STATUS OF TRR-II PROJECT: CONCEPTUAL DESIGN

Y. C. Chou and TRR-II Project Team, *S. H. Chen, **D. Y. Hsia

ABSTRACT

The Taiwan Research Reactor (TRR) operated by the Institute of Nuclear Energy Research (INER) went critical in 1973 but was permanently shut down in 1988. In order to reconstruct the original TRR into a new multi-purpose and state-of-the-art research reactor, a "TRR System Improvement and Utilization Promotion" (TRR-II) project was proposed by INER since 1989. After a long series of review and modification processes, the TRR-II project finally got a green light from the government in October 1998. The major tasks of the project include removing the old reactor vessel from its original location, dismantling the old core internals, constructing a new open-pool type reactor, installing various modern experimental facilities, and training personnel necessary for operation and utilization of the new reactor as well. Most of the conceptual design of these tasks have been completed by the TRR-II project team and reviewed by a team of international experts. This paper describes the major characteristics of TRR, the way of handling the original TRR reactor vessel, the design concepts of the new reactor and the experimental facilities associated with it. Finally, the strategy as well as the approach to promoting the utilization of the new reactor will also be outlined.

*Professor, Department of Nuclear Engineering,
M. I. T. Cambridge, MA02139, USA

**Director, Institute of Nuclear Energy Research

Presenting author: Y. C. Chou
Manager, TRR-II Project
Institute of Nuclear Energy Research
1000, Wenhua Road, Chiaan Village
Lungtan, Taoyuan, Taiwan, 325, ROC.
e-mail: ycchou@iner.gov.tw

Key Members of TRR-II Project Team:
D.J.Shieh, C.J.Wu, S.K.Chen, T.R.Yeh, K.C.Tu, D.I.Lee, and Y.H.Huang

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I. Introduction

TRR was a 40 MW heavy water moderated research reactor, designed and constructed by AECL, Canada. It first went critical on January 1973 and, after a little more than 15 years in operation, was permanently shutdown in 1988. A side view of TRR reactor vessel is shown in Fig. 1. The reactor core was enclosed in a zircaloy calandria which was a cylindrical tank containing heavy water and 199 vertical tubes for natural uranium fuel rods, control rods and irradiation sample rods. The fuel rods were cooled by light water going through these vertical tubes. The maximum thermal neutron flux was 6×10^{13} neutrons per square centimeter per second. The major application of TRR included radioisotope production, nuclear fuel and material test, water and radiological chemistry study, neutron activation analysis, neutron radiography, and so on.

After TRR was shut down, a program was launched in INER to study how to deal with TRR, whether a new research reactor is needed, and what type of the new reactor should be if it is needed. Since the expense of TRR decommissioning was evaluated to be about eighty million US dollars and that for reconstruction of TRR into a new reactor was about one hundred million US dollars, a “TRR System Improvement and Utilization Promotion“ (TRR-II) project was proposed by INER in 1989. After a long series of review and modification processes, the TRR-II project finally got a green light from the government on October 1998. The total budget of the project is about one hundred million US dollars and the duration will be seven years from July of 1998. The major tasks of the project include removing the old reactor vessel from its original location, dismantling the old core internals, constructing a new open-pool type reactor, installing various modern experimental facilities, and training personnel necessary for operation and utilization of the new reactor as well.

II. The Objectives of TRR II Project

As that mentioned in the introduction section, the review and modification processes of TRR II project proposal have been lasted for almost 10 years. During this long and torturous period, various options have been discussed or even argued. One very important argument is whether we should buy a new research reactor from foreign country or build it as much as we can. Finally, from the view point of budgetary saving and improving indigenous capability, to do the project by collaboration between INER, local companies and foreign consultants is highly recommended by most of the reviewers. Based on this essential strategy, the objectives of TRR II project and their bases are described as follows.

1. To develop and preserve domestic expertise in nuclear technology

It is important to develop and preserve domestic expertise in nuclear technology so that we will not have to totally rely on foreign technology in the future. Even though our nuclear power plants are all imported from foreign countries, their safe and efficient operation demand that we continue to develop and maintain our own nuclear manpower and expertise.

2. To enhance domestic decommission capability of nuclear reactor

Two small research reactors have been decommissioned in Taiwan. One is 1 kW Argonaut Reactor of Tsing-Hua university and the other is 100 kW Water Boiler Reactor(WBR) of INER. In TRR II project, the old TRR reactor vessel will be removed, the old core internals will be dismantled, and several old systems will be replaced. Therefore, a variety of techniques associated with removing heavy weight components, cutting high radioactive structures, decontaminating contaminated materials etc. will be developed. Comparing with Argonaut Reactor and WBR, the power of TRR was higher, the structure of reactor vessel and its internals are more complicated, and the radioactive level inside TRR core is higher too. Consequently, the domestic nuclear reactor decommission capability is expected to be enhanced through the performance of TRR II project.

3. To improve domestic design and construction capability of research reactor

Table 1 and 2 show some information of research reactors in Taiwan. For kW grade reactors listed in these tables, domestic engineers have participated in design and construction with different extents. However, two MW grade reactors were basically built through turn-key projects. Since the TRR II reactor will be designed and constructed by local team to the maximum extent, the relevant capability can certainly be improved.

4. To build a modern research reactor with multi-purpose capability in Taiwan

As shown in Table 1, for all currently operating research reactors, the power levels are relatively low, the neutron fluxes are not high, and hence, the application areas are very limited. However, materials research using neutron beams is of interest to physicists, chemists, biologists and material scientists from universities. In addition, use of neutrons in industrial application could include power reactor fuel testing, evaluation of radiation effects in power reactor components, short half-life isotope production for industrial diagnostics, neutron activation analysis of trace elemental samples, and so on. Therefore, to build a new research reactor with appropriate level of neutron flux and modern experimental facilities are very essential to the aforementioned applications.

5. To provide an essential tool for advance materials research in Taiwan

In the area of material research, the most obvious applications of thermal or cold neutron beams are neutron diffraction by which atomic or molecular structures of solids, liquids and gases are determined. Comparing with x-rays and electron beams, neutrons have much lower energy and magnetic moment. The Synchrotron Radiation Research Center (SRRC) in Taiwan has been successfully operated and the size of user's group keeps on growing. Therefore, the neutron sources generated by TRR II could be complementary to the light and X-ray sources generated by the SRRC. Together they provide a complete set of tools for domestic materials research communities.

6. To promote domestic neutron utilization scope and technology

To ensure successful and productive operation of TRR II facilities after they are built, potential domestic user groups should be organized and educated through the project. A certain critical number of instrument scientists should also be recruited and trained.

III. Disposal of TRR

In order to utilize the original TRR plant facilities as much as possible, the new reactor is going to be constructed at the same location as the old one. Therefore, the old reactor vessel has to be removed from its original spot. Figure 2 shows the concept of TRR reactor vessel removal. A dismantling building is going to be constructed to the south of the old reactor hall. The old reactor vessel will be cut from its base and transferred to the dismantling building then. It is estimated that the whole reactor vessel weighs about 3000 tons after cut from its base. Therefore, the whole transferring processes including separation of the vessel from its base, lifting and transportation of the vessel from the old reactor hall to the dismantling building are very challenging. This part of work is scheduled to complete within 3 years.

After the old reactor vessel is settled in the dismantling building, the internal components of which will be dismantled piece by piece. As shown in Fig. 1, the internal components include upper biological shields, thermal shields, graphite reflectors, core calandria and so on. To perform this part of work, a lot of cutting technology including plasma cutting, abrasive high- pressure water cutting, sea-jet cutting etc. will be developed. Under-water maneuvering practices are also necessary for treatment of high radioactive materials. The high radioactive waste generated from the dismantling work will be temporarily stored in the storage tank besides the dismantling building. (ref. Fig. 2) In addition, most of the old TRR systems such as primary cooling system, reactor control system, heavy water treatment system, and so on need to be replaced. All these systems have also to be dismantled within three years after the beginning of the project. On the other hand, facilities could be reused include reactor hall, part of electrical system, secondary cooling system, and some auxiliary systems. These systems will be modified and maintained for reuse.

IV. Design Concept of TRR-II Reactor

According to the results of TRR-II conceptual design, the new reactor is a pool type, light water cooled and moderated reactor. To maximize the usage of thermal neutrons, the reactor core is surrounded by heavy water in a ring-shape tank. Fast neutrons leaked out from the core will be slowed down in this reflector tank. Consequently, a peak of thermal neutron flux will be generated in the reflector tank for experimental usage. In the core design, several options have been studied to obtain the best choice. These options include core configuration of 6×6, 6×6 with one row of Be block, 6×5 and 5×5 as shown in Fig.3. Two criteria were set up for this optimization process. One is the safety limits associated with "Departure from Nuclear Boiling" and "Flow Instability" must not be violated.

The other is the neutron flux at the location of cold neutron source has to be as high as possible. With these two criteria, the 6×5 core configuration was chosen as the best one. In this configuration , the highest unperturbed thermal neutron flux in the reflector region is estimated to be about 2.8×10^{14} neutrons per square centimeter per second. This 6×5 core consists of 21 standard fuel elements, 4 control fuel elements (control rod followed by partial fuel section), and 5 vertical experiment channels. The dimension of the core is about 49 cm×41cm, and the height of it is 60 cm. Each standard fuel element consists of 21 U_3Si_2 plates with low enriched (<20%) uranium.

The schematic layout of TRR-II reactor pool and working pool is shown in Fig. 4 and the detailed side view of these pools is shown in Fig. 5. The diameters of the upper and the lower parts of the reactor pool are 5.1 m and 4.5 m respectively. The depth of the water in the pool is about 11.5 m, and distance from the top of active core to the water surface is about 9 m. The control rod drive mechanism is located in the basement beneath the reactor pool. The control rods are push up from bottom of the core during normal operation but drop by gravity in case of reactor trip. The working pool will be on the top of the cold neutron guide tunnel. The water depth of this pool is about 6.7 m and the surface area is 8.5m×6.5m. To the western side, a hot cell is designed on the top of the working pool.

There are 5 reactor systems and 10 plant systems in TRR-II conceptual design. Fig. 6 shows the block diagram of these systems. Major reactor systems include reactor components and pool, fuel handling facilities, I&C system, fuel elements, control elements and its driving mechanisms. On the other hand, important plant systems include primary and secondary cooling systems, heavy water system, electrical system, HVAC system, radiological protection system, emergency cooling system and so on.

V. Design Concept of TRR-II Experimental Facilities

The experimental facilities to be installed in the TRR-II project include neutron beam experimental facilities (NBEF), boiling water reactor material irradiation test facility (BMIF), neutron activation analysis facilities (NAA), radio-isotope research and production facilities (RIRP), and neutron transmutation doping facility (NTD). A general arrangement of these experimental facilities is shown in Fig. 7. The NBEF and some NAA facilities will be installed in the beam ports surrounding the reflector tank. The NTD facility and some RIRP channels will be placed in the reflector tank. Meantime, the BMIF and some RIRP channels will be arranged in the core region. For NBEF, guide tubes with length of several tens of meters need to be provided for more cold neutron utilization. Therefore, a neutron guide hall (as shown in Fig. 8) will be constructed to the west of the reactor hall. Four spectrometers including one powder diffractometer, one triple-axis spectrometer, one small angle neutron diffractometer and one reflectometer associated with NBEF will also be installed in the reactor hall or neutron guide hall. In addition to these experimental facilities, future expansion spaces are left for each of the aforementioned experimental area. Table 3 summaries the experimental facilities to be constructed in the project and future expansion capacities for each experimental area.

VI. Promotion of Domestic Neutron Utilization

The most obvious application of thermal or cold neutron beams are neutron diffraction in determining atomic or molecular structures of solids, liquids and gases. Neutron scattering spectroscopic techniques have also been applied to the studies of polymer chain dynamics in melts and to elucidate physical mechanism in high Tc super-conductors. These research areas are of interest to physicists, chemists, biologists and materials scientists from universities. Potential industrial applications of TRR-II research reactor center around the following items.

a. Power reactor fuel testing
b. Evaluation of radiation effects in power reactor components
c. Characterization of advanced polymeric and ceramic materials
d. Short half-life isotope production for industrial diagnostics
e. Neutron activation analysis of trace elements in environmental samples
f. Neutron transmutation doping for power transistor semiconductor production

In addition, the neutron radiography technique has been proven useful in non-destructive testing of metallic objects and in identifying archaeological and art objects. The neutron tomography technique can be used to detect micro-cracks in turbine blades or airplane wings due to absorption of hydrogen gas. The boron neutron capture technique is also very promising in brain tumor therapy. With these potential application areas, it is expected that TRR-II reactor can serve about 200 regular users from universities and industrial companies in the future. To achieve this goal, several measures of neutron utilization promotion are planed as follows.

a. To send domestic fresh Ph.D. to famous research institutes or universities in developed countries for advanced study in neutron application techniques.
b. To support Ph.D. students who go from Taiwan to famous universities in developed countries for advanced study in neutron application techniques.
c. To support domestic professors and their graduated students in developing instruments or techniques in neutron application.
d. To support domestic professors and their graduated students in doing leading research in neutron application areas.
e. To work out a mechanism of offering permanent positions for ten or more senior neutron application researchers and instrument specialists to form a core of successful and productive operation of the TRR-II experimental facilities.

VII. Conclusion

TRR-II project is a very important project for the nuclear community in Taiwan. Various opinions and options have been discussed during the long and tortuous proposal review processes. The goals and tasks of the approved version of the project are very challenging for domestic engineers. To assume the major responsibility of the project, INER will do her best to collaborate with domestic experts, scholars, companies and foreign consultants to complete this important project. To oversee the performance of project staff, a Steering Committee consisting of high ranking officers and prestigious scholars has been established. The direction of this Committee will guide the progress of the project. In addition, a Technical Review subcommittee and a Neutron Application Review subcommittee are also established under the Steering Committee. The former one reviews all technical aspects associated with design and construction of TRR-II reactor and the associated experimental facilities. The latter one reviews the performance of utilization promotion. Regular review meetings are held between project staff and these Committees. These review activities are certainly helpful in assurance of the project quality.

Table 1 Operating Research Reactors in Taiwan

Reactor	**Power**	**First Critical**	**Peak Thermal Flux (n/cm^2sec)**	**Utilization**
THOR(1)	2 MW	1960.4.13	1.5×10^{13}	training, neutron radiography, neutron activation analysis, isotopes production, BNCT
ZPRL(2)	30 kW	1970.2.2	2×10^{11}	neutron radiography, neutron activation analysis
THMER(3)	0.1 kW	1975.11.19	5×10^{6}	education

(1) THOR : Tsing-Hua Open Pool Reactor

(2) ZPRL : Zero Power Reactor Lungtan

(3) THMER : Tsing-Hua Mobile Education Reactor

Table 2 Shutdown Research Reactors in Taiwan

Reactor	Power	First Critical	Peak Thermal Flux (n/cm^2sec)	Status
TRR(1)	40 MW	1972.1	6×10^{13}	shutdown in 1988.1 in safe enclosure now
THAR(2)	1kW	1974.4	1×10^{10}	shutdown in 1991.5 decommissioned
WBR(3)	100kW	1983.2	8×10^{11}	shutdown in 1991.4 decommissioned

(1) TRR : Taiwan Research Reactor

(2) THAR : Tsing-Hua Argonaut Reactor

(3) WBR : Water Boiler Reactor

Table 3 Experimental Facilities to be constructed in TRR-II project and Future Expansion Capacities

Item	Facilities To Be Constructed In The TRR-II Project	Future Expansion Capacity
NBEF	1 cold neutron source 2 cold neutron guide tube 1 powder diffractometer 1 triple-axis spectrometer 1 SANS 1 reflectometer	one hot swore 2 more cold neutron guide tubes second SANS cold neutron Triple axis spectrometer nigh resolution liquid diffractometers spin echo spectrometer Time-of flight quasielasfic spectrometer
NFMD & WRC	1 test rig 1 hot cell	1 ramp test facility, 1 test rig 2 test loops
NAA	1 fast rabbit 1 PGAA 2 spectrum analyzers	PGAA in guide hall
RIRP	5 irradiation sample holders and associated equipment	
BNCT	epithermal neutron beam tube and experimental room(reserve space only)	uranium thermal to epither mal neutron converter system and medical facilities
NTD	1 set of irradiation facility	1 more sets

Fig.1 Side View of TRR Reactor Vessel

Institute of Nuclear Energy Research

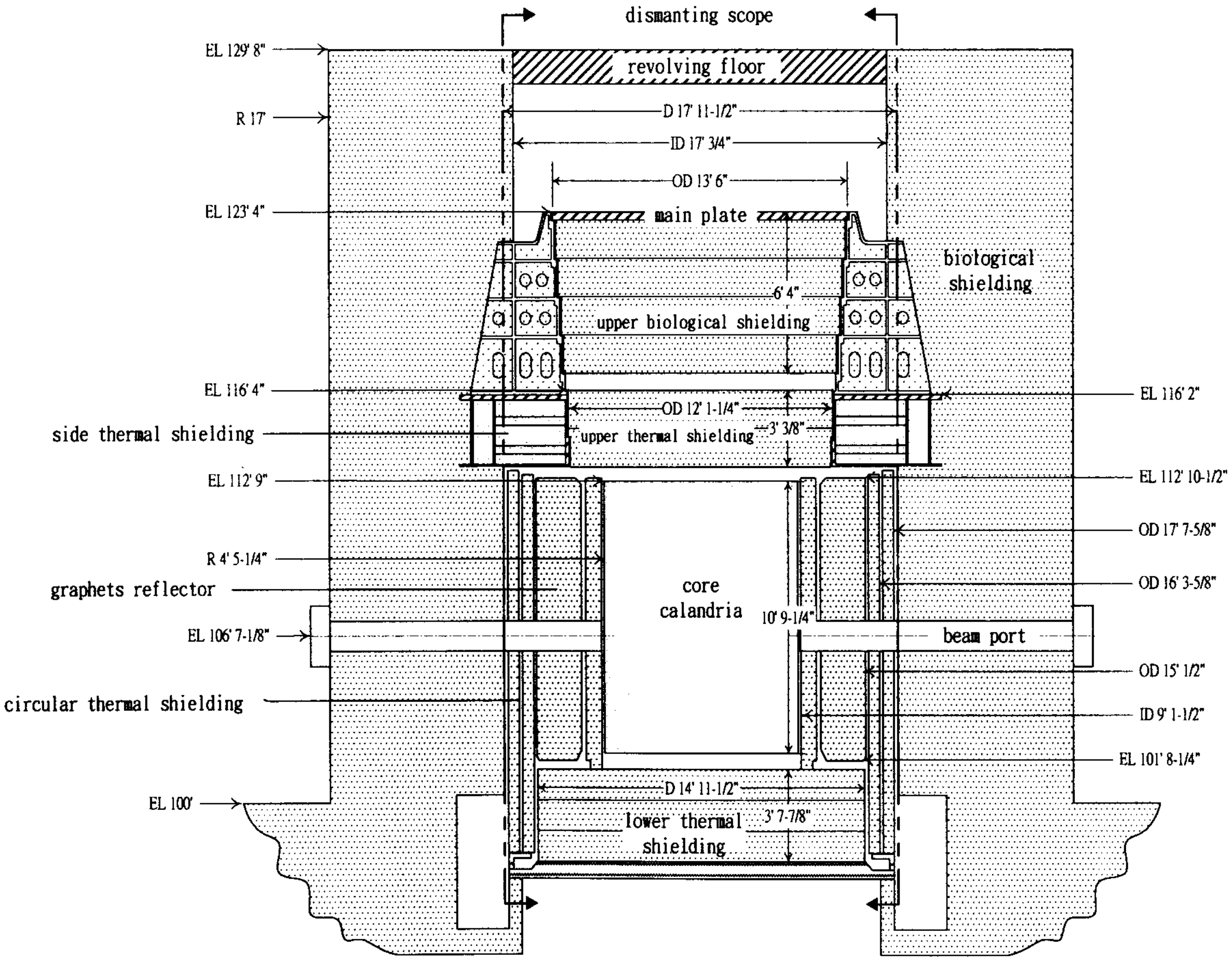


Fig. 2 Removal Path of TRR Reactor vessel

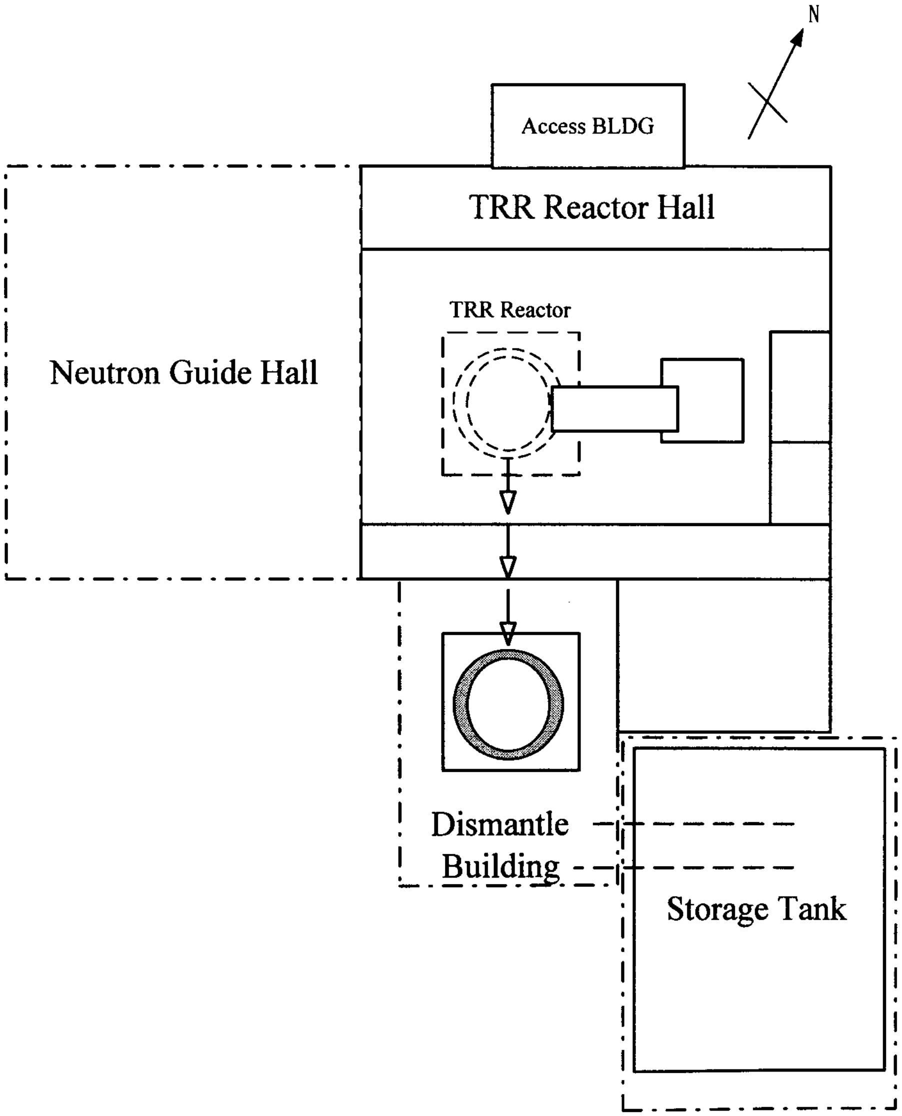
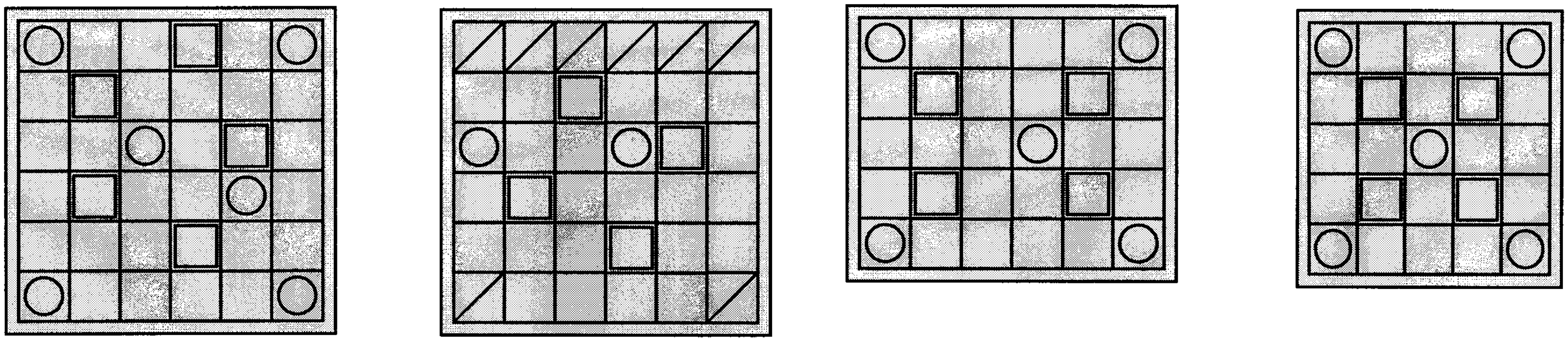


Fig.3 Design Optimization of TRR-II Reactor Core



6 × 6

25 SFE
5 CFE
6 Test Elements
(Fuel with BP)

6 × 6
(with Be Row)

22 SFE
4 CFE
2 Test Elements
8 Be Blocks
(Fuel with BP)

6 × 5

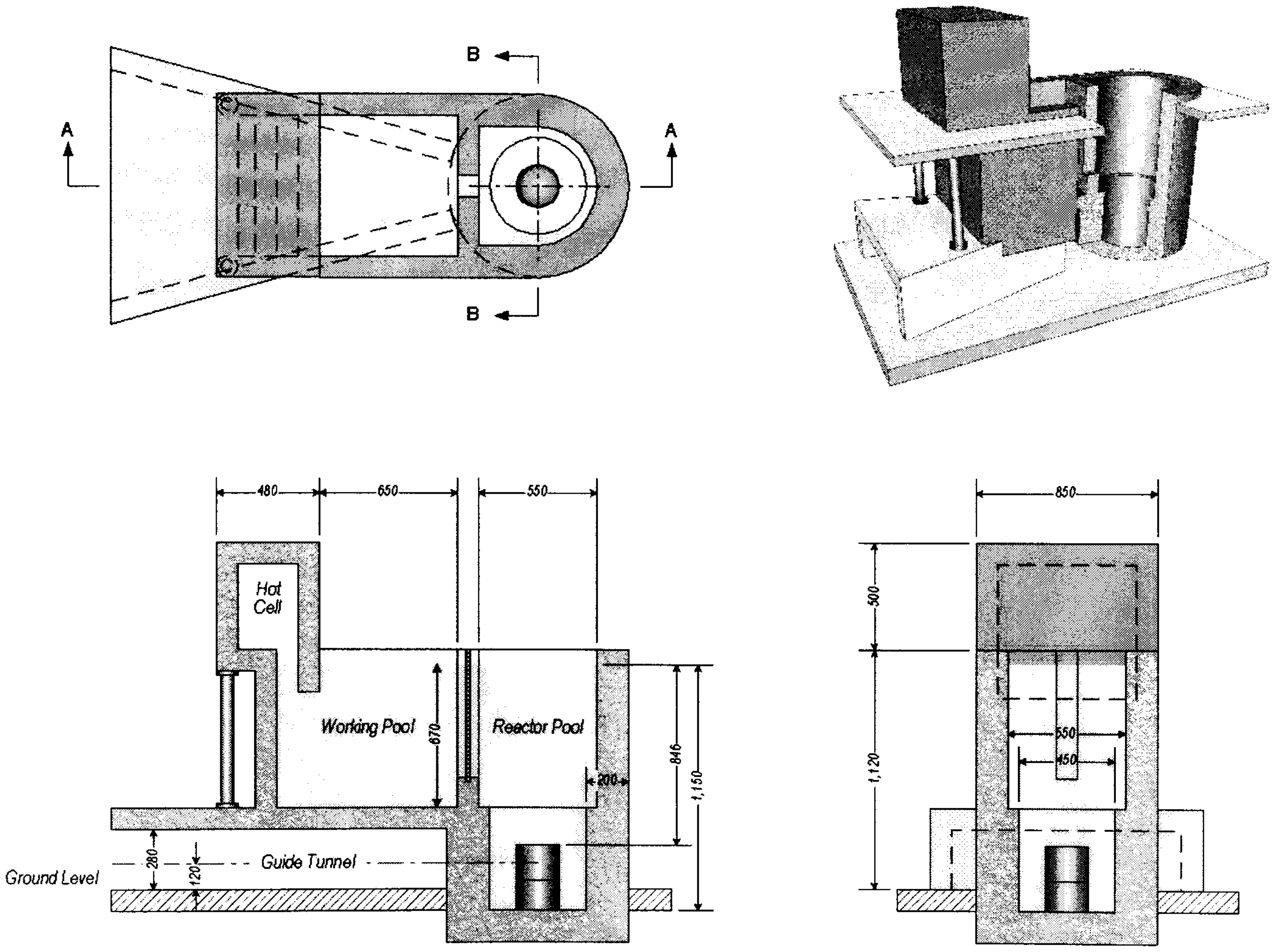
21 SFE
4 CFE
5 Test Elements
(Fuel w/o BP)

5 × 5

16 SFE
4 CFE
5 Test Elements
(Fuel w/o BP)

Note:SFE-Standard Fuel Element, CFE-Control Fuel Element, BP-Burnable Poisson

Fig.4 Layout of TRR-II Reactor Pool and Working Pool



SECTION A-A

SECTION B-B

Fig.5 Side View of TRR-II Reactor Pool and Working Pool

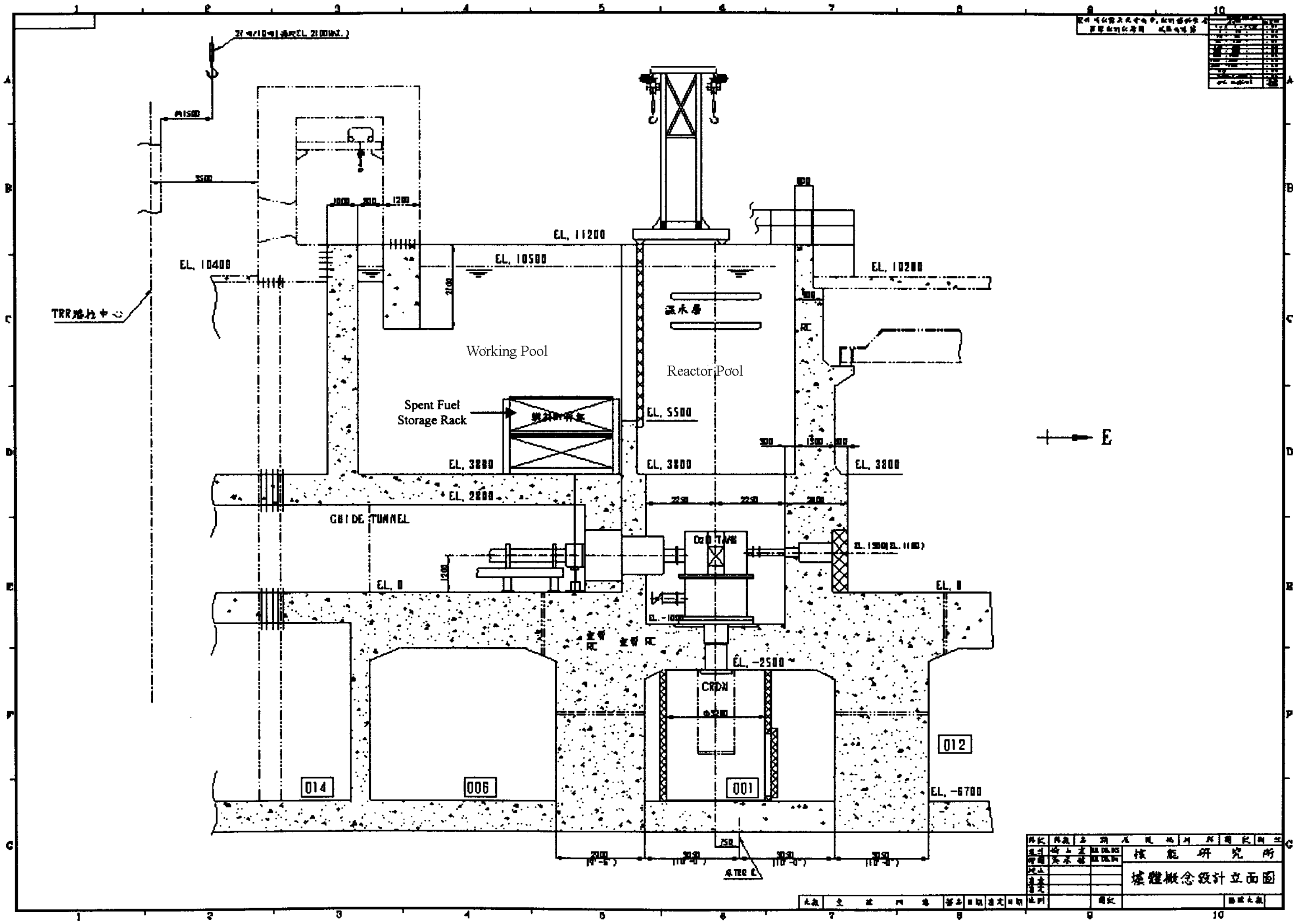


Fig.6 TRR-II System Block Diagram

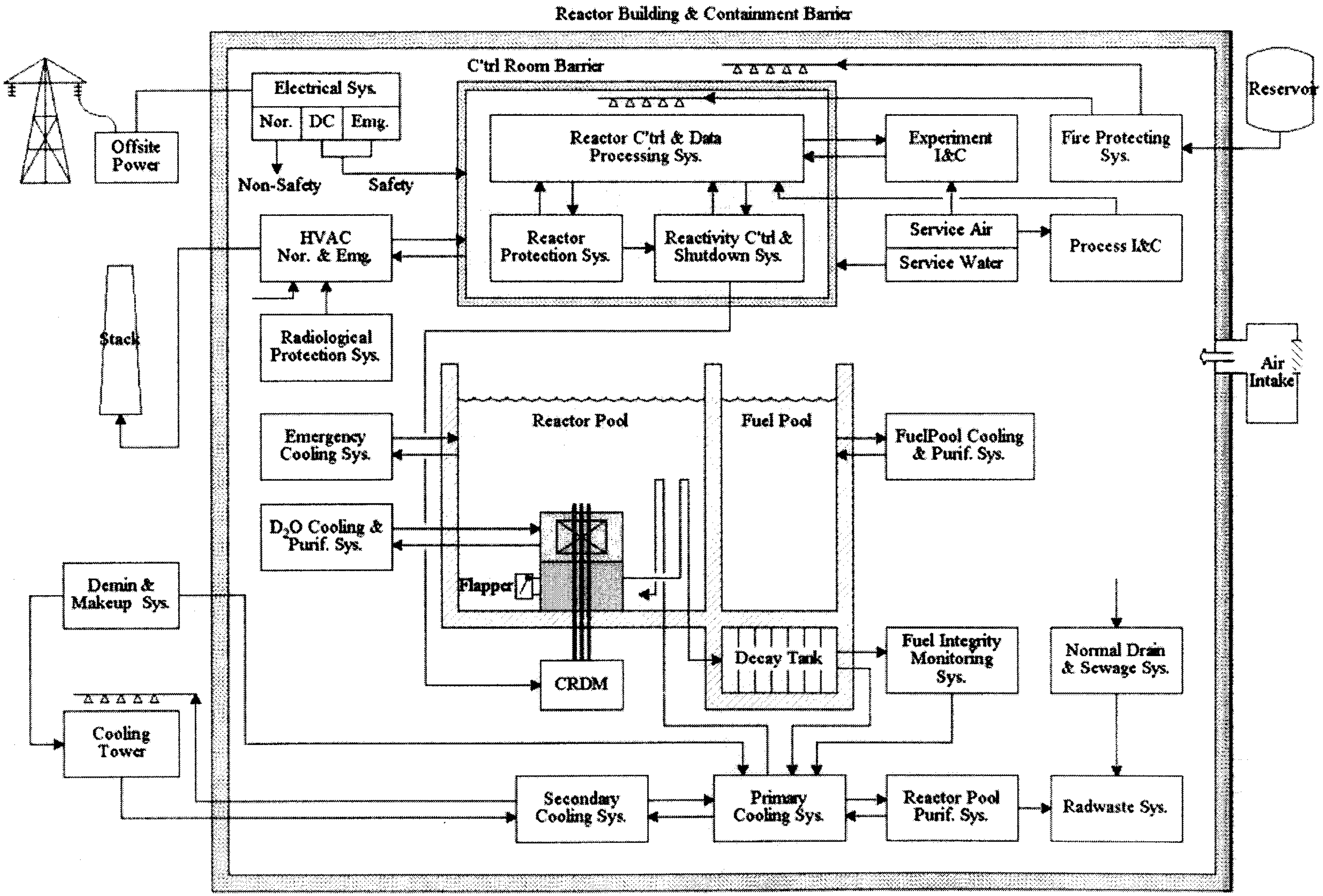
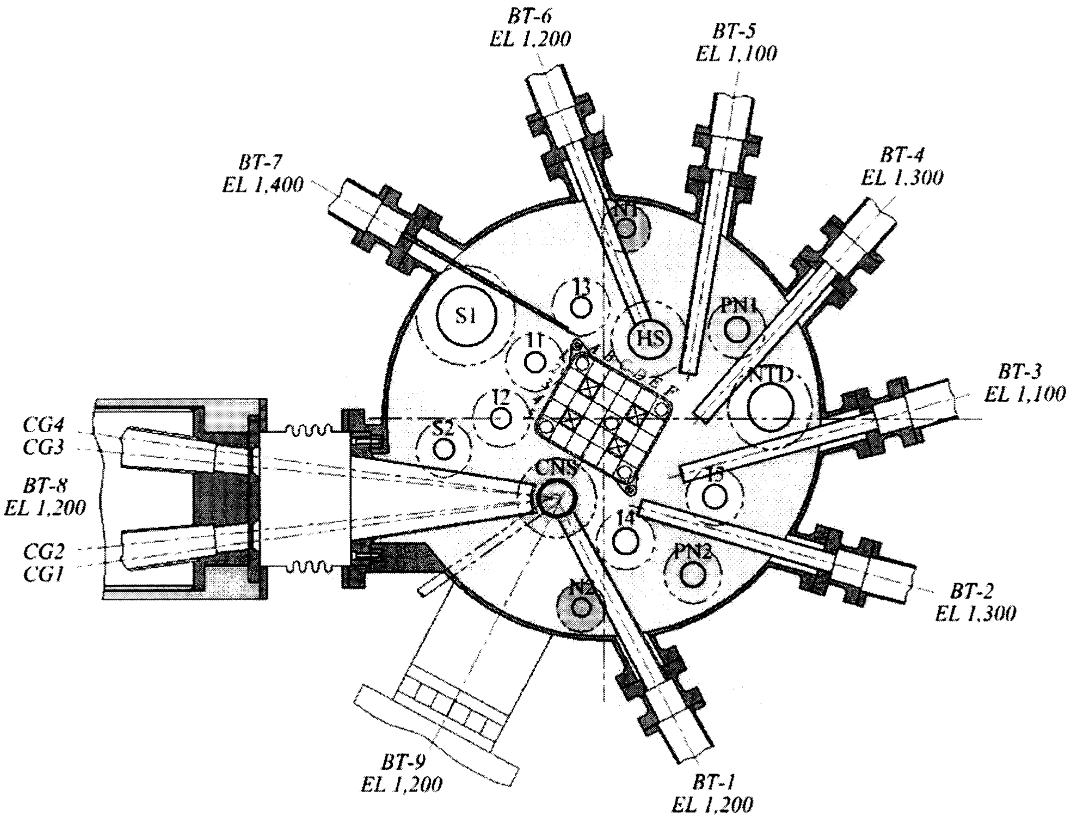


Fig.7 Locations of TRR-II Experimental Facilities



Horizontal Beam Tubes

BT-1	Cold Source (Reserved)
BT-2	Reflectometer
BT-3	Reflectometer
BT-4	TAS
BT-5	HRPD
BT-6	HS
BT-7	NR (under water)
BT-8	Cold Source
BT-9	BNCT

Vertical Irradiation Positions

PN1	INAA/RNAA	90
PN2	CNAA	90
I1	Co60, W188	60
I2	Ir192	60
I3	Re186, Ho166	60
I4	Mo9990	
I5	Sm153, I125	90
NTD	Si Irradiation	170
CNS	Cold Source	200
HS	Hot Source	180
N1 / 2	Cover Gas	3 / 3
S1 / 2	Spare	270 / 100

Fig.8 Plant Layout of Reactor and Neutron Guide Hall