DESIGN AND DEVELOPMENT OF FAST PNEUMATIC TRANSFER SYSTEM (PTS) FOR INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS AT JORDAN RESEARCH REACTOR

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ABSTRACT

A pneumatic transfer system (PTS) is one of the important types of equipment used for the neutron irradiation of a target material for an instrumental neutron activation analysis (INAA) in a research reactor. In particular, the rapid pneumatic transportation of an irradiation capsule is essential for an accurate measurement of a short half-life nuclide. Three types of PTSs for the NAA facility at the Jordan Research & Training Reactor (JRTR) were newly developed for a functional improvement involving a manual and an automatic system equipped with a programmable logic controller, software, and thirteen devices used to facilitate the optimal operation of the system. In this paper, the designs and construction of these PTSs, the operation and control of the system are described. In addition, functional and operational tests of the system were carried out as one of the basic requirements and characteristic parameters, the results of which were reported to provide user information as well as the management and safety of the reactor.

1. Introduction

The development of the Jordan Research and Training Reactor (JRTR), including the neutron activation analysis facility (NAAF), was launched by KDC (KAERI/DAEWOO Consortium) in 2010. The NAAF, as a research reactor utilization facility, generally consists of an NAA laboratory for sampling and sample preparation, pneumatic transfer systems (PTSs) for sample irradiation with reactor neutrons, and gamma-ray spectrometric equipment for data treatment for an instrumental neutron activation analysis (INAA). A reactor neutron activation analysis has an inherent advantage of being a non-destructive, simultaneous, multi-elemental analysis with a high accuracy and sensitivity. In contrast to other analytical methods, further advantage of an INAA is a simple sample preparation and manipulation of samples for radio-activation under a radiation safety control system. There are several methods and neutron irradiation facilities for activation of a sample in many research reactors around the world. The pneumatic transfer system (PTS) is one of these facilities in such a research reactor. This system may be helpful for INAA users, including beginners. It creates a different functional assembly according to the purpose and needs of the utilization, and an alternative design is possible according to the constraints faced under the reactor conditions. The design requirements of a PTS are also based on parameters such as the neutron flux and distribution, the temperature and gamma heating of an irradiation site, a cooling of the irradiation tube, the transportation speed, the material and type of the irradiation capsule, an activation of the pressured gases, the radiation dose rate, the shielding assembly, the safety of the reactor operation, and so on [1– 6].

In this paper, the design and conception of a PTS, and the facilities used for the irradiation of a target, are described, and the operation and control of these systems and their future applications are presented.

2. Design Concept of PTS

The design of the PTS for the INAA installed at the JRTR was carried out under consideration of the functional and performance requirements such as the irradiation site configuration, interfacing systems, functional components of the PTS, the system performance, environmental conditions, the system maintainability, nuclear and radiation safety, and quality assurance.
There are three PTSs - PTS #1, PTS #2 and PTS #3, for the fast transportation of sample capsules between the NAA laboratory and three respective irradiation positions of the JRTR. Each PTS is controlled either by manual or automatic mode for the transportation of the sample capsule. The PTS at the JRTR for an INAA is a simple shuttle system where a sample capsule is sent to three irradiation holes from a capsule loader in a NAA laboratory using compressed N_2 gas at a pressure between 10 and 50 psi depending on the length of the transfer paths, and returns to each capsule receiver or loader-receiver after the irradiation time is elapsed. The timing of the sample irradiation is carried out manually or automatically using a pushbutton timer of the system controller. Manual timing is involved by actuating an IN and OUT pushbutton. Automatic timing is initiated by the sample capsule actuating a photo-sensor situated at the top of the reactor irradiation tube which starts the irradiation timer. The irradiation time can be selected by the timer pushbuttons from zero to 999.9 seconds, minutes, or hours. When the selected time expires, the sample capsule is automatically transferred to the capsule loader/receiver and/or capsule receiver through a two-way-diverter. Irradiation holes (NAA 1- 3) and the general arrangement which is located in both of the reactor and the service building for the INAA at the JRTR are shown in *Fig. 1*.

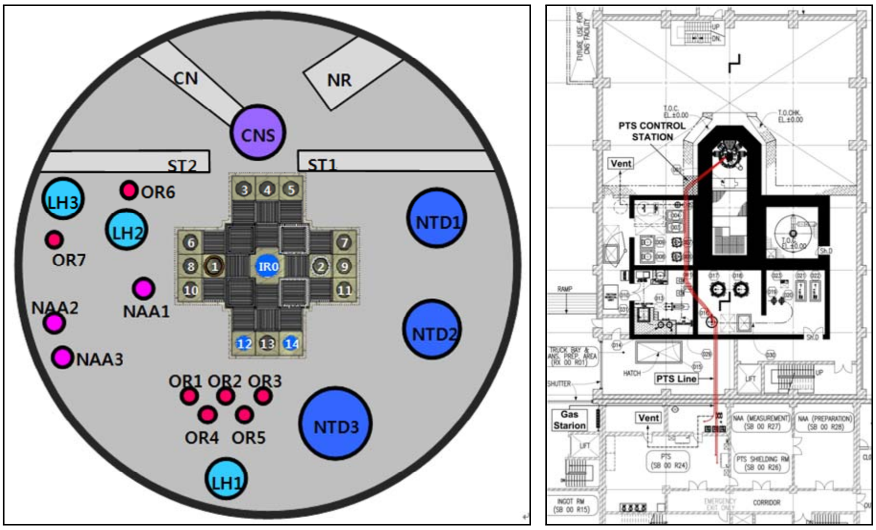

Fig 1. General arrangement and irradiation sites for PTS at the JRTR.

The system is manually and automatically operated by a programmable logic controller (PLC) and personal computer (PC) controller. A schematic diagram of the PTS is presented in *Fig. 2*. The basic structural component consists of five systems as follows: 1) irradiation and transport system (system controller, reactor irradiation tube, transport tube, capsule loader, loader and receiver, capsule receiver, air cushion valve assembly, two-way-diverter, photo-sensor, and high purity polyethylene capsule), 2) N_2 gas supply and purging system of the loaders, loader and receiver, 3) gas exhaust system, 4) emergency withdrawal system, 5) shielding system (loader & receiver, capsule receiver).

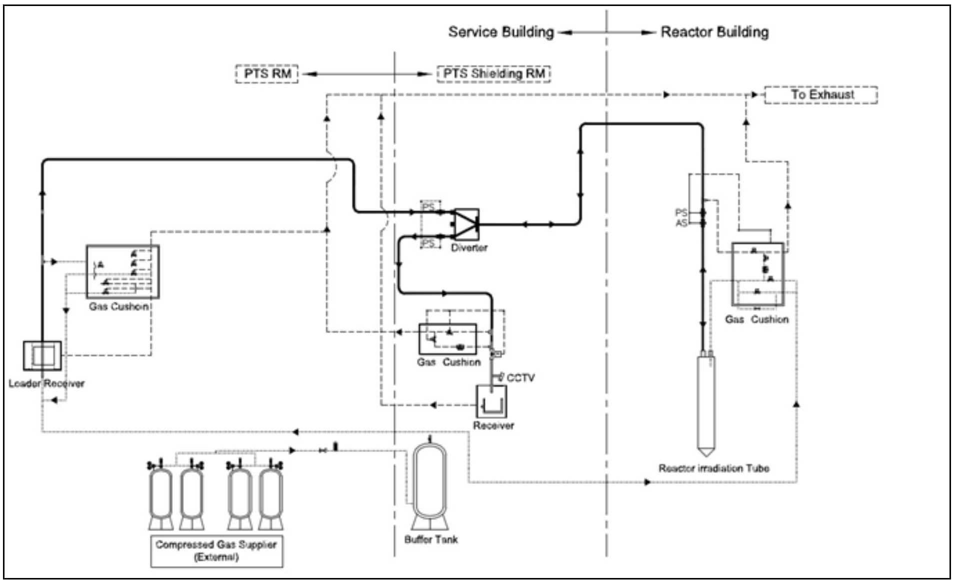

Fig 2. Schematic diagram of PTS.

The sample capsule is transferred at a speed of more than 20 m/s according to the adjustment of the gas pressure regulator. The irradiation times may be set on the PTS control panel either manually or automatically. Normally, reactor irradiation tubes are placed in the reactor region where the total neutron flux is within the 10^{12} ~ 10^{14} $n.cm^{-2}$ s^{-1} with a well thermalized spectrum (high cadmium ratio). The thermal to epithermal neutron ratio and thermal to fast neutron ratio at the selected irradiation sites will be at least several decades for a minimization of the nuclear interferences. The temperature of the reactor irradiation sites will be maintained so as not exceed 50 ℃ for use of polyethylene sample capsules over a long irradiation time.

3. System Description of PTS

The system is controlled using a PLC, a personal computer equipped with a full keyboard, an LED display monitor, a USB port and a CD disk drive. The computer program provides hardware control to the mechanical components of the transfer system, such as the air cushion valve assemblies, diverters, solenoid valves, and photo-sensors. All data such as irradiation and delay times, number of samples, and the irradiation tube to be used are input through a keyboard using a user friendly program. All data for the given batch of samples to be analyzed are written to a disk file. After the run is completed, the number of samples analyzed will be written to the disk and the file will be closed. The controller is associated with the display panel showing the line diagram of the capsule transfer path. LED indicators show the position of each diverter and the location of a capsule in the system at any given time. The main menu of the control logic diagram for operation of the PTS is presented in *Fig. 3*. In the NAA holes of the reflector region of the reactor, the reactor irradiation tube is made of a concentric design with two different diameters of holes in the outside diameter. The out-gas supply is travelled in an annulus around the capsule transfer tube to an opening below the capsule location to allow the capsule to be blown from the irradiation site. Just above the core region, the capsule transfer tube and out-gas supply tube are separated from each other. The capsule transfer tube is a type 6061 aluminum tube of about 30 mm in inner diameter, with a 3 mm wall thickness. The out-gas supply tube is made a type 6061 aluminum tube of about 16 mm in inner diameter, with a 3 mm wall thickness. Both tubes are clamped side by side until above the surface of the pool water, where they are held in a height adjustable mounting plate that fastens to the side of the reactor pool. All materials of the irradiation tube assembly are type 6061 aluminum. A rubber gasket made of EPDM (ethylene-propylene-diene monomer), which is used to connect between the irradiation tubes and/or transfer tubes in the reactor poo, which is validated for its quality under the effect of radiations. A high density polyethylene irradiation capsule with about a 20 cc usable interior volume: about a 20 mm inner diameter, a 70 mm maximum inside length and about 30 mm outer diameter. The capsule transfer lines are a maximum of 50 meters long. The manually operated capsule loader and capsule loader/receiver shielded with about 50 mm thick of lead are attached with high purity N_2 gas purging system to remove air in the loader and/or loader & receiver. The capsule receiving station connected with gas exhaust line is shielded with about 80 mm thick of lead to protect a worker from the radiation emitted by the irradiated sample. The photo-sensors are installed at the upper part of the reactor irradiation tubes, capsule receivers, and side of the two-way capsule diverters. The signal of them are indicated the passage of a sample capsule, and are used to start the irradiation timer during automatic operation mode. Capsules pass in either direction through the diverter. An improved two-way capsule diverter is used as a motor driven sliding mechanism to direct the sample capsules to either of two paths. The connecting tube holder in the diverter is vertically moved with a slider controlled by an electrical motor. The diverter uses an O-ring connection to Teflon sealing surface to protect from a gas leak. Divert positions can be identified by means of reed switches mounted on the slider. Capsules are automatically sent for irradiation using a motor driven vertical diverter, which allows capsules to pass in one direction only, one at a time. A gas cushion control valve assembly has a manual adjustment capability of capsule deceleration rates, as it approaches either the stopper of the reactor irradiation tube or shielded capsule receiver and capsule loader/receiver. The inlet gas pressure system comprises an 12.7 mm NPT filter followed by an 12.7 mm NPT pressure regulator (range, 0 - 125 psig) equipped with pressure gauge to regulate the gas pressure used for capsule transfer. It is necessary to ballast the buffer tank in both of the PTS room and reactor hall for a high purity nitrogen gas supply from outside the service building. All gas used to transfer sample capsules to the reactor, as well as gas used to remove capsules from the irradiation site to capsule loader/receiver, diverter, and capsule receiver, will be exhausted to the building active exhaust duct through a HEPA filter. This system is operated to withdraw an irradiated sample capsule from the reactor irradiation tube and transfer tube by the system controller manually or automatically. The abnormal capsule is directly recovered to the capsule receiver. The radiation detector is measured the radioactivity of the irradiated sample capsule, and is mounted close to each receiver and set to alarm if the radiation fields exceed 1 μSv/h. In this case, the activated sample capsule can be decayed more or drop out of the receiver into a heavier shielded box. The display monitor is located at the top of the system controller.

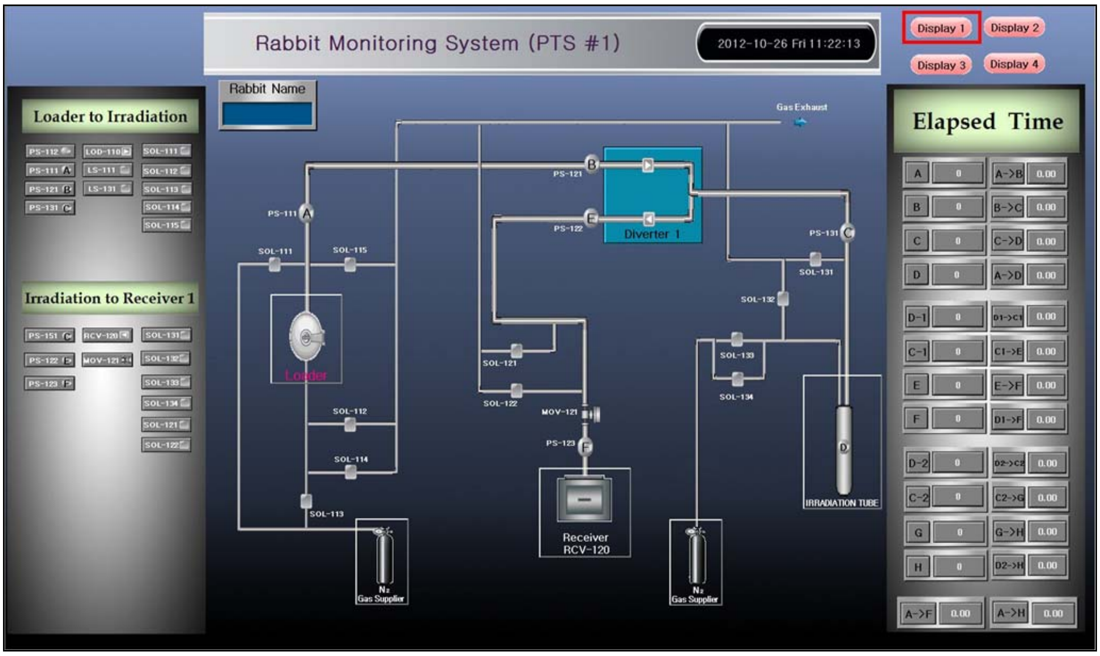

Fig 3. Main menu of PTS controller.

4. Discussion & Recommendations

For the safety of a pneumatic transfer system and a reactor operation, the inner temperature and gamma heating level of a reactor irradiation tube, cooling of an irradiation tube, and its radiation dose rate are important parameters. They also affect the irradiation time, the material and type of irradiation capsule, and the radiation shielding design. Another effect is a loss of volatile trace elements from a sample owing to an overheating of a capsule and sample. PTS and capsule materials should be highly purified to be below 1 mg/kg for their trace element contents. After an exposure to a neutron fluence of about 10^{19} n.cm^{-2} and a decay of one week, the radiation dose rate at the surface of an irradiation capsule was not significant [7]. For example, a graphite capsule can be used repeatedly and irradiated for as long as possible, if it is not contaminated on its inside. For an accurate analysis, the transport time of a capsule in PTS systems should be pre-checked. In particular, the speed of a capsule in the PTS for an INAA is related to the technique of moving and stopping the capsule at the terminals of the PTS, and the length of the pneumatic transport tube. Therefore, the control system of a fast PTS should be automated. The newly designed PTS will be used mainly for instrumental neutron activation. In addition, the system will be used for the production of a radioactive tracer, an irradiation test of several materials, a nuclear fission track method, etc. For a promotion of the utilization and effectiveness of the improvement of a PTS for INAA in the JRTR, a functional test and leak test of the system, and an irradiation test, shall be carried out, and the results of the parameters measured, such as the transport time, the neutron flux, the temperature of the irradiation position with the irradiation time, and the radiation dose rate when the capsule is returned, will also be experimentally reported.

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