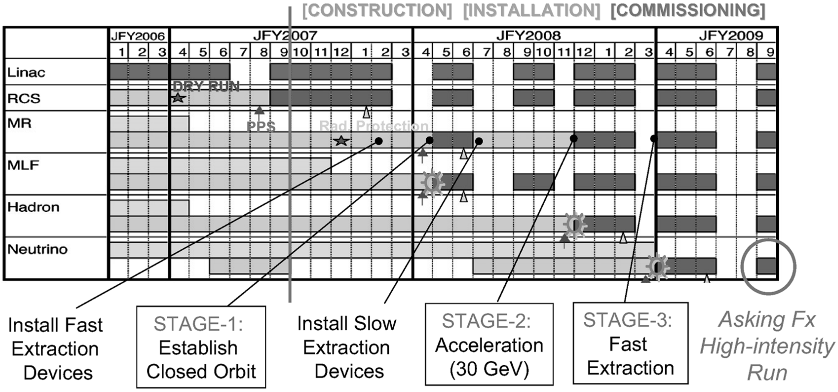

Fig. 3 Beam commissioning plan of the accelerators and facilities. Original table is obtained from Ref. [16].

Materials and Life Science Facility (MLF)

The Materials and Life Science Experimental Facility (MLF) has a muon source[17] and a spallation neutron source[18]. The facility is located at the interior of the MR. A pulsed proton beam from the RCS, with a current of 333 μA and repetition rate of 25 Hz, is passed through a beam transportation facility termed 3NBT[‡] to the MLF. After penetrating a carbon target for muon production, the proton beam is incident on a liquid mercury target for neutron production. Four muon beamlines and 23 neutron beamlines will be constructed. The intensity of the muon and neutron flux is the highest in the world, and a wide variety of researches on material and life sciences would be promoted. By the end of last April, the construction of the experimental hall was complete. Various components, devices, and equipments are now being manufactured and installed, the completion scheduled for within FY2007. The first beam for the MLF is expected in early FY2008.

The Hadron Hall

The Hadron Hall is an experimental site of the Nuclear and Particle Physics Facility, together with the neutrino beamline. The main purpose of the facility is to realize a kaon factory for promoting hypernuclear spectroscopy, studies for the strangeness degree in nuclear matter, kaon rare decay search, hadron spectroscopy, etc. Various short-lived hadrons, including kaons and pions, will be produced from the interaction between the fixed targets and the slowly-extracted proton beam. In July 2007, the civil construction of the hadron hall was complete. The operation of the hall is scheduled by the end of CY2008.

On the first day, the facility will have a single primary beamline and a target (T1), while adequate space is kept in the switch yard for the installation of more primary beamlines for future extension.

The T1 target is a system comprising 5 Nickel disks of 360 mm-ϕ and 54 mm total width, which are partly soaked in cooling water. They are rotated at the rate of one cycle per beam flat top to disperse the heat over the circumference. The beam loss due to the interaction on the target is approximately 30 % of the beam intensity, and approximately 200 kW of heat will be released to the downstream components. Beam windows made of beryllium will be installed on both the sides of T1 with pillow seals. Downstream of T1, a large vacuum chamber, central

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[‡] The 3NBT crosses over the orbit of the MR and the decay volume of the neutrino beamline.

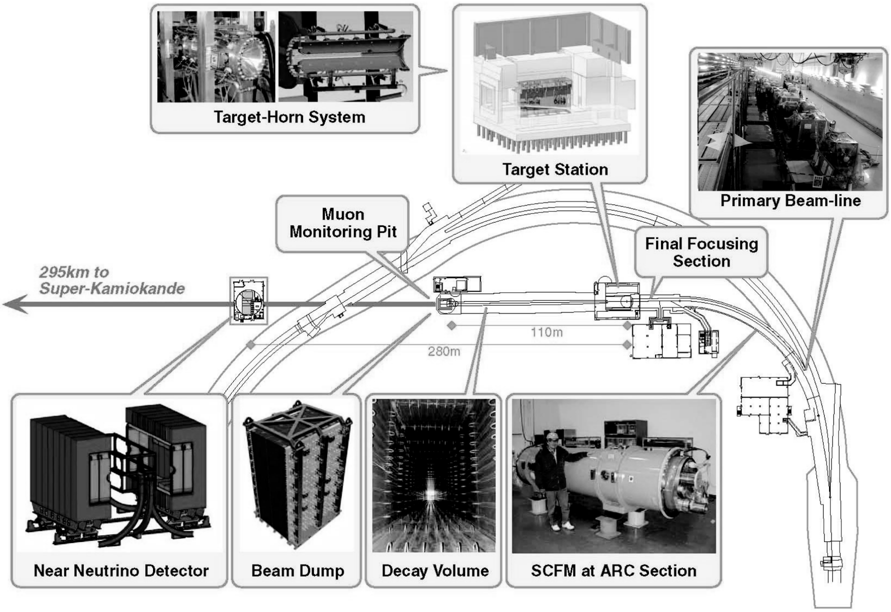

Fig. 4 Schematic view of the neutrino beamline.

box, will be placed, where a copper collimator and radiation-hard magnets will be enclosed. The primary protons, which travel straight through T1, are collimated and lead to a beam dump. It is made of 180 tons of thick copper plates with a tapered hole at the beam center and 90 tons of iron plates.

There are three kaon beamlines that lead out from T1: K1.8/K1.8-BR (left to the target), K1.1/0.8 (right), and KL (center). On the first day, K1.8 is prioritized for $\Xi(S{=}-2)$ hypernuclear spectroscopy with the Superconducting Kaon Spectrometer (SKS)[19]. By assuming the operation on the first day as 30GeV-9 μA (270 kW), the K^- single rate is expected to be more than 8×10^6 *ppp* before the beam analyzer section, and the intensity of the negative kaon with 1.8 GeV/c is 1.4×10^6 *ppp* at the final focus (for 750 kW, it will be larger by a factor of 5). The K^-/π^- ratio is expected to be 7. Λ-Hypernuclear gamma-ray spectroscopy involving a large Ge detector array (Hyperball-J) and SKS will also be performed[20].

On the other side of K1.8, K1.1 (and branch K0.8) will be constructed. The beam intensity for the 1.1 GeV/c-negative kaon is expected to be 1.2×10^6 *ppp* for the 50-GeV-15-μA operation, which is stronger than that of K1.8.

The KL line used to study the rare decay of the neutral kaon, particularly aims at measuring the branching ratio of $K_L \to \pi^0\nu\overline{\nu}$[21]. The probe is sensitive to direct CP violations in the quark sector. So far the KEK-PS experiment has the best upper limit, 2.1×10^{-7} at 90 %C.L.[22], which could be compared to that predicted by the Standard Model, 2.8×10^{-11}. The forthcoming experiments aim at improving this limit to 10^{-13}.

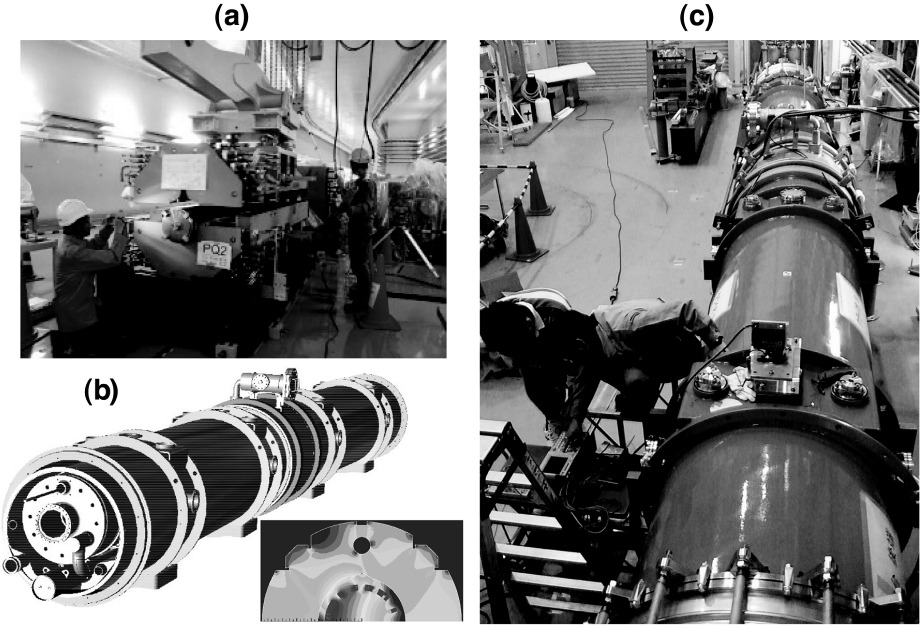

Fig. 5 (a) Installation of a normal-conducting Q-magnet to the preparation section (September, 2007). (b) Schematic view of a "doublet" of the Superconducting Combined Function Magnets (SCFM). (c) An alignment test for the cold mass. It was found to be well under control (spring 2006).

3. The Neutrino Beamline

The layout of the neutrino beamline is illustrated in Fig. 4. It comprises a primary beamline, target station (TS), decay volume (DV), beam dump (BD), muon monitors, and near neutrino detectors 280 m downstream from the target. A unique feature is that this is the first application of the off-axis (OA) beam configuration[23], where the center of the neutrino beam direction underground is shifted by a few degrees with respect to the far detector. By adjusting the off-axis angle from 2° to 2.5°, we can tune the peak of the semi-monochromatic beam to the expected oscillation maximum (E_ν = 0.8∼0.65 GeV). It is to be noted that quasi-elastic interactions are dominant under 1 GeV energy, which is sufficiently suitable for minimizing the electron-like shower background caused by π^0, which are produced through neutral-current inelastic interactions. The length of the DV (100 m), which is shorter than that of K2K (200 m), also reduces the beam-intrinsic ν_e contamination resulting from the muon and K_{e3} decays. The ν_e contamination is estimated to be 0.4% for OA2.5, lower than that of K2K by a factor of 5.

For the beamline construction, the KEK neutrino beamline construction subgroup plays a core role. Meanwhile, international contributions also play essential roles for the crucial components of the beamline, such as target and horn designs (UK/US), remote handling of the target (UK), beam-window design (UK), OTR design and production (Canada), SCFM quench detection system (France), beam dump design (UK), and beam monitors (US/Korea).

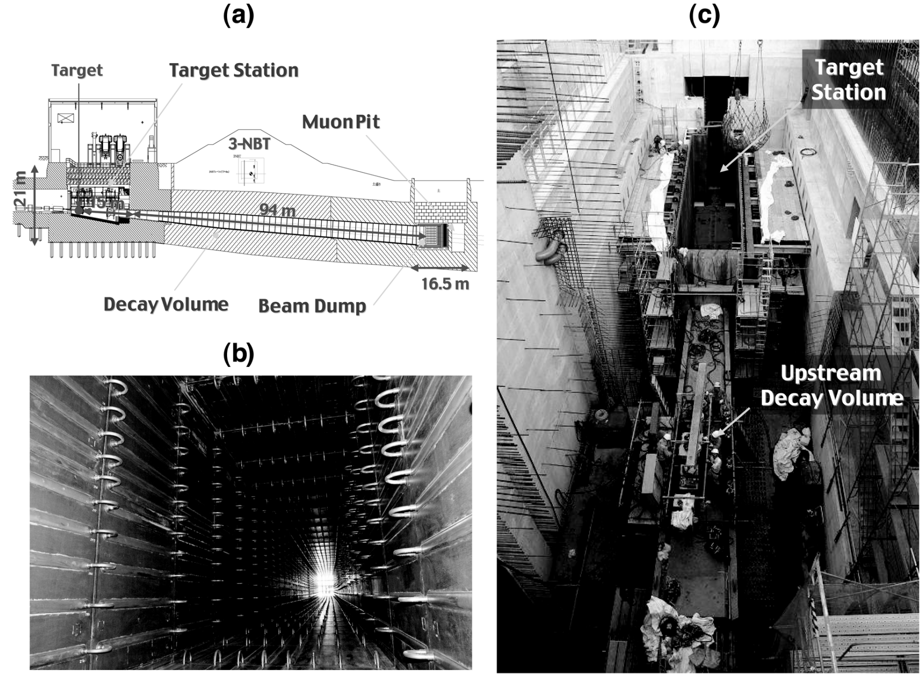

Fig. 6 (a) Cross-sectional view of the secondary beamline. (b) Interior of the decay volume under 3NBT, a beam transport line from RCS to MLF (October 2005). It has a rectangular shape for accepting the off-axis beam between 2° and 3°. (c) Installation of the target station and upstream of the decay volume (August 2007).

Primary beamline

The primary beamline transfers the fast-extracted proton beam from the MR to the production target. It comprises three sections: a preparation section, an arc section, and a final focusing section.

The preparation section comprises 12 normal conducting magnets and collimators, which accommodate 60-*mm·mrad* beam emittance. In the arc section, where the radius is 104 *m* and length approximately 150 *m*, the beam is bent by approximately 80° by 28 Superconducting Combined Function Magnets (SCFM)[24]. This is the first attempt to develop a combined function magnet as a superconducting device. It is 3.3 *m* long, where the dipole and quadrupole components are 2.6 *T* and 18.6 *T/m*, respectively. The applied current will be 7,345 A for the 50-GeV operation. Two SCFM magnets are assembled inside one cryostat (doublet). The final focusing section comprises 10 normal conducting magnets.

Intensity (current transformer), position (electrostatic monitor), profile (segmented secondary emission monitor), and beam-loss monitors will be installed.

Target station, target, and horn system

The target station is a building with a remote-handling crane for maintaining the highly irradiated horns and target from a distance. The main component is a large vacuum vessel made of 100-*mm*-thick iron plates, where a production target, magnetic horn system, decay volume collimators, and related apparatus are installed and maintained under a helium atmosphere. The surfaces of the

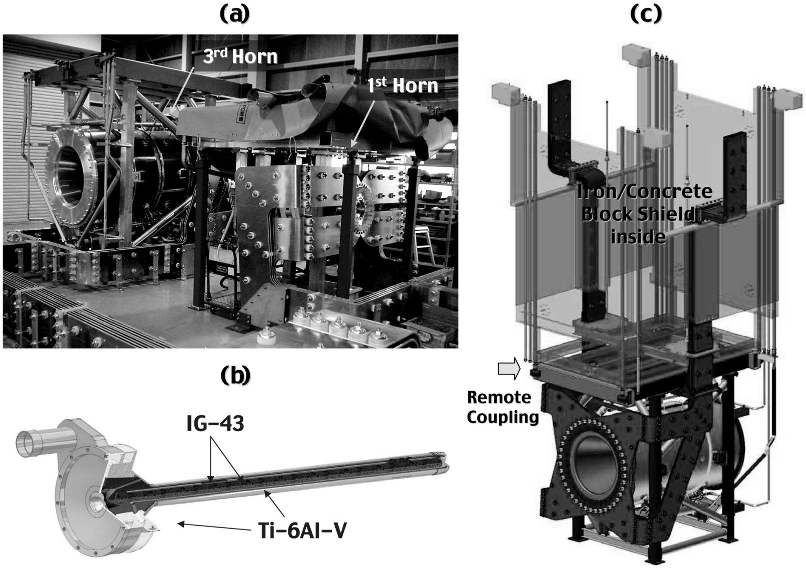

Fig. 7 (a) The 1^{st} and 3^{rd} horns subjected to a long-term current operation test (May 2007). (b) Schematic view of the production target, made of isotropic graphite and Titanium alloy. (c) The support module of the 3^{rd} horn.

100-*mm*-thick iron plates are covered with water paths (plate coil) to remove the heat released from the target. The ceiling of the vessel is a large flange, which is closed and sealed with 120-*mm*-thick aluminum plates. The helium vessel is enclosed in iron cast blocks and concrete shield blocks weighting thousands of tons for radiation protection.

At the upstream of the TS vessel, a beam window separates the helium atmosphere and the vacuum of the primary beam pipe. It is made of two layers of Ti-alloy cooled by helium gas flowing between them. The window has pillow seals on both sides for remote handling.

The production target is enclosed in the inner conductor of the 1^{st} horn. It is an isotropic graphite rod 26 mm-ϕ / 900 mm long, enclosed in two layers of sleeves made of a 2-*mm*-thick graphite and 0.3-*mm*-thick titanium alloys, respectively. The heat load on the target (69 kJ/spill) is removed by helium gas flowing between the sleeves.

An Optical Transition Radiation (OTR) monitor is positioned in front of the target entrance window to monitor the beam position and width on the target. It has 8 reflector Ti-alloy foils stored in a rotating disk to automate the exchange work.

Three magnetic horns will be operated to focus the generated pions in the forward direction. They comprise inner and outer conductors and large bus-bars made of aluminum. By applying a 320-kA pulsed current synchronized to the spill timing, a toroidal magnetic field is generated between the inner and outer conductors. To reduce the Joule heat and energy deposits caused by the beam, water spray nozzles are installed inside the horns. Upstream of the 1^{st} horn, we will install a graphite baffle to guard it from the occasional miss-steered beam.

The magnetic horns and baffle are supported from the walls of the helium vessel

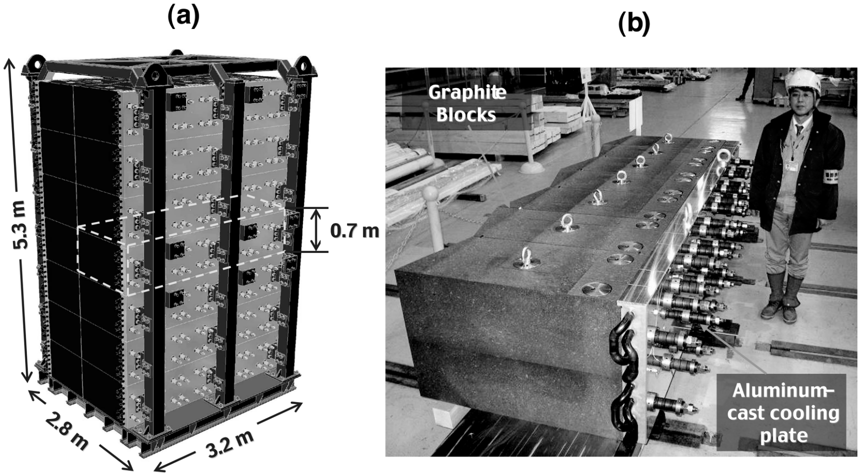

Fig. 8 (a) Schematic view of the hadron absorber, comprising 14 core modules and a support frame. (b) The 1^{st} core module made of 7 graphite blocks and an aluminum cooling plate (March 2007).

shielding by support modules. Nineteen pieces of 2.2-*m*-thick iron cast blocks (∼470 tons in total) and the 1-*m*-thick concrete blocks will also be supported from the wall, covering the top of the entire horn system for radiation protection. On top of the concrete blocks exists a service pit, where maintenance work by the personnel will be carried out.

For the maintenance of the horns and target, the iron blocks in the helium vessel will be handled remotely by a twist-lock system. After the horns and support modules are brought into the maintenance area, they are disassembled from the top of the module through the shielding blocks. A remote exchange mechanism of the target from the 1^{st} horn with a remote manipulator is also being developed. There is a waste-storage area, where broken horns and targets can be stored.

Decay volume and beam dump

The TS, DV, and BD make up a big vacuum/helium vessel of approximately 1,700 m^3 volume. At the entrance of the DV, there are three layers of collimators with 200-*mm*-thick iron plates covered with plate coils. The cross section of the DV is rectangular, tapering out from 1.4 m × 1.7 *m* at the entrance to 3.0 *m* × 5.1 *m* at the exit. It can accept the off-axis beam configuration between 2° and 3°. The DV is made of 16-*mm*-thick iron plates supported by stud anchors embedded in the concrete wall. The interior of the DV is covered with 40 channels of serially connected plate coils.

The beam dump is located downstream of the DV helium vessel, where a hadron absorber, the core of the beam dump, is installed together with water-cooled iron shields. The upper surface of the hadron absorber is 109 *m* downstream of the production target. It comprises 14 core modules and a frame supporting them. It measures 3.1 *m* × 5.4 *m* × 3.2 *m* and weighs 70 *t* totally. A core module comprises 7 large extruded graphite blocks fastened to an aluminum cast plate with cooling water paths in it. To maintain the flatness of 0.1 *mm* for the cooling surface and loading surface, 7 graphite blocks are simultaneously machined together. A design with multiple spring washers is adopted to fasten graphite and aluminum,

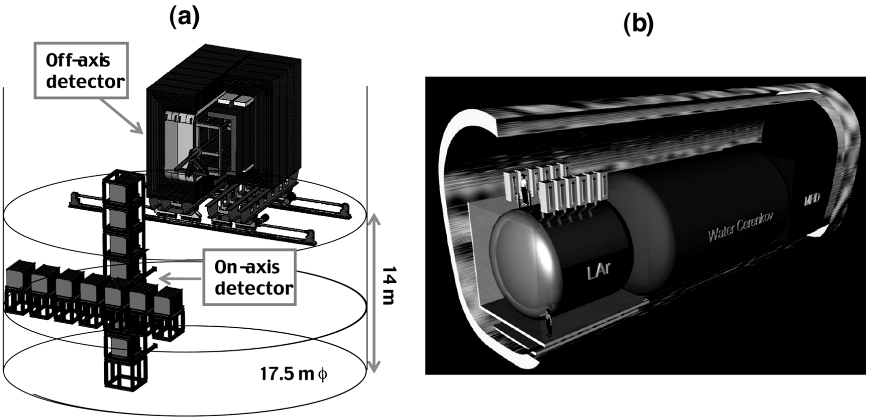

Fig. 9 (a) Schematic view of the near neutrino detectors located 280 *m* downstream from the target. (b) Near detectors at 2 *km* downstream from the target, whose LOI is submitted to the J-PARC program advisory committee.

for minimizing the reduction in the joint force, *i.e.*, heat convection between them, by temperature rise during the beam operation.

Muon monitors and neutrino detectors

A muon monitor system is placed in a pit downstream from the beam dump. Since muons are produced together with neutrinos, the profile center of the former indirectly indicates that of the latter. Although almost all the hadrons are absorbed in the beam dump, muons with momenta greater than 5 GeV/c can penetrate it. There are two independent monitors: a semi-conductor diamond detector array (13 channels) and ionization chamber tubes (7 channels × 7 tubes), covering an area of 1.5 *m* × 1.5 *m*. These monitors can provide the muon profile on a spill-by-spill basis with a precision of a few *cm*s.

We will have an experimental hall, located 280 *m* downstream from the target. It is cylindrical with an inner diameter of 17.5 *m* and depth of 33 *m*. Two independent detector systems will be installed. One is placed on the beam axis for OA2.5, and the other is placed on the off-axis, at the direction of the far detector.

The purpose of the on-axis detector is to monitor the direction and intensity of the neutrino beam. It has a grid layout, 7 units in X and 7 units in Y, where each unit comprises 10 layers of 100-*mm*-thick 1 *m* × 1 *m* iron plates sandwiched between scintillator bars. Approximately 1.5 events per spill are expected for the center unit, which can realize a resolution of few *cm* for the center of the neutrino beam.

The off-axis detector system comprises multiple detector components such as a fine-grained scintillator, π^0 detector, time projection chambers, calorimeter, and muon range detector. They are all enclosed in the UA1 magnet, which will be imported from CERN. The purpose of the detector is to measure the spectrum of the neutrino during their production. It also aims to measure the intrinsic electron neutrino contamination in the beam, and to study the electron-like background events caused by the inelastic interactions.

To predict the neutrino spectrum at the far site, it is vitally important to know near-to-far extrapolation ratio, which is dependent on the pion production on the target. The T2K/NA61 experiment will be conducted at CERN[25], which will investigate the proton and carbon thin/thick target interactions in the region of

30 to 50 GeV.

The far site detector, SK, is a water Cherenkov detector with a fiducial volume 22.5 *kt*. It has the capability to distinguish a ν_e event from a ν_μ event by using Cherenkov ring image pattern recognition. The timing information of the beam spill will be provided via the GPS, which is used for the timing cut. With OA2.5, we expect 2,200 (1,600) ν_μ (charged-current) interactions per year for the case without oscillations.

Recently, the T2K collaboration has submitted a proposal to the J-PARC Program Advisory Committee to construct an intermediate detector 2 *km* downstream from the target[26]. At this distance, almost the same neutrino energy spectrum is measured as the un-oscillated spectrum would be at the far detector. This directly verifies the prediction based on the off-axis detector at near site and T2K/NA61 experiment. The 2-*km* detector system will comprise a large cylindrical 9 $m\phi\times$ 13 *m*-long water Cherenkov detector (100 *t* fiducial volume), surrounded by a fine-grained tracking detector at upstream and a muon range detector at downstream. We also plan to replace the former with liquid Argon TPCs.

Construction and production status

The neutrino beamline has been under construction since FY2004. The central part of the DV, which crosses beneath the 3NBT line, was already constructed in FY2005. The civil construction of the primary beamline was completed in December 2006, where the installation of the normal conducting magnets is being started at the preparation section this July. Most of the SCFM doublets have been fabricated and stored at the Tokai campus. The installation will commence in January 2008.

The civil construction upstream of the DV and TS is currently underway. The parts of the huge helium vessel were transported to a port near the Tokai campus, and the installation is now in progress. Civil construction is also in progress downstream of the DV, BD, and the near detector hall, and is expected to be complete in FY2008. Many tenders are now underway to produce iron shield blocks in the TS, DV collimators, helium vessel of the beam dump area, etc.

Long-term pulse operation tests for the 1^{st} and 3^{rd} horns have been performed without encountering serious troubles. A full-scale mock-up test for the 3^{rd} horn with the support module will also be conducted this winter. The 2^{nd} horn will be produced at US, which will be transported to KEK for further tests. The 1^{st} prototype of the target will be delivered this December, and a long-term helium gas flow test will be started.

Following the success associated with the fabrication of the 1^{st} core module, all the parts of the hadron absorber units will be produced within this FY. The assembly work will gradually be started from the end of this year.

The seismic analysis and reinforcement design for the UA1 magnet are in progress. The UA1 magnet will be installed at the near detector hall in April 2008, parallel to the civil construction of the experimental hall.

By referring to the recent works[27], the off-axis angle at the SK is now determined to be 2.5° on the first day. Although it is possible to vary it between 2.0° and 2.5° in principle, significant replacement of hardware is required, such as the magnets at the downstream of the final focusing section, monitor stack, beam window, baffle and horns.

4. Summary and Future Prospects

T2K, the Tokai-to-Kamioka neutrino oscillation experiment, employs a low-energy, quasi-monochromatic off-axis neutrino super-beam, produced by a brand new beamline facility at J-PARC. The civil construction of the beamline is progressing almost on schedule, and rapid progress is being made on the production/fabrication of the equipments. We have crossed some critical milestones, such as the production of SCFM doublets, long-term operation test of horns with 320-kA pulse current, and production of a hadron absorber core module. Meanwhile, a significant amount of hardwork is required for the timely completion of the facility for beam commissioning, which is scheduled in April 2009.

After the first day, the beam power has to be improved within a few year. In the current hardware configuration of the accelerators, the nominal beam power of 270 kW (30 GeV × 9 μA) is to be achieved in FY2012. However, the intensity delivered to the neutrino beamline is less since the number of beam bunches is reduced for the fast extraction. In order to obtain the 1^{st} result with sufficient impact, we request a 100-kW operation of the MR for more than 10^7 seconds, *i.e.*, several months before the summer shutdown in FY2010. To achieve this, a preferable solution is to increase the repetition rate, which does not require hardware upgrades. The repetition cycle can be reduced from 3.04 s to 2.04 s since less acceleration/reset time is required for the 30-GeV operation.

To recover the intensity of the MR to the original value of 750 kW, significant hardware upgrade for the accelerators is required. The Possible measures are as follows:

- Linac energy recovery by installing ACS. It should be started immediately after the completion of the neutrino beamline in April 2009.
- Improvement of Ring RF cavities to achieve the high-field acceleration as designed.
- Improvement of the fast extraction kickers to achieve a nominal rise time.
- MR energy boot-up from 30 to 40(50) GeV.

What will be the possible scenario for the further intensity upgrade to 4 MW requested by the future projects such as T2K Phase-II and T2KK ? Another idea is proposed to reduce the harmonic number of the RCS booster from 2 to 1, and inject 8 pulses so that the intensity of the beam accumulated in the MR is twice that of the original.

Meanwhile, we should not forget that most of the apparatus in the neutrino beamline, target-horn system, beam window *etc.*, should be upgraded when the beam becomes stronger than 1 MW. It is also desirable to add more materials (such as a beam plug downstream of the 2^{nd} horn) inside the TS to maintain an increased safety margin for DV and BD, whose maintenance is not possible. Needless to say, severer beam control will be required to reduce irradiation.

Firstly, there is considerable scope for learning from the successful operation of the accelerators and beamline as scheduled. The apparent factor is that we are responsible for the construction of the beamline with sufficient tolerance for promoting neutrino physics in the upcoming several tens of years.

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