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JAERI/KEK Joint Project for High Intensity Proton Accelerators

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KEK (= High Energy Accelerator Research Organization) and JAERI (= Japan Atomic Energy Research Institute) are presently proposing a new accelerator complex with high-power proton accelerators. Our hope is that this project be approved officially for construction to start in JFY2001 (which begins in April, 2001). In this presentation I will review a) the project itself, b) scientific goals, and c) the present status of the project.

KEYWORDS: high-power proton accelerator project

§1. Introduction

The JAERI/KEK Joint Project is a new accelerator proposal to produce 1 MW power for proton beams. Originally, KEK (= High Energy Accelerator Research Organization) had a hadron accelerator project called the Japan Hadron Facility (JHF) which consisted of a 50 GeV proton synchrotron and a 3 GeV booster ring where the projected power of the latter was 0.6 MW. On the other hand, JAERI (= Japan Atomic Energy Research Institute) had a high-power spallation neutron source project with a proton linac, in which 3 MW pulsed beams were planned for neutron scatterings and 5 MW continuous beams were planned for nuclear transmutation. Since both projects have a common goal to attain high-power proton beams (see Fig. 1), these two projects were combined into one Joint Project.

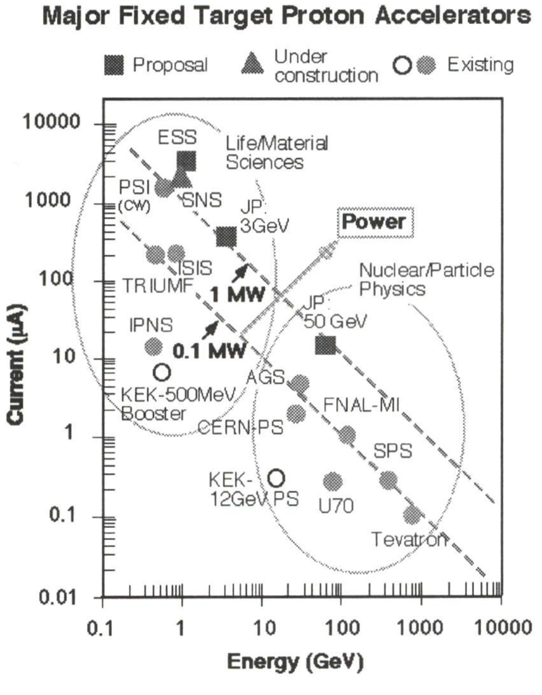

Fig. 1. Present status of proton accelerators in the world.

The project has the following components:

- 400 MeV proton linac (normal conducting) to inject beams to 3 GeV PS.
- A superconducting linac to accelerate protons from 400 MeV to 600 MeV. The 600 MeV proton beams will be used for R&D toward nuclear transmutation.
- 25 MHz 3 GeV proton synchrotron with 1 MW power. This will be used primarily for life and material sciences with neutrons and muons.
- 50 GeV proton synchrotron with slow extraction for kaon beams etc. and fast extraction for neutrino beams to SuperKamiokande.

The usage of various secondary particle beams (neutrons, mesons, antiprotons, etc.) that are produced in proton-nucleus reactions, together with daughter particles of the secondary beams such as muons and neutrinos, is the prime purpose of the project. With these secondary and successive decay particles, three major scientific goals will be attained: a) nuclear-particle physics, b) life and material sciences, and c) R&D for nuclear transformation. The accelerator complex will be constructed at the Tokai site. The present estimation of the total cost is about 189 billion yen, and the proposed construction period is six years. The configuration of the accelerator complex is illustrated in Fig. 2.

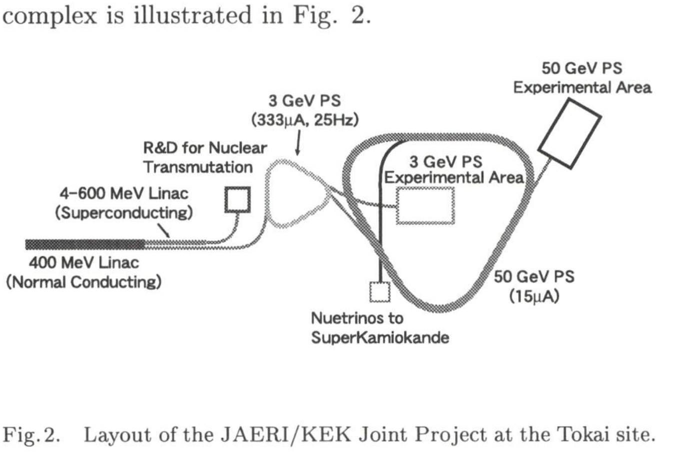

Fig. 2. Layout of the JAERI/KEK Joint Project at the Tokai site.

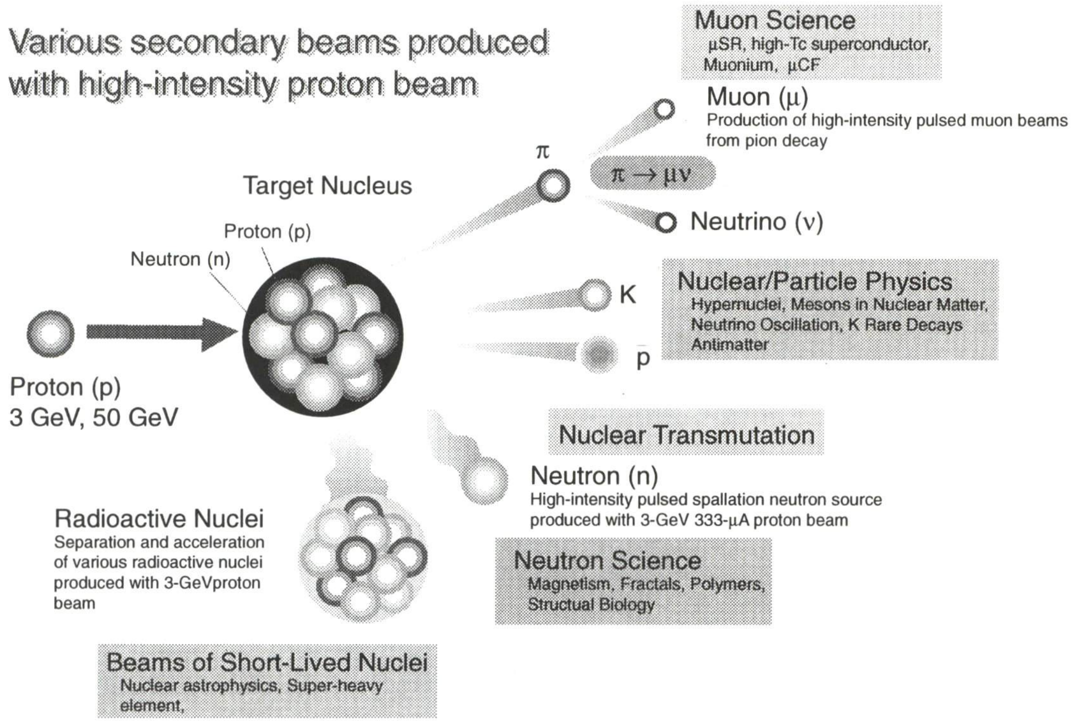

Fig. 3. Production of secondary beams and the usage of these beams.

§2. Scientific Goals

Figure 3 is a summary of sciences at the Joint Project. The atomic nucleus is made of protons and neutrons. When a low-energy proton (typically, at the energy of 1 GeV) hits the nucleus, the constituents of the nucleus will be ejected with the proton-induced spallation reaction. Typical particles are neutrons. Also, a part of the nucleus, which usually forms an unstable nucleus with respect to the β-decay, will also be emitted. Thus, neutron sciences as well as sciences with radioactive nuclei can be done with neutron- and radioactive nuclear beams, respectively. Also, in this beam energy region, a copious production of pions is expected, so that the research on sciences with low energy muons, for example, μSR or muonium science, can be conducted. At higher beam energies, typically 50 GeV, the proton-nucleus collisions will produce kaons, anti-protons, and high-energy neutrinos. The usage of these beams will open frontier nuclear/particle physics.

2.1 Nuclear and particle physics

In nuclear and particle physics one of current interests is to study the origin of the mass. Here, I explain two examples. One is related to the mass of matter. It is known that over 99% mass of the matter is carried by atomic nuclei. As described above, the nucleus is an assembly of protons and neutrons. Each proton or neutron is made of three quarks. One puzzle which has not been solved quantitatively until now is that the mass of proton (or neutron) is $\cong 1$ GeV/c^2, whereas the constituent quark mass is less than 1/100 of the proton mass. It is believed that the creation of a large proton mass is due to the symmetry breaking (called the chiral symmetry breaking), while a quantitative nature of this symmetry breaking has not been studied well. Theoretically, it is expected that the quantitative aspect of the symmetry breaking can be studied by inserting a meson (which is made of quark and anti-quark) or a baryon (which is made of three quarks) in the interior of extreme conditions and by studying the change of its mass. Inserting mesons or baryons in a hot matter, which would be created by heavy-ion reactions, is one approach. The other approach is to implant mesons or baryons in the interior of nuclear matter. At the Joint Project the latter trial will be made. In both cases, a restoration of symmetry breaking is expected theoretically, so that the the mass of meson or baryon would be reduced in these extreme conditions.

The other is related to the mass of neutrino. From the most fundamental principle there are no reasons to prohibit from having a mass for a neutrino, although it has been believed for many years that the neutrino has zero masses. In a recent experiment at SuperKamiokande, it was demonstrated that muon neutrinos (ν_μ) from the sky (which is called the atmospheric neutrinos) might be converted to another type of neutrinos called tau neutrinos (ν_τ) while traversing through the Earth. This phenomenon is called the neutrino oscillation and it can occur only when the neutrino carries a mass. In order to pin down this observation at the SuperKamiokande, it is planned at the Joint Project to produce ν_μ beams from the 50 GeV accelerators and to measure the ν_μ flux both at the immediate exit of the accelerator and at the site of SuperKamiokande which is located at a distance of 300 km from the Tokai city. This type of experiment is already conducted at KEK by having ν_μ beams from the 12 GeV PS. Our Joint Project, however, can produce high-flux neutrino beams with intensity of more than 100 times of the flux for which the present KEK facility can provide. Thus, a high accuracy experiment on the origin

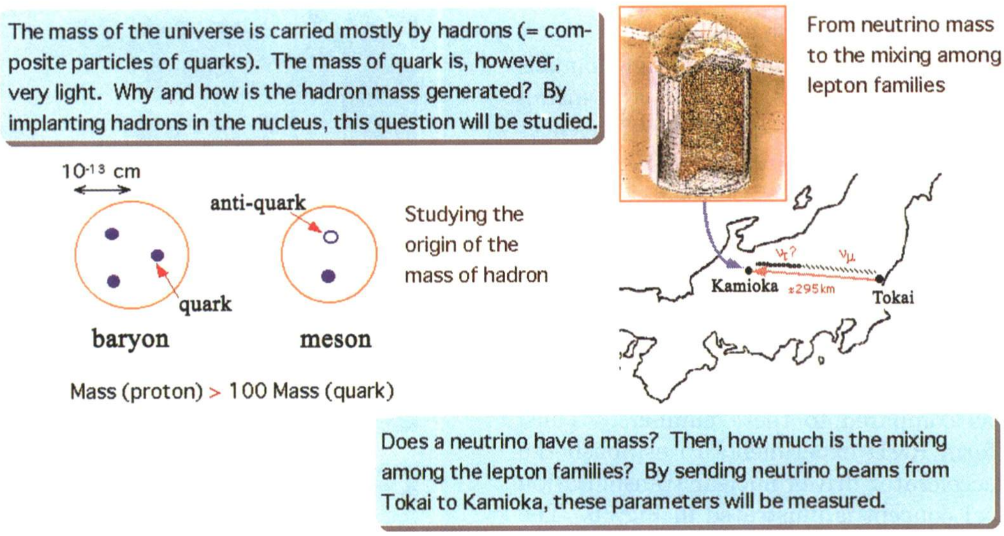

Fig. 4. Examples of nuclear and particle sciences at the Joint Project.

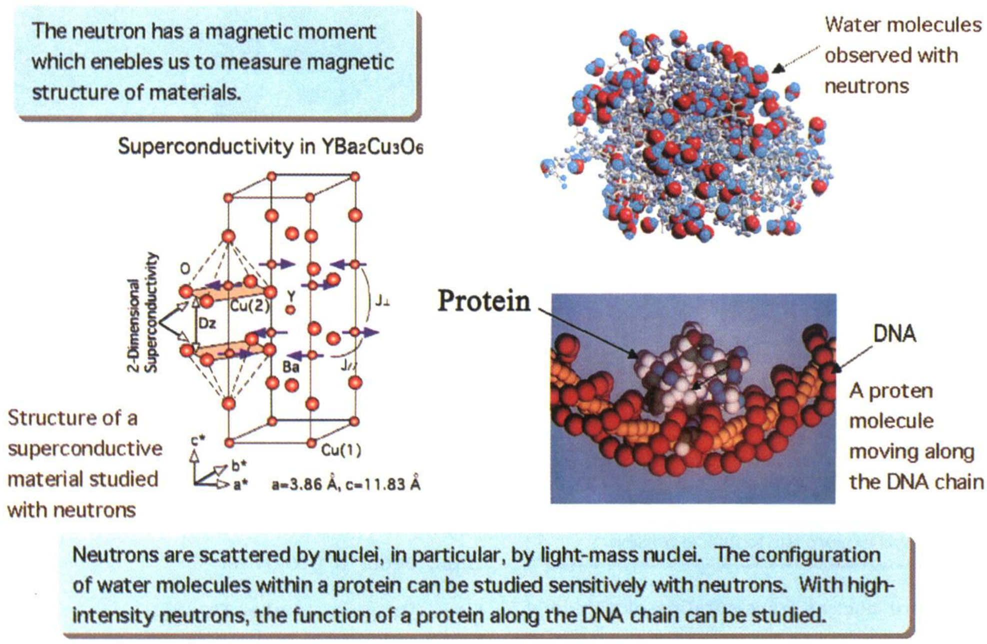

Fig. 5. Examples of life and material sciences at the Joint Project.

of the neutrino mass can be done at the Joint Project.

2.2 Life and material sciences

In life and material sciences the neutron beams are very important and useful. The neutron carries two unique features. One is that the neutron does not have any electric changes and it has a mass which is close to the proton mass. Thus, neutrons are scattered by atomic nuclei, in particular, by light-mass nuclei (nuclei with small atomic numbers, Z). This feature is unique if one compares neutrons with synchrotron X-rays. X-rays are scattered by electrons, so that X-rays observe atoms with large atomic numbers. An example of the protein structure determined by neutron scatterings is shown in Fig. 5. Walter molecules (H_2O) which are made of small-Z atoms are clearly seen by neutron scatterings. In the future, the movement of a protein molecule along the DNA chain can be studied with high-flux neutron beams, since it is believed that water molecules play an important role for the movement of the protein along the DNA chain. The Joint Project will allow experiments toward the study of dynamical structure of protein molecules.

The other unique feature of the neutron is that it carries a magnetic moment. The neutron is the microscopic magnet. Thus, magnetic scatterings of neutrons will reveal the microscopic magnetic structure of the material. Figure 5 shows one example. A typical high-T_C superconducting material, $YBa_2Cu_3O_6$ has an antiferromagnetic structure and this magnetic structure was determined by a neutron scattering experiment. Recently, fluctuations of macroscopic magnetic layers have also been discovered by neutron scatterings. Magnetic structures and their fluctuations will provide us with a deep insight of the superconducting mechanisms. Basic studies of superconducting materials are also useful towards the development of the applications of high-T_C

superconducting materials for industries.

The Joint Project will prepare over 30 beam channels for neutron sciences. Also, the Project plans to install powerful muon lines for the life and material sciences with muon beams.

2.3 R&D toward nuclear transmutation

The third goal of the Joint Project is to reduce long-lived radioactivities produced in nuclear fuel plants. It is believed that the proton power required for the real industrial treatment of nuclear waste transmutation is on the order of 20-50 MW. Our Joint Project has a much smaller power as compared to these numbers. Thus, we plan to perform R&D experiments to establish the concept of the accelerator driven nuclear transmutation (ADT). The ideal concept is illustrated in Fig. 6. The present Project will give an answer if the scheme shown in this figure is realistic. Many different mechanical tests together with data taking of nuclear reactions under various critical conditions will be performed.

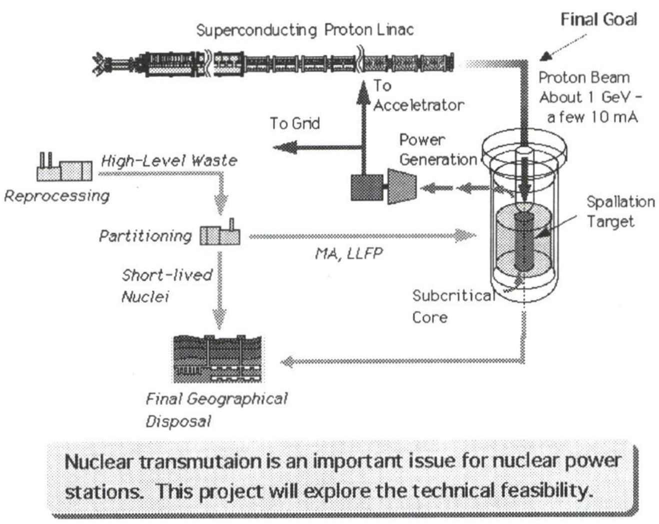

Fig.6. R&D studies toward nuclear transmutation at the Joint Project.

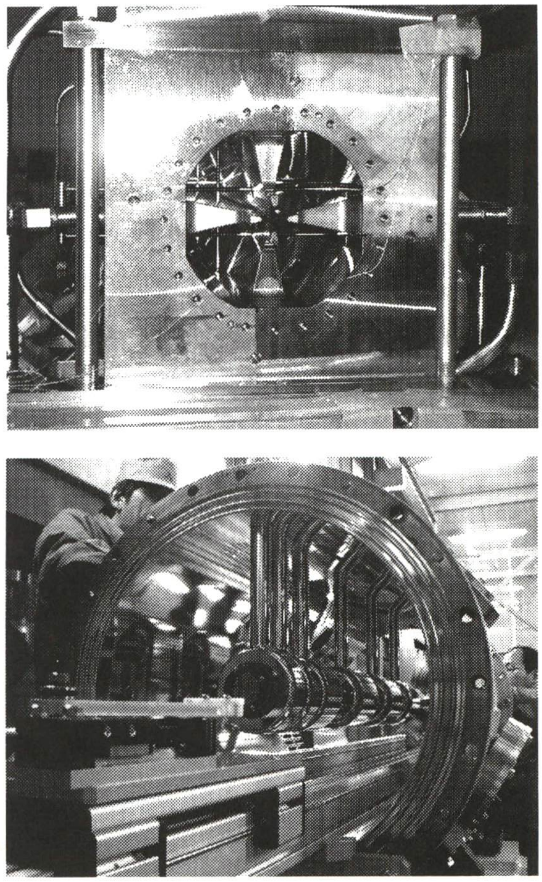

Fig.7. RFQ with π-mode stabilizing loop (top) and DTL with quadrupole magnets imbedded (bottom).

§3. Accelerator Development

Efforts on accelerator design and construction are in progress. The present accelerators have many unique features. For example, design for synchrotron magnets was performed so as to have no transition energies in the ring. A novel idea of the RF cavity with a high voltage gradient up to 50 kV/m was already attained by using a specific magnetic alloy. For the linac, an injector part (up to 60 MeV) of the high current linac is presently under construction at KEK. For example, the prototype RFQ linac is now completed, as shown in Fig. 7, and its beam commissioning will start soon in the fall of 2000. A unique idea of the π-mode stabilizing loop (PISL), which is one of the devices invented at KEK to stabilize the fields in an RFQ, allows acceleration energy above 3 MeV with frequency range from 300 to 400 MHz. Also, a new drift-tube linac (DTL), which is shown in Fig. 7, was constructed. It has newly-developed coils for the electro-quadrupole magnets, in order to drastically improve a packing factor. A full RF power of 3 MW has already been achieved with a full rating of 3 percent (600 ms and 50 Hz).

The accelerator development and construction have, thus, been in progress.

§4. Status of the Project

A joint effort between KEK and JAERI for one proton facility in Japan was started two years ago. Half a year later, in March of 1999, two institutions officially agreed to promote this project together, and a formal MoU (Memorandum of Understanding) between KEK and JAERI was signed by the directors of these two institutions. Subsequently, a booklet of a Joint Proposal was published, and the project was reviewed in April of 1999, by an International Committee which was chaired by Yanglai Cho (ANL). This Committee strongly endorsed the Joint Proposal.

According to a new law in Japan, which was established very recently, any big scientific projects must pass a third-party review committee organized by the Government. Here, the third-party committee must include a broad body of people; professional scientists (physicists, chemists, biologists, etc.), institutional administrators, journalists, economists, company presidents, etc. Clearly, the Joint Project is a big project, so that this project was assigned as a first example for the third-party review. The committee members were assigned in the late fall of 1999 and they discussed the project until August of 2000. According to the review document, the committee endorsed strongly this Joint Project. It emphasizes how important the project is for the world sciences as well as for the Japanese sciences and technologies. On the other hand, the committee recommended also that we must set priorities among various components of the project, since the present Joint Project contains many different elements and the cost is high.

The project team re-evaluated the project accordingly. First, the project team discussed and agreed with the Government that the entire facility must be constructed eventually within ten years, while the project team also agreed with the Government in setting priorities. Presently, we set the first priority on the construction and completion of the accelerators (both 3 GeV at 1 MW and 50 GeV), whereas some of the experimental facilities can be funded during an elongated period.

Presently, both STA (Science and Technology Agency which supports JAERI) and Monbu-sho (the Agency which supports KEK) are fully convinced to proceed this Joint Project into a real funding process. Both agencies have worked very hard during the summer of 2000 on the finances of the project. Even today, they are working very hard to create an wisdom of how to create as much budget as possible for the project. The final decision at the Agency of Finances (if the project is officially approved or not) shall be made at the end of December of 2000.

We are also in the process of discussing the present project with the Local Governments (both Ibaraki Prefecture and Tokai Village) as well. In Tokai Village, an official committee was created to review the project. This village is enthusiastic about the project. Also, the Ibaraki Prefecture, the local unit which contains both Tokai (where JAERI is located) and Tsukuba (where KEK is located), decided to support officially the promotion of the project. Those local movements are important for the project.

Clearly, many scientific communities support strongly this Joint Project. We thus hope that our project be approved officially for construction to start in JFY2001.

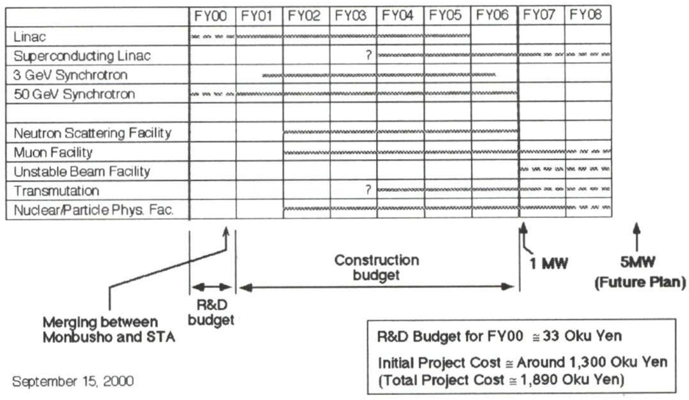

Fig. 8. Proposed schedule of the Joint Project.

Acknowledgements

The project team has many people who are working day and night, even in the weekends and holidays. I would like to thank all the members of the Project Team. Also, I would like to send my sincere thanks to all administrative members at JAERI and KEK for their strong support to the project.