INSPECTION AND EVALUATION OF DIGITAL INSTRUMENTATION AND CONTROL SYSTEM OF THE DALAT NUCLEAR RESEARCH REACTOR

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Abstract

The Dalat Nuclear Research Reactor (DNRR) was reconstructed from the 250 kW TRIGA Mark II reactor built in early 1960s. The reconstruction work was started in March 1982 and the first criticality of the reconstructed reactor was achieved on 1st November 1983. The reactor has been operating at a nominal power of 500 kW since March 1984. The original analogue Instrumentation and Control (I&C) system of the DNRR was designed and manufactured by the Joint Stock Company "Specialized Scientific Research Institute for Instrumentation Engineering" (JSC *SNIIP*) which from 1994 re-named as JSC "SNIIP-SYSTEMATOM" (SSA). In April 2007, on the basis of the concluded Contracts with the Vietnamese Side and IAEA, SSA has made replacement and commissioning of the initiating part of Control and Protection System (CPS) of the reactor by the ASUZ-14R complex (*Complex of Equipment for Control and Protection System ASUZ-14R for Dalat research reactor*).

Up to now, although the ASUZ-14R complex has been operated for more than 11 years with high reliability and low failure rate but according to the manufacturer's technical criteria, its appointed service lifetime has been expired. Therefore, it is required to carry out works of its inspection and re-calibration for purposes of technical evaluation and possible extension of the specified lifetime. These works were performed by the SSA specialists and the DNRR staff in April, 2019.

This paper summarizes the obtained inspection and evaluation results from the above works. In addition, some issues related to the operation experience of the ASUZ-14R Complex since its installation in 2007 are also presented.

Keywords: *Dalat Nuclear Research Reactor (DNRR), Instrumentation and Control (I&C), ASUZ-14R complexfor DNRR, Control and Protection System (CPS).*

I. INTRODUCTION

The DNRR is a light water moderated and cooled, pool-type reactor fueled with 19,75 % enriched VVR-M2-type U-Al alloy. The reactor nominal power is 500 kW. At full power, the maximum thermal neutron flux in the reactor core is about 2.1×10^{13} neutrons/cm^2.s. The original reactor was an US-made 250-kW TRIGA Mark II, which was commissioned in 1963 and operated till 1968. After that, the reactor was in extended shutdown state from 1968 to 1974, in 1975 the fuel elements were unloaded from the core, shipped back to US, and the operation was ceased.

The present facility was modified and upgraded by the former Soviet Union in 1983. The modifications and upgrading resulted in an unique facility namely IVV-9 reactor with 6.2 m deep and 2 m diameter tank of a TRIGA MARK II reactor. The reactor went criticality for the first time in November 1983, while the regular operation started on March 1984.

The original analogue instrumentation and control (I&C) system of the DNRR [1] was put into operation in November 1983. In general, it was reliable and had proven its capability to ensure safe reactor operation. After many years of operation, the obsolescence of equipment, the unavailability of spare parts, an increased failure rate of the I&C system leading to frequent reactor shutdowns, and long repair periods were the main reasons for its modification [2]. After the second modification, all of its analogue neutron measurement and signal processing parts were replaced by the Control and Protection System Equipment complex (namely ASUZ-14R) which was designed and manufactured by the SSA. The digital I&C system was successfully installed and the DNRR has been operating with the ASUZ-14R complex since April 2007.

After more than 11 years of safety and reliability operation, according to the recommendations of SSA specified in the ASUZ-14R data sheets [3], it has to be inspected and re-calibrated for purposes of technical evaluation and possible extension of the specified lifetime. These works were performed by the SSA specialists and the DNRR staff in April 2019 in the framework of the MOST's research project during 2018 - 2019. Main obtained results are presented and discussed in this paper. In addition, some issues related to the operation experience of the ASUZ-14R Complex since its installation are also presented.

II. DESCRIPTION OF ASUZ-14R COMPLEX

2.1. Basic technical design principles and system features

Reactor control and protection systems as systems important to safety should meet a number of specific requirements aimed at achieving high reliability and fault-tolerance in capability of a system to perform safety functions [4, 5]. The reactor protection system should have redundancy, predictable failure state and fail-safe design, meets criterion of independence (functional independence, electrical isolation, physical separation, etc.). Taking into account all mentioned above requirements, SSA has designed and developed the integrated Control and Protection System Equipment for Nuclear Research Reactor (CPSE-NRR) complex [6] in which, the basic unit of the system is integrated reactor protection channel which has all instrumentation to process the full set of process parameters and signals needed to perform reactor protection and control functions. The ASUZ-14R is only a simplified version of the CPSE-NRR complex with all of reactor protection, control and monitoring functions are performed by the same of detection device and processing units. The structure of the ASUZ-14R Complex is described in the section below.

2.2. Structure of ASUZ-14R Complex

The ASUZ-14R complex (**Fig. 1**) consists of three detection devices, three Control Safety System (CSS) channels, a Reactor Data Display System (RDDS) which includes graphic and digital displays, a control console and an archiving, diagnostics and recording (ADL) equipment.

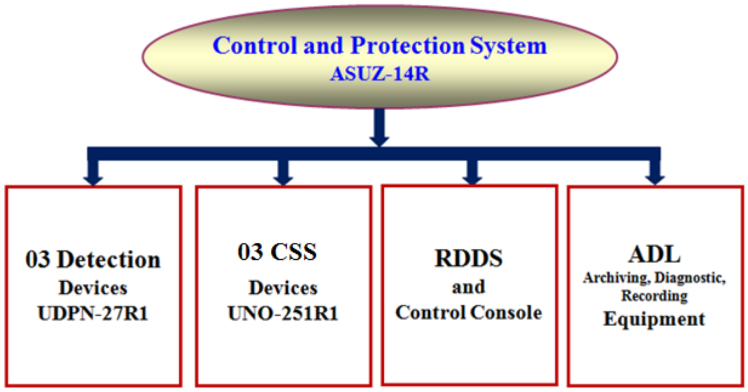

Fig. 1. Block diagram of ASUZ-14R complex

It is intended for fulfillment of control, keeping and emergency stop of chain fission reaction and combines both protection and control functions of safety and normal operation of the DNRR, its structural diagram is shown in **Fig. 2**.

The ASUZ-14R complex carries out its functions by means of the following channels and equipment:

- Channels for monitoring reactor power and period by thermal neutron flux density (NFME channels);
- Channels for monitoring process parameters (PPME channels);
- Channels for logical processing of signals from NFME channels, from technological and supporting systems for generation of control signals for the protection safety system, and for normal operation system (SLPE channels);
- Channel for automatic power regulation (APR channel);
- Channels for reactivity monitoring (RME channels);
- Channels for monitoring the control rods position (RPME channel);
- Information channels for displaying operative information at the control panel;
- Buttons and keys on the control panel;
- Equipment for archiving, diagnostics, and recording (ADR equipment).

The designed structure of the ASUZ-14R complex is based on a functionally and structurally designed integrated unit of the control safety system (CSS), also called the UNO-251R1 cabinet (UNO), consisting of a combination of independent different channels fulfilling the functions of emergency protection, control, checking, and monitoring. Each CSS channel is functionally independent from other channels in the ASUZ-14R complex.

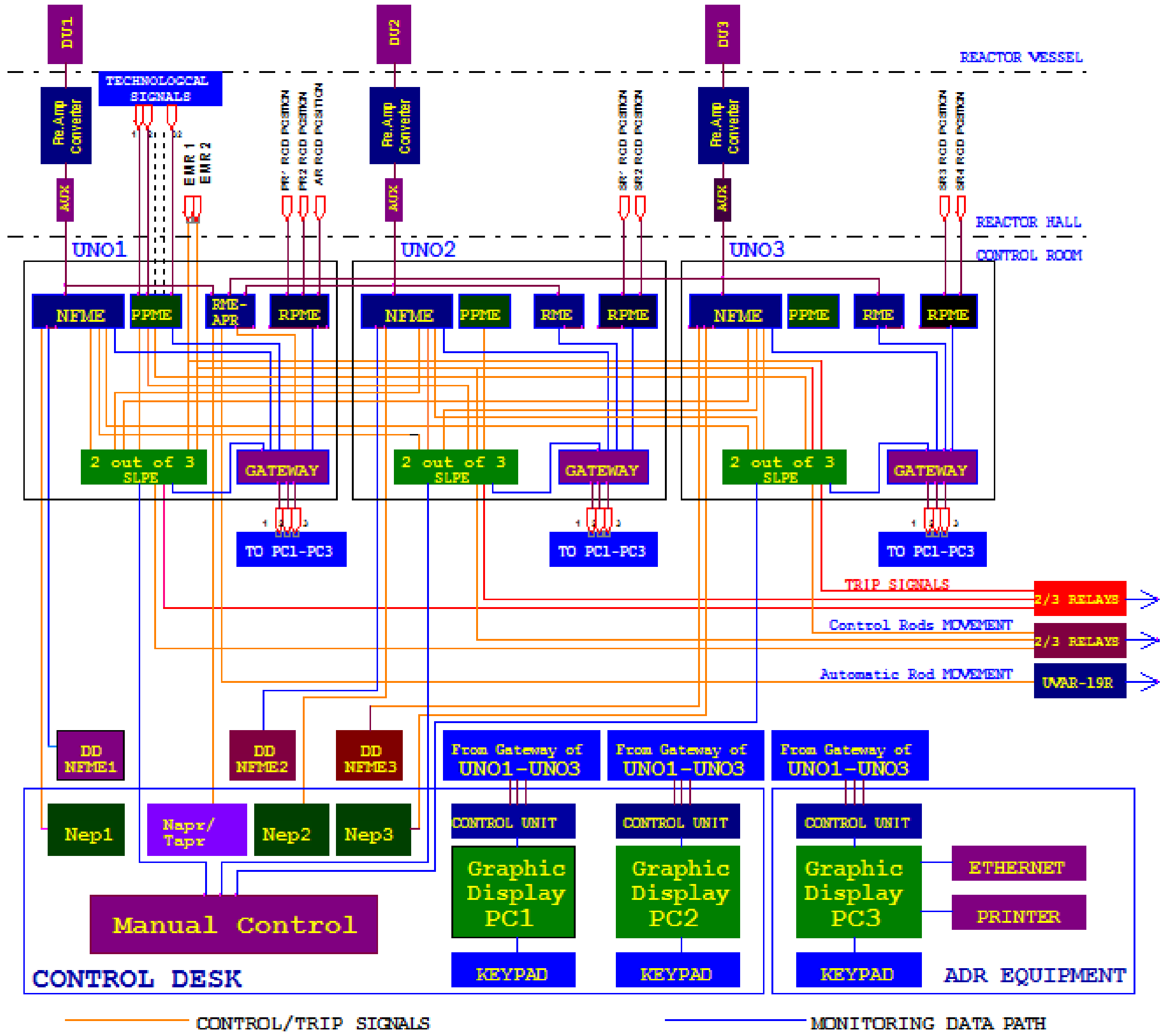

Fig. 2. Structural diagram of ASUZ-14R complex

Note:

DU- detection unit of neutron flux; **AUX-** auxiliary unit; **NFME-** unit for monitoring reactor power and period by thermal neutron flux density; **PPME-** Unit for protection and monitoring by thermal-hydraulic parameters; **SLPE-** unit for logical processing of signals from NFME channels, from technological and supporting systems for generation of control signals for protection safety system, and for normal operation system; **RME/APR-** unit for reactivity monitoring and automatic power regulation; **RPME-** unit for monitoring of control rods position; **GATEWAY-** unit for accumulation and receipt/transfer of information; **DD-** digital display of NFME; **Nep-** unit for setting threshold value of emergency protection by power; **Napr/Tapr** – unit for setting preset values of power and period for automatic power controller.

There are three unmovable multi-range detection units (DU). These DUs combine up to three neutron detectors with high/medium/low sensitivity, and could withstand high neutron flux and gamma dose. Each detector of the DU has an output (pulse or current) which is connected to the corresponding signal conditioner: amplifier for pulse channels and current-to-pulse converter for current channel. Then all signals in the pulse form are processed by a digital controller (NFME controller) which automatically selects active range, calculates reactor neutron power and period, and compares them with safety value settings to produce channel's warning and emergency signals.

NFME controller has individual serial data interfaces with each of three logic units (one in the same UNO and to other UNOs) and with the gateway of the same UNO, each serial data line has electrical isolation. Warning and emergency signals as well as ready/fault (and other signals needed for reactor protection and control) are sent to logic processing units (SLPE). The same information together with all other channel data (reactor power, period, set points, active range, etc.) sent to the UNO gateway to transfer to the graphic displays (PC1, PC2 and PC3) for local monitoring in the control room (**Fig. 3**).

Fig. 3. Main console in the control room of DNRR

The SLPE unit of each UNO receives data from NFME controller of the same UNO and from two other UNOs, compares it and, if it's found an emergency condition at least in two channels, produces common trip signal. Trip signals from three UNOs are compared again with each other on external 2-out-of- relay unit and finally activate safety action. All three UNO logic units process the full set of binary signals needed for reactor protection and control: warning and emergency signals from every source (nucleonic, process parameters important for safety, SCRAM buttons, etc.), keys and buttons of reactor control system, control rod's limit switches and others. Each logic unit forms signals to drive reactor control rods, to switch on/off automatic regulator and other control signals taking into account all interlocks and reactor operation modes specific the research reactor. Same logic units drive signaling indicators which duplicate displays in control room with most important safety system status information, and also drive sound alarms. All output signals (except channel operation status for signaling) from UNO logic units go to external 2-out-of-3 relay unit, resulting signals connected to corresponding drives. Described ASUZ-14R structure allows processing various numbers of independent redundant measurement channels of selected parameter.

The APR channel is placed in the UNO1. It can not only stabilize the reactor power at a given level, but also automatically change the reactor from one power level to another, both in the direction of increasing power and its reduction. The change in power can be carried out with preset period (35 and 70 seconds), and with maintaining a constant (fixed) rate of change in the neutron (thermal) power. The APR may support both operation modes and switch between them automatically depending on reactor power level. The regime with the maintenance of a constant rate of power change allows reducing the thermal load on reactor elements.

The gateway in UNO is a part of monitoring system. It receives data from all UNO modules via serial data interfaces with full information about measured parameters, system settings, actual states of every input signal, internal system variables values. Gateways of each UNO are connected to the main monitoring system (main console) via redundant RS-422 interfaces. RS-422 switches distribute the information between three displays (two on main console and other on the cabinet of ADL equipment). Complete information on all control channels and the status of the control and protection system are displayed on each of the three displays. All information are presented on several slides; slides are switched on each display independently and can be adjusted depending on the current reactor operation mode or the preference of the reactor operator.

III. INSPECTION AND EVALUATION OF ASUZ-14R COMPLEX

Base on the Inspection Program [7], the ASUZ-14R Complex was inspected and re-calibrated by the SSA specialists and the DNRR staff in April, 2019. These works consist of: review on statistic and categorization of the ASUZ-14R failures, visual inspection, calibration of measuring channels, revision of spare parts and testing all its functions during reactor operation on power levels less than 20 % P nomal. An ASUZ-14R technical evaluation report [8] was issued and submitted to the DNRI's Director Board following the inspection program. Its main offered conclusions are as follows:

3.1. Statistic and categorization of the ASUZ-14R failures

After more than 11 years of its operation, ASUZ-14R complex operation time nearly matches the reactor operation time. Reactor operation time for every year since 2007 is shown in **Table 1** below.

Table 1. Reactor operation time and number of campaigns

Year of operation	Time of operation (hour)	Number of campaigns
2007	1131	12
2008	1300	13
2009	1380	13
2010	1338	13
2011	511	5
2012	1034	10
2013	1040	10
2014	1460	12
2015	1500	12
2016	1570	12
2017	1499	12
2018	2200	14
Up to April 2019	400	3

Total operation time (approx.): 16 500 h (1,9 years)

Up to now, ASUZ-14R complex has been operated with high reliability and low failure rate. Its statistic of failures is shown in **Table 2.** Failures of ASUZ-14R can be categorized into 5 main types:

- Failure of functional modules/units/equipment;
- Loss of position indication of control rods (when other information on the main screen such as reactor power and period are in normal values);
- Loss of all information from Process Instrumentation System (PIS) on the screen of technical parameters in the same time;
- Occurrence of abnormal signals of on the screen of signalization;

- Loss of information by lightning.

Abnormal and malfunction phenomenons mentioned above were not caused by the true signals. The detailed report on statistic and categorization of the ASUZ-14R failures is attached as a separate document [8].

Table 2. Statistic of failures of ASUZ-14R

Year	ASUZ-14R lifetime, years	Amount of failures
Since April 2007	Put in operation	8
2008	1	6
2009	2	7
2010	3	2
2011	4	3
2012	5	8
2013	6	7
2014	7	3
2015	8	6
2016	9	4
2017	10	5
2018	11	4
2019	12	2

3.2. Visual Inspection

- Cases of cabinets and units have good condition, no significant damages or degradation were found;
- Wires and cables, connectors are in good condition, no significant damages or degradation were found;
- Electronic boards, backplanes are in fine condition, no corrosion or soldering degradation was found, connectors have no corrosion or oxidation.
- Several electronic boards with damages or damaged electronic parts were found in UNO cabinets (mostly tantalum capacitors).

3.3. Calibration

- Calibration of measurement channels of ASUZ-14R Complex was performed on April 2-4, 2019. Nucleonic instrumentation calibration results are positive**,** it is acceptable for use as a part of CPS of IVV-9 RR;
- Calibration of process parameters monitoring channels of ASUZ-14R Complex was performed on April 2, 2019. Process parameters monitoring channels of ASUZ-14R Complex are functioning properly and ready for operation as a part of CPS;

- Calibration of Control rod position monitoring channels of ASUZ-14R Complex was performed on April 3, 2019. Control rod position monitoring channels calibration results are positive, channels are acceptable for use as a part of CPS.

3.4. Revision of spare parts

- Most of spare modules of ASUZ-14R Complex are in good condition and ready for use;
- Some failed/used modules were checked and repaired.

3.5. Reactor start-up and operation for evaluation of nucleonic instrumentation

- Reactor was run normally according to the Working program of reactor start-up and operation for ASUZ-14R inspection purpose on April 4, 2019. Settings and adjustments of nucleonic instrumentation were evaluated during reactor startup.
- The operation condition of nucleonic instrumentation of ASUZ-14R is acceptable. Whole range of neutron flux deviation within the reactor power range from reactor stop state to 120 % Pnom is covered by nucleonic measurement channels of ASUZ-14R Complex.
- Nucleonic measurement equipment operates within specified characteristics.
- Quality of automatic power regulation at various power levels was evaluated. Automatic Power Regulator of ASUZ-14R has shown good functioning in both modes of operation (power increase/decrease and stabilization).

IV. CHALLENGES AND LESSONS LEARNED

- The ASUZ-14R design originates from the begin of 2000 years and most of the electronic equipment, especially the process computers used in monitoring system (gateways, display drives) with additional interface cards were already outdated. Moreover, its functional modules were not manufactured, the problem of spare parts availability and compatibility became significant.
- Trouble shooting is much more difficult as failures can both occur in hardware and software. Some errors were localized within a short time, some other errors were more difficult to overcome. Software is almost inaccessible for the DNRR staff and can only be handled with close cooperation of the SSA.
- ASUZ-14R complex is designed with the use of processor means in the emergency protection control and reactor monitoring. Therefore, there is a risk of introducing common mode failures through the software. This risk can be reduced through the proper use of software verification and validation (V&V) and diversity. But until now, this work has not been carried out yet.
- Although ASUZ-14R complex provided its functions satisfactorily during the past years, the DNRR's I&C is facing challenges in with ageing and obsolete components and equipment such as: relay blocks in control rod driver and "2 out of 3" vote logic, control rod actuator. With license renewals, the long-term operation and maintenance of obsolete I&C systems may not be a cost-effective and reliable option. The effort needed to

maintain or increase the reliability and useful life of existing I&C systems may be greater in the long run than that of modernizing I&C systems or replacing them completely with new digital or hybrid systems.

- With the reactor protection system triggers warning (alarm) signals (from PIS) on the basis of the measurement of the following parameters:
  - Temperature of the water in the reactor pool-coolant inlet temperature;
  - Temperature of the water in the reactor pool-coolant outlet temperature;
  - Flow rate of primary circuit water;
  - Flow rate of the secondary circuit water ;
  - Level of the water in the reactor pool.

  ASUZ-14R complex does not provide for the adjustment of the set points for these parameters. The set points are built-in the system and could be modified by correction of the software that is only accessible to the manufacturer. The scram action that is based on the last three parameters is generated according to "1 out of 1 logic". The redundancy criterion is not applied in those cases and, therefore, there is no design provision for the protection against a single failure.

V. CONCLUSION

The DNRR has been safely operated and effectively utilized for more than 35 years. Till now, ASUZ-14R complex has operated with high reliability and low failure frequency for the safety of operation in all reactor operation modes: during reactor start-up, when keeping at set power level, during refueling (fueling), at occurrence of emergency situation and at shutdown reactor.

A strategic plan for the DNRR is needed and a plan for the refurbishment, upgrade, and modernization of its technological systems, including ASUZ-14R complex is still necessary in order to continue safe operation and effective utilization of the DNRR to at least 2030. To ensure these goals, the DNRR staff has to master the DNRR's I&C system not only for managing and safety operation of the reactor but also for the development of human resources in serving new research reactor project in the years to come.

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Kiểm tra và đánh giá hệ điều khiển lò phản ứng nghiên cứu hạt nhân Đà Lạt

Tóm tắt

Lò phản ứng nghiên cứu hạt nhân Đà Lạt (DNRR) được khôi phục lại từ lò phản ứng TRIGA Mark II 250 kW, xây dựng từ những năm 1960. Công việc khôi phục được bắt đầu vào tháng 3 năm 1982 và đạt trạng thái tới hạn đầu tiên vào ngày 1 tháng 11 năm 1983. Lò phản ứng đã và đang hoạt động với công suất danh định 500 kW từ tháng 3 năm 1984. Hệ thống điều khiển ban đầu của lò phản ứng hạt nhân Đà Lạt được Công ty SNIIP-SYSTEMATOM (SSA) thiết kế và chế tạo. Vào tháng 4 năm 2007, thông qua dự án của IAEA và kinh phí trong nước, SSA đã thay thế hệ điều khiển lò phản ứng hạt nhân Đà Lạt bằng hệ ASUZ-14R.

Cho đến nay, mặc dù hệ ASUZ-14R đã hoạt động được gần 12 năm với độ tin cậy cao và tỷ lệ sai hỏng thấp, nhưng theo yêu cầu kỹ thuật của nhà sản xuất, thời hạn sử dụng của nó đã hết. Mặt khác, hầu hết các thiết bị điện tử, đặc biệt là các máy tính đã lỗi thời và không còn được sản xuất. Do đó, cần phải thực hiện các công việc kiểm tra và hiệu chuẩn lại để đánh giá kỹ thuật và có thể kéo dài tuổi thọ quy định. Những công việc này được thực hiện bởi các chuyên gia SSA và nhân viên của Viện Nghiên cứu hạt nhân vào tháng 4 năm 2019.

Bài viết này tóm tắt các kết quả kiểm tra và đánh giá thu được từ các công việc trên. Ngoài ra, một số vấn đề liên quan đến kinh nghiệm vận hành của hệ ASUZ-14R kể từ khi lắp đặt vào năm 2007 cũng được trình bày.

Từ khóa: Lò phản ứng nghiên cứu hạt nhân Đà Lạt (DNRR), Thiết bị và điều khiển (I & C), hệ ASUZ-14R cho DNRR, Hệ thống kiểm soát và bảo vệ (CPS).