Instrumentation & control system for “SAMOP” reactor experimental facility

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Abstract. The instrumentation and control system (ICS) for a subcritical assembly for molly-99 production (SAMOP) reactor experimental facility is presented in this paper. The system is designed based on the defense-in-depth concept. SAMOP reactor is fuelled by uranyl nitrate and driven by an external neutron source from Kartini reactor beam-port. The ICS was designed using 2 neutron detectors of fission chamber and compensated ionization chamber types and provided with a safety rod made from boral used for shutting-down the reactor in emergency condition. The method used for reactor protection system is based on hardwire with a fail-safe principle. The safety rod drive mechanism is designed by using rack and pinion, and provided by the safety button of key release and electromagnetic holder status.

1. Introduction

The SAMOP reactor experimental facility is being constructed at the Centre for Accelerator Science & Technology (CAST), National Nuclear Energy Agency (BATAN) [1,2]. The similar facility is being developed by SHINE which plans to produce at least one-half of the U.S. need for ⁹⁹Mo by 2016 [3,4].

The SAMOP experimental facility as a test facility which use an external neutron source from the Kartini TRIGA reactor [5,6]. It is expected that the SAMOP system will reduce much less waste than current ⁹⁹Mo production methods. The use of subcritical aqueous homogenous reactors driven by accelerators presents an attractive alternative for producing ⁹⁹Mo. In this method, the medical isotope production system itself is used to extract ⁹⁹Mo or other radioisotopes so that there is no need to irradiate special targets. In addition, it can operate at much lower power compared to a traditional reactor to produce the same amount of ⁹⁹Mo by irradiating targets [7,8]. Study to produce ⁹⁹Mo with activation method using TRIGA reactor have also been done to fulfill the need of ⁹⁹Mo as ⁹⁹mTc generator [9-11]

The SAMOP experimental facility as a subcritical reactor system actually does not need a reactor power control system. Albeit, it is provided by a central control rod for controlling the subcriticality levels. The instrumentation and control system (ICS) of SAMOP experimental facility is therefore, emphasized to the neutron flux and monitoring system of subcriticality level and the reactor protection system as the safety system. The aim of the paper is to describes of how the ICS of SAMOP reactor is designed and implemented with emphasizes on how the neutron flux detection are prepared and tested for its operation.
2. Materials and methods

2.1. Description of SAMOP Experimental Facility
The SAMOP experimental facility as a test facility which use a continuous external neutron source from the radial beam-port of Kartini reactor. The external neutron source has been identified as thermal neutron in order of $10^6 - 10^7$ n/cm$^2$ s [5,6]. The SAMOP core consists of annular cylindrical tube containing uranyl nitrate [UO$_2$ (NO$_3$)$_2$] or UN as fuels and target, surrounded by ring of UO$_2$ (NO$_3$)$_2$ tubes. The TRIGA fuel elements is loaded in the ring together with UO$_2$ (NO$_3$)$_2$ tubes to increase neutron multiplication factor. The enrichment of all UN used in SAMOP is 19.75% $^{235}$U.

The SAMOP reactor core and reflector is located in the cooling tank. The SAMOP experimental facility is provided by an instrumentation and control system in such that if there is a criticality indication, the boral control rod neutron absorber will dropped automatically inserted to the SAMOP reactor core. The layout of SAMOP experimental facility reactor is shown in Figure 1.

![Figure 1. Location of SAMOP in the Kartini reactor](image)

The schematic diagram of basic SAMOP-ICS is described in Figure 2. Instrumentation and control system (ICS) of SAMOP experimental facility consisted of the neutron flux and monitoring system (neutron detectors) and neutron absorber /control rod drive mechanism, process computer and reactor parameter display system.

![Figure 2. The diagram basic concept of SAMOP instrumentation & control system](image)
2.2. Requirements of SAMOP instrumentation & control system

The main requirement of the ICS of SAMOP experimental facility is that the ICS capable to monitor and to maintain the subcriticality levels of the SAMOP reactor. The ICS should be implemented using a neutron absorber (control rod) as a tool to adjust and to maintain the subcriticality levels. The signal processing module for signal from neutron detector should be based on microcontroller system, and serial communication facility for interfacing with human machine interface (HMI) computer.

The ICS of SAMOP should also be provided with the current monitoring facility, conversion from neutron pulse count rate to subcritical assembly power and period systems, display systems of neutron count rate, neutron detector high voltage (HV), reactor subcritical power, and reactor period. For the safety system, the ICS should generate trip signals if power, period or HV detectors are out of allowed safety limit value. The ICS must be able to monitor the subcriticality level of SAMOP in the loading process of UN fuel. Firstly, the UN fuel is loaded to the annular core, then followed by the Triga fuels and UN-tube loaded into the ring of annular core. The fuel loading steps is done in accordance with procedure for optimum sub-criticality approach. After a higher sub-criticality level (k\text{eff} ~ 0.90) is achieved, then the optimum condition (k\text{eff} ~ 0.98 − 0.99), is approached by adjusting the fuel follower control rod. All requirements are required to full fill specific safety and in accordance with the national regulation [12] as well international regulation [13].

2.3. Performance test of instrumentation system

The performance test of instrumentation system should be done in order to make sure that the neutron monitoring system is working properly. The neutron flux instrumentation systems should be consisted of 2 different type neutron detectors i.e. fission chamber (FC) and compensated ionization chamber (CIC). The FC detector is design for wide range neutron detection system, from very low up to the highest neutron flux levels, whiles, the CIC detector is dominantly for neutron flux detection at the higher level.

The SAMOP neutron detection and instrumentation system test procedures cover the scope, sequence and expected results of these tests are prepared in appropriate detail and in accordance with the quality assurance requirements. The results of all neutron instrumentation systems tests, will be used for further ICS integration and its test performances.

3. Result and discussion

The ICS of SAMOP has been implemented with refer to the SAMOP ICS requirements, such as shown in Figure 3. The ICS constitute of the neutron flux and monitoring system (1) and (3) and the reactor protection system or RPS (2) as the safety system, reactor operation parameters monitoring systems (4), data acquisition system (4) and HMI or Human Machine Interface (6). The ICS is essentially a monitoring system designed based on supervisory control and data acquisition (SCADA), so the system consists of local control, master control and database. In addition, this system separates software-based control instrumentation systems and hardwired-based protection systems.

The neutron flux detection and monitoring system use fission chamber (FC) and compensated ionization chamber (CIC). The reactor protection system (RPS) uses the linear power channel and the log rate trip signals as the trip parameters to prevent reactivity-induced accidents. The fuel follower control rod absorber (FFCR) absorber is installed in central of reactor core. The FFCR made of boron aluminium (boral) tube followed by UN tube with the function to adjust or to control the subcriticality level. The RPS signal is connected to FFCR drive mechanism as a reactor safety system.

The main goal of subcriticality monitoring in SAMOP experimental facility is to guarantee a sufficient margin against criticality during all stages of operation of SAMOP experimental facility, this is implemented by using FFCR system. The method used for reactor protection system is based on hardware with a fail-safe principle. The safety rod drive mechanism is designed by using rack and pinion, and provided by the safety button of key release and electromagnetic holder status. Signal coming from fission chamber (FC) and compensated ionization chamber (CIC) neutron detectors, after going through the signal conditioning module and comparator, generating neutron flux data and trip signals that will be read by the analog input module, data acquisition and protection system.
The status trip occurs at high voltage (HV) FC (HV <300 volts), CIC (HV <550 volts) and the neutron flux rate status (flux > 10^5 count/ second) are acquired using the digital input acquisition module and the trip status is displayed on the trip indicator light on the console control. The trip circuit of the SAMOP ICS as a hard wire's reactor protection system, which works automatically based on the fail-safe principle is shown in Figure 4. The subcritical assembly trip parameter is shown in Table 1. As an additional security system, the key release button and electromagnetic holder status are also installed.

**Figure 3.** The schematic diagram of SAMOP-ICS based on design analysis result

**Figure 4.** Trip circuit (reactor protection system) of SAMOP ICS.
**Table 1.** Source and limiting condition of reactor trip initiation.

| Trip actuation | Limitation | Range of trip signal |
|----------------|------------|----------------------|
| HV CIC detector | HV < 550 volt | Standard TTL |
| Cps CIC detector | Cps > 10^5 (I > 10^{-5} A) | Standard TTL |
| HV FC detector | HV < 300 volt | Standard TTL |
| Cps FC detector | Cps > 10^5 | Standard TTL |
| Watchdog CRIO | CRIO hang /not responding | Standard TTL |
| Reset trip | manually | Standard TTL |
| Manual SCRAM | manually | Standard TTL |

The performance test of FC and CIC detectors as neutron flux detection instrumentation systems have been done with a schematic diagram such as shown in Figure 5. The PuBe isotopic neutron source was used for this purpose as well as neutron source from the Kartini reactor. The HV for FC and CIC were set at 510 V and 560 V respectively. The test results shown that the sensitivity of CIC detector have a good performance i.e. 1.65 \times 10^{-14} A/nv, whiles the sensitivity of FC detector is 0.004 cp/nv, slightly lower compared than general FC detectors [14]. The CIC test result was in good agreement with the standard performance of such kind of detectors [15,16]. The CIC sensitivity and its correlation with Linear Power Channel (LPC) module as function of Kartini reactor power level (neutron flux) where CIC is located at about 2.5 m from the outer reactor core is shown in Figure 6. It is shown that the LPC module has a good linearity.

![Schematic diagram of FC/CIC performance test](image)

**Figure 5.** Schematic diagram of FC/CIC performance test

![CIC sensitivity and performance of linear power channel](image)

**Figure 6.** The CIC sensitivity and performance of linear power channel

The safety rod drive mechanism is being installed as well as the instrument rack (console). At a whole it is expected that the ICS is ready to support the commissioning of SAMOP reactor experimental facility at the beginning of 2019.
4. Conclusion

The instrumentation & control system of SAMOP experimental facility have been designed using 2 neutron detectors of fission chamber and compensated ionization chamber types, and provided by a fuel follower control rod absorber in the central of reactor core to control subcriticality level. The instrumentation system has been tested and gives a good performance.

5. References

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