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DESIGN AND USE OF THE ORNL HFIR PNEUMATIC TUBE IRRADIATION SYSTEMS*

F. F. Dyer, J. F. Emery, L. Robinson, N. A. Teasley
Analytical Chemistry Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

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ABSTRACT

A second pneumatic tube that was recently installed in the High Flux Isotope Reactor for neutron activation analysis is described. Although not yet tested, the system is expected to have a thermal neutron flux of about 1.5×10^{14} cm^{-2} s^{-1}. A delayed neutron counter is an integral part of the pneumatic tube, and all of the hardware is present to enable automated use of the counter. The system is operated with a Gould programmable controller that is programmed with an IBM personal computer. Automation of any mode of operation, including the delayed neutron counter, will only require a nominal amount of software development. Except for the lack of a hot cell, the irradiation facility has all of the advantageous features of an older pneumatic tube that has been in operation for 17 years. The design of the system and some applications and methods of operation are described.

INTRODUCTION

This report describes a second pneumatic tube irradiation system, PT-2, that was recently installed in the High Flux Isotope Reactor (HFIR) of Oak Ridge National Laboratory (ORNL). The facility was constructed to replace an existing pneumatic tube that had been in operation for nearly 30 years in the Oak Ridge Research Reactor (ORR). Planning for and design of the new system were begun in April 1982 when it became evident that the ORR would soon be permanently shut down, an even that has now come to pass. The PT-2 system is similar to and complements the use of another pneumatic tube system, PT-1, that was installed in the HFIR in 1970 and is still in use. Although the PT-1 facility has been described previously,[1,2] some aspects of it will be re-iterated here to contrast its design and operation with the new facility. Laboratory floor space for the two irradiation systems has been expanded to 123 m^2 an area nearly three times the size of the space for the PT-1 system.

The new pneumatic tube has a special delayed neutron counter (DNC) for fissile nuclide analysis that will replace the DNC in the lost ORR system. The DNC can be operated in either a manual or an automated mode. During the past decade approximately 100,000 samples were analyzed for uranium by DNC in the ORR system. About three fourths of those samples were generated by the National Uranium Resources Experiment (NURE) and many of the remaining came from, and are still arising from, the Formerly Utilized Sites Remedial Action Program (FUSRAP).[3] It is anticipated that significant demand will continue for determination of uranium and the new system has been designed to meet whatever demand develops.

The new pneumatic system is operated by a Gould programmable controller that has been set up with software modules to permit manual operation for normal neutron activation analysis and use of the delayed neutron counter. Because of the simple design that was adopted for the rabbit loading station, it will be possible to easily configure the software modules of the controller for various modes of automation, including delayed neutron counting at little additional expense. The Gould Controller is a highly versatile system that has been programmed with a personal computer to operate the pneumatic system by opening and closing valves, and monitoring several sensors. The HFIR analytical laboratory has a Zymark general purpose programmable robot, which along with the Gould controller, is expected to permit many other special automated functions to be effected as experience with the new facility is gained. Some of these expected capabilities will be described in this paper.

Due to the fact that the HFIR has been shut down for almost a year for safety evaluation, the new system has not been operated. The reactor was shut down in the November of 1986 because mechanical tests made then on metal specimens that had been in the reactor for a long time, indicated that a small degree of embrittlement of the carbon steel pressure vessel, especially near the neutron beam ports, had occurred from the action of fast neutrons. Because sample irradiations have not been carried out in the new system, this paper will be limited to a description of the design of the system and applications that are planned when operation resumes. At the present time it seems likely that the reactor will be restarted early in 1988.

SYSTEM DESIGN

The design of the new pneumatic tube is functionally illustrated in Figure 1. The location of the various components of PT-2 are much like that of PT-1 which is portrayed in the isometric drawing in Figure 2. Surrounding the fuel element of the HFIR are two beryllium reflectors, one near the fuel element that is removable, the other further out that is permanent. Both pneumatic tubes terminate in the permanent reflector. For details of the HFIR itself, the reader is directed to reference 4. The first tube is placed in a vertical irradiation hole in the permanent

Fig. 1. Schematic of second pneumatic tube of HFIR.

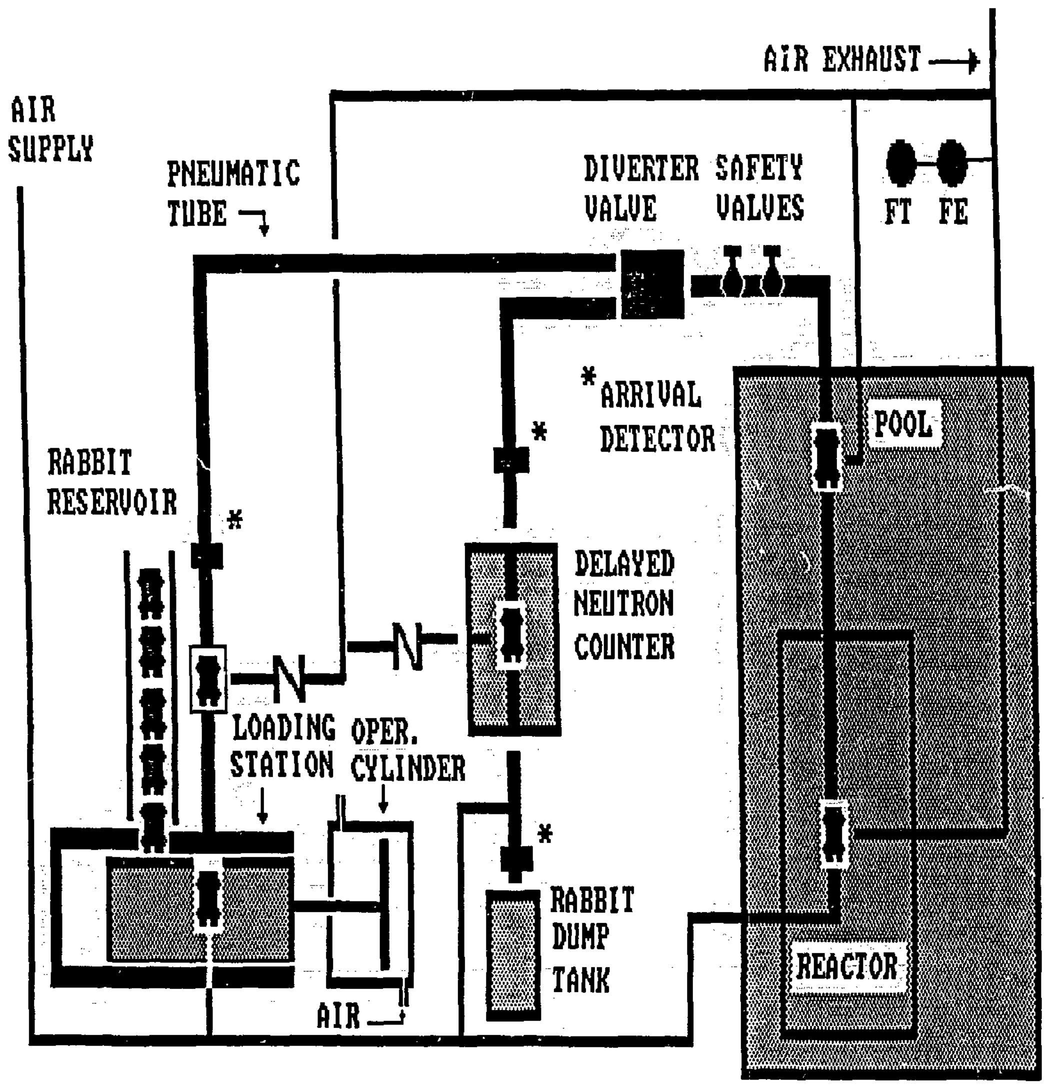
AIR EXHAUST
AIR SUPPLY
PNEUMATIC TUBE
DIVERTER VALVE
SAFETY VALVES
FT
FE
* ARRIVAL DETECTOR
POOL
RABBIT RESERVOIR
DELAYED NEUTRON COUNTER
LOADING STATION
OPER. CYLINDER
RABBIT DUMP TANK
REACTOR
AIR

Fig. 2. Isometric drawing of first pneumatic tube of HFIR

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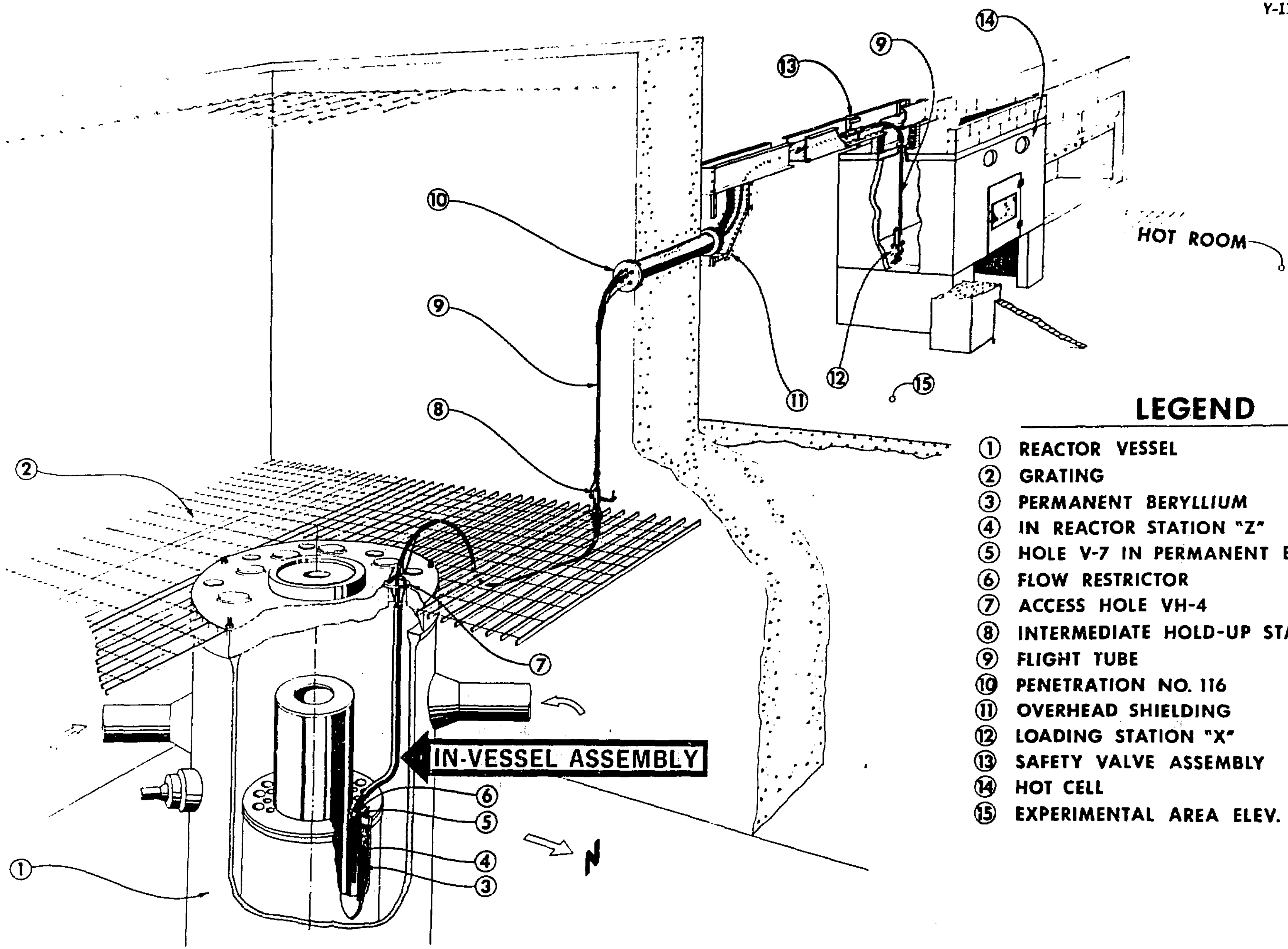

LEGEND

① REACTOR VESSEL
② GRATING
③ PERMANENT BERYLLIUM
④ IN REACTOR STATION "Z"
⑤ HOLE V-7 IN PERMANENT BERYLLIUM
⑥ FLOW RESTRICTOR
⑦ ACCESS HOLE VH-4
⑧ INTERMEDIATE HOLD-UP STATION "Y"
⑨ FLIGHT TUBE
⑩ PENETRATION NO. 116
⑪ OVERHEAD SHIELDING
⑫ LOADING STATION "X"
⑬ SAFETY VALVE ASSEMBLY
⑭ HOT CELL
⑮ EXPERIMENTAL AREA ELEV. 833'-0"

beryllium reflector about 180 mm from the edge of the fuel element. The second tube is located in a slant neutron beam facility that barely intersects the permanent beryllium reflector; the irradiation station in this system is about 320 mm from the fuel element. The principal differences that result from the different locations of the two systems are their neutron fluxes and gamma heating rates. The thermal neutron flux of PT-1 is about 5E14 neutrons $cm^{-2} \times s^{-1}$, and the gamma heating rate is nominally 5 watts/gram. The resonance neutron flux of PT-1 is about 3 percent of the thermal flux and the fast flux is approximately 5 percent of the thermal. In PT-2, the thermal flux is expected to be about 1.5E14, and the gamma heating rate is estimated to be about 1 watt/gram. The ratios of the resonance and fast neutron flux to the thermal flux in PT-2 are expected to be much lower than in PT-1.

Both irradiation systems consist of flight tubes, air supply and exhaust lines, loading stations at which sample containers (rabbits) are introduced into the flight tubes, and irradiation stations to which rabbits move to be irradiated. The inner diameter of the flight tubes is 15.88 mm whereas the outer diameter of the rabbit is 14.48 mm. The clearance between the rabbit and the flight tube walls is thus about 0.2 mm. Both flight tubes accept the same rabbits which have an internal volume of about one cubic centimeter. The loading station of PT-2 is located in a fume hood, whereas, that of PT-1 is in a hot cell. Several features of the two systems are functionally equivalent. Both systems operate with air entering both ends of the flight tube. A rabbit in either of the flight tubes thus moves to the location where an air exit line is opened and stops on counter-current columns of air. Air exit lines are located at the loading stations, and at the irradiation stations in the reactor pressure vessel. During irradiation, cooling air continues to flow and cause the rabbit to remain at the point in the reactor where the air exit line is located. As shown in Figure 1, an air exit line is also placed in the delayed neutron counter. Because rabbits stop on counter current air columns, brittle materials, including graphite rabbits, can be irradiated. Test made with a mock-up before the first system was installed, showed that even when a rabbit was filled with lead (about 7 grams) it did not get very close to hitting the end of the flight tube. The significance of the use of graphite rabbits will be described later in this paper. Both pneumatic tubes also have air exit ports located at stations in the reactor pool at which rabbits can be optionally stopped after irradiation to allow some decay of short lived radionuclides that are present at levels too high for safe return of the sample directly to the loading station. These locations are referred to as decay stations.

Modular programs for the Gould controller have been written to provide manual operation of the new system that is similar to that of PT-1. A rabbit can be manually placed in the loading station, sent to the irradiation station for a preset time and returned to the loading station in the fume hood when the irradiation time elapses. Similar manual operation of the system for DNC has also been programmed. When DNC is to be carried out, a rabbit is sent from the loading station to the irradiation station and the diverter valve is switched to place the neutron counter in the pneumatic tube circuit. After the irradiation time elapses, the rabbit returns to the neutron counter where it is held by the counter-counter air currents until a preset counting time has elapsed. Air to the system is then removed to permit the rabbit to fall into the rabbit dump tank shown in Figure 1.

Automatic operation will be easy to accomplish because of the modularity of the Gould system programs and a simple loading station into which rabbits can be fed by gravity from a rabbit reservoir. The loading station and rabbit reservoir are indicated in Figure 1. The loading station consists of a cylinder that contains a cavity into which rabbits are introduced from the reservoir. The reservoir consists of a tube that is filled with rabbits and placed over the loading station. When the loading cylinder is extended so that the loading cavity is under the reservoir, a rabbit in the reservoir falls into the cavity and the cylinder can be retracted to the flight tube position. All that is necessary for automatic operation is to provide a program module for the Gould controller that will cause the manual program to loop to the beginning of the cycle after the rabbit from the previous irradiation has fallen into the dump tank. This automated feature of the system can also be used to irradiate a series of samples what will be used for purposes other than DNC.

Because the piping of both systems are exposed directly to the pressurized water of the operating reactor, it was necessary to provide adequate safety features to protect system operators, as well as the reactor, in case a leak should develop. For air supply lines, protection is provided by two serially placed check valves that prevent back flow of air and flow of water into the air supply system. The flight tubes of both systems have dual in-line ball valves through which rabbits travel. These valves are denoted in Figure 1 as a safety valve assembly. One ball valve is electrically operated and controlled by the Gould instrument. The Gould controller keeps this valve closed except when a rabbit is either in or traveling to or from the irradiation station. The controller also monitors a water sensor in the pneumatic tube piping, and should water be detected during an irradiation, the controller will eject the rabbit to the pool decay station and close the flight tube ball valve. The other ball valves that are in the flight tubes are manually operated and is left closed when the pneumatic tubes are not being used. Both PT-1 and PT-2 have sound annunciators that would be actuated should water be detected. Air exhaust lines, which are connected to the reactors closed hot off-gas system, have electrically operated valves that will close as well as hand valves that can be manually closed should the water be detected in the system. Both systems have radiation monitors that are located near the flight tube a few meters from the loading stations. Alarms on the monitors informs operators of the systems of the radiation level in the flight tubes.

DISCUSSION

The high gamma heating rate of 5 watts/gram of PT-1 severely limits the use of high-density polyethylene rabbits due to their tendency to soften. The heating rate in PT-2, 1 w/g, is about the same as in the system that existed in the ORR and no difficulty in the use of plastic rabbits is anticipated. An empty plastic rabbit can normally be safely irradiated in PT-1 from 10 to 20 minutes. Some variation in softening among individual specimen seems to occur due probably to variations in positioning of the rabbit in the cooling air during irradiation. The addition of sample material to a plastic rabbit dramatically increases its tendency to soften. The useful irradiation time of a plastic rabbit filled with material such as soil is effectively limited to the time required to warm the material to the softening point of the polyethylene - approximately 20 s. A limitation in the irradiation of small samples placed inside polyethylene rabbits is the temperature the specimens attain, even when there is no danger of melting. Small samples of biological materials, such as hair or feathers, need to be placed carefully in contact with the rabbit walls to permit maximum loss of heat that is generated. Loss of volatile trace elements from samples due to overheating is a possibility that has had little study.

As indicated previously, the fact that rabbits are stopped on counter current columns of air permits the use of rabbits made of graphite. This aspect of the older pneumatic tube was previously emphasized in the analysis of semiconductor potting plastics for uranium and thorium[5] and the determination of U and Th in refractory materials such as tungsten and tantalum by fission track counting.[6] This procedure carried out with fission track recorders made of Supersil, a high-purity quartz, was first reported by Riley.[7] Rabbits, fabricated by Union Poco from Grade AXF-5Q1 graphite purified to 5 ppm or less of trace element content, satisfy all requirements for purity, physical stability, and resistance to the effects of moisture and heat. After hundreds of irradiations, some with the same rabbits for many hours, no breakage has occurred. After exposure to a neutron fluence of 10^{19} cm^{-2} and a decay of one week, the radiation dose rate at the rabbit's surface is insignificant. Thus these graphite rabbits can be used repeatedly and for as long as necessary if they are not contaminated inside. Although graphite rabbits cost about ten times that of plastic ones, reuse of the graphite rabbits tends to make their cost comparable.

The technique of moving and stopping rabbits on counter-current air columns does not provide a rabbit velocity as high as would be possible if air were entering only one end. The rabbit travel time in PT-1 averages about 3.4 s, whereas, the travel time in the ORR system in which rabbits hit the tube ends was about 1.5 s. The lengths of the ORR and HFIR pneumatic tubes are comparable. Although it is possible to operate either of the HFIR systems so that air flows from only one direction and thus increase rabbit velocity, such a mode of operation has not been used for PT-1.

Current plans are to use the Zymark robot and the PT-2 system to obtain a completely automated system for DNC and possibly other applications of NAA. With the addition of a few hardware items, the robot will be able to load rabbits with soil and other materials commonly analyzed for uranium. The robot can place lids on the rabbits (plastic), heat seal the lids to the rabbit body, weigh and then stack them in rabbit reservoir tubes for the PT-2 system. A balance operated in this manner by humans, that is interfaced to a PC, has been in use for about one year. During counting with the DNC, data will be automatically processed, i.e. corrected for background, sample weight, and concentration calculated and results stored on a personal computer. This capability has also been employed, but with manual sample irradiation. Finally the data will be transferred to a central data management facility.

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