IPMU Interview

with Masatoshi Koshiba

Interviewer: Kunio Inoue

Making every effort to win the competition

Inoue: Professor Koshiba, you started neutrino research using Kamiokande, from which subsequently the Super-Kamiokande and KamLAND, and then K2K and T2K experiments evolved. I think that Japan now takes a leading role in the world in the field of neutrino research. I would like to hear about how you started the neutrino research using Kamiokande, and how Kamiokande was able to achieve such developments.

Koshiba: These are difficult questions, and not easy to answer. Kamiokande was initially designed for the purpose of searching for proton decays. But when our proposal was about to be accepted by the Monbusho (Ministry of Education, Science, and Culture) the IMB project in the US suddenly emerged. It had a much larger budget, much larger water volume, and PMTs (photomultiplier tubes) of comparable photon sensitivity to ours. I thought that we would lose the competition, and spending tax payers' money on an experiment which we were bound to lose would not be justified. My conclusion, after careful thinking, was that I would not even try to request more money, but rather improve the sensitivity of each PMT by orders of magnitude.

I approached the president of Hamamatsu Television (now Hamamatsu Photonics). I had known him for the previous 10 years or so because my group was developing new PMTs for an electron-positron collider experiment in Germany. Through this experience, I knew that the company would be willing to become involved in new developments. I tried to talk him into the idea of developing a large 20" diameter PMT. He was hesitant at first. The chief engineer accompanying him was opposed to the idea, saying, "That's out of the question, sir!"

Masatoshi Koshiba is Honorary Professor Emeritus of the University of Tokyo. He was awarded the 2002 Nobel Prize in Physics jointly with Raymond Davis Jr. for pioneering contributions to astrophysics, in particular, the detection of cosmic neutrinos. Among many other distinguished awards he received, particularly noteworthy was the 1997 Order of Cultural Merit conferred by The Emperor of Japan in person.

It took more than three hours to persuade him to go ahead. I assigned Teruhiro Suda, Atsuto Suzuki, and Katsushi Arisaka [★1], from my group for the project. Subsequent development went well and we got good PMTs. It was the spring of 1983.

We immediately began installation of those PMTs, and more or less completed the work by August. Then we filled the water tank and started to take data from September. We found the data to be of unexpectedly good quality. In other words, we could see a beautiful energy spectrum of decay electrons from muons which entered the 3,000-ton water tank and stopped. We could clearly see the spectrum down to as low as 12 MeV. Below that, however, the background increased drastically and buried the signal completely.

★1: At that time the late Professor Teruhiro Suda, Kobe University, was an associate professor at ICRR, the University of Tokyo; Professor Atsuto Suzuki, now Director General of KEK, was an assistant professor at the University of Tokyo; and Professor Katsushi Arisaka, UCLA, was a graduate student of the University of Tokyo.

Our experiment would have been like buying a lottery using tax payer's money if it had only searched for proton decay, as I said earlier. So I thought, since we could see these low-energy electrons cleanly, we should try to reduce the background by orders of magnitude and try to see electrons below 10 MeV cleanly. If we could achieve that, we would be able to measure electrons scattered by solar neutrinos. This way we ought to have been able to make real-time observations of the arrival time, incoming direction, and energy spectrum of solar neutrinos.

Giving chances to capable young people

But, after a simple calculation, it was obvious that we could have collected at most only one event per week, even if we had 1,000-ton fiducial mass.

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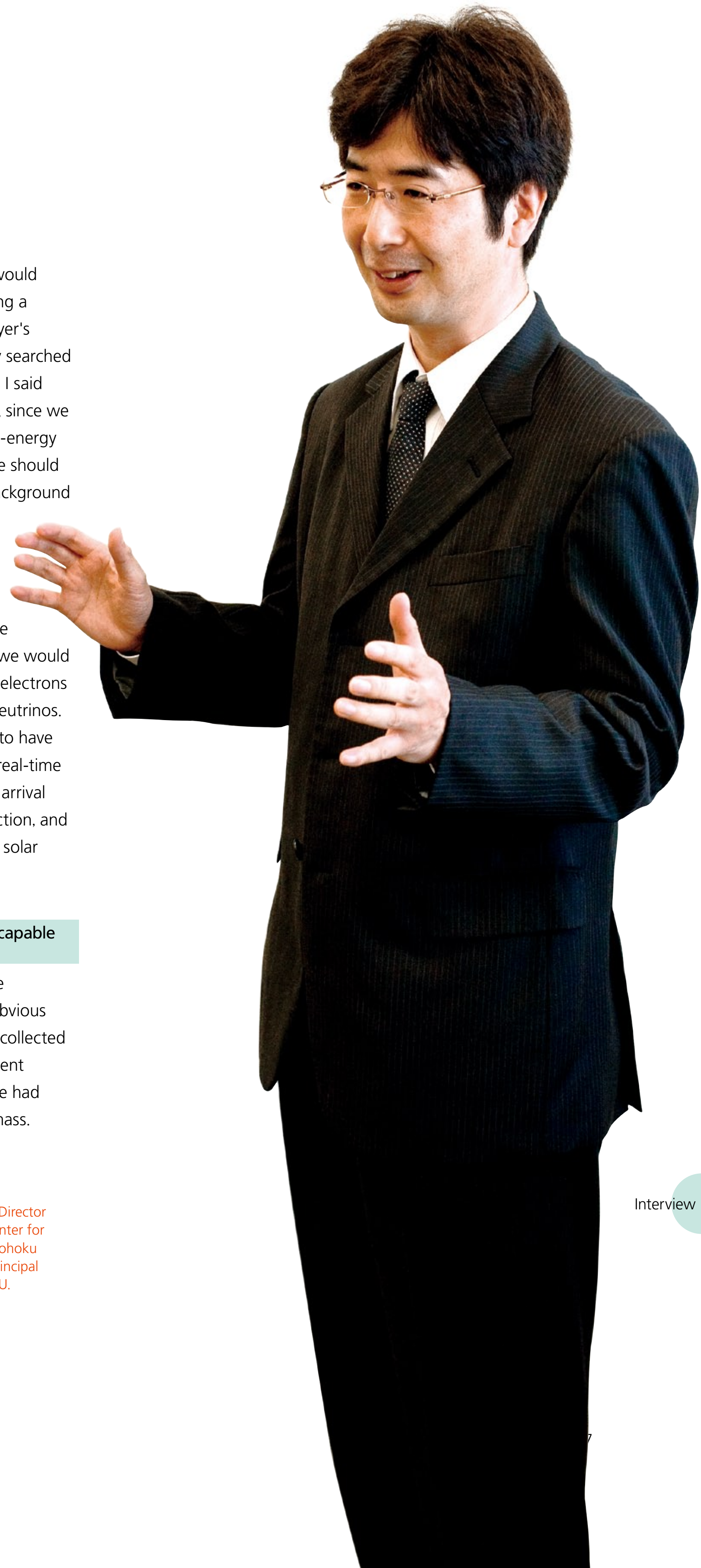


The question was, could we further reduce the background of several events per second. This required purification of the water. So I appointed Atsuto Suzuki to take charge of a project to produce "the cleanest water in the world". I was pleasantly surprised when he, completely new to this business, made numerous investigations and succeeded in producing the cleanest water in the world in less than a year.

I am often invited to lecture at business executives' meetings in Japan. I mention that you should boldly appoint capable people to responsible positions, even if you think they may be too young. Such people are sure to make great progress. I tell them that I have seen several such cases in the Kamiokande experiment, and one was the case of Atsuto Suzuki.

One of the key elements for the success of Kamiokande was that I seldom said "do that" or "do this" to the young members of my group. I tried to create a situation where each member understood what they had to do. I think this is an important point for making progress in a project.

Inoue: Do you think a secret key to Kamiokande's success was giving chances to young people and letting them having big responsibilities?

Koshiba: I think so. The other thing was choosing the name "Kamiokande." Earlier proton decay and solar neutrino experiments were low-profile work, but had to continue for many years. Therefore, it was important to attract the local people's attention to the project in order for it to operate smoothly. So, I took "Kamioka" as the first part of the experiment name hoping that people would feel closer to the project. Then, I added "NDE" as an acronym for "Nucleon Decay Experiment".

As you know, since Kamiokande had been producing physics results, mostly concerning neutrinos, people worldwide tend to think "NDE" stands for "Neutrino Detection Experiment". I don't mind. Either way is OK with me.

Toward solar neutrino observations

Anyway, we needed more money. In order to detect solar neutrinos using this method, we had to select one event or so per week out of the background. We had to reduce the background by orders of magnitude.

To do this, we first had to install an anti-counter having 4π solid-angle coverage and capable of surrounding the entire detector. The other thing we needed was upgraded electronics. At that time, lack of money meant that we had only digitizers to record signal pulse height (ADCs). We had to have digitizers capable of recording signal timing (TDCs) to make more precise measurements. These upgrades required money, but it was not realistic to request additional funding from the Monbusho. We had to look around for other sources of money.

Also at that time, there were quite a few objections to the upgrade plan amongst the collaborators, although the group was still small.

Inoue: Were the objections from within the group?

Koshiba: Yes, from within the group. If we wanted to detect solar neutrinos, we had to install a 4π anti-counter, as I told you. To do this, we had to remove the PMTs in the bottom part of the detector, which we had worked so hard to install, and had to re-install them at a higher level. We had to waste a lot of time and lose a significant part of the fiducial mass. This meant a loss of the fiducial mass for a proton decay search, so the objections were rather strong.

But I made a decision to go ahead as a group leader. Now I had to look around for the sources for TDCs and the funds for installing the anti-counter. About three months later, in January 1984, an international conference on baryon number non-conservation, called "ICOBAN", was held in Park City, Utah. I attended this conference and presented the preliminary results from Kamiokande, and at the same time presented two proposals.

First I explained that we could make a clean detection of electrons down to as low as 10 MeV because of new PMTs with high sensitivity. I continued to explain that we wanted to pursue the possibility of an astronomical observation of solar neutrinos by observing electrons. My first proposal was to invite collaborators who could bring TDCs, associated electronics, and some other resources. Mann [★2] and his group from University of Pennsylvania responded to this proposal and said they wanted to take part.

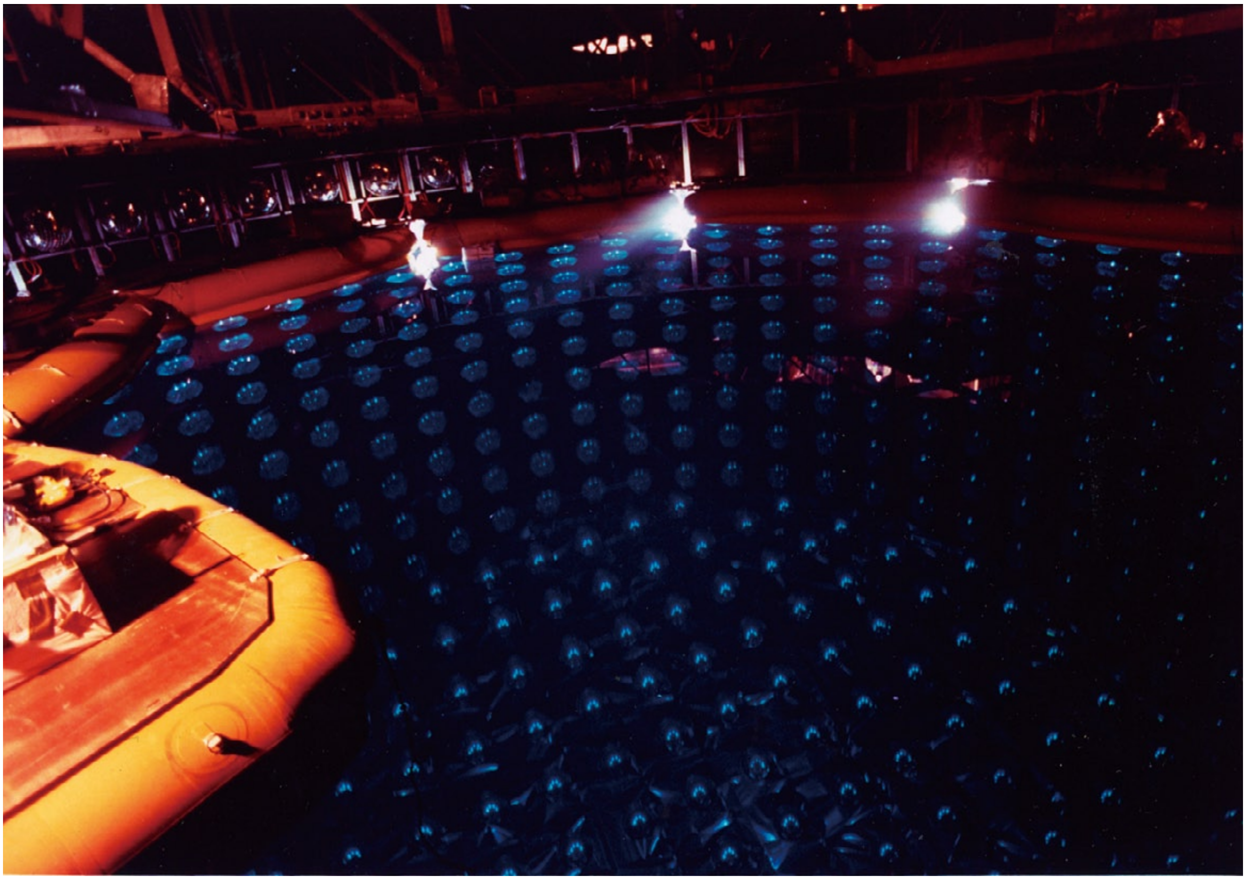
I stressed that this was just to show feasibility because even if we succeeded in making astrophysical observations of solar neutrinos with Kamiokande, the facility was not big enough. To go beyond the feasibility experiment and into real observation of solar neutrinos with this method, a considerably bigger detector would be needed. So my second proposal was to invite collaborators to build Super-Kamiokande, containing 50,000-tons of water.

Supernova neutrinos detected!

Inoue: I'm impressed that you had a master plan from very early on.

Koshiba: Yes, it was January 1984. But, there was no response to the second proposal. I made these two proposals in the first week

★2: Alfred Mann, now Professor Emeritus at University of Pennsylvania, was a professor there at the time.



Inside Kamiokande. The detector was located 1,000m underground in the Kamioka Mine. The cylindrical detector tank, 15.6m in diameter and 16m in height, contained 3,000 tons of pure water. The interactions of elementary particles inside the detector were observed by 948 photomultipliers with a diameter of 50cm, the largest in the world. Kamiokande's observations ceased in 1995 as the construction of Super-Kamiokande approached completion. Later, KamLAND was constructed at the former Kamiokande's site. (©ICRR)

of January 1984. Mann and his group came to Japan in February and visited Kamioka. They made it clear that they wanted to work together. They would provide 1,000 channels of TDCs and a new computer. We managed to get some money to build the 4π anti-counter with the bottom PMTs re-installed at an upper level, and to further purify the water.

As you know, the Kamioka mine produced heavy elements, so there is plenty of radioactive radon gas in the mine tunnel. Its concentration is roughly ten times higher compared to other tunnels. Radon gas easily dissolves in water. Since we had to supply cold underground water to prevent a temperature rise, radon caused more and more background.

In order to cope with this problem, we tried several methods, such as storing the water in a buffer tank for some period, or further improving the filtering system developed by Atsuto Suzuki. We reached a point where we reduced the background to a manageable level for starting the solar neutrino observation in January 1987. In early January, the radon peak finally disappeared, and we were set to embark on the neutrino data-taking. Within two months I began to receive frequent phone calls from many different places, saying that a supernova had occurred in the southern sky. They wanted to know if we had seen a signal of the neutrino pulses that should have been produced when the supernova explosion was triggered. I called the Kamiokande site and told the person on duty to send the magnetic tapes to the University of Tokyo right away. When we analyzed the tapes in our computer, we found the signal.

Inoue: That is a fascinating story. Did you have a plan to detect solar neutrinos from the beginning of the Kamiokande-I proton decay experiment?

Koshiba: You probably don't know this. I was determined to show at the Utah conference in January 1984 that we could detect solar neutrinos using this method. Also, in the budget request for 1985, which was submitted in spring 1984, I attached a small pamphlet explaining that a certain number of neutrinos could be detected if a supernova explosion were to occur in our galaxy, in addition to detecting solar neutrinos using the method I just described. The pamphlet also mentioned the possibility of detecting neutrino oscillation.

Inoue: I see. You had tremendous foresight.

Koshiba: Well, I was having a variety of discussions with people around me those days. So these ideas may not necessarily have been my own. But new possibilities appear when we really think hard about what we can do with what we have.

Inoue: With whom did you have these discussions? Your collaborators or people from wider fields?

Koshiba: I retired from the University of Tokyo in March 1987. In those days, namely between 1984 and 1987, Yoji Totsuka had already joined my group, and Teruhiro Suda and Jiro Arafune were participating in many workshops at ICRR [★3].

★3: Yoji Totsuka, Honorary Professor Emeritus of the University of Tokyo, was an associate professor at that time, and Jiro Arafune, Professor Emeritus of ICRR, the University of Tokyo, was a professor.

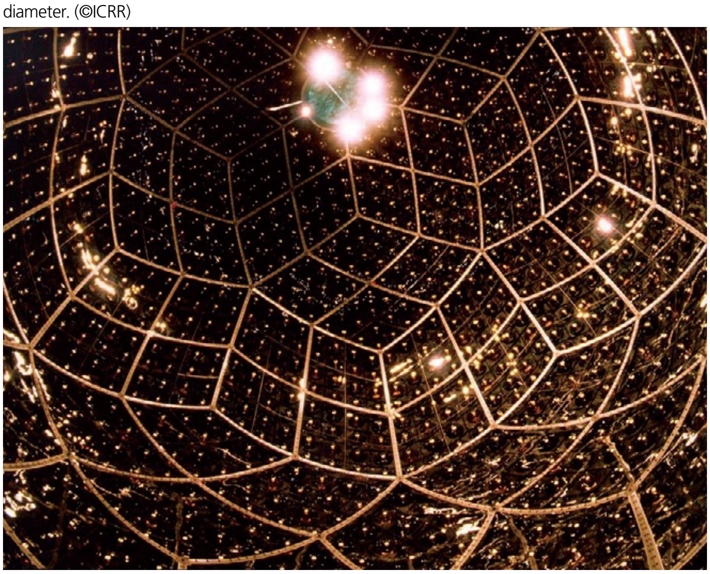
Future of neutrino physics

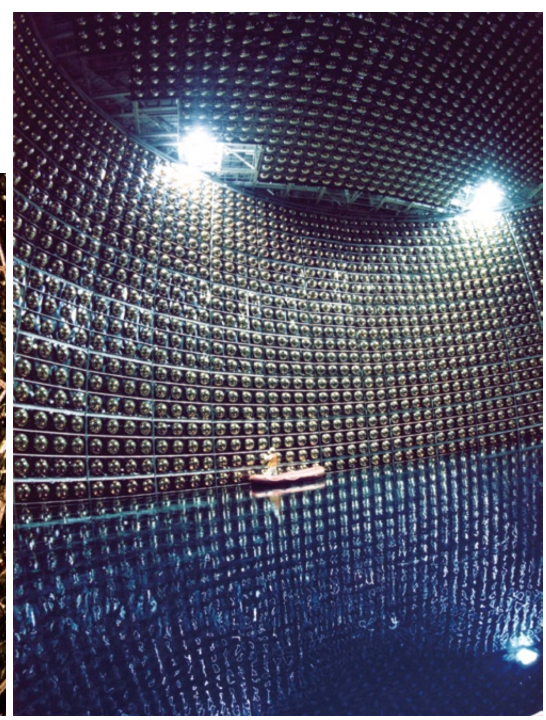
Inoue: It's interesting to hear that discussion was taking place in those places. After your pioneering work on neutrino astronomy, Super-Kamiokande measured solar neutrinos with impressively high precision, and KamLAND detected geoneutrinos. Although in a slightly different direction, we now have neutrino experiments in the South Pole and undersea. What's your opinion about close ties with other fields in neutrino research. I guess there are merits in it.

Koshiba: Neutrino research was the least developed branch of particle physics experiments over the past few decades. The main reason is that among elementary particles, neutrinos are the only ones that do not carry an electric charge. Particles with an electric charge are easy to detect. But we have to let those without an electric charge interact in matter and convert into charged particles in order to observe them. This is a difficult process.

It was only recently that the neutrino mass, which was believed to be zero, was found not to be zero, as you well know. I think neutrino physics has entered a new era, but there are still many things we don't know about neutrinos. We don't know θ_{13} among the oscillation parameters. We

Left: Inside KamLAND. The inner surface of the spherical 18-m diameter detector tank is fitted with 1,897 giant photomultipliers. This photo shows the upper part of the detector, viewed from the bottom. At the center of the tank is located a 13-m diameter transparent balloon filled with 1,000 tons of liquid scintillator. (It was not yet installed when this photo was taken.) (©RCNS)
Right: Inside Super-Kamiokande. The inner surface of the cylindrical detector tank, which contains 50,000 tons of pure water, is fitted with 11,146 photomultipliers measuring 50cm in diameter. (©ICRR)





don't know the CP violation parameter, either. We might find out more regarding why only matter remained after the Big Bang and all of the anti-matter disappeared, by knowing these parameters.

I want to stress that we must have a clear understanding of neutrino oscillation in order to understand the observed results in neutrino astrophysics. This is clear from the case of solar neutrinos.

As you know, COBE observed microwaves in the universe and obtained information about the universe of 370,000 years after the Big Bang. The same thing can be done with the background neutrinos if we can ever detect them.

But how to detect them is really a difficult problem. For the past several years I have been approaching theorists whom I respect with an idea that neutrinos with such low energy would go through total reflection. I have asked various people about this possibility, which is still based on my own intuition. I first asked Yoichiro Nambu, who sent me a two-page response, saying "it might be correct". But his two-page note was too difficult for me to understand, so I wrote to Gyo Takeda in Sendai asking for an explanation [★4]. He responded, saying that Yoichiro Nambu's answer was "more or less correct." I asked him again to study it more seriously.

Professors Takeda and Arafune have been working hard on this problem recently, and finalized their results into an article. This phenomenon is not as simple as electromagnetic waves, because three different neutrinos oscillate among them. So compared with the equations corresponding to the electromagnetic wave passing through matter, they become diffusion equations that are an order of magnitude more difficult. It is indeed a very difficult problem. They think, however, they have made enough progress so they will publish their article as an ICEPP preprint.

Super-Kamiokande should continue reliable data-taking

Inoue: I have a final question. IPMU is pursuing projects at Super-Kamiokande and KamLAND. Super-Kamiokande will try to measure θ_{13} and the CP violation parameter, which you mentioned earlier, in T2K. It is also preparing for the detection of relic supernova neutrinos (neutrinos from past supernova explosions) by adding gadolinium to the water. KamLAND will try to detect neutrinos from the solar CNO cycle. Also, it aims to observe double beta decay by adding xenon to liquid scintillator. In future, what do you want to see from these two experiments or from neutrino research in general?

Koshiba: It will be exciting if one could catch even a hint of relic neutrinos.

Inoue: Oh, you mean 1.9K relic neutrinos originating from the Big Bang.

Koshiba: Yes. But it will be very, very difficult. So people should not start haphazardly, or they may waste a few decades.

I want to add one thing in particular, which I said recently to Takaaki Kajita, who has just become the Director of ICRR [★5]. Super-Kamiokande started full operation with all PMTs installed. You can now continue data-taking for quite some time. You should continue further solar neutrino observation seriously. Besides that, the data from Super-Kamiokande will play an essentially important role should a supernova explosion occur in our galaxy. There is no other detector in the world of comparable capability.

Inoue: I agree with you.

Koshiba: So it is very important. You must continue reliable data-taking so that you can be ready for a supernova explosion to occur at any time. This is one point.

The other point which I want to stress is not to forget the very original aim of the experiment, proton decay. Super-Kamiokande can pin down the signals, not only those predicted by Glashow's SU(5) theory, but those from several other decay processes. You should pin down the lower limits of partial life for all possible decay modes studied from the Super-Kamiokande data, and make them public. How about doing this by the end of the year?

Inoue: Do you have anything you want to see from KamLAND?

Koshiba: I think Atsuto Suzuki has done an excellent job in nurturing that facility. I often mention, when asked to give lectures, that it was KamLAND that made it possible to catch anti-electron neutrinos from the isotopes inside the earth. If one can utilize this technique and continue measurements for a few years with several of the similar detectors across the world, one can conduct earth tomography, with all the data of the places and the quantities of the materials. This would be a revolutionary occurrence in the field of geophysics.

I think it is important to carry on this project as a worldwide project. I try to convince audiences about this whenever I give lectures. For example, people in Hawaii want to do it, and I hear the SNO group is also interested. There is a movement in Europe as well. I did not seriously think about the possibility of anti-electron neutrino detection. Atsuto Suzuki brought this idea to reality by building KamLAND. That was a very good thing.

Inoue: Thank you for your time today.

★4: Yoichiro Nambu is Distinguished Service Professor Emeritus of the University of Chicago. Gyo Takeda is Professor Emeritus of Tohoku University.

★5: Takaaki Kajita is the Director of the Institute for Cosmic Ray Research, the University of Tokyo (since April 2008). He is also a principal investigator of IPMU.