OPERATION EXPERIENCE OF THE RESEARCH REACTOR HANARO

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ABSTRACT

Operation experiences and the status of utilization facilities are presented in this paper. Problems in the reactor regulating system, diesel generator, cooling fan, and fuel handling are described, along with their causes and the actions taken. Most of the problems were caused by instrument error but the problem in the cooling fan could be classified as a human error. Such problems are minor but give a lesson in reactor operation and maintenance. More kinds of radioisotopes are being produced every year in parallel with improvements in production technology. The number of neutron activation analyses and neutron radiography tasks done for customers is increasing. In the Hanaro reactor five beam tubes are reserved for neutron beam research and in three of them the beam facilities are already installed or are in installation. Non-fissile material testing using a capsule was performed and fissile material tests are planned for the beginning of 1999. The fuel test loop is expected to hold its first fuel test in the year 2000. Fission molybdenum, cold neutron source, and neutron capture therapy are in the stage of conceptual or basic design. The use of HANARO will be more and more in demand as installation of utilization facilities increases year by year.

INTRODUCTION

Since steady power operation started in January 1996, HANARO has been operating at a power level of 15 MWth in its first cycle and full power of 30 MWth will be eventually achieved in the equilibrium core. Until now, we have operated HANARO up to the power level where fuel integrity is guaranteed. The higher power will be achieved safely, in a step by step fashion because HANARO is a unique reactor of its kind in the world.

Based on operational experience, the component, system, and tool design have been improved. The inadvertent occurrences in reactor operation give good lessons and have become material for operator education. They are filed as a database and provided to the IAEA. The operational procedures have been revised accordingly. Since HANARO is the only research reactor in Korea, it has to some extent to fulfill the needs of every field. Therefore, the role of HANARO is multifold; radioisotope production, neutron beam research, material test, neutron capture therapy, etc. Each field has its own plan and the reactor condition required by each field will be different. The conflict between the utilization itself and the installation of utilization facilities will be unavoidable for at least several years. As the demand for reactor utilization grows, neutron availability will be the key issue, not only to the reactor management group, but also to the users. The current status and installation plan of the utilization facilities are presented here briefly. The role of HANARO in Korea is mentioned at the end of this paper.

PROCEDURE REVISION

After the system performance tests and system integration tests, HANARO reached its initial criticality in February 1995. Based on experiences made during the reactor commissioning period, most of the periodic surveillance, maintenance, and operational procedures were revised in September and October of 1995. As shown in Table 1, 80% of the procedure revisions were made in 1995 and those were related to system operation, inspection, and maintenance. Eighteen procedures have been merged with other procedures for simplification or to avoid redundancy. Nineteen procedures have been added, mostly for instrument calibration and surveillance. In particular, a visual inspection procedure of the fuel assembly was introduced in March of 1997. Fewer than 10 procedures required revision every year, except in 1995.

Table 1 Revision Status of Reactor Operation Procedures

Procedure	**Revised**					**Merged**
Year:	94	95	96	97	Total	
Technical Administration	-	1	4	3	8	1
Quality Control	-	-	-	-	-	QC manual
Operation	-	22	-	1	23	1
Warning and Alarm	-	-	-	-	-	-
Surveillance Inspection	4	43	3	2	52	4
Periodic Inspection	-	13	1	-	14	1
Maintenance	1	15	-	-	16	5
Core Management	2	-	-	1	3	6
Radiation Safety	-	-	-	-	-	-
Special Test	1	-	1	-	2	-
Total	8	94	9	7	118	18

EXAMPLES OF INADVERTENT OCCURRENCES

Neutron Flux Monitoring System

Six wide range fission chambers are being used for neutron flux monitoring; three for the reactor regulating system and the others for the reactor protection system. Pulse counting is used in the lower 5 out of the 10 decades and the mean square voltage (MSV) is used in the upper 5 decades. Linearity in the switching region between the pulse counting and the MSV was not satisfactory and there was an inadvertent shutdown due to a spuriously high log rate. After several calibrations, the circuit was replaced but the system still did not produce good linear signals in the switching region. This problem does not cause any major troubles in operation but we are nevertheless contacting the supplier to resolve it.

Control Rod Driving Mechanism

There are three shutdown signals which indicate the failure of the control rod driving mechanism. (a) A 3 mm discrepancy between the controller calculated and measured rod position, (b) a 3 step discrepancy between the number of steps ordered by the interface card and the number of steps fed back from the rotary encoder, which is the actual number of steps moved by stepping motor, and (c) the motion of the failed rod (MOFR). The control rod was jammed due to mechanical deterioration of the component in the driving assembly. The control rod had departed from the upper part against the magnetic force, which caused the reactor shutdown by MOFR due to the motion of the control rod which was declared as failed by a 3 mm discrepancy. The jammed part was fixed afterwards.

Controller

There are two controllers for redundancy and both are running at the same time; one as a primary controller and the other as a back-up. These controllers have a control algorithm for the reactor regulating system and process systems. The controller failure alarm was annunciated and the reactor was shut down due to control rod failure. Based on the error code shown by the printer, the initial cause turned out to be a failure of the power supply to primary controller rack B. Due to this failure, repeated switching between the primary and back-up controller was induced. During this switching, the field data on control rod position were wiped out and the reactor was shut down due to the control rod failure signal. After replacement of the power supply, the problem was resolved.

Diesel Generator

In the loss of off-site power on August 5, 1997, the diesel generator was supposed to supply class III power within one minute but it failed to start-up. The manual start-up in the diesel generator room, as well as in the control room, failed afterwards. Finally, it was started by a manual engine start-up. The indicator in the outside oil tank annunciated the low-level alarm in the loss of off-site power and initiated the engine stop signal. This was why the engine stopped and the diesel generator start-up failed. In other words, oil should be supplied for engine cranking after the start-up motor started but the solenoid valve was not opened due to the engine stop signal. The oil low level was modified to annunciate the alarm only and was excluded from the engine stop parameters.

Cooling Fan

There are four cooling fans in the secondary cooling system. The cooling fan stopped twice due to vibration problems on June 30, 1995 and July 2, 1997. The vibration level in the switch for fan #4 was set higher than the required value. Hence the fan blade was already damaged when the abnormal vibration was observed. The vibration switch of fan #3 was frequently erroneously turned on and the fan was operable only after resetting the vibration switch. The shaft of fan #3 was eventually dislocated when it was started after resetting. The blades and reducer shaft of fan #4 and the reducer shaft and hub of fan #3 were replaced and those are now operating normally. The vibration of fan #3, however, is relatively high and the weight balance tests for fan shaft and blade are in preparation to find the cause. A monitoring system for fan vibration is under consideration.

Fuel Handling

Fuel handling is performed by a 12 meter handling tool hanging on a hoist. Sometimes the tool does not completely grip the fuel or the fuel sticks to the tool and is difficult to release. Actually, a fuel assembly was once dropped to the pool bottom. When the fuel was loaded and the tool released from the loaded fuel, the fuel could be also released from the spider. To resolve these problems, potential modifications of the tool include improvement of the ball lock pin; modification of the pin which is to fit in the grapple head; shortening of the tool; a modification to prevent the tool bending, etc.

STATUS OF UTILIZATION FACILITIES

Radioisotope Production

A three-phase radioisotope development plan started this year. More than 40% of the domestic demand will be fulfilled and even some export is expected at the end of the plan. Only 5% of the domestic demand of Mo-99 (Tc-99m) is supplied by KAERI. When the fission molybdenum production facility is completed, most of the domestic needs will be satisfied and it can then be exported to Asian countries. Other isotope production includes: I-131-MIBG used for neuroblastoma treatment and its use is gradually increasing; the Ho166-Patch for skin cancer and Ho-166-CHICO (chitosan complex) for liver cancer which will be in commercial use within 2 years. In particular, Ho-166-CHICO is effective for peritoneal cancer metastasized from stomach cancer, ovarian cancer, and rheumatoid arthritis in knee joints by local injection. In the development of radioisotope production technology, I-131 production is enhanced by applying the sublimation purification technique, high purity P-32 is produced by distillation under reduced pressure, the automatic source fabrication instrument for Ir-192 source is developed, and the production of Cr-51 using an enriched target is also developed. Twenty-eight lead hot cells and four concrete hot cells are currently in operation.

Neutron Transmutation Doping (NTD)

NTD facilities will be installed around the year 2000, and their total irradiation capacity for Si ingots will be about 10 tons per year. The target precision for resistivity at the first stage is less than 5% and its variation will be less than 3% in the radial direction and less than 5% in the axial direction.

Neutron Activation Analysis (NAA)

Automatic and manual pneumatic transfer systems are installed at three irradiation holes for R&D and analytical services of NAA. One of the irradiation holes is lined with cadmium. An available thermal neutron flux at each irradiation site is in the range of 3.9×10^{13} - 1.6×10^{14} n/cm^2 sec and the cadmium ratio is 50-250. One system is designed for the analysis of short-lived nuclides and other system is designed for the analysis of medium and long-lived nuclides. Both systems are operated by the electronic controller.

To date, the application fields of NAA in Korea are industry, agriculture, geology, monitoring of atmospheric pollution and water contamination, material science, biomedical science, archeology, forensic science and so on. The number of analyses for customers is gradually increasing and it will total more than 1,000 by the year 2000.

Neutron Radiography

The neutron radiography facility had been installed at HANARO and its various performance tests and characterizations have been done satisfactorily. It has two exposure cells for radioactive samples and general industrial objects. The thermal neutron flux at the first exposure cell is 1.08×10^7 n/cm^2 sec and 4.02×10^6 n/cm^2 sec at the second cell, respectively. The neutron beam purity and sensitivity have been investigated using an ASTM standard and the quality of the neutron beam belongs to Category I with 75-8-7. A typical irradiation time of about 8 minutes is required to get a film density of 2.5. An electronic imaging system is under development based on a high sensitivity TV camera unit. This unit has been applied already to the NDT inspection of industrial objects and student training as well.

Neutron Beam Research

Phase I of the neutron beam instrument development started in 1992 and Phase II was entered in mid 1997. Due to the design, fabrication and installation programs over the last five years, around the seven horizontal ports based on the Phase I programme, the installation of the High Resolution Powder Diffractometer (HRPD) at the ST2 beam port was completed and now in the testing and calibration stage. It will be finished at the end of 1997 and full-scale neutron diffraction works will commence in January, 1998. The Four Circle Diffractometer and optional system to the HRPD for Texture and Residual Stress measurement will be installed in early 1998. Development and component-wise installation of the Small Angle Neutron Spectrometer (SANS) and Polarized Neutron Spectrometer (PNS) has been half completed by the end of l 1997 and is expected to be installed at the end of 1998. The Phase II programme was started in 1997 and will end in 2002. It consists of the development and application of neutron scattering based on the instruments developed in Phase I and external user formation, and the installation of a reflectometer and a triple axis spectrometer on the ST3 and ST4 beam ports in the reactor hall together with the development of utilization technology of various neutron mirrors, guides and benders.

Capsule

The HANARO capsule development plan consists of three phases. In the first phase, the HANARO standard capsule for a non-fissile material irradiation test has been designed and manufactured as an output of the first phase development. Seismic and stress analyses were performed and flow-induced vibration and pressure drop tests were carried out using the mock-up in HANARO. The capsule temperature control system, including the vacuum and multi-stage heater control systems has been also developed to control specimen temperature by adjusting the electrical power of heaters and gas thermal conductivity. The capsule supporting system of the canti-lever type has been already installed in the reactor pool. The in-pool capsule cutter and capsule-handling tool have been also prepared. The second phase (1997 - 2001) is currently in progress, during which time the fuel irradiation capsule and in-situ instrumented capsule are in development. The development of a re-instrumented capsule is in planning for the third phase.

Test Loop

The licensing for a test loop is in progress and installation will commence in the beginning of 1998. After the commissioning, an irradiation test will be possible from the year 2000. The design of a transient test loop will be initiated in the middle of 1999. The measurement technology of fuel characteristics in the irradiation test is under development. Fuels such as DUPIC, CANFLEX, and fuel for the next generation reactor are waiting for irradiation tests in the test loop.

Cold Neutron Source

The conceptual design of a cold neutron source has been completed with the collaboration of PNPI, Russia, in July of 1997. In this stage, the experiment facilities were selected and neutron guide tubes and an experimental hall appropriate to these facilities was designed. The characteristics of cold moderators have been studied to obtain the maximum gain of cold neutrons. Analysis of radiation heat and the design of hydrogen, vacuum, and helium systems have been also performed. The installation, maintenance, and quality assurance program are included in the conceptual design report. A full-scale performance test of thermosyphon and a hydrogen explosion test in the containment are scheduled for the first phase through the year 2000.

Boron Neutron Capture Therapy (BNCT)

The conceptual design for a thermal neutron BNCT unit is in progress. A shielding shutter of water is considered for BNCT operation. A Si single crystal and Bi crystal are placed for fast neutron and gamma filtering in preliminary analysis. Maintaining the filter at liquid nitrogen temperature is considered to enhance the thermal neutron flux.

ROLE OF HANARO

Here is the projection of HANARO to the year of 2000. More than fifteen radioisotopes, including tracers, will be produced for both domestic and international users. Five percent of the NTD-Si world production will be produced through HANARO. After many fuel irradiation tests with capsules, the first irradiation test using the fuel test loop will be performed in the year 2000. The basic design for CNS will be completed.

HANARO is a bridge between the TRIGA reactors under decommissioning and the next generation research reactor in Korea. Neutron beam research, neutron radiography, radioisotope and tracer production, and neutron activation analysis have been studied using the TRIGA Mark-II and III. Their neutron beam facilities used anti-filter type spectrometer, spinning crystal spectrometer, two circled diffractometer, and triple axes polarized spectrometer. Medical, industrial and research oriented radioisotopes have been produced in TRIGA Mark-III. The experiences accumulated with the TRIGA reactors were applied to the design of HANARO for more advanced utilization. Neutron transmutation doping technology has been developed and will be realized in HANARO. In the design stage, it was called KMRR, Korea Multipurpose Research Reactor. The research, which has been carried out in TRIGA, continues, and the material test using test loop, fission molybdenum, and neutron capture therapy have been newly introduced in HANARO. Every research field has to be developed further before a single-goal-focused research reactor is born. Only the successful utilization of HANARO will promise the next generation research reactor in Korea.

KEY WORDS

HANARO, operation experience, inadvertent occurrences, reactor utilization, holmium, High Resolution Powder Diffractometer, isotope production.