1.19 STATUS OF NEUTRON BEAM UTILIZATION AT THE DALAT NUCLEAR RESEARCH REACTOR

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ABSTRACT

The 500-kW Dalat nuclear research reactor was reconstructed from the USA-made 250-kW TRIGA Mark II reactor. After completion of renovation and upgrading, the reactor has been operating at its nominal power since 1984. The reactor is used mainly for radioisotope production, neutron activation analysis, neutron beam researches and reactor physics study.

In the framework of the reconstruction and renovation project of the 1982-1984 period, the reactor core, the control and instrumentation system, the primary and secondary cooling systems, as well as other associated systems were newly designed and installed by the former Soviet Union. Some structures of the reactor, such as the reactor aluminum tank, the graphite reflector, the thermal column, horizontal beam tubes and the radiation concrete shielding have been remained from the previous TRIGA reactor. As a typical configuration of the TRIGA reactor, there are four neutron beam ports, including three radial and one tangential. Besides, there is a large thermal column. Until now only two-neutron beam ports and the thermal column have been utilized.

Effective utilization of horizontal experimental channels is one of the important research objectives at the Dalat reactor. The research program on effective utilization of these experimental channels was conducted from 1984. For this purpose, investigations on physical characteristics of the reactor, neutron spectra and fluxes at these channels, safety conditions in their exploitation, etc. have been carried out. The neutron beams, however, have been used only since 1988. The filtered thermal neutron beams at the tangential channel have been extracted using a single crystal silicon filter and mainly used for prompt gamma neutron activation analysis (PGNAA), neutron radiography (NR) and transmission experiments (TE). The filtered quasi-monoenergetic keV neutron beams using neutron filters at the piercing channel have been used for nuclear data measurements, study on radiation hardness of electronics components, and other researches.

Because of lacking of budget, another two beam tubes are still empty and we have no chance to set up some other facilities for neutron beam study, such as small angle neutron scattering (SANS) facility, neutron diffractometers at the beam tubes, as well as boron neutron capture therapy (BNCT) facility at the thermal column.

This report presents the status of neutron beam facility at the Dalat reactor and its utilization for some typical research activities. An outlook on possibility for participation in the FNCA co-operation program on the utilization of the research reactors has also been given.

INTRODUCTION

The Dalat nuclear research reactor was reconstructed and upgraded from the TRIGA MARK II reactor, and put into operation at nominal power of 500-kW sine March 1984. Neutron beam utilization is one of the main activities at the reactor.

The reactor has four horizontal beam tubes, which provide beams of neutron and gamma radiation for a variety of experiments. They also provide irradiation facilities for large specimens up to 15cm in diameter in a region close to the reactor core. In configuration, three of the beam tubes are oriented radically with respect to the center of the core, and one beam tube is tangential to the outer edge of the core. Besides, there is a large thermal column with outside dimensions of 1.2m by 1.2m in cross section and 1.6m in length *(Figure 1)*.

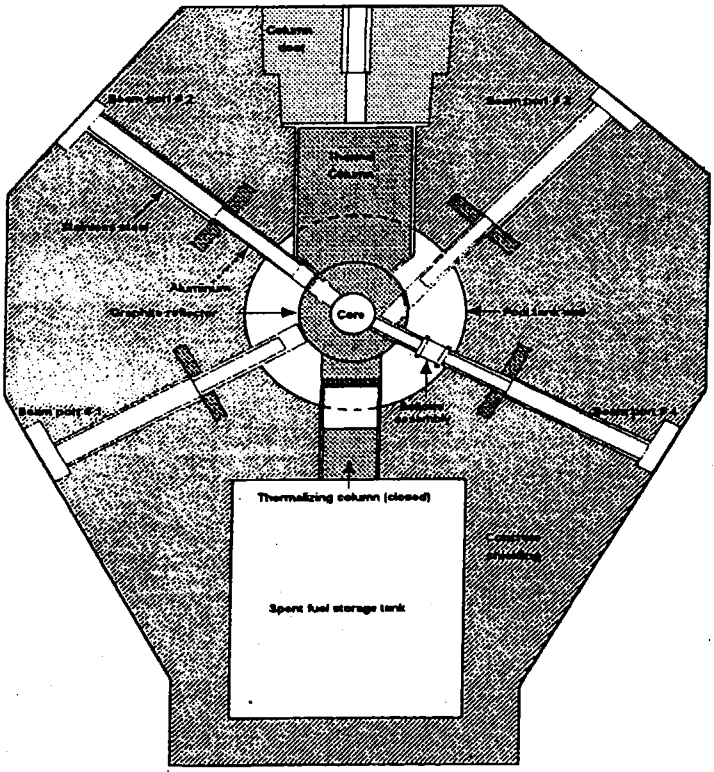

Fig. 1. Horizontal section view of the Dalat research reactor

The two neutron beams (No.3 and No.4) of the reactor have been utilized since 1988. The filtered thermal neutron beams at the tangential channel No.3 have been extracted using a single crystal silicon filter and mainly used for PGNAA, NR, TE. The filtered quasi-monoenergetic keV neutron beams using neutron filters at the piercing channel No.4 have been used for nuclear data measurements; study on radiation hardness of electronics components, such as transistors, avalanche photodiodes (APD), PiN diodes; and other researches.

It is well known that the research reactor is an intense source not only of thermal neutrons, but also intermediate as well as fast neutrons. So, nuclear reactors can also be used very efficiently for material research by utilizing the neutron scattering technique and for medical applications. But because of lacking of budget, until now we have no chance to set up small angle neutron scattering (SANS) facility, neutron diffractometers, as well as boron neutron capture therapy (BNCT) facility at our reactor.

In this report, we present the main research activities carried out at the two existing beam ports.

DESCRIPTION OF THE REACTOR

In the framework of the reconstruction and renovation project of the 1982-1984 period, the reactor core, the control and instrumentation system, the primary and secondary cooling systems, as well as other associated systems were newly designed and installed by the former Soviet Union. Some structures of the reactor such as the reactor aluminum tank, the graphite reflector, the thermal column, four horizontal beam tubes and the radiation concrete shielding have been remained from the USA-made TRIGA MARK II *(Figure 2)*.

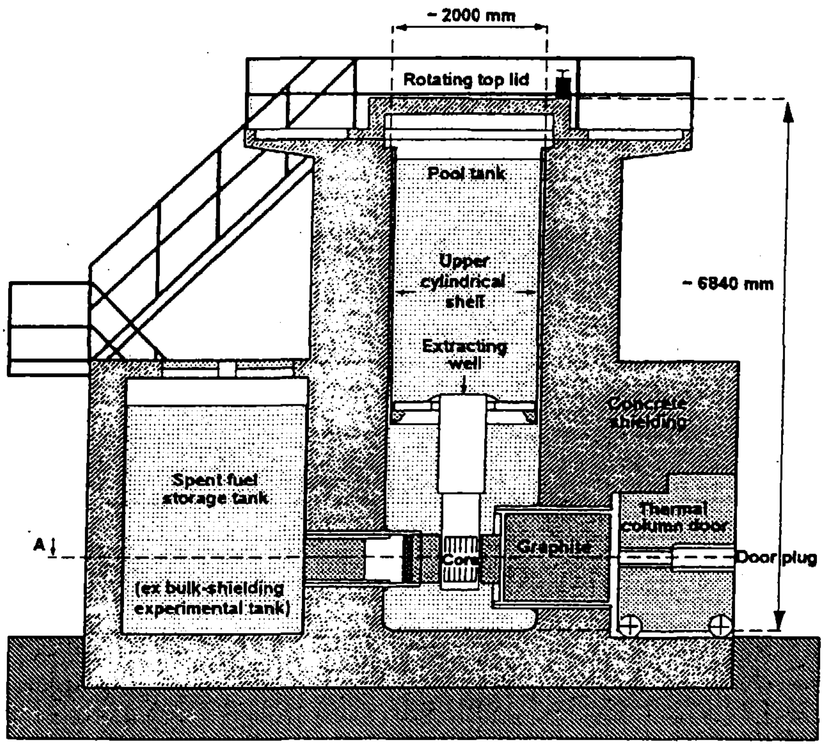

Fig. 2. Vertical section of the Dalat research reactor

The main characteristics of the Dalat reactor are as follows:

- Reactor type: swimming pool type, cooled and moderated by light water
- Norminal power: 500 kW thermal
- Fuel elements: WWR-M2 type, U-Al alloy with 36% enrichment in ^{235}U
- Number of fuel elements in the core: 100
- Number of control rods: 2 safety rods, 4 shim rods and 1 regulating rod
- Reflector: Beryllium and graphite
- Number of horizontal beam tubes: 4 (3 radial and 1 tangential)
- Number of thermal column: 1
- Number of vertical irradiation channels: 4 (1 neutron trap, 1 wet and 2 dry channels).

Neutron irradiation positions and its neutron flux (at 500 kW) shown in *Table 1*.

Table 1: Neutron flux and cadmium ratio at some positions in Dalat reactor

Position	Thermal neutron flux ($n/cm^2/s$)	Cadmium ratio
Neutron trap at the centre	2.2×10^{13}	2.5
Rotary specimen rack	4.0×10^{12}	3.4
Vertical (wet) channel 1-4	1.2×10^{13}	2.0
Vertical (dry) channel 7-1	4.5×10^{12}	5.7
Vertical (dry) channel 13-2	4.6×10^{12}	5.5
Thermal column	5.8×10^{9}	82
Horizontal beam tube No.3	2.5×10^{6}	-
Horizontal beam tube No.4	1.8×10^{7}	-

DESCRIPTION OF THE NEUTRON BEAM PORTS

It is a typical configuration of the neutron beam ports of TRIGA reactor. It means, the four beam tubes penetrate the concrete shield and the aluminum tank and pass through the reactor water tank to the graphite reflector *(see Figure 1)*. Two of the radial tubes (No.1 and No.2) terminate at the outer edge of the reflector assembly. The remained radial tube (No.4) penetrates into the graphite reflector and terminates at the inner surface of the reflector assembly. The tangential beam tube (No.3) terminates at the outer surface of the reflector. Up to now only two beam tubes No.3 and No.4 have been utilized.

Because the radial (or piercing) beam tube No.4 terminates at the inner surface of the reflector, just at the outer edge of the reactor core, so the flux intensities of thermal and fast neutrons as well as gamma radiation at this beam tube are the highest among the beam tubes of the reactor. To produce quasi-monoenergetic neutrons of 24keV, 25keV, 55keV, 75keV, 144keV and 1.2MeV as well as thermal neutrons for nuclear data measurements and other applications, some neutron filters, such as Si, Al, Fe, S, Ti, B, Pb and PE (Polyethylene) have been installed in this beam tube. Main characteristics of these filtered neutron beams are given in *Table 2*. In the case of the filtered neutron beam at 1.2MeV, the value of neutron flux was measured directly behind filters at the distance of about 2 m from the reactor core. For other neutron beams, it was measured at the outlet of the beam tube No.4.

Table 2. The characteristics of filtered neutron beams at the radial channel No.4

Neutron	Filter combination	Neutron flux ($n.cm^{-2}.s^{-1}$)	R_{Cd} or FWHM
Thermal	98cm Si + 10cm Ti + 35g/cm² S	1.8×10^7	143
144 keV	98cm Si + 10cm Ti + 0.2g/cm² Bo^{10}	1.2×10^7	22 keV
55 keV	98cm Si + 35g/cm² S + 0.2g/cm² Bo^{10}	4.0×10^6	8 keV
25 keV	102.3cm Al + 0.2g/cm² Bo^{10}	1.2×10^6	-
24 keV	20cm Fe+20cm Al +25g/cm² S+0.2g/cm² Bo^{10}	1.0×10^6	-
75 keV	45g/cm² S + 0.2g/cm² Bo^{10}	1.1×10^6	-
1.2 MeV	17.5cm Pb + 2cm PE + 0.2g/cm² Bo^{10}	5.3×10^7	-

The outer end of the beam tube No.4 is equipped with the shielding house that provides neutron and gamma shielding and permits to take out radiation beams from the reactor *(Fig. 3)*. The experimental equipment for total neutron cross-section measurement and in-beam neutron capture gamma ray spectroscopy has been set up.

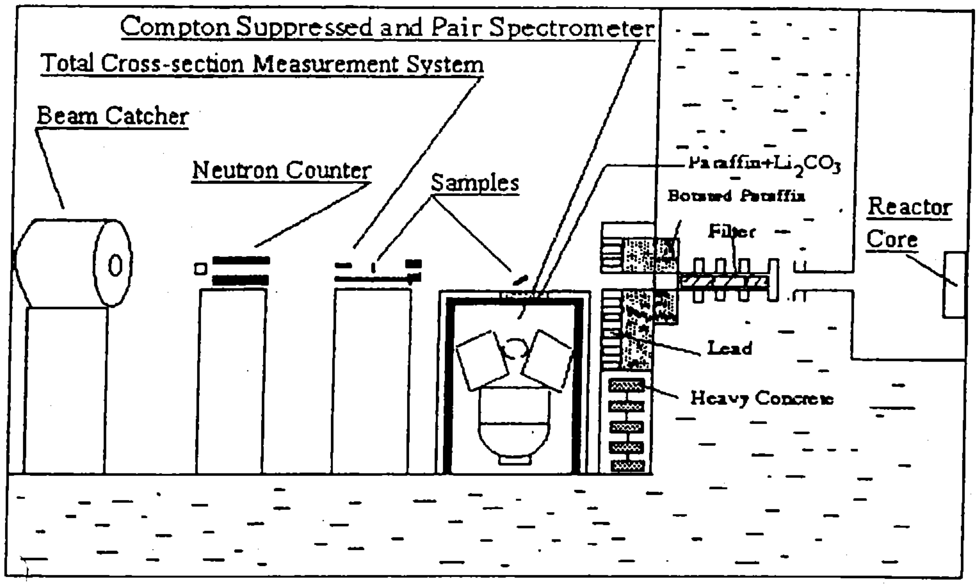

Fig. 3. Horizontal experimental radial channel for neutron beam application

The tangential beam tube terminates at the outer surface of the reflector, but is also aligned with a cylindrical void, which intersects the piercing tube in the reflector graphite. This channel provides a radiation source giving a minimum amount of core gamma radiation. *Fig. 4* shows the experimental beam facility on the tangential channel. It consists of a water-containing tube-shaped can 1500mm long and 80mm in diameter and a flexible collimating system following outwardly. Depending on the each experiment the collimating system can be changed. Main characteristics of filtered neutron beams at the channel No.3 are given in *Table 3*.

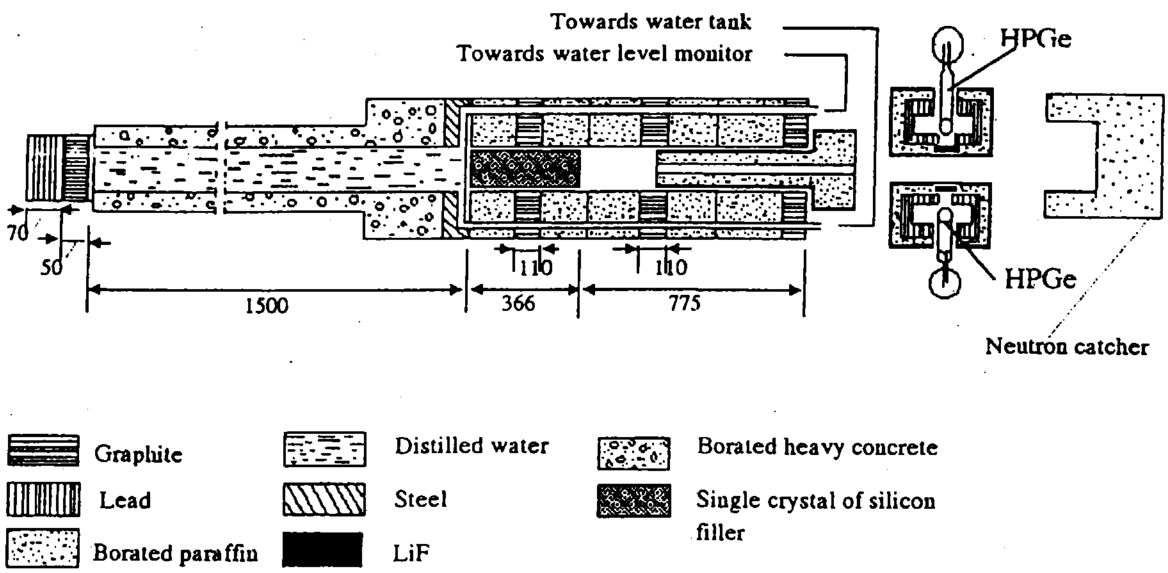

Fig. 4. Horizontal experimental tangential channel for neutron beam application

Tab. 3. The characteristics of filtered neutron beams at the tangential channel No.3

Composition of the filter assemblies	Flux (thermal) ($n.cm^{-2}.s^{-1}$)	Flux (>1 MeV) ($n.cm^{-2}.s^{-1}$)	R_{Cd}(Au)	Gamma dose (R/h)
No filter	$5.8x10^7$	10^5	5	4
80 mm C + 50 mm Pb	$1.2x10^7$	10^4	12	1.8
80 mm C + 100 mm Pb	$5.5x10^6$	10^4	19.5	0.8
80mm C+100mm Pb+366mm Si	$3.5x10^6$	10^1	77.5	0.22

In case of using this tangential channel for neutron radiography, the basic parameters of the n-ray facility are as follows:

- Useful beam area: $120x120\ mm^2$
- D = 80 mm, L = 4240 – 5920 mm
- Thermal neutron flux: $6.7x10^6\ n/cm^2/s$
- Gamma radiation level: 200 mR/h
- Cadmium ratio: 120

TYPICAL RESEARCH ACTIVITIES USING NEUTRON BEAMS

1. Neutron physics and Nuclear data measurement

In the keV energy region, filtered neutron beams are the most intense sources, which can be used to obtain neutron data for reactors and other applications. The following experiments have been carried out at the Dalat research reactor:

- Total neutron cross section measurement for ^{238}U, Fe, Al, Pb on filtered neutron beams at 144keV, 55keV, 25keV and evaluation of average neutron resonance parameters from experimental data.
- Gamma ray spectra measurement from neutron capture reaction of some reactor materials (Al, Fe, Be, etc.) on filtered neutron beam at 55keV and 144keV.
- Measurement of average neutron radioactive capture cross section of ^{238}U, ^{98}Mo, ^{151}Eu, ^{153}Eu, ^{121}Sb, ^{123}Sb, ^{128}Te, ^{134}Ba on the 55keV and 144keV neutron beams.
- Measurement of isomeric ratio of $^{82m,g}Br$ created in the reaction $^{81}Br(n,\gamma)^{82}Br$ on the 55keV and 144keV neutron beams.
- Other investigations, such as average resonance capture measurements, using the γ-γ coincidence spectrometer for study on the (n,2γ) reaction, etc.

2. Applied neutron capture gamma ray spectroscopy

- Development of PGNAA technique using the filtered thermal neutron beam in combination with the Compton-suppressed spectrometer for analyzing Fe, Co, Ni, C in steel samples; Si, Ca, Fe, Al in cement samples; Gd, Sm, Nd in uranium ores, Sm, Gd in rare earth ores; etc.
- Utilization of the PGNAA method for investigating the correlation between boron and tin concentrations in geological samples as a geochemical indication in exploration and assessment of natural mineral resources; analyzing boron in sediment and sand samples to complement reference data for such samples from rivers.
- Development of the PGNAA method for in-vivo activation analysis of essential elements Ca, Cl, N and P in the whole body and of the toxic elements Cd, Hg in a body organ for medical diagnosis of various diseases.

- Development of the spectrometer of summation of coinciding pulses applitudes for (n,2γ) reaction research and for measuring activity of activated elements with high possibility of cascade transitions.

3. Neutron radiography

- Development of NR method as a NDT technique for various kinds of objects, such as electrical and electronic products, mechanical details, biological samples, etc. by direct method.

4. Other applications

- For study on production of TLD neutron dosimeters, our staff utilized the filtered neutron beams for research on estimation of the radiobiological effectiveness (RBE) of different energy neutrons and on calibration of neutron dosimeters.
- Utilization of transmission measurement method on the thermal neutron beam for determining thermal absorption cross section of soil samples from drill-holes in oil exploitation.
- Utilization of transmission measurement method on the thermal neutron beam for determining boron content distribution along glass tubes used in the electric fluorescent lamp industry.
- Irradiation of electronic components and equipment for studying radiation effects on them involving fast and thermal neutrons as well as gamma radiation.
- In the framework of the regional co-operation in the field of the utilization of research reactors, the Dalat NRI has participated in the study and manufacture of Sb doped high temperature superconductors.

PROPOSED PLAN FOR NEUTRON BEAMS UTILIZATION

1. Modification of neutron radiography facility

Because of that the existing neutron radiography facility was set up from 1988, so now it is facing with some disadvantages, such as the collimator system is not in divergent, the quality of materials is not good enough, etc., so the modification of the existing neutron radiography system is needed in the future.

2. Small angle neutron scattering

It is well known that neutron scattering techniques have been used very effectively for the structure analysis of superconductors, magnetic materials, actinides, monolayer molecules, martensite alloys, ceramics, etc., and for studying various excitations in the condensed matter, such as spin-wave of heavy fermion system, magnetic scattering and phonon of the pseudo two-dimensional materials, lattice dynamics of supper ionic conductors, etc. The SANS technique has also been used effectively in molecular biology research; for a structural analysis of homopolymer in block copolymer microdomains which is a very interesting problem in morphology of the polymer mixtures and for studying microstructure of Co-Cr thin films, which is a promising material for magnetic recording with higher recording density, etc.

At the Dalat NRI, the solid state physics laboratory has been established and equipped with X-ray diffractometer and other related devices for the structure analysis of magnetic materials, ceramics and others. In order to enlarge neutron beam experiments on material researches and other applications, a project on SANS should be prepared and submitted.

3. Boron neutron capture therapy

If a drug containing ^{10}B can be concentrated in malignant tumors, then flooding that region of the body with thermal neutrons will release more radiation energy in tumor than in normal tissues by reaction: $^{10}B(n,\alpha)^{7}Li$ + 2.4 MeV. The alpha particles have a short range (a few μm) and a high LET, so they are very damaging to the tumor cells.

At the Dalat reactor, besides four horizontal experimental channels, there is a large thermal column, which can be utilized for setting up the BNCT facility in the future.

TOPICS CAN BE DISCUSSED FOR COLABORATION

Basing on the existing neutron beam facility and on our experiences, the following topics could be discussed for collaboration in the future:

- The techniques for extracting filtered neutron beams: thermal, 24keV, 25keV, 55keV, 75keV and 144keV
- The method and equipment for total neutron cross section measurements
- The method for measurement of average neutron radiative capture cross section
- The technique on the compton supressed and pair spectrometer for neutron in-beam researches
- The technique of using spectrometer for summation of coinciding pulses amplitudes for (n,2γ) reaction study
- The method and equipment for neutron radiography
- The method and equipment for PGNAA, including Ko-method
- The methods of instrumental neutron activation analysis with short-live and long-live isotopes
- The technique of delay neutron detection.

CONCLUSION

Using the tangential and piercing beam tubes, the neutron beam experiments have been carried out at the Dalat reactor. In these experiments, the neutron filter technique has been used to produce neutron beams with a relatively high neutron flux density despite the low power reactor. Thanks to the filtered neutron beams and other experimental equipment, our staff has carried out the studies on neutron physics, nuclear data measurement, neutron radiography, PGNAA and other application researches. Based on the obtained experiences and knowledge we can set up research programs for utilization of neutron beams more effectively. We do hope that the FNCA project on utilization of research reactors will play an important role in encouraging and helping us to improve and enlarge neutron beam experiments and other applications at the Dalat nuclear research reactor.