<Technical Note>

CHARACTERISTICS OF THE PNEUMATIC TRANSFER SYSTEM AND THE IRRADIATION HOLE AT THE HANARO RESEARCH REACTOR

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This paper describes the results of an irradiation test and the specifications of the pneumatic transfer system (PTS) in the NAA #3 irradiation hole at the HANARO research reactor, which was reinstalled after some modifications of the operation mode at the end of 2004. The outer and inner diameters of the PE transfer tube are 34.1 and 27.5 mm, respectively. PE rabbit was used for sample irradiation. The N_2 gas pressure of the PTS lines was adjusted to 0.75 bar. The average sending time to the reactor was 8.5 $\pm$0.3 s and the average receiving time back to the receiver was 3.2 $\pm$0.2 s. The internal and external temperature of the irradiation tube was measured in a range of 50 to 80°C for a 40 s to 80 s irradiation time, respectively. The optimum irradiation time was estimated to be less than 80 s. The thermal, epithermal and fast neutron flux at 30 MW thermal power were 1.42 $\pm$0.01 x 10^{14}, 1.51 $\pm$0.04 x 10^{13} and 9.48 $\pm$0.69 x 10^{11} n · cm^{-2} · s^{-1}, respectively. The cadmium ratio was approximately 9.40. The data obtained will be applied to supplement user information and for reactor management.

KEYWORDS : HANARO Research Reactor, Neutron Activation Analysis, Pneumatic Transfer System, Irradiation Rabbit, Neutron Irradiation Parameter, Neutron Flux, Cadmium Ratio

1. INTRODUCTION

A pneumatic transfer system (PTS) is one of the instruments used for irradiation of a target material for an instrumental neutron activation analysis (INAA) in a research reactor. There are two kinds of PTS in three irradiation holes (NAA #1, 2, 3) at the HANARO research reactor: a manual system (PTS #1) and an automatic system (PTS #2) with and without a Cd lined tube for the thermal NAA and epithermal NAA, respectively. The PTS has been operated since 1995 [1]. This pneumatic transfer system consists of many devices and assemblies for the sending and loading of irradiation capsules, so-called rabbits, from the NAA laboratory into the three irradiation holes in the reflector tank of the reactor as well as for retrieval of the irradiated capsules after the irradiation time has elapsed. Experimental equipment for neutron activation analysis has been developed and installed to achieve the best measurement capability, and has been effectively used during the past decade [2, 3]. PTS #2 has not been operated since 2001 due to contamination of the Cd lined tube (NAA #2), which was removed in Oct. 2004. However, a new PTS, referred to as PTS #3, was reinstalled in NAA #3 after some improvements to the assemblies and modification of the transfer line at the end of 2004.

This paper describes an irradiation test and the characteristics of the reinstalled PTS #3 for safe transfer system and operation, user information, and reactor management.

2. STRUCTURAL COMPONENTS

The PTS basically consists of the following five systems: 1) an irradiation and transfer system for the controller, irradiation tube, transfer tube, loader-receiver, receiver, air cushion valve assembly, diverter, photo-sensor, and a high purity polyethylene irradiation capsule (rabbit); 2) a N_2 gas supplier system; 3) a gas exhaust system; 4) an emergency system; and 5) a shielding system for the loader-receiver and the receiver. The irradiation holes and the layout of PTS #3 at the HANARO research reactor are shown in Fig. 1. A rabbit is transferred by gas pressure at both ends of the transfer tube and the N_2 gas pressure

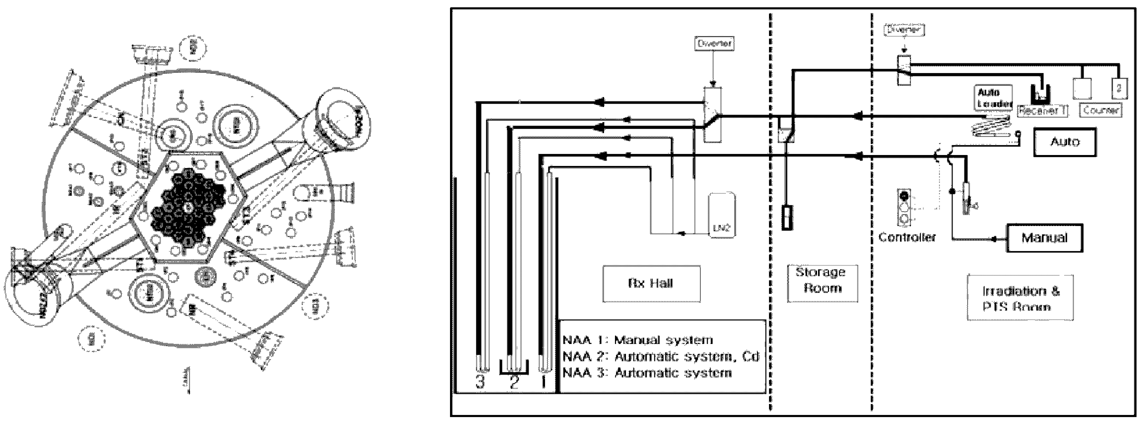

Fig. 1. Irradiation Holes (NAA #1, 2, 3) and the Layout of PTS #3 at the HANARO Research Reactor

from the main supply line is typically between 10 and 15 kg(wt)cm^{-2}. The rabbit thus moves to the irradiation tube from the loader when the gas solenoid valve and exhaust line are opened, and it stops at a pre-defined receiving position. The gas supply and exhaust line are equipped at both the loading and sending positions in the PTS room and the irradiation system in the reactor and the pressure tank. The rabbit can be manually placed into the loader/ receiver, sent to the irradiation tube for a preset time, and returned to either the receiver or the loader/receiver when a given irradiation period is completed. The transfer path of the rabbit can be controlled by a diverter. An air cushion valve, a safety ball valve, and a photo-sensor in the system are also equipped and they are electrically operated and controlled by the PTS #3 mechanical controllers. All of the valves in the transfer system are automatically operated and are closed when the pneumatic system is not in use. The system has radiation alarm monitors that are located near the receiving systems [4-6].

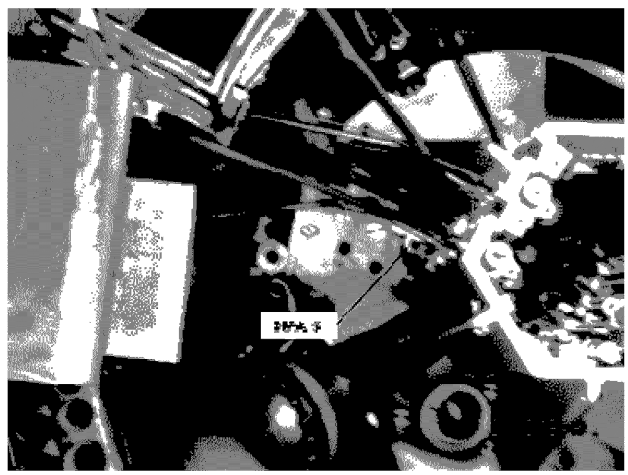

Fig. 2. General View of the PTS #3 Irradiation Tube at the HANARO Research Reactor

3. DECONTAMINATION AND REINSTALLATION

The irradiation tube of PTS #3 is located at the NAA #3 hole in the reflector of the reactor, approximately 47.2 cm from the core. A picture of PTS #3 after the removal of PTS #1 and PTS #2 (Cd lined) is shown in Fig. 2. The length of the irradiation tube is about 14 m from the bottom of the core to the top of the reactor and that of the transfer tube is about 28 m from the end of the irradiation tube to the receiver in the PTS room of the radio-isotopes production building. For reuse of the irradiation tube in PTS #2, the inside of the tube was decontaminated via brushing and wiping with a cloth using a cleaning solution. The former PTS #2 transfer tube was removed and the line was replaced with a new polyethylene tube.

When a PTS is designed, the reactor parameters such as the neutron flux and distribution, temperature, gamma heating of the irradiation site, cooling of the irradiation tube, the radiation dose rate, material and type of rabbit, and the safety of the reactor operation should be considered and checked. The automatic operation mode was changed to manual mode by using the controller of the old PTS #1. The loader/receiver was remodeled for fitting the old, small rabbit. The connection between the irradiation tube and the transfer tube was utilized with the coupling method so as to prevent collision resulting from rapid transfer of the rabbit. The outer and inner diameters of the polyethylene transfer tube are 34.1 and 27.5 mm, respectively.

4. TRANSPORTATION OF RABBIT

The rabbit and sample vials were prepared by a high density polyethylene (HDPE). The impurity level and physical stability were considered in the preparation of the samples. Fig. 3 shows the rabbits and vials used for the sample irradiation. The internal volume of the two kinds of rabbits were 35 ml and 60 ml, respectively, a small rabbit was used for PTS #3. In addition, seven kinds of small vials which have volumes from 0.5 ml to 10 ml, were used. These vials can be more effectively used by a combination of them for preparation of many samples at a time.

The sending and receiving of the rabbit in the PTS is controlled by a system controller with a preset timer, either manually or automatically. Movement of the rabbit is detected by a photo-sensor, which is equipped at the transfer tube. In order to obtain an accurate and precise irradiation time, the transfer time of the rabbit in PTS #3 was re-measured using a stopwatch. This is accomplished via an acoustic method according to the arrival sound at the loading and irradiation positions, for both the manual and automatic modes of the controller. The average sending time to the reactor was 9.8 ± 0.5 seconds and the average receiving time back to the receiver was 3.2 ± 0.3 seconds. The PTS line N_2 gas pressure was adjusted to be within a range of 0.5 to 1.0 kg(wt)cm^{-2} under the control of both the response time of the amplifier and the speed of the irradiation capsule. An air cushion valve controlled by the sensitivity and response time of the amplifier, which is coupled to a photo-sensor attached to the transfer tube, is used to minimize the impact at the end of the irradiation tube and the receiver. Finally, the N_2 gas pressure of the PTS lines is adjusted to 0.75 kg(wt)cm^{-2} based on consideration of the weight variation of the rabbit by the amount of the sample.

5. MEASUREMENT OF THE IRRADIATION TEMPERATURE

The requirements of irradiation for the PTS are based on parameters such as the neutron flux and distribution, temperature, gamma heating of the irradiation site, the radiation dose rate, and the materials and types of the rabbit and the sample for safe operation of the reactor. In particular, the lifetime and corrosion of the irradiation tube and vulcanization of the polyethylene (PE) transfer tube are important factors with respect to safety and maintenance of PTS. Therefore, the condition of the irradiation tube and transfer tube should be checked regularly.

The gamma heating rate was estimated to be about 5 Watts · g^{-1}. The temperature for the irradiation position of the PE rabbit must be limited to less than 80 °C, because the melting point of the PE is about 120 °C. The temperature of the irradiation site was measured for an irradiation time ranging from 10 to 80 seconds using a thermo-label (range of 40 to 120 °C, Japan) for the inside and surface of the rabbit. As shown in Figure 4, the measured temperature was in a range of 50 to 80 °C. In terms of safe irradiation, the maximum irradiation time was estimated as 80 seconds.

The radiation dose rate of the near receiver, as measured by a survey meter, was in a range of 20 to 70 μSv h^{-1} and that of the transfer line in the reactor hall was less than 15 μSv h^{-1} for an irradiated rabbit that has been returned without a sample.

6. MEASUREMENT OF THE NEUTRON FLUX AND CADMINUM RATIO

For neutron flux monitoring and measurement of the cadmium ratio, R_{Cd}, activation wires (R/X activation

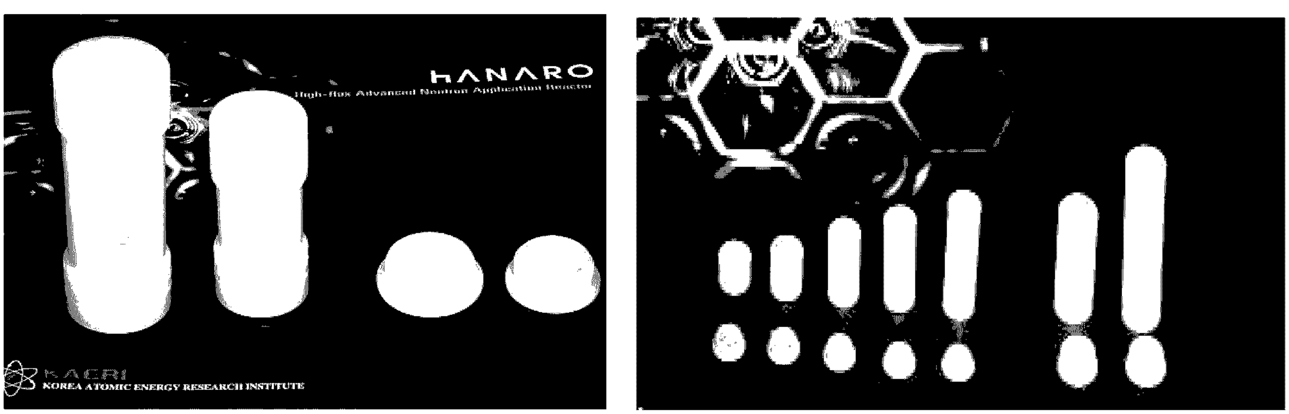

Fig. 3. Rabbits and Sample Vials for Irradiation

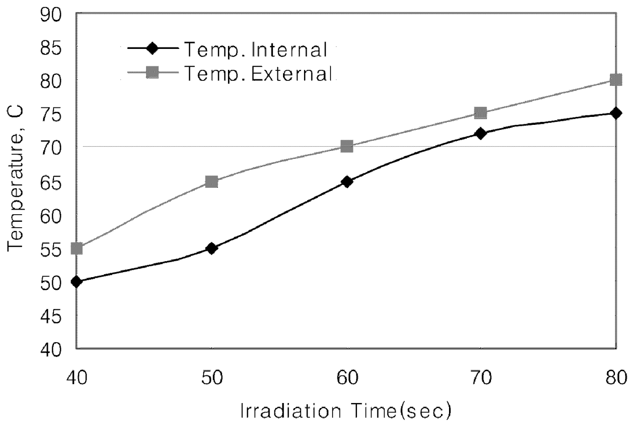

Fig. 4. Temperatures at the Rabbit Position at PTS #3 with Irradiation Time

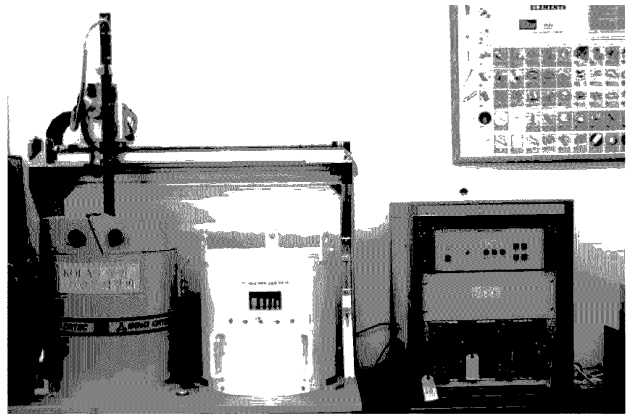

Fig. 5. Gamma-ray Spectrometer with an Automatic Sample Changer

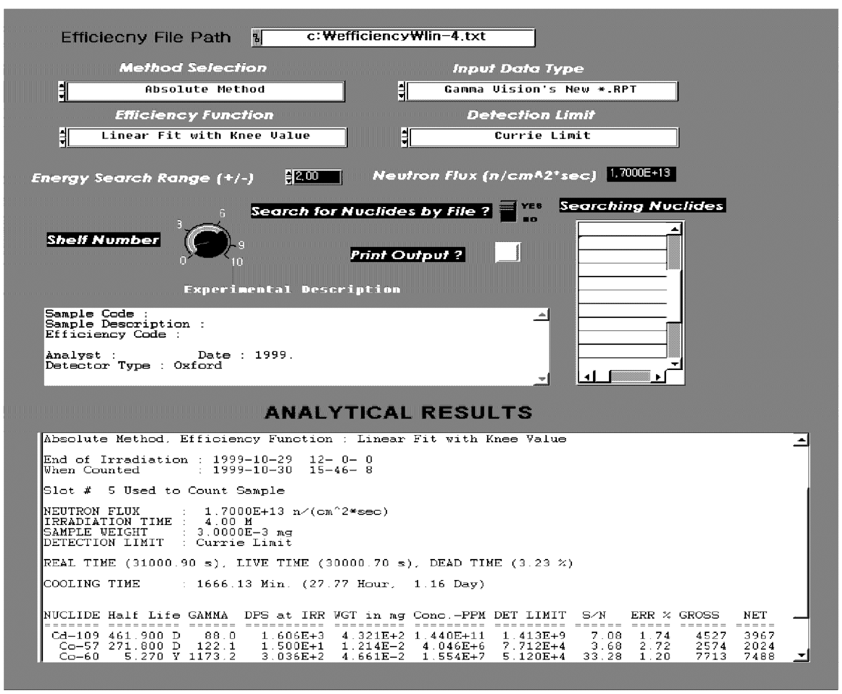

Fig. 6. Main Screen of POWER-NAA Program

wire, Reactor Exp. Inc.; Au-Al, Co, Fe, Ni, and Zr) and a Cd box were used. Thermal, epithermal, and fast neutron fluxes were measured by using target nuclides from the following high purity metal monitors: ^{197}Au, ^{94}Zr, ^{96}Zr, ^{59}Co, ^{54}Fe, ^{58}Ni, etc. The Cd-ratio using ^{198}Au was determined by a comparison of the activities produced from a bare and Cd-covered monitor during irradiation. The measurements were carried out using a calibrated gamma-ray spectrometer (HP Ge detector, GEM/GMX series and 919A MCB, Gamma Vision software, EG&G ORTEC). Energy and efficiency calibrations were conducted using multi-nuclide reference sources (Isotope Products Lab., ML 7500 series,

Table 1. Characteristics of NAA #1, #3 Irradiation Holes (30 MW)

Characteristics	Specific Feature
NAA #1	
Neutron Flux, Thermal	3.0×10^{13} n/cm^2.sec
Epithermal	2.8×10^{10} n/cm^2.sec
ast	3.9×10^{10} n/cm^2.sec
Cd-ratio (^{198}Au)	80
Temperature	40 ~ 60 °C
Max. Irradiation Time	~ 4 hrs
NAA #3	
Neutron Flux, Thermal	$1.42 \pm 0.01 \times 10^{14}$ n/cm^2.sec
Epithermal	$1.51 \pm 0.04 \times 10^{13}$ n/cm^2.sec
Fast	$9.48 \pm 0.69 \times 10^{11}$ n/cm^2.sec
Cd-ratio (^{198}Au)	9.4
Temperature	50 ~ 80 °C
Max. Irradiation Time	~ 80 s

0.3 mm active diameter, disc type) traceable to NIST (National Institute of Standards and Technology, U.S.A). A gamma-ray spectrometer with an automatic sample changer was used for the detection of medium and long lived nuclides. A gamma-ray measurement system with an auto-sample changer is shown in Fig. 5. Data acquisitions and peak analysis from the report file of the measured spectrum were carried out using Gamma Vision software (EG&G ORTEC). The elemental concentrations in the samples were accurately determined using POWER-NAA, a software program available in the Windows environment, , which was developed for fast and accurate calculation. The data for the operation of this program consists of the detector efficiency, nuclear data, count rates of the gamma -ray energy and the thermal neutron flux. The determination of the elemental concentration using the POWER-NAA is based on a produced radioactivity equation for a neutron activation analysis [7]. Fig. 6 shows the main display of the POWER-NAA program. The calculation was carried out using the new Windows PC-code, Labview software of KAERI with the nuclear data library [8, 9], which was developed at this laboratory for rapid and simple data treatment for the gamma-ray spectrum obtained at these preset detection conditions.

For a comparison of the characteristics with the positions of the irradiation holes, the measured results of NAA #3 together with those of NAA #1 are presented in Table 1. The measured thermal, epithermal, and fast neutron fluxes of NAA #3 at 30 MW thermal power were $1.42 \pm 0.01 \times 10^{14}$, $1.51 \pm 0.04 \times 10^{13}$ and $9.48 \pm 0.69 \times 10^{11}$ n · cm^{-2} · s^{-1}, respectively. The cadmium ratio, R_{Cd}, was about 9.40. The ratio of the thermal to epithermal neutron of NAA #1 is more than 1000, but that of NAA #3 is less than 10. The neutron of the NAA #1 irradiation hole is thermalized well relative to NAA #3.

7. CONCLUSIONS

During the past ten years, the NAA facilities in HANARO have been successfully utilized for the purpose of basic and applied research. Presently, the irradiation facilities and the measurement systems are being improved so as to enable further effective use and much safer operation in accordance with user demand. For an efficiency and safety through the utilization of the reinstalled PTS #3, irradiation tests were carried out and the results of the measured parameters such as the neutron flux, the temperatures of the irradiation position with irradiation time, the radiation dose rate when the rabbit is returned, etc. were reported. The experimental characteristic values will provide useful information for several kinds of users and for reactor management. The results will be used for wider applications for the NAA in many fields by enlargement of the HANARO utilization facility.

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