RENEWAL OF HOR NUCLEAR INSTRUMENTATION: FROM ANALOG TO DIGITAL SYSTEM

A.A.R. WETZELS, C.N.J. KAAIJK
Reactor Institute Delft,
Delft University of Technology,
Delft,
The Netherlands

Abstract

This paper describes the renewal of the nuclear instrumentation of the research reactor named HOR in Delft. This research reactor was built around 1960. Because of ageing effects, the nuclear instrumentation was completely replaced in 1980, together with the construction of a new control room outside the containment. In 2010, after 30 years of successful operation, it became a real challenge to repair the nuclear channels because of obsolete components. Of course, this problem was identified earlier, and a project was started in 2008 to select and replace the electronics of the nuclear channels. For this purpose a European tender was started to select a manufacturer for the new electronics in accordance with the requirements. The boundary conditions to be fulfilled by the manufacturer were: a) The functionality of the instrumentation and the interface to the plant should remain the same, and b) The proposed type of equipment should have been installed and commissioned successfully at other research reactors of comparable type earlier. Only the electronics should be replaced, detectors and cabling are reused. We selected a digital system based on two microcontrollers, each one checking the other one. It turned out to be a flexible system. It was easily adapted to our needs, showing adequate provisions for guaranteeing data integrity. In the summer maintenance period of 2010 the instrumentation was successfully installed and commissioned. This paper will describe the steps taken and the tests performed.

1. INTRODUCTION

The Reactor Institute Delft (RID) is part of the Faculty of Applied Physics which belongs to the Delft University of Technology. The RID is the Dutch national centre for multidisciplinary research and education involving the Hoger Onderwijs Reactor (HOR), nuclear radiation and radionuclides. Until 2005 the institute was an interfaculty facility. Since 2005 the interfaculty facility is split in the new research department 'Radiation, Radionuclides and Reactors' (R3), and the Reactor Institute Delft running the research infrastructure. Together they form the national focal point of expertise in the fields of reactor physics, neutron and positron beam research (including radiation detection), as well as radiochemistry. At the heart of the reactor institute is the HOR as a source of neutron, positrons and radioisotopes. The HOR is a pool type research reactor operated 24 hours per day, 5 days a week at a thermal power level of 2 MW, attaining a steady thermal flux of about $2\times10^{13}\ cm^{-2}s^{-1}$.

In the sixties, the HOR was built with a control room inside the containment from which the operator had a good view at the reactor. At that time the reactor instrumentation was using vacuum tube equipment. Over the years, the power and the operation time per day were increased considerably. The instrumentation aged and the control room was uncomfortably small for 24-hour shift operation. In the early eighties a new control room was built outside the containment with new instrumentation (see Figure 1), detectors and cabling. A computer for data acquisition was introduced. With this instrumentation, the reactor was operated successfully for 30 years until 2010. Ultimately, it became more difficult to calibrate and repair the equipment because of components becoming obsolete. To cope with the ageing phenomenon a project was started in 2008 to select and install new instrumentation.

FIG. 1. The old nuclear instrumentation.

2. PROJECT HOR NUCLEAR INSTRUMENTATION REFIT

2.1. Scope

The scope of this project is confined to renewing only the aged electronics in the control room and the preamplifiers in the “field”. The detectors are still in good condition and spare parts are available on stock. New detectors of the same type could be procured if necessary. The cables are reused and for ensuring their good condition, they have been retested during the commissioning phase.

The design of the safety system is not changed. All new nuclear channels have the same functionality as the channels of the old system. The reactor protection system is not renewed in this project, so the interface of the new channel system to the reactor protection system remains unchanged.

A no-break installation for the power supply of the instrumentation is not required for safety functions because of the “failsafe” design, but for uninterrupted data registration purposes it is preferred to have this option. Therefore the manufacturer was also required to implement Uninterruptable Power Supply’s.

The nuclear channels that have been replaced are listed in table I.

TABLE I: CHANNELS REPLACED

Channel Name	Channel Type	Number of Channels	Safety Class
Neutron Flux Level	Safety	4	1
Pool Gamma Monitor	Safety	1	1
Bridge Gamma Monitor	Safety	1	1
Stack Off Gas Activity	Safety	1	1
Pool Outlet Gamma Monitor	Safety	1	1
Primary Coolant Flow	Safety	1	1
Differential Pressure Heat Exchanger	Safety	1	1
Lin/Log Channel	Process	1	2
N16 Reactor Power	Process	1	2
Fission product activity (forced cooling)	Process	1	2
Area Gamma Monitor	Process	3	3

2.2. Requirements

As the Reactor Institute is part of Delft University of Technology, according to Dutch rules a European Tender Procedure is obligatory for selecting a manufacturer/supplier. For this purpose, general requirements and instrumentation requirements were formulated and incorporated in an invitation for tendering. The most important requirements to be fulfilled are:

— Every instrument channel should have the same functionality as the old channel;
— Interface to the plant should be kept the same, using the existing detector and reactor protection system;
— The proposed type of equipment should have been installed and commissioned successfully at other research reactors of comparable type earlier;
— Response time of the new equipment should be equal or faster;
— Standards: KTA 3501/3505 or equivalent, IEC80660 for software purposes, ISO9001 QA system;
— Flexibility to adapt to future needs, for instance a power increase;
— Calibration and testing should be user friendly, e.g. without the need for disconnecting cables;
— Installation should take place in the summer maintenance period of 2010.

2.3 Project milestones

— June 2008: approval of project proposal by the Dean of Applied Physics;
— June 2008: start of preparation for the European tender;
— 2008 Start of discussion with the supervising authorities: In good cooperation, it was agreed to accept the qualifications of the manufacturing country of origin;
— October 2008 Specifications are written;
— March 2009: Selection of the manufacturer, contract with the manufacturer is signed;
— 2009: Several meetings with the authorities: According to KTA regulations the Factory Acceptance Test is witnessed by an independent third party. For this purpose and with the consent of the authorities we selected the TUV-Nord;
— The software of the safety channels is certified and approved by the TUV-Nord by a dedicated, independent software department;
— November 2009: Detailed proposal sent to the authorities;
— June 2010 Proposal accepted by the authorities;
— June 2010 Factory acceptance test (2 weeks): Performed by the manufacturer and witnessed by the TUV-Nord, RID and the authorities;
— July 2010 Start of installation, by the two employees of the manufacturer and two RID-employees;
— July 2010 (end): Site Acceptance Test: Performed by the manufacturer, the RID and witnessed by the authorities;
— August 2010: start-up (2 weeks): Started with “cold” test, followed by the “hot” test with step increases in reactor power;
— August 16 2010: Reactor at its nominal power for regular 24-hours/day operation as scheduled.

2.4 Old versus new

Following the tender procedure, Mirion Technologies (MGPI H&B) GmbH was selected as the manufacturer/supplier of the new nuclear instrumentation (see Figure 2). All the channels with a radiation detector are based on the Digital Signal Processing Channels TK250. This system is a flexible modular system that could be adapted for the functionality we needed in every single channel.

These channels have remote signal generators and signal simulation built in and are qualified according to KTA 3501/3505, IEC 60 880.

FIG. 2. The new nuclear instrumentation.

One of the big differences beside the digital implementation is the auto ranging feature in most of the channels. In the old system the range was set with a range switch. The trip is set to 100% of the selected range and thus depending on the position of the range switch. In this case it's not possible to switch to a more sensitive measuring range because the trip will also have a different value.

The new channels have a fixed trip which is stored in EEPROM and is not changeable by the operator. The range switching is done automatically by the software. The advantage is a better view of the process parameters during start-up of the reactor due to the use of the more sensitive measuring ranges.

For power control of the reactor, a combination of N16 for the integral absolute power measurement and a wide range channel for measuring the fast power changes is used. This wide range channel has a logarithmic and a linear output (saw tooth) with 18 ranges over the total power range. Switching to a lower range for the linear channel is done automatically during power decreases. However, for power increases the operator has to activate range up switching by pressing a button. The operator is guided with a lamp in the button if the linear signal exceeds the 80% level in the current range. At 135% of each linear range, a trip signal for the Automatic Rundown of the control rods is generated, in conformity with the requirements. With full automatic range up-switching the 135% level trip would only be reached in the highest range. In order to comply with the specific requirements in force for controlling the HOR during power increases, we implemented this kind of semi-automatic range up switching.

3 IMPLEMENTING FLOW BLOCKAGE PROTECTION

The HOR is an open pool reactor. From this point of view there is a possibility of a flow blockage of a cooling channel caused by an object dropping into the pool during operation of the reactor [1]. Subsequently, the object may be trapped on a fuel element upper inlet section, thereby blocking the coolant flow into one or several channels. As a consequence, the flow in the affected cooling channels will either be reduced or completely interrupted. The channels will dry out and the plates will heat up rapidly. If the reactor is not scrammed in time the melting temperature of the fuel plates is reached. Voiding of coolant channels causes the neutron flux to decrease by the feedback mechanism on reactivity.

3.1 The previous analogue implementation

The previous HOR protection system was equipped with a power Shut-Down Amplifier with a special feature. In addition to the usual protective function regarding the overall neutron flux level, they respond to sudden changes in neutron flux. The current signals are received from ionization chambers (four-redundant). If the input current deviates excessively from an automatically adjusted internal reference level, a trip condition is generated.

To generate a trip, the current from the ionization chamber is converted to a proportional voltage representing the power signal. From this power signal a power reference signal is generated internally as a parameter that is electrically adjusted in a closed loop control system. The system maintains a fixed ratio between the power reference signal and the power signal at steady state. Both signals are compared and the resulting difference signal is amplified to provide the Margin signal. This signal is a sensitive indicator of the input current variations which is used for detection purposes.

As the power signal varies, the power reference signal will vary in sympathy with it, and produces the margin signal equal to the “demanded” margin. Under transient conditions with power decreasing, the power reference signal can only follow the power signal within the limits of the maximum decreasing tracking rate of the system. If the power decreases faster the margin signal deviates from its quiescent state until the excess margin trip condition is reached, generating a reactor scram. The requirement for this system is to generate a trip within one second at a power decrease of 10%.

3.2 The digital implementation

The replacement for this special shutdown amplifier should be a fast system. The manufacturer selected the DGK250 from their TK250 range. It is a neutron flux safety channel for the power range with the possibility to have 2 signal paths for two detectors. One signal path is used for the power signal and the other one is used to calculate the margin signal by the software. This HOR system uses only one detector per channel. The response time is <9ms. The reference and margin signals are calculated according to their analogue electronic equivalent. In the previous analogue electronics version the set points like the tracking rate are adjusted by potentiometers. In the new digital version the safety critical parameters are stored in EEPROM and can not be changed by the operator. Calibration factors can be changed but are protected by procedure and a special key to unlock parameter writing.

To test the system performance during the design phase a software simulation provided by the manufacturer was applied. The proper functioning of the software was tested with this tool, also checking if the requirement of a trip in 1 second at a sudden decrease of 10% power could be met.

During the start-up phase following the cold test, a live test was performed to check if the trip on “excess power differential” was excited, thereby scramming the reactor. In accordance with the test protocol, at a power of 1 MW one of the 4 control rods was dropped into the core to create a sudden power decrease of at least 10%. Indeed, as a result the other 3 remaining rods dropped into the core instantaneously following trip excitation.

4 LESSONS LEARNED

- We started in an early stage discussion with the authorities. This gave us the possibility to respond to their questions in due time. For instance the authorities asked to have a third party analyse the suitability of the new equipment for the Delft application. For this purpose we hired the TUV-Nord to do an assessment and check if the old and new channels have the same functionality;
- In the discussions with the authorities we discussed the way how the manufacturer handles the protection against Common Cause Failures. For this purpose IAEA

Technical Report NP-T-1.5 is used [2]. With the overview in this document the additional points of CCF (software) were checked against the measures taken in the channel design. The results were discussed with the Reactor Safety Committee and with the authorities [3]. The conclusion is that the set of measures that is provided in the channels are adequate in preventing CCF as stated in IAEA Technical Report NP-T-1.5;

- For the channel Pool Outlet Gamma Monitor the response time is of importance. This channel is the second line of defence in the safety system and trips in the case that fission products are released to the primary coolant in significant quantities. This channel plays a role in the safety analyses reported by Siemens [4]. Due to the signal filtering with a time constant depending on the input signal, the response time became too long. We decided to use the unfiltered (raw) signal for the trip generation and to use the filtered signal for the analogue output. The analogue output is used only for data registration. We didn’t expect spurious trips by the non-filtered signal because the signal is quite large during normal operation. In this way the safety analyses are still valid;
- The range switching in the gamma channels is done by software and is more or less artificial. It’s not needed for the sensitivity of the system but implemented to make the difference between the old and the new system smaller. Therefore also the number and the end of the ranges are kept the same as in the old system. It turned out to be very practical; the operators still have the same “feeling” with the reactor;
- The European tender process is a time consuming process caused by certain pre defined time steps. We gain benefit from an internal Procurement department which helps us with the legal issues for the tender;
- In cooperation with RID, the manufacturer organised training sessions for the operational staff. These sessions were held before the actual commissioning. Test channels were used for this purpose, with the same software and Dutch menu structure as the channels that have been installed. The staff has been trained in signal processing in the different channels, maintenance and periodical testing, including practical exercises. The training effort turned out to be very effective for a smooth transfer from the old to the new situation. All staff received a certificate after successful course completion;
- The new instrumentation is qualified according to the strict rules of KTA 3501/3505. Therefore every module that needs repair or testing is sent back to the manufacturer. This is a new requirement with respect to the old situation. To cope with this new situation we have 2 spare modules of every different module.

5. CONCLUSIONS

- The MGPI system turns out to be a very flexible system that could easily be adapted to our needs;
- Testing during checkout is user friendly by using the built-in signal sources and output simulations;
- The time for the operating staff to adapt themselves to the new situation was minimized due to good preparation and training;
- The project was done in time and within the budgetary planning;
- Until now the equipment showed good performance without any errors in the channels.

REFERENCES

[1] DE VRIES, J.W., VAN DAM, H., GYSLER, G., Protection system for minimizing the consequences of a flow blockage incident at a pool-type research reactor, IAEA-SM-310/86P, Chalk River, 1989

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Protecting against Common Cause Failures in Digital I&C Systems of Nuclear Power Plants, IAEA Nuclear Energy Series No. NP-T-1.5, IAEA, Vienna (2009).
[3] WINKELMAN, A.J.M., WETZELS, A.A.R., Veiligheidsstudie ten behoeve van vernieuwing HOR nucleaire instrumentatie, Delft, 2010.
[4] SIEMENS, Contributions to the safety analysis report of HOR, ident-No. KWU-NLS2/93/0013, 1993.