TEXONO/98-03
February 24, 1998

A Pilot Experiment With Reactor Neutrino in Taiwan : Challenges in Atomic and Nuclear Sciences [1]

Prepared by

the Academia Sinica

on behalf of

the TEXONO [2] Collaboration

Abstract

A Collaboration comprising Taiwan and mainland Chinese scientists has been built up since 1996 to initiate and pursue an experimental program in neutrino and astro-particle physics in Taiwan. A pilot experiment to be performed at the Nuclear Power Station II in Taiwan is now under intense preparation. Some of the techniques involved in the design and construction of the experiment have more general applications in the atomic and nuclear sciences. The experience in the design, construction and operation of the experiment will enhance the vigour and versatility of the fields. This short summary serves as a supporting document for our funding request to the National Science Council/Atomic Energy Council Grant.

[1] Funding Request to the National Science Council/Atomic Energy Council Grant
[2] Taiwan EXperiment On reactor NeutrinO

1 Introduction

In 1996, under the initiation of the Academia Sinica, a Collaboration was built up to pursue the goal of performing a world-standard particle physics experiment in Taiwan. A proposal of doing a pilot experiment with the power reactor was submitted and subsequently approved by the National Science Council under the contracts NSC 86-2811-M-001-001R- and NSC 87-2112-M-001-034.

The principal objectives of the Neutrino Collaboration are to initiate a program in experimental neutrino physics and astro-particle physics in Taiwan, as well as to build up a qualified experimental team for future projects. A good local research program is complementary to the participation of international projects elsewhere, and is essential to the solid foundation of international collaborative basic research in the country. As the field grows and matures, the community has to acquire the experience of conceiving, formulating, fighting for, and then implementing and coordinating a big project (that is, the experience of being responsible to "generate an experiment and make it work" in its totality). A local program also serves as a base for training young students and scientists, as well as promoting the discipline of large-scale basic research to the public. It will also be a necessary "launch pad" for more ambitious projects beyond.

The Neutrino Collaboration (TEXONO) has been growing steadily since its foundation. Our plans and visions have been well received by local students and scientists. Students find our program attractive since it can be done at home and they can have more thorough and balanced exposure to the wide spectrum of techniques deployed in a big modern particle physics experiment. Local scientists, especially those from the existing nuclear physics and nuclear engineering community, appreciate the inter-disciplinary approach of the Project. They contribute tremendously with their expertise and infrastructures, while finding the new ingredients (for instance, large-scale detector systems, modern electronics applications, modern software practices, collaboration in a big and diversified group ... etc.) beneficial to their own research program. In a positive sense, the Neutrino Project serves as a means where Taiwan can build up an experimental high energy/particle physics foundation based on the existing nuclear physics experience and resources, while the nuclear and atomic scientists can be exposed to the the technical and organizational sophistications on how to conduct big international collaborative research efforts thereby enhancing the vigour of their program. Students and young scientists being trained in the process would eventually have the board and balanced exposure to enable them contribute further to both fields as their careers proceed.

By early 1998, there are more than 40 collaborators with the diversified expertise (as shown in Table 2 in the Status Report enclosed) from Taiwan, mainland China and the United States. Besides being the first "high-energy-physics-style" experiment to be performed in Taiwan where local scientists are taking the major and defining role, this is also one of the first collaborative efforts in basic research among Taiwanese and mainland Chinese physicists. Tremendous pioneering spirits are involved in launching and realizing such an experiment. Our efforts are not only about "doing basic science", and also about the "foundation" and "development" of it.

The "pilot" efforts will be to perform an experiment with a 600 kg CsI(Tl) crystal scintillator at a site of about 30 m from the reactor core at the Nuclear Power Plant II at Kuo-Sheng. Over a longer time-frame, the Collaboration will conduct a feasibility study on an ultimate full scale long baseline neutrino oscillation experiment using the reactor neutrinos.

2 Participation of the Nuclear Sciences Community in Taiwan

The pilot experiment focuses on neutrinos from the power reactors and hence is essentially an experiment at the MeV scale. It involves a lot of atomic and nuclear physics and engineering issues which the nuclear sciences community is at a very appropiate position to contribute.

Approval of using the site and infrastructure support at the Nuclear Power Station II has been officially granted by the Taiwan Power Company. The Collaboration is also allowed access to the reactor operation data - the essential inputs for the derivation of the neutrino spectrum and flux. Two sites has been selected where the pilot experiment will be performed, as depicted in Figures 1 and 2, and background measurements have been made near the sites. Technical support will be provided during detector installation.

The Nuclear Engineering, Atomic Sciences and Health Physics departments of the National Tsing Hua University are involved so far in : (a) the measurements of trace radiopurity of experimental components with low background germanium detectors, (b) monitoring of the experimental sites with Thermoluminescent Dosimeters (TLD), (c) background studies with the neutron transport MCNP software packages, and (d) provision of a thermal neutron beam from their research reactor for test beam measurements.

The Physics and Engineering groups from the Institute of Nuclear Research play a major role in : (a) the engineering design of the shieldings for the pilot experiment, (b) the measurements of trace radiopurity of experimental components with the neutron activation techniques and with low background germanium detectors, (c) R&D program towards the production of B_4C plates from powder with the plasma combustion technology.

In addition, the China Institute of Atomic Energy is also a collaborating institute. They will provide engineering support and have the facilities for performing accelerated mass spectroscopy for measuring trace compositions.

The nuclear science aspects are further elaborated in Section 4.

3 Related Documents

This brief summary is written specifically for the National Science Council/Atomic Energy Council funding request. Enclosed with it are a few documents describing in further details the field of neutrino physics, and the Taiwan Neutrino Project:

1. "A Pilot Experiment with Reactor Neutrino in Taiwan : A Status Report for the National Science Council" - a status report written in January 1998 giving an more detailed overview of the planned pilot experiment, its pioneering spirits, physics motivations and experimental approach.

2. Official Letter from Taiwan Power Company approving us to use the site of the Nuclear Power Station II to conduct the experiment.

3. Official Letter from Taiwan Power Company approving us to use the reactor operation data to evaluate the reactor neutrino spectra.

4. "The Starting Up of a Neutrino Project in Taiwan" - our contributions to two international conference proceedings in 1997.

5. "Neutrino Physics : An Overview" (in Chinese) - a popular article written for non-experts published in "National Science Newsletter" and "Physics Bi-Monthly Magazine" in 1997.

6. "Massive Neutrinos as Dark Matter ?? An Overview of Experiments" - an review of experimental status world-wide with focus on the role of neutrinos in cosmology, to be published in an Astronomy conference proceedings.

4 Nuclear Science Aspects of the Pilot Experiment

Since the pilot experiment will be performed in Taiwan where local scientists will be taking a leading and defining role, there will be many technological challenges we have to confront and overcome to make the experiment a success. These experimental techniques are related and applicable to many areas of nuclear science and engineering. Some examples include :

- **Shielding Design :** The pilot experiment involves measurements of neutrino interactions which take place at a rate of only a few events per hour. Elaborate and efficient shieldings must be built to suppress the various external background. The current design is depicted in Figure 3, where the lead and iron are for suppressing the gamma-rays, the boron-loaded polyethylene are for absorbing the neutrons, and the veto scintillators are for identifying the cosmic-rays. The entire system will be in a dry nitrogen atmosphere to prevent the diffusion of radioactive radon gas into the system. The tasks of shielding design and construction are taken up the Institute of Nuclear Research and the Academia Sinica.

- **Trace Radioactivity Measurements :** Selection of materials and components to be used inside the shielding is very important. We have access to several facilities studying different aspects of the problem : low background germanium detector (National Tsing Hua University, Institute of Nuclear Research), neutron activitation (Institute of Nuclear Research), accelerated mass spectroscopy (China Institute of Atomic Research). For instance, we are the first group to measure a trace level of 10^{-18} g/g of the radioactive ^{137}Cs and 40 ppm of ^{23}Na in a CsI(Tl) crystal. A list of the purity level of the naturally occuring ^{40}K, ^{238}U and ^{232}Th in some of the components tested are shown in Figure 1.

- **Production of B_4C plates :** B_4C in powder form is inexpensive and readily available. In plate form, it can be a very efficient and compact neutron-absorption material (^{10}B has high thermal neutron capture cross-section). However the plates are very difficult to make and very expensive commercially. We are currently pursuing a R&D program to produce the B_4C plates from powder using the Plasma Combustion Technology at the Institute of Nuclear Research. There will be much commercial value in nuclear engineering for neutron attenuation applications if one can devise less expensive ways (for instance, putting in trace admixtures of additives) for producing B_4C plates. We have already achieved some success in making the plates at 1350^{o}C, a big reduction from the typically temperature of 2000^{o}C.

- **Gamma Interactions and Neutron Transport Modelling :** To complement the shielding design, the gamma-ray interactions and neutron transport in the shieldings are studied via modeling and simulations. A summary of the neutron transport results with our present shielding configuration is shown in Table 2, indicating the neutron capture probabilities among the various materials.

- **Reactor Neutrino Modelling :** The rector neutrino spectrum can be evaluated using as inputs the reactor thermal power output and the compositions of the main fissile isotopes (^{235}U, ^{238}U, ^{239}Pu, and ^{241}Pu), their variations during a reactor cycle as well as their spatial distribution inside the core. These data are continuously monitored during the reactor operation, and the availability to the experiment has been officially approved by Taiwan Power Company and the Nuclear Power Station II.

Another important aspect of the pilot experiment is on the education and training of young students and scientists. With the techniques and exposure in both nuclear and high energy physics acquired during the experiment, they will be well equipped to pursue a career in areas like nuclear science and engineering, as well as reactor research and operation. The diversified background of the incoming young people will in turn enhance the vigour of the disciplines. The large scale operation of detector and electronics systems, as well as the techniques in software management and international communications among the collaborating institues, will have much to offer to the nuclear sciences students.

5 Funding Request

We request the funding for

1. The labour cost in the manufacturing and installation of the shielding. The engineering design is the responsibility of INER.

2. Part of the material and labour cost for the production the electronics system. An expert from the Institute of High Energy Physics at Beijing will take charge of the engineering design.

3. Part of the material and labour cost for the assembling of cables and connectors.

4. A postdoc and a Master-level Research Assistant position with experimental physics or engineering background. Their major responsibilities will be on the items listed above : shieldings construction, B_4C plates production, trace radioactivity measurements.

The existing available funding is not yet sufficient to completely construct the pilot experiment to our specifications. (See Status Report Table 6). Moreover, our purchasing power have been adversely affected by the recent changes in exchange rates. Further funding support for the provisions of raw materials and manpower, as well as the availability of positions in this labour intensive phase, will be necessary and crucial. The shielding materials can be re-used at the reactor or elsewhere when the pilot experiment is completed.

6 Summary

The investigations of neutrino masses and mixings remain a major experimental challenge in fundamental research, the outcome of which will have significant impact in particle physics, astrophysics and cosmology. There may be a unique opportunity to perform a long baseline neutrino oscillation experiment in Taiwan, profiting from the power reactors which provide an abundant supply of neutrinos and the local mountainous geography where an underground laboratory can be built.

The TEXONO Collaboration is preparing to carry out a pilot experiment at Nuclear Power Plant II, the first step towards this goal. Besides the interesting and motivated physics issues the pilot experiment may address, it is expected that this experience will equip us with the necessary experimental techniques in the field and will help us to build up a qualified team to make major contributions in future efforts.

A host of technical and engineering challenges have to be overcome to make the pilot experiment a success. The experience may find applications in other areas of nuclear science and engineering, and will be a good training ground for students and young scientists and engineers.

We request the funding support from the National Science Council/Atomic Energy Council Grant in 1998.

Samples	**Range of Activity (μg/g)**		
	^{40}K	^{232}Th	^{238}U
CsI(Tl) Crystal	< 0.0004	< 0.03	< 0.008
B_4C Powder	< 0.0004	< 0.03	< 0.008
Silicon PIN Photo-diode	< 3.5	< 0.03	< 0.008
LEDs	< 3.5	< 0.03	< 0.08
Photo-multipliers Tubes	15000	0.6	2
Circuit Board (Fiber Glass)			
I	< 3.5	6	10
II	< 3.5	2	5.8
III	< 3.5	10	13
Circuit Board (Bread Board)	< 0.0004	< 0.03	< 0.008
Flat Cable	< 3.5	0.65	0.9
LEMO Cable	< 0.0004	< 0.03	< 0.008
Teflon-coated Cable	< 0.0004	< 0.03	< 0.008
Teflon Wrapping Sheets	< 0.0004	< 0.03	< 0.008

Table 1: A summary of results on the radioactive contaminants in various candidate components based on measurements with low background germanium detectors.

Default Configuration :

Initial Energy			**Capture Probability**		
	External	Iron	Water	B_4C	CsI
Exterior Shooting In:					
1 keV	0.82	0.17	0.008	0.	0.
10 MeV	0.60	0.22	0.18	0.0017	0.
Iron-water Interface Shooting In:					
1 keV	0.0003	0.47	0.53	0.0	0.
10 MeV	0.033	0.10	0.79	0.066	0.0056
At Center of Crystal:					
1 keV	0.	0.	0.0001	0.044	0.96
10 MeV	0.0011	0.0026	0.17	0.63	0.20

Configuration with Water-Iron Swap :

Initial Energy			**Capture Probability**		
	External	Water	Iron	B_4C	CsI
Exterior Shooting In:					
1 keV	0.61	0.39	0.	0.	0.
10 MeV	0.61	0.37	0.019	0.0015	0.
Water-Iron Interface Shooting In:					
1 keV	0.	0.0006	0.020	0.98	0.
10 MeV	0.	0.10	0.086	0.69	0.12
At Center of Crystal:					
1 keV	0.	0.	0.	0.044	0.96
10 MeV	0.0011	0.068	0.07	0.66	0.20

Table 2: Results of neutron transport simulations with different shielding configurations and neutron energies, indicating the neutron capture probabilities among the various materials. The "Default Configuration" is one similar to the geometry described in the text, except with water replacing polyethylene, and iron plates with 25 cm in thickness. The second configuration is with the positions of the gamma and neutron absorbers swapped, such that water is exterior to the iron.

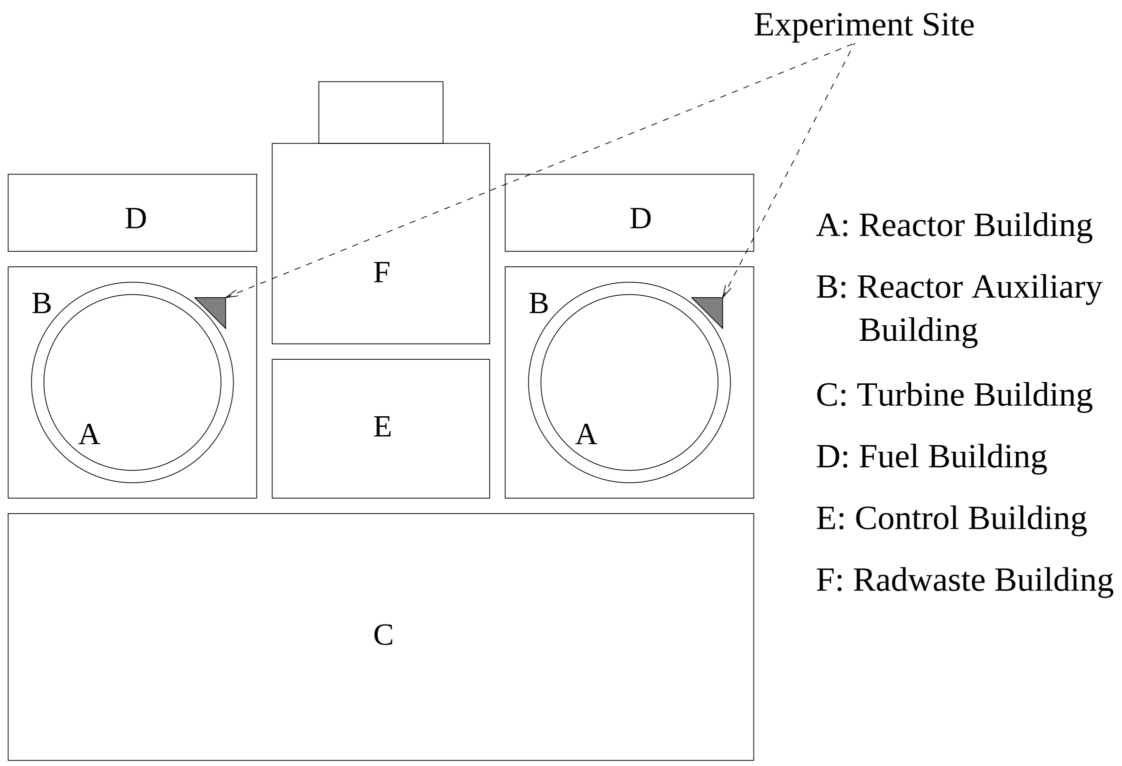

Figure 1: Schematic top view, not drawn to scale, of the NP2 Reactor Complex, indicating the experimental sites.

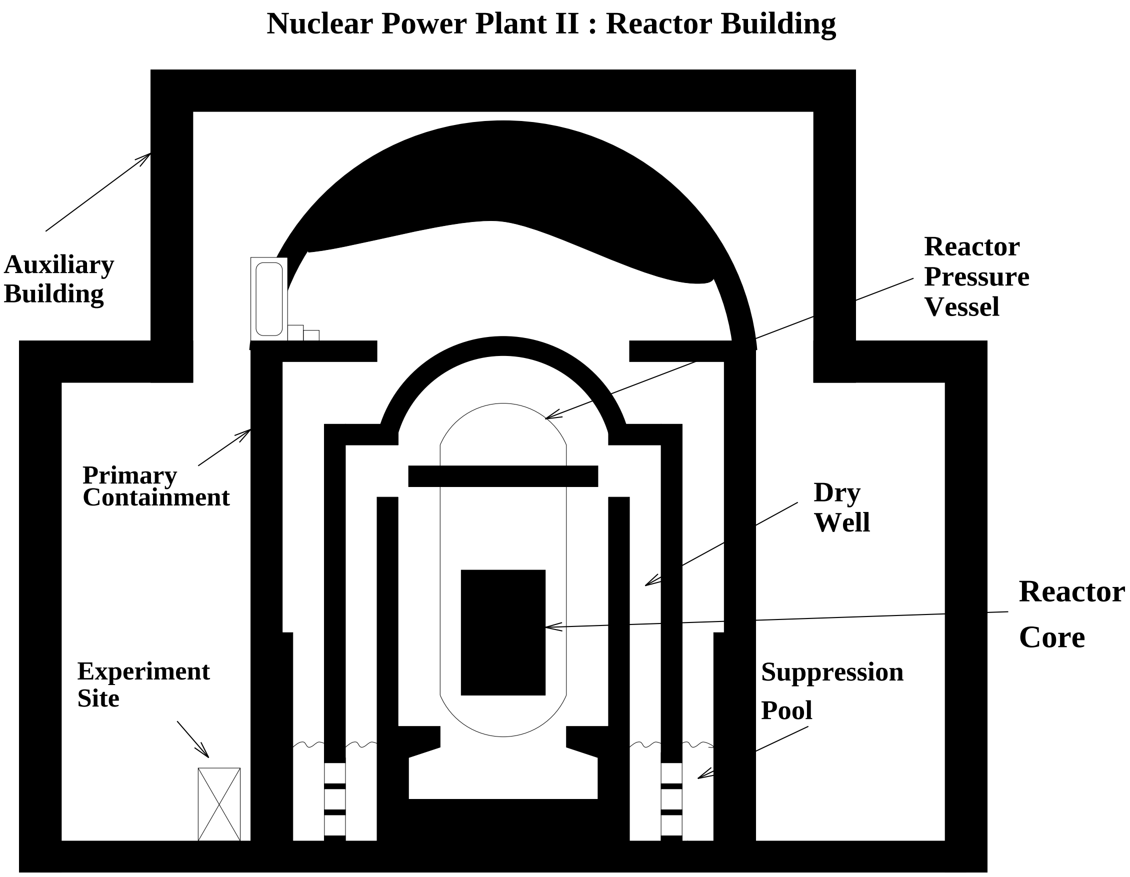

Figure 2: Schematic side view, not drawn to scale, of the NP2 Reactor Building, indicating the experimental site. The reactor core-detector distance is about 30 m.

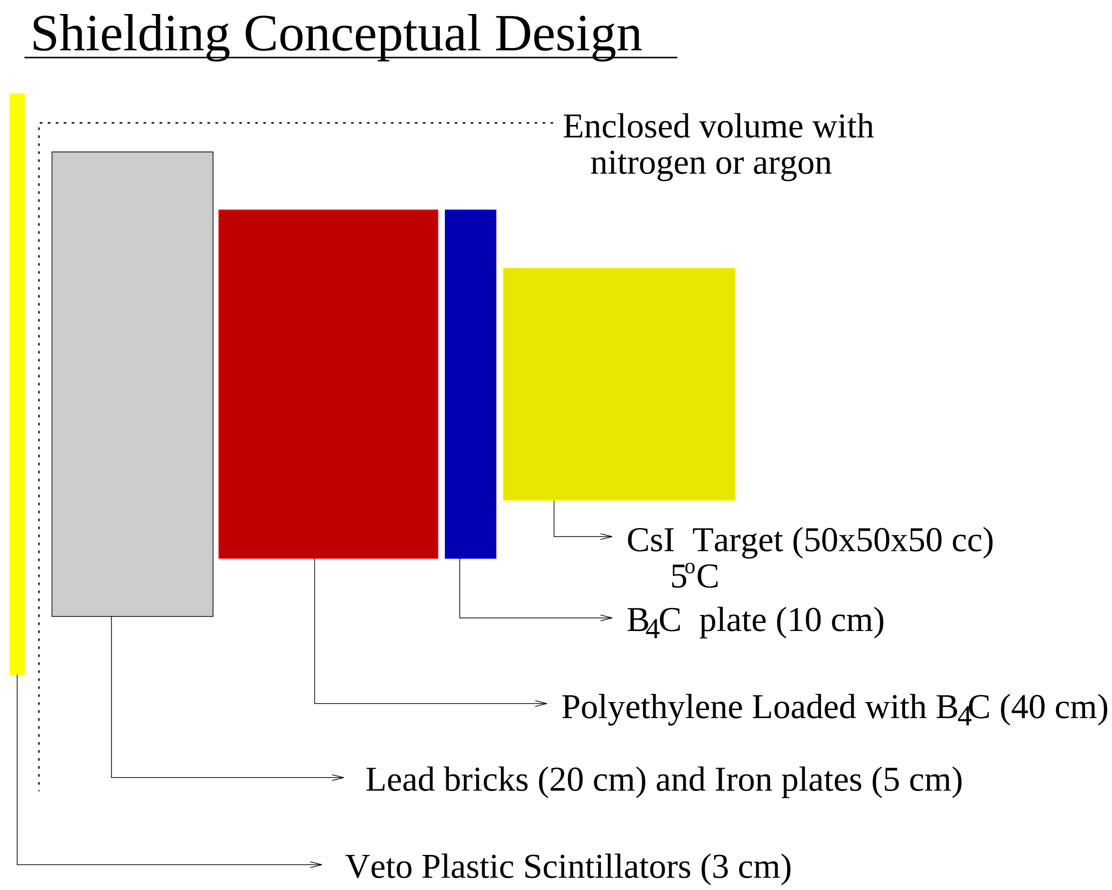

Figure 3: Schematic layout of the shielding. The coverage is 4π but only one face is shown.