Current Status of Operation and Utilization of Dalat Nuclear Research Reactor and Strategic Plan in the Next Decade

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Abstract: Dalat Nuclear Research Reactor (DNRR) with the nominal power of 500 kW is today the unique one in Vietnam. The reactor was reconstructed and upgraded from TRGA Mark II research reactor, and restarted operation on March 20, 1984. Under the framework of the program on Russian Research Reactor Fuel Return (RRRFR) and the program on Reduced Enrichment for Research and Test Reactor (RERTR), the project for full core conversion of the DNRR from high-enriched uranium fuel (HEU) to low-enriched uranium fuel (LEU) was implemented during years 2008 - 2012. Since January 2012 the reactor has been operated with a working core configuration consisting of 92 VVR-M2 LEU fuel assemblies of 19.75% enrichment.

Up to mid 2015, the reactor has been operated with the total of about 40,250 hrs of safety and effective exploitation. During the last 31 years of operation, the DNRR was efficiently utilized for: (1) Producing about 400 Ci per year of radioisotopes including I-131, P-32, Tc-99m generator, Cr-51, Sm-153 for medical use; (2) Developing a combination of nuclear analysis techniques (INAA, RNAA, PGNAA) and physic-chemical methods for quantitative analysis of about 70 elements and constituents in various samples of geology, crude oil, agriculture, biology, and environment; (3) Carrying out experiments on the reactor horizontal beam tubes for nuclear data measurement and nuclear structure study; and (4) Contributing on nuclear education and training programs for human resource development in the country.

In the next ten years, the DNRR will be considered to implement the operation regime of 150 hrs/cycle in order to increase the quantity of radioisotope production as well as the number of irradiation samples for NAA. The use of the reactor for nuclear education and training in order to support the human resource development for the national nuclear power program will be also paid much attention. Besides, in preparation for the effective utilization of a new research reactor in future, the broadening of researches on production of various radioisotopes (such as Mo-99, Y-90, Ho-166, Lu-177 and Ir-192), neutron radiography and gemstone coloration will also be planned to carry out at the DNRR. As the high power research reactor is expected to put into operation between 2023-2025, the DNRR will shift its utilization purpose and mainly use for NAA, basic researches, and education and training.

This paper presents the current status of operation and utilization of the DNRR. In addition, the strategic plan for the reactor in the next decade is also mentioned in the paper.

Keywords: *DNRR, HEU, LEU, RRRFR, RERTR, VVR-M2, NAA, INAA, RNAA, PGNAA.*

I. INTRODUCTION

The DNRR is a 500-kW pool-type reactor loaded with the Soviet VVR-M2 fuel assemblies. It was reconstructed and upgraded from the USA 250-kW TRIGA Mark-II reactor built in early 1960s. The first criticality of the renovated reactor was on the 1st November 1983 and its regular operation at nominal power of 500 kW has been since March 1984. The first fresh core was loaded with 88 fuel assemblies enriched to 36%.

In the framework of the program on RERTR and the program on RRRFR, the DNRR core was partly converted from HEU to LEU with 19.75% enrichment in September 2007. Then, the full core conversion of the reactor to LEU fuel was also performed from 24th November 2011 to 13th January 2012. Recently, the DNRR has been operated with a core configuration loaded with 92 VVR-M2 LEU fuel assemblies and 12 beryllium rods around the neutron trap at the core center.

The reactor is used as a neutron source for the purposes of radioisotopes production, neutron activation analysis, basic and applied researches, and education and training. As an unique research reactor in Viet Nam, the DNRR has played an important role in the research and development of nuclear technique applications as well as in nuclear power development program of the country.

II. BRIEF REACTOR DESCRIPTION AND ITS OPERATION

The DNRR is a pool type reactor, moderated and cooled by light water. Main specifications of the DNRR are shown in Table 1.

Table 1: Specifications of the DNRR.

Reactor type	Swimming pool TRIGA Mark II, modified to Russian type of IVV-9
Nominal thermal power	500 kW, steady state
Coolant and moderator	Light water
Core cooling mechanism	Natural convection
Reflector	Beryllium and graphite
Fuel types	VVR-M2, dispersed UO_2-Al with 19.75% enrichment, aluminium cladding
Number of control rods	7 (2 safety rods, 4 shim rods, 1 regulating rod)
Materials of control rods	B_4C for safety and shim rods, stainless steel for automatic regulating rod
Neutron measuring channels	6 combined in 3 housings with 1 CFC and 1 CIC each
Vertical irradiation channels	4 (neutron trap at core center, 1 wet channel, 2 dry channels) and 40 holes at the rotary rack
Horizontal beam-ports	4 (1 tangential and 3 radial)
Thermal column	1
Maximum thermal neutron flux	$2.2x10^{13}$ $n.cm^{-2}.s^{-1}$ (in the neutron trap)

Fig. 1 shows the vertical section view of the DNRR. The reactor core has a cylindrical shape with a height of 60 cm and a diameter of 44.2 cm, that is constituted of 92 LEU fuel assemblies, 7 control rods, a neutron trap and 3 in-core irradiation facilities. Type of fuel with a ^{235}U enrichment of 19.75% of UO_2+Al covered by aluminum cladding is used. Each LEU fuel assembly contains about 50.5 g of U-235, distributed on three coaxial fuel tubes, of which the outermost one is hexagonal shaped and the two inner ones are circular.

A number of irradiation facilities are present inside and around the reactor core, consisting of a central neutron trap, one in-core vertical wet and two in-core dry (pneumatic transfer) irradiation channels, a rotary specimen rack at the graphite reflector around the core, a graphite thermal column, and four horizontal beam-ports. The neutron trap with the highest thermal neutron flux of $2.2x10^{13}$ $n.cm^{-2}.sec^{-1}$ and the in-core vertical wet channel at cell 1-4 with fast neutron flux of $1.0x10^{13}$ $n.cm^{-2}.sec^{-1}$ are used mainly for radioisotope production (RI). The rotary rack providing 40 wet irradiation positions with thermal neutron flux of $5.0x10^{12}$ $n.cm^{-2}.sec^{-1}$ is also used for RI and NAA as well. The two pneumatic transfer channels at core perimeter with a thermal neutron flux of $5.0x10^{11}$ $n.cm^{-2}.sec^{-1}$ are used for NAA only.

The reactor has four horizontal beam ports (3 radial beam ports and 1 tangential beam port), which provide beams of neutron and gamma radiation for a variety of experiments. They also provide irradiation facilities for large specimens in a region close to the reactor core. Besides, the reactor also has a large thermal column with outside dimensions of 1.2m by 1.2m in cross section and 1.6m in length.

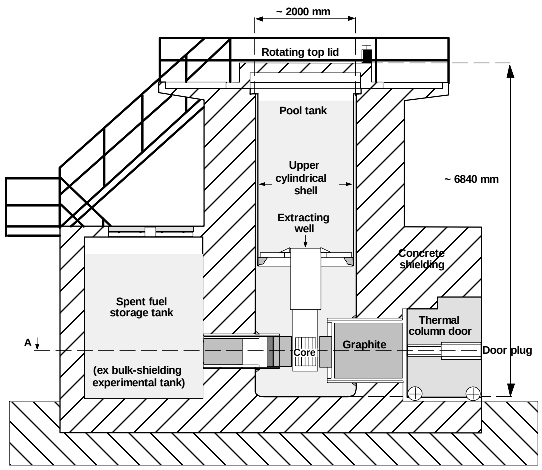

Fig. 1. Vertical section view of the DNRR.

At present, the DNRR is operated mainly in continuous runs of 130 hrs at full power, once every 4 weeks, for radioisotope production, neutron activation analyses, basic and applied researches. The remaining time between two consecutive runs is devoted to maintenance activities, physics experiments, and education and training. The total time of reactor operation from the beginning of 1984 to the end of 2014 is about 39,340 hrs, namely a yearly average of 1300 hrs, and the total energy released is about 787 MWd. Detailed yearly operation time of the DNRR and statistics of the events causing reactor scrams in the time period from 1 January 1984 to the end of 2014 are given in Fig. 2 and Fig. 3.

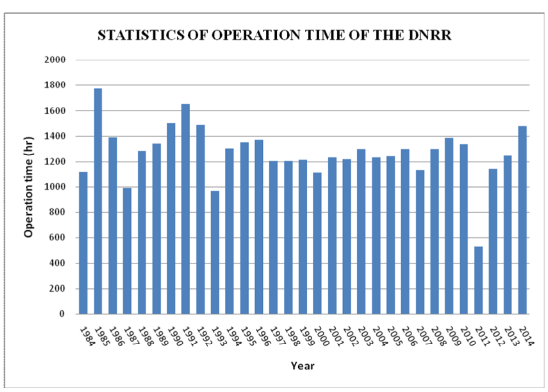

Fig. 2. Yearly operation time of the DNRR.

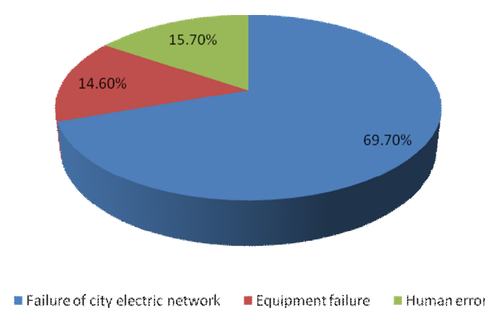

Fig. 3. Statistics of causes resulting in reactor scram.

The unscheduled shutdowns are mainly due to unstable working of the city electric network (69.7%); the scrams caused by equipment failures and human errors are 14.6% and 15.7%, respectively. So far, the reactor has proved to be safe and reliable and annual operation schedules have been rigorously respected.

III. MAIN UTILIZATION OF THE REACTOR

3.1. Radioisotopes and radiopharmaceuticals production

For medicine applications, the main radioisotopes such as ^{131}I in NaI solution and ^{131}I capsule type, ^{32}P applicators for skin disease therapeutics and ^{32}P in injectable solution, and ^{99m}Tc generator of gel type by $^{98}Mo(n, \gamma)^{99}Mo$ reaction have been produced and delivered to 25 hospitals throughout the country. Other radioisotopes as ^{51}Cr, ^{60}Co, ^{65}Zn, ^{64}Cu, ^{24}Na, etc. were also produced in a small amount when requested. Totally, about 4,600 Ci of radioisotopes have been produced and supplied to medical uses so far with a yearly average in the last 5 years of about 400 Ci/year.

In order to support the application of ^{99m}Tc and ^{113m}In radioisotopes in clinical diagnosis and therapeutics, the preparation of radio-pharmaceuticals in Kit form for labelling was carried out in parallel with the development of ^{99m}Tc generator systems. About 17 labeled compounds kits have been regularly prepared and supplied including Phytate, Gluconate, Pyrophosphate, Citrate, DMSA, HIDA, DTPA, Macroaggregated HSA and EHDP, etc. The annual production rate is about 1000 bottles for each Kit which is equivalent to 5000 diagnostic doses.

Other applications of radioisotopes produced at the DNRR are radiotracer technique in sediment studies, oil exploitation, chemical industry, biology, agriculture and hydrology. Some main products which have been used in radiotracer technique are ^{46}Sc, ^{192}Ir, ^{198}Au, ^{131}I, ^{140}La, etc. In addition, some small sources of ^{192}Ir and ^{60}Co with low radioactivity have also been produced for industry applications.

3.2. Neutron activation analysis

The relatively high neutron flux in irradiation channels of the reactor allows elemental analysis using various neutron activation approaches, such as Instrumental NAA (INAA), Radiochemical NAA (RNAA), Delayed NAA (DNAA) and Prompt gamma NAA (PGNAA). By the end of 2014, a total of about 60,000 samples have been irradiated at the reactor with a yearly average of 2000 samples. It can be estimated that those make up 60% of geological samples, 20% of environmental samples, 10% of biological samples, 7% of soil and agriculture materials, and 3% of industrial materials.

In order to determine the elements having short-lived radionuclides, the method of cyclic INAA with the alternation of irradiation and measurement was implemented by using the thermal column and vertical irradiation channel in the reactor core. A new auto-pneumatic transfer system was also installed in 2012 at the DNRR which can transfer a sample from irradiation position to measuring detector within 3 seconds.

The k-zero method for INAA has also been developed to analyze airborne particulate samples for investigation of air pollution, and crude oil samples and base rock samples for oil field study. Based on developed k0-INAA method, a multi-elements analysis procedures have been applied to simultaneously determine concentration for about 31 elements including Al, As, Ba, Br, Ca, Cl, Cr, Cu, Dy, Eu, Fe, Ga, Hf, Ho, K, La, Lu, Mg, Mn, Na, Sb, Sc, Sm, Sr, Th, Ti, V, Yb, Zn.

3.3. Neutron beam utilization

Only three out of four beam ports are currently utilized for researches and applications. A BGO-HPGe gamma-rays Compton suppression spectrometer installed at the beam port No.2 is used for PGNAA and experimental researches on neutron capture reactions. The filtered thermal neutron beams extracted from the tangential beam port No.3 are aimed at nuclear structure studies, especially for experimental determination of nuclear energy levels and level density in regions below neutron binding energy. The filtered neutron beams at the piercing beam port No.4 with quasi-monoenergies of 24 keV, 54 keV, 59 keV, 133 keV and 148 keV are used for the measurements of neutron total and capture cross sections. In addition, these neutron beams are also applied for practical study on radiation shielding design. Typical research activities using neutron beam of the DNRR are listed below.

3.3.1. Neutron physics and nuclear data measurement:

The following experiments have been carried out at the DNRR:

- Total neutron cross section measurement for ^{238}U, Fe, Al, Pb on filtered neutron beams at 144 keV, 55 keV, 25 keV 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 beams at 55 keV and 144 keV;

- Measurement of average neutron radioactive capture cross section of ^{238}U, ^{98}Mo, ^{151}Eu, ^{153}Eu on the 55 keV and 144 keV neutron beams;

- Measurement of isomeric ratio created in the reaction $^{81}Br(n, \gamma)^{82}Br$ on the 55 keV and 144 keV neutron beams; etc.

3.3.2. Application of 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 spectrometer of summation of amplitudes of coinciding pulses for (n, 2γ) reaction research and for measuring activity of activated elements with high possibility of cascade transitions.

3.4. Education and training

Concerning the utilization of the DNRR for education and training, at present the DNRI offers two types of training course related to reactor engineering: an one-week practical training course for students (undergraduate and graduate) and a two or three-week training course on reactor engineering for professionals (researchers, regulators, engineers, and teachers from universities). The training program of one-week practical course includes introductory lectures, computer code exercises, reactor experimental exercises and reactor facility visit. This training program is aimed at complementing theoretical lectures which the students have learned at the universities. The training program of two or three-week course on reactor engineering comprises introductory lectures, theoretical lectures, computer code exercises, experimental exercises carried out at the reactor and laboratories, and reactor facility visit. The purpose of this training program is to offer the knowledge of reactor engineering for the people who are involves in the national nuclear power programme.

Through VINATOM, the DNRI has also participated in the education of PhD students and master students in the fields of nuclear physics, theoretical physics, analytic chemistry, radio-chemistry, and inorganic chemistry. In addition, the DNRI has also established the bilateral co-operation with the NuHRDeC/Japan Atomic Energy Agency and Bhabha Atomic Research Center (BARC) of India in order to conduct various training courses in the nuclear field.

IV. STRATEGIC PLAN FOR THE NEXT DECADE

The purpose of this strategic plan is to establish a framework that will allow the DNRI to join "*Strategy for Peaceful Uses of Atomic Energy up to the year 2020*" in Viet Nam. The strategic plan has been developed to focus on the safe and reliable operation of the DNRR and the improvement of its utilization in order to meet the needs of the society. In addition, a new research reactor with power level of 15 MW is expected to put into operation between 2023-2025, and therefore, this strategic plan has also taken into account the connection with the strategic plan for the new research reactor project.

4.1. Role of the DNRR in the national policy direction

On 3 January 2006, the Prime Minister signed a decision on launching the "*Strategy for Peaceful Uses of Atomic Energy up to the year 2020*", which determines the objectives and road-map for atomic energy development in Viet Nam on both non-power and power applications.

According to "*Strategy for Peaceful Uses of Atomic Energy up the to 2020*" the DNRI will participate in the project on establishment of a Center for Nuclear Science and Technology (CNEST) with a new 15-MW research reactor. In connection with the project on the first NPP in Viet Nam, the DNRI will also participate in other areas such as environmental monitoring and assessment, site survey, emergency planning, and public information.

4.2. Mission, major and specific objectives

The mission, major objectives and specific objectives are outlined in the Fig. 4. Its major objectives focus on expanding capacity through: 1) maintaining safe and reliable operation of the reactor, and 2) expanding the reactor utilization in order to meet the needs of the society. The plan's first set of specific objectives addresses activities to ensure that the objective of safe and reliable operation of the reactor is reached while the plan's second set of specific objectives focuses on measures to enhance and expand the capability of reactor utilization in the next decade.

4.3. Detailed action plans

4.3.1. Implement the effective programme for ageing management of the reactor

To achieve this specific objective, the methodology used to detect and evaluate ageing degradation and countermeasures used for prevention and mitigation of ageing degradation will be continued to improve. In addition to updating of the ageing management programme for the DNRR, other safety documents will also be updated to maintain their conformity with the actual status of the reactor.

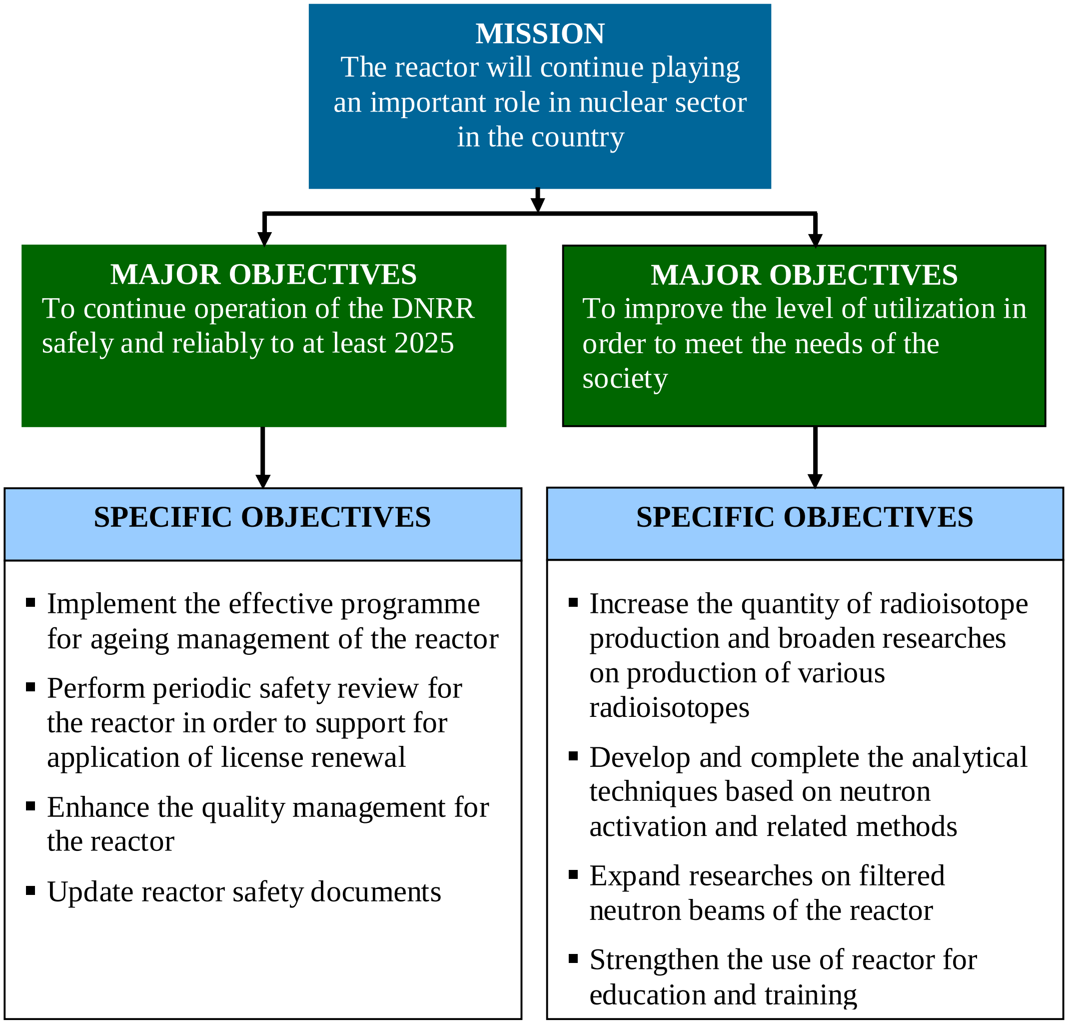

Fig. 4: Strategic plan for the DNRR.

To cope with ageing degradation of SSCs important to safety, the measures such as mitigation, refurbishment or replacement of some components/systems will be carried out in stages 2017-2020, namely:

- Beam ports: enhancement of ensuring the quality of the reactor water in order to mitigate the development of defects due to corrosion;
- Electric power system: replacement of the existing transformer system by a new one;
- Reactor cooling loops: re-design and replacement of the existing pump of primary loop by a new one, upgrading the cooling tower.

4.3.2. Perform periodic safety review for the reactor in order to support for application of license renewal

After fulfillment of full core conversion from HEU to LEU fuels for the DNRR, the license for operation and utilization of the reactor with the validation of the 10-year duration was granted on 7 February 2013.

For the purpose of application of license renewal, the periodic safety review of the DNRR will be conducted in years 2018-2022 comprising 4 phases: (1) Preparation of the PSR project (2018 -2019), (2) Conduct of the PSR (2019-2021), (3) Regulatory review (2019-2021) and (4) Finalization of the integrated implementation plan (2020-2022). The safety assessment of the reactor will be based on the safety factors as recommended in the IAEA Safety Guide.

4.3.3. Enhance the quality management for the reactor

The enhancement of quality management for the DNRR will focus on the following work:

- Continue to improve and complete the existing quality assurance programme of the DNRR based on the annual assessment of the results of reactor operation and utilization, staff quality, completeness of safety documents, record keeping, etc.
- Perform a gap analysis to move from the management system based on quality assurance programme to the integrated management system according to IAEA guidance.

4.3.4. Update the the reactor safety documents

This objective aims at ensuring safe operation and implementing the effective ageing management for the DNRR. The updating of safety documents is to maintain their conformity with the actual status of the reactor and reflect modifications of existing experimental devices and systems. The updating will consist of safety analysis report, operational limits and conditions, operating procedures, the emergency plan and decommissioning plan.

4.3.5. Increase the quantity of radioisotope production and broaden researches

The increase of the quantity up to about 550 Ci per year of radioisotopes and broadening of researches on production of various radioisotopes (such as Mo-99, Y-90, Ho-166, Lu-177 and Ir-192) will be a priority in the next ten years. To achieve the objective of increasing the radioisotope quantity, the reactor operation regime of 150 hrs/cycle instead of 130 hrs/cycle at present will be applied and the facility upgrade for RI production will also be carried out. The research and production of various radioisotopes on the reactor will also be carried out through the implementation of national research projects in the next few years.

4.3.6. Develop and complete the analytical techniques based on neutron activation and related methods.

Development and completion of nuclear analytical techniques with and without use of reactor and related analytical techniques in order to offer a wide range of materials elemental analysis will continue to pay much attention at DNRI in the next ten years. Especially, the research and development of analytical methods such as cyclic NAA, epithermal NAA, k-zero method in prompt gamma neutron activation analysis (k0-PGNAA) and the improvement of automatization for NAA techniques will be one of the priority issues at the DNRI. This is being carried out under a ministerial research project during the years 2015-2017.

4.3.7. Expand researches on extracted neutron beam of the reactor

Among the activities using filtered neutron beams of the DNRR that will continue to be pursued are:

- Continue to carry out the measurements for neutron physics and nuclear data, and continue to improve the precision and sensitivity for PGNAA technique using the neutron beams extracted through beam port of the reactor;
- Expand the basic and applied researches on extracted neutron beams by developing neutron scattering and neutron radiography facilities.

4.3.8. Strengthen the use of reactor for nuclear education and training program

In order to meet the rising demand in development of human resources for national nuclear power program, the DNRR will continue to play an important role in the nuclear education and training for students from universities and professionals with interest in reactor engineering.

In the next ten years, the DNRI will continue to offer two types of training course utilizing the research reactor as mentioned above: an one-week practical training course and a two or three-week training course on reactor engineering. The reactor will also be used for training staff who will participate in the operation and utilization of the new research reactor of CNEST. Besides, the association with universities in the country and the bilateral co-operation with international organizations will continue to be promoted.

V. CONCLUSIONS

More than 31 years of operation of the DNRR shown that the reactor has been safely operated and played an important role in the use of atomic energy for peaceful purpose in Viet Nam. The reactor has been effectively used for radioisotope production for medicine and industry purposes; application of NAA in geological, crude oil and environment samples; performance of fundamental and applied researches on nuclear and reactor physics; as well as creation of a large amount of human resource with high skills and experiences on application of nuclear techniques in the country.

In order to join actively in the national strategy for peaceful uses of atomic energy and meet the demand of the society, a strategic plan and long-term working plan for the DNRR has been set up to continue its safe operation and effective utilization at least to 2025. After the year of 2025, as the high power research reactor puts into operation, the DNRR will shift its utilization purpose and mainly use for NAA, basic researches, and education and training.

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