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REACTOR CONTROLS RELIABILITY AND MAINTENANCE AT THE ORR

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ABSTRACT

Early evaluation and study of the various criteria for the ORR clearly established the requirements for the fundamental safety and control instrumentation, and the instrumentation was well integrated into the design and construction of the plant. However, it was not designed for the optimum of maintenance convenience and minimum reactor down time in the event of instrument failure. This paper will attempt to describe the revisions and additions that have been made in the physical plant and maintenance which have resulted in a definite reduction of reactor down time due to instrument failure in both the reactor and in the experiments.

INTRODUCTION

In preparing a paper on reactor controls reliability and maintenance at the ORR, the intent was not to present detailed information on all of the changes which have been made to the original control and safety system. Although specific examples are given, it is intended that these examples illustrate the methods of thought and action which have led to increased reliability and improved maintenance at the ORR. Further, the maintenance program and the results of that program are described.

The experiences described in this paper are presented in a form intended to make it most useful to reactor operating personnel. Therefore, instrument maintenance personnel may not find the presentation as complete as they might desire.

DESCRIPTION OF ORIGINAL ORR CONTROL AND SAFETY INSTRUMENTATION

The original ORR control system and instrumentation were designed and safety limits determined after careful analysis of the primary reactor parameters such as fuel, control-rod* worth and motion, moderator, coolant, etc. This design resulted in the use of instrumentation similar to that installed in both the LITR and the MTR and, in addition, contained a provision for an automatic start mode. Automatic power reduction was provided by: (1) "Setback" - controlled insertion of the servo-controlled rod, (2) "Reverse" - simultaneous, motor-driven insertion of all shim rods, (3) "Slow scram" - simultaneous release of all shim rods by using relay contacts to cut off electrical power supply to the magnet amplifiers, (4) "Fast scram" - simultaneous release of all shim rods by electronically reducing the output current from the magnet amplifiers as the voltage of the sigma bus increases (Sigma-bus voltage is increased by any of three independent safety-level channels as reactor power increases above about 100% of full power or by one Log-N period channel as reactor period decreases. When reactor power reaches about 150% of full power or when reactor period reaches about one second, the output current from the magnet amplifiers is reduced to the point at which the shim rods are released, shutting down the reactor.)

Raising the power of the reactor from source level to N_L on the Log-N scale (i.e., 1% of full power) under surveillance of a fission-chamber, count-rate channel could be done either manually or by using the automatic start mode. Power increase from 1% to 100% of full power

*At the ORR the words control rod and shim rod are synonymous.

with safety-level and Log-N period protection could be accomplished either manually or by using the servo-control system. Reactor-coolant temperature control during reactor power increase was automatic by step-function control of the water-to-air heat-exchanger fans.

Process instrumentation monitored reactor coolant flow, reactor differential temperature, and reactor outlet temperatures. Signals from these monitoring instruments would initiate a power reduction by setback, reverse, or slow scram as dictated by the degree of the error signal.

The experiments were provided with reactor-power-reduction circuits, if required. These circuits were capable of initiating setback, reverse, or slow scram if an experiment parameter were to exceed preset control limits. Each type of reactor-power-reduction circuit (e.g., setback) from all experiments is tied into a common circuit in the reactor control room; if any experiment requires such reactor-power reduction a single signal from this common circuit is transmitted to the reactor control system. The use of this type of common circuit is referred to as "summing", although coincidence is not required. Since there was usually some distance between the reactor and the experiment control rooms, a highly reliable system of dual instruments and double tracks of signal information, similar to those in use at the LITR and MTR, was designed to activate the power-reduction controls.

Building and experiment equipment-chamber containment was provided by a system of negative-pressure off-gas and ventilation systems, automatic closure of major building openings, and a radioactive-gas scrubber system which includes a particulate filter.

The basic concepts, criteria, and operation of the above mentioned protective instrumentation and safety systems have not been altered to any large degree; but false shutdowns, inconvenience of operation, inconvenience of instrument maintenance which resulted in extended shutdowns, and a continuous re-evaluation of reactor controls have prompted numerous revisions and additions to the over-all instrumentation of the plant.

CHANGES IN CONTROL AND SAFETY INSTRUMENTATION

The changes in the control and safety instrumentation will be described by indicating the reasons they were made, how they were accomplished, and their composite results.

Nuclear Instrumentation and Control System

Control Rods, Magnet Amplifiers, and Related Instrumentation

The problem of frequent dropping of individual control rods (73 instances from July 1958 to September 1959) was attacked by making changes in the control-rod magnets as well as in the electronic instruments and electrical interlock system associated with the control rods. These changes were as follows: (1) The rod clutch switch was paralleled with the seat switch in such a manner that intermittent loss of the clutch-switch indication would not result in interruption of magnet current and subsequent rod drop; (2) Installation of longer-lived silicon rectifiers and replacement of the OA2 regulators with the 5651 tube corrected variations in the magnet supply voltage which were caused by intermittent failure of these regulation and power-supply components; (3) The gain of the magnet amplifier was increased by reducing the negative feedback to permit larger magnet currents without raising the scram level significantly; (4) Magnets with greater holding force were fabricated and installed;

(5) An additional magnet amplifier was provided for each control rod and electrically interlocked with the original magnet amplifier so that either would sustain the required, normal magnet current upon the complete or intermittent failure of the other. (The attempt to operate magnet amplifiers as single, independent units to save money, time, and control-room space was not successful. Magnet amplifiers were originally designed and installed in the LITR and MTR for parallel operation. This design provided that each pair of magnet amplifiers would respond as a unit to give both fast and slow scrams; it further provided that maintenance could be performed on either of a pair of amplifiers during reactor operation.)

It might be well to note at this point that, although there is redundance in the safety-level, fast-scram circuits, coincidence is not required to produce a scram. Each amplifier is driven from an independent neutron-sensitive chamber, and each is capable of shutting down the reactor. The redundance does, however, permit de-energizing and removing for repair any one channel during operation since it is considered that two operating channels are sufficient to maintain the required reliability for shutdown. Since repair can be made with the reactor in operation, there have been only six false power reductions due to a faulty channel during the past 24 months. It should be made clear that the removal of a level-safety channel is not accomplished by a simple arrangement of manually or automatically operated switches. Such removal and reinsertion action requires close coordination by both Operations and Instrument personnel, as well as carefully planned and supervised manipulation of the components and electrical connections. Although the electronics and recorders of each system can be replaced during operation, such is not true of the safety chambers.

Effect of Beam-Hole Environment on Neutron-Sensitive Chambers

Soon after the reactor began operation at design power, it was found that substantial error would exist in the signals from the neutron-sensitive chambers if one of the beam holes, which are adjacent to the control and safety chambers, were to become filled with water. The resulting decrease in the neutron flux at the chambers would not only be interpreted by the servo as a request to increase power but would also effectively raise the scram level setting of the level-safety channels. Some protection against such an occurrence has been provided by the installation of dual, independent gamma-level safety channels (other protection has been provided by administrative control and by changes in beam-hole equipment[1]). The gamma-sensitive chambers provide a margin of safety in the event of beam-hole flooding since gamma is attenuated less by changes in the environment around the core; and if the chambers sense only hard gamma the chamber output will be proportional to the neutron flux. At present the gamma-level safety channels are in the slow-scram circuit only, primarily because gamma chambers with sensitivity and reliability adequate for their use in the fast-scram circuit have not been developed. Such development is presently underway, and it is anticipated that, in the near future, redundant channels of gamma-level information will be added to the present neutron-flux-level fast-scram system.

Log-N Period Channel

There was initially only one Log-N period channel available for use in the fast-scram circuit; but it was soon recognized that failure of this channel could seriously lengthen a reactor shutdown if the failure were to occur during, or immediately prior to, a reactor startup. A spare channel, from ionization chamber to the period amplifier, including recorders, has been added; this additional channel is not used to obtain safety redundancy but to minimize reactor down time due to the failure of a single channel. Either of the two channels may be connected into the control circuitry at the operator's discretion. Lights are provided in the control room to indicate the channel in use; various circuit features monitor the channel in use to ensure that the desired reliability (to initiate a scram due to a short reactor period) is retained.

Fission-Chamber Count-Rate Channel

Experience indicates that two independent fission-chamber count-rate channels are highly desirable from the standpoint of trouble-free reactor startups as well as facilitating maintenance. A design and development program is in progress to provide two new fission chambers and drive units (permanent replacements for the existing fission-chamber and auxiliary fission-chamber channels[1]). Guide tubes presently installed in the reactor pool provide for the fission chambers to be positioned adjacent to the reactor pressure vessel while their drive motors and associated components are readily accessible (above water with the pool filled).

Level-Safety Protection for Reactor Operation at Low Power

To evaluate reactor fuel loadings and reactivity effects of experiments being installed in the ORR, the reactor must be operated at low power levels (up to 0.01% of full power) with the reactor pressure vessel open to the surrounding pool. Since such low power operations are performed frequently, the reactor safety-control system must be capable of reliable performance under two widely different reactor conditions. It has been ORNL policy to avoid adjustable safety-trip-points; but when it became necessary to employ a two-level trip, each level-safety channel was provided with an individual method of switching which is automatic and independent of operator error. Such an automatic, low-level trip is now installed to safely limit the power to 1.5% of normal full power when the reactor is being operated for special low-power tests. Analysis has shown that power rises on periods as short as 10 milliseconds are handled equally well at both the high-and low-level scram settings.

General Problems with Nuclear Instrumentation

The removal and replacement of a reactor-control monitoring chamber is extremely difficult during reactor operation because the physical manipulations of chamber and associated cables must be done under 25 feet of water while, at the same time, avoiding damage to and shading of, adjacent chambers. The immediate solution to the problem was to install spare chambers in all of the eight positions now available. Although considerable difficulty was encountered during the design phase of the reactor in justifying eight chamber positions, more are needed now, and still more are known to be required in the near future. Since additional positions can only be provided with considerable difficulty, the solution is to fabricate multipurpose chambers in the same container. Development of a singly contained, but electrically independent, gamma and neutron chamber is being actively pursued.

Radiation damage experience has led to a program of replacement and repair of all chambers on an annual basis. Chamber life and reliability could be considerably increased if suitable radiation-resistant insulation could be provided.

A really satisfactory compensated chamber has not yet been designed. Although many mechanical problems (poor internal connections, poor compensation-volume control, etc.) have been solved, a method to achieve suitable compensation over a range of 6 to 8 decades has not yet been developed. Development programs are underway, but no immediate solution is in sight.

Instrumentation and Control of Reactor Process Systems

Probably the greatest amount of revision was required in the process instrumentation.

Reactor-Coolant Outlet Temperature Monitoring Instrumentation

The reactor-coolant outlet temperature was monitored by thermocouples; the signals were displayed on a multipoint, potentiometer-type recorder. Back-set switches, tripped by the balancing system of the recorder, initiated reactor-power reduction when high outlet temperature occurred. Obviously, the action of the system could be nullified by failure of the thermocouple selector switch to contact the proper thermocouple; and the time response would be excessive if a high exit temperature were to occur when the selector switch was on some point other than the exit temperature. Also a false power-reduction signal could be iniated if another point displayed on the same instrument were to indicate a temperature in excess of the set point. The reactor exit temperature is now monitored by two independent, single-point, potentiometer recorders in each of which the balancing bridge receives its signal from a resistance-type thermal bulb. The response of these thermohms is somewhat slower than the thermocouple, but this constitutes no significant addition to the coolant-transport lag of about 7 seconds from the reactor to the sensing element. Since the thermohms are the in-line well type, improvement of the time response was made by packing the bulb in the well with aluminum wool. The redundancy of instruments, installed to increase the reliability of the system, does permit the removal and repair of recorders during reactor operation. The sensing elements can only be reached when the reactor is shut down because of their location in an area of high gamma radiation. No shutdowns have resulted from a failure of either the recorders or the thermal bulbs.

Reactor-Coolant Differential-Temperature Monitoring Instrumentation

Initially the reactor-coolant differential temperature was monitored by thermocouples in the inlet and exit water lines, but the low differential temperature provided a signal so low that special amplification was necessary before it could be used as a reactor control (e.g., at 20 Mw the differential was $8^{\circ}F$ and the signal was only 0.24 mv). Since there are two exit lines from the reactor and since the reactor heat-balance computation is based on the differential temperature, the revised system is arranged to operate directly into recorders from a bridge network of resistance thermal bulbs which are averaged in both exit lines and then in differential with one of the inlet lines. Dual channels of ΔT instrumentation are provided; either of which, under prescribed conditions, may be repaired during reactor operation.

Reactor-Coolant-Flow Monitoring Instrumentation

The flow-monitoring system is now arranged so that independent reactor-power-reduction signals are developed from a venturi flow meter in the primary coolant line and also from the differential pressure developed across the reactor core; redundant channels are provided to monitor both parameters. The relatively long coolant-rundown time (27 seconds from 20,000 gpm to 1000 gpm) due to coast down of the primary pumps and due to kinetic energy stored in the coolant permits the use of pneumatic means for transmitting flow information. All three primary pumps are presently used to maintain coolant flow at a reactor power of 30 Mw, and a redundant system has been added to automatically reduce the reactor power to 18 Mw if coolant flow or differential pressure decreases to that provided by two pumps; the setpoints for this latter system were determined to be conservative based on prior reactor operation, but they are subject to revision as determined by subsequent operating data. At the present time, if a further reduction in coolant flow to 14,000 gpm or of the differential pressure to the equivalent of a flow of 14,000 gpm occurs, complete reactor shutdown will be automatically initiated.

Following a normal reactor shutdown the coolant is circulated by an electrically driven pump which delivers about 10% of normal flow. Following a reactor shutdown due to an electric power failure the afterheat protection was originally provided by an automatically started gasoline-motor-driven pump (with slightly less capacity than the electrically driven pump). However, emergency systems which must start on demand are not considered adequately reliable for afterheat protection. Protection is now provided by continuously operating, battery-powered, auxiliary motors which are installed on the shafts of the three primary pumps.

Reactor-Cooling-System Control Instrumentation

A complete revision of the coolant load system was required prior to increasing the reactor power to 30 Mw. The original heat-dissipating system consisted of a series of water-to-air heat excahngers for which the only control was a step function of fan speed and louver closure. Although rated at 20 Mw, the capacity of this system during the summer months was about 16 Mw which resulted in a yearly average operating power of about 18 Mw. The present system constitutes a distinct improvement and consists of four water-to-water heat exchangers and a crossflow, two-cell cooling tower as a heat sink. Continuous temperature control is achieved by use of a flow by-pass valve on the primary side of the heat exchanger; regulation of the secondary heat sink is achieved by a similar by-pass valve (making use of a function signal generated from the reactor-coolant outlet temperature and from the position of the primary by-pass valve) and fan-speed control. These control components are not installed in duplicate since it is felt that the small consequence of failure of components does not warrant the usual redundancy. Manual control of the by-pass valve is provided in such a manner that the reactor can be operated satisfactorily at a moderately reduced power level until valve replacement can be made on a scheduled shutdown.

Instrumentation and Control of Auxiliary Process Systems

Many revisions and additions have been made to the instrumentation monitoring various auxiliary process systems. Most of these changes have not been made to utilize redundant techniques for safety and reliability but for purposes of improving maintenance and reducing reactor shutdown time. Such changes have been made in the pool cooling system, the reactor-coolant degasifier and demineralizer systems, and the process radiation monitoring. Additional instrumentation channels for initiating reactor-power reduction have been installed to monitor the off-gas systems, the building-exhaust system, and the cooling systems for the two large experiment facilities.

Instrumentation Monitoring Reactor or Reactor-Associated Systems: Summary

In general, the previously mentioned revisions and additions to the reactor controls have tended toward a dual redundancy, but not coincidence, of instrumentation. This arrangement permits the removal and repair of one information channel during reactor operation. However, it is of primary importance that disarming of instrument channels is not indiscriminate: it must be determined that instrument malfunction rather than system failure has occurred. Thorough investigation of the specific symptoms and their relationship with other possible malfunctions must be made, then the corrective steps to be taken must be administratively approved before the removal of any single channel.

EXPERIMENT INSTRUMENTATION AT THE ORR

The experiments at the ORR fall into three categories: (1) neutron-beam and associated neutron physics studies, (2) static material-irradiation studies and isotope production, and (3) material and fuel studies involving complex, static or dynamic "loops" which require some form of automatic reactor-power-reduction control. Although each type of experiment requires a great deal of instrumentation and local control (i.e., at the experiment control station) for which maintenance is required, only those experiments that are connected to the reactor control system will be discussed here. The safety and useful life of these experiments are dependent on the instrumentation which, therefore, must be of maximum reliability. Failure of these experiment protective instruments, as well as failure of the reactor controls themselves, can result in the reduction of reactor operating time.

Before describing the maintenance and reliability aspects of the experiment-protective controls, it might be well to point out the basic criteria for such instrumentation. (1) The experiment protective instrumentation serves the purpose of protecting the experiment and provides the first line of defense for protecting the reactor and operating personnel; the second line of defense for protecting the reactor and operating personnel is provided by the experiment containment. (2) The above is reliably accomplished by the use of two independent protective instruments and trip channels for each parameter which can initiate a reactor-power reduction. (3) The instruments used are "off-the-shelf" items but are subjected to special, periodic checkout procedures to ensure that the required reliability is maintained.

Since the lifetime of a particular experiment in the reactor is not precisely known, it was desirable to have a relatively easy and readily acknowledgeable method for disconnecting the experiment from the reactor-control-system which would not jeopardize the connection of other experiments by its use. To this end, each experiment-safety-instrument system is summed at the experiment and independently transmitted to the reactor-control system through an individually keyed and locked disconnect switch which is located in the reactor control room. Operation of the switch is administratively controlled, and its position is monitored both in the reactor control room and at the experiment control center.

As in the reactor control circuits, the experiment instrumentation is redundant, but not coincident, in its operation. This arrangement, as noted earlier, permits removal of one of a pair of channels for repair. The requirement of investigation, planning, and administrative approval prior to removal is identical to the requirement for removal of a reactor control channel. No single disconnect or other simple means is provided for the removal of a particular information channel. The de-energizing, for maintenance purposes, of one channel of a dual channel does not inhibit the operation nor reduce the reliability of the remaining double-tracked information to the reactor control room.

Standardization and Maintenance of Experiment Instrumentation

A rather intensive effort has been made to standardize experiment-protective instruments and their method of transmitting to the reactor-control circuits. Standardization of acceptable instruments is implemented by the use of a list of preferred industrial instruments for experiments in ORNL reactors (maintained by the Instrumentation and Controls Division, ORNL). This list has been of considerable assistance in establishing the present degree of reliability of the protective instrumentation. Primarily, the purpose of such standardization is to eliminate the use of those instruments for which there is no statistical history of satisfactory service life and for which there are no spare parts and/or maintenance information. The use of the list of preferred instruments has also minimized the possible misapplication, and subsequent failure, of an otherwise satisfactory instrument (i.e., if a generally satisfactory instrument is unsatisfactory for a particular application, this information is recorded in the listing).

Standardization of acceptable instruments has by no means limited the use of new instrument systems; however, it requires that a rather thorough evaluation of the new system components be made before their acceptance and use in experiment protective circuitry. Until recently, for example, many false shutdowns due to instrument failure of potentiometer-type instruments were caused by the malfunction of the mechanical standardization switch, reference cell, and bridge supply battery. These components have been replaced by a Zener regulated-constant-voltage supply after the Zener had been accepted following thorough evaluation.

Standardization of the method[2] by which the experiment protective instruments develop and transmit control signals to the reactor control circuits has resulted in each experiment's having, to an identical degree, the reliability to initiate a reactor-power reduction as well as reducing the time for installation and for operational checkout. Prior to the construction and operation of each experiment the design of its protective and control instrumentation is given a thorough review by Instrumentation and Controls Division personnel. These reviews have resulted in the continual upgrading and standardization of instrumentation as well as the correction of possible design errors prior to fabrication.

In addition to the previously mentioned standardization and modification of instrumentation, there are some rather subtle actions which have also been effective in reducing the reactor down time due to instrument failure. Many of the early experiments were designed to deliver a slow-scram signal to the reactor if a parameter were to get beyond preset limits. Only 7 channels of information capable of initiating a scram are active among the 21 experiments now in the reactor. Since the scram is irrevocable (even though the initiating signal may be of a short transient nature), and since a minimum of 14 minutes is required to resume reactor power operation, the reduction of the over-all number of scram-initiating channels has significantly decreased the lost time due to instrument failures. The reduction of the number of scram-initiating channels was not made at the expense of the safety of the experiment or the reactor, but due to: (1) a more thorough analysis of the transient and static behavior of an experiment before its installation and operation, (2) an improved, more reliable, and more adequately monitored primary and secondary containment of experiments, and (3) the use of setbacks rather than scrams when the setback time response is adequate to protect the experiment. The change from a 4-week to an 8-week basic cycle of reactor operation has also assisted in reducing the number of instrumentation failures. The longer cycle permits a more thorough programming of preventive maintenance measures; such programming has minimized the human error and also optimized the number of times that an instrument has a complete "shakedown" checkout.

Results of Standardization and Maintenance Program

The duplication of the reactor and experiment control channels has made it possible to operate the reactor on an average 135-hour week basis (i.e., the reactor has been in operation about 80% of the time) with instrument and controls maintenance personnel working on a 40-hour-week, one-shift basis. Reactor shutdown time due to instrument malfunction has averaged one hour per month. Since it is permissible to de-energize one of the channels under certain controlled conditions, the repair of the faulty channel may often be postponed until the regularly scheduled maintenance personnel are available. Above-average maintenance procedures and practices must be established if these multiple, independent channels of information are to track within the specified degree of accuracy of the instruments (e.g., two instruments each capable of accuracy to within 2% must be made to agree within 2%). Having established maintenance procedures and practices to meet these unusually stringent requirements results in improved system reliability. A further, less-tangible result is the continual upgrading of the ability of maintenance personnel in establishing and conforming to superior procedures and practices.

The testing of the control signals during the bi-monthly, end-of-cycle, reactor shutdown is both time-consuming and tedious; a minimum of 165 manhours is required during a typical shutdown period. A method of "built-in" testing which will reduce the time required and still provide the necessary reliability checkout is being investigated.

For the past 18 months, the experiment protective systems and the reactor control systems have contained an average of 280 independent tracks of control information which are capable of initiating a reactor-power reduction. Many of these independent tracks of control information are composed of multi-instrument computer systems for integration, differentiation, etc.; thus increasing the actual number of control channels to well over 500 for the entire system.

During the past two years an average of 16 experiments have been connected to the reactor-control system through the experiment tie-in system. The range of complexity of experiment-protective instrumentation is considerable. For example, one simple static-irradiation experiment in the ORR has a single parameter capable of initiating a reactor-power reduction; however, a complex dynamic experiment in the ORR has 14 parameters capable of initiating a reactor-power reduction. The latter experiment contains numerous local control loops which will, in the event of failure, drive one of the 14 monitored parameters beyond its preset limits and initiate a reactor-power reduction. This experiment also contains 80 alarm circuits which are summed to actuate a single annunciator in the reactor control room.

DESCRIPTION OF THE MAINTENANCE PROGRAM

A standard maintenance practice involves, primarily, one-for-one field replacement of a malfunctioning controls component. This is followed by repair, visual checking, aging (i.e., operating the component for about 100 hrs with no load), and performance testing (under load). This program has practically eliminated the repetitive failure of instruments. Instrument-maintenance personnel make daily visual checks of reactor and experiment protective-control systems. A daily review is made of the performance of these systems during the preceding 24 hours. Reported malfunction or erratic operation of any instrument system is evaluated by the maintenance staff and, if possible, is immediately corrected. If such immediate correction is not possible, a concentrated effort is applied using auxiliary test equipment to further evaluate the problem and perform the necessary repair. Minor routine maintenance is performed during the daily instrument checks. Routine maintenance of those instruments which cannot be readily removed from the control system is made during the regularly scheduled reactor shutdowns. Major maintenance or overhaul of the instrument systems are also made during the scheduled shutdown periods, and are closely scheduled with other activities to achieve maximum use of both time and personnel. Any addition or modification which would alter the fundamental concepts of operation or safety of the reactor is performed only from appropriately authorized documentation.

Maintenance Staff at ORR

The final, and perhaps most important, action that has been taken for the improvement of instrument maintenance and reliability has been the addition of competent and trained personnel to the on-the-site staff. Although the staff has similar responsibilities for instrument and control activities at the OGR, LITR, and associated experiments,* it has made additional engineering and craft foremen specifically available for (1) more intensive studies of elusive control-system troubles, (2) safety evaluation and field modifications of experiments, (3) more thorough study of design problems revealed as a result of operational experience, (4) liasion of activities between the Operations, Engineering and Mechanical, and Instrumentation and Controls Divisions for both routine work, major maintenance, and installation of new systems, (5) design of special test equipment, (6) establishment of procedures for maintenance and testing, and (7) training of new personnel. The staff personnel have shown a high degree of integrity in their work, and this has resulted in minimizing human errors and elimination of oversights in maintenance practices.

Both the engineers and foremen take an active part in on-the-site training of all personnel with respect to new instruments and instrument

*The man-hours which the staff devotes to ORR and ORR-related experiments is equivalent to a staff consisting of 2 1/2 engineers, 1 1/4 foremen, and 9 1/2 technicians.

systems. Such training is not rigorously scheduled because of the commitment to perform "immediate repair" in the event of instrument troubles. Each foreman and engineer is expected to make specific studies related to the program and some are sent to special instrument-manufacturers' training schools for additional information. The average instrument technician has had three years of a formal ORNL apprentice-training program and usually a year of general practice throughout the Laboratory before coming to the Reactor Controls Department. Additional on-the-site training has been established by rotating the maintenance technicians, on an approximately annual basis, through the various phases of reactor and experiment work. Formal training of the reactor-controls maintenance personnel has been adopted and makes use of the instrumentation instructors and laboratories of the Oak Ridge School of Reactor Technology.

REFERENCES

1. W. H. Tabor and R. A. Costner, Jr., Problems Encountered During Four Years of ORR Operation.*

2. J. T DeLorenzo, Guide for the Design of Safety Instrumentation for Experiments in the LITR and ORR, ORNL TM-77 (Dec. 11, 1961).

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* Paper presented at the "Conference on Light-Water-Moderated Research Reactors," ORNL (June, 1962).

APPENDIX

APPENDIX

Reactor Controls Malfunctions at the ORR

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
7/27/58	16.617	Reverse from hi reactor exit temperature followed by scram of unknown origin.	Reason unknown.
9/2/58 to 9/6/58	69.475	Spurious scrams.	Installed suitable noise spike filters in sigma and magnet amplifiers. Set sigma amplifier Jordan button circuit to deliver a simulated 1.7 N_F power level. Increased shim rod magnet current.
10/5/58	0.100	Reverse - failure of No. 1 safety recorder.	Repaired standardization switch.
10/5/58 to 12/27/58	29.533	Dropped rods--reasons unknown. No. 3 magnet short to ground. Tube failure in No. 6 magnet amplifier.	Wired clutch switch in parallel with seat switch. Investigated load requirements of shim rod magnets. Installed new rectifiers and regulators in magnet amplifiers. Increased gain of magnet amplifiers. Installed clamping diodes to improve current characteristics between N_L and N_F.
2/13/59	003890	No. 6 magnet amplifier failure.	Replaced amplifier.
3/2/59	000933	Human error--shorted instrument.	
4/30/59	0.033	No. 3 safety increased to 113 N_L.	Reason unknown.
6/8/59	0.050	Faulty Log N recorder.	Repaired standardization switch.

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
6/12/59	0.400	HN-1 Experiment scram. Faulty instrument.	
6/25/59	0.300	No. 3 magnet amplifier failure.	Replaced amplifier.
7/8/59	7.667	Scram - N.E. Gamma Chamber failure.	Replaced chamber. Moisture found on chamber connectors.
7/9/59	0.267	Scram - S.E. Gamma Chamber failure.	Moisture found on chamber connectors.
7/28/59	0.283		
7/28/59	0.283	Scram-- HN-1 Experiment. Recorder failure.	Repaired standardization switch.
9/12/59	0.200	Setback - GE Experiment. Thermocouple burnout	Transferred to spare thermocouple.
9/7/59 to 9/11/59			Installed parallel magnet amplifiers for each shim rod magnet. Installed new magnets with greater holding force. Installed new gamma chambers.
10/14/59	0.050	Reverse - No. 2 safety recorder failure.	Repaired standardization switch.
12/27/59 to 12/31/59			Replaced shorted No. 6 magnet and No. 6A magnet amplifier. Replaced No. 3 safety chamber due to moisture on connectors. Replaced grounded fission chamber with modified insulators of higher resistance to radiation damage.

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
1/1/60 to 2/23/60	Total lost time 15 hrs.	Mechanical failure in servo limit switch drive unit.	Replaced drive motor.
		Servo amplifier failure.	Replaced servo amplifier. Repaired buffer voltage circuit in d-c amplifier.
		Servo amplifier erratic action.	Replaced output tubes and d-c chopper.
		Servo amplifier erratic action.	Replaced tachometer.
		Servo amplifier erratic action.	Revised buffer voltage circuit in d-c amplifier.
		No. 1 safety chamber failure.	Replaced chamber due to B^+ short to ground.
		Gamma chamber failure	Replaced chamber due to moisture on chamber connectors. Initiated repair and routine replacement program of all reactor control chambers.
2/3/60	11.350	Log N chamber failure	Replaced chamber due to moisture in connector housing. Replaced again due to same fault. Repaired hole in connector housing. Human error by crossing hi voltage and signal leads.
2/9/60	0.033	Setback - MSR Experiment recorder failure.	Repaired standardization switch. Initiated installation of Zener reference voltage supplies in recorders.
2/14/60	0.083	Setback - MSR Experiment recorder failure.	Installed Zener reference voltage supply.

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
3/7/60	0.317	Setback - MSR Experiment recorder tube failure.	Replaced vacuum tube.
3/13/60	0.333	Setback - GCR Experiment recorder failure.	Replaced vacuum tube. Initiated program for pre-aging vacuum tubes in an identical, but not protective, instrument.
4/9/60	0.383	Setback - GE Experiment thermocouple burnout.	Transferred to spare thermocouple.
4/19/60 to 6/29/60	Total lost time 0.517 hr.	No. 3 shim rod magnet short.	Replaced magnet.
		Cooling water multipoint recorder failure.	Repaired leads to standardization reference cell.
		No. 2 safety recorder failure.	Replaced fiber drive gear.
		Count rate recorder failure.	Replaced broken signal lead in recorder.
		Log N period spikes.	Replaced Log N period amplifier.
		Count rate and count rate period erratic.	Replaced preamplifier and A-1 amplifier. Recalibrated count rate motor.
		Pool cooling secondary pH control failure.	Replaced acid make-up valve (twice).
			Initiated program for supervised bench check and records of electronic systems.

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
4/25/60	0.233	Setback - GE Experiment. Failure of coolant controller.	Replaced controller.
4/26/60	0.167	Setback - GE Experiment. Thermocouple burnout.	Transferred to spare thermocouple.
6/8/60	0.133	Setback - MSR Experiment recorder tube failure.	Replaced tube. Initiated program for cooling recorder amplifiers.
6/11/60 to 6/17/60			Corrected design error in a-c supply to E-panels. Prepared control room for change tc 30 Mw operation. Installed temporary magnet supply for two additional beryllium-cadmium shim rods. Added an annunciator and appropriate circuitry for "two safety roubles".
6/22/60	1.233	Scram - Experiment tie in panel wire failure.	Replaced E-panel.
6/29/60	0.017	Setback - GE Experiment. Human error in disconnecting thermocouple.	
7/5/60	0.033	Setback GE Experiment. Recorder spike.	Reason undetermined.
7/6/60	0.200		
7/6/60	0.200	Setback GE Experiment. Thermocouple failure.	Transferred to spare thermocouple.
7/7/60	0.183	Reverse GE Experiment - human error, removed wrong wire during maintenance.	

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
7/9/60 to 7/29/60			Completed control changes for 30 Mw operation.
9/16/60	0.083	Setback GE Experiment. Thermocouple failure.	Transferred to spare thermocouple.
9/17/60	0.083	Setback GE Experiment. Thermocouple failure.	Transferred to spare thermocouple.
9/22/60	0.067	Setback GCPR Experiment. Thermocouple failure.	Transferred to spare thermocouple.
10/19/60	0.033	Setback MSR Experiment. Recorder failure.	Replaced standardization mechanism.
10/24/60	0.150	Setback GE Experiment. Thermocouple	Transferred to spare thermocouple.
12/20/60		Noted simultaneous spiking of gamma recorders.	Installed separate power supplies for gamma chambers. Removed S.E. gamma recorder from control circuit.
12/22/60	0.243	Setback GCPR Experiment. Recorder failure.	Repaired standardization switch.
12/22/60	0.217	Setback GE Experiment. Recorder failure.	Replaced vacuum tube in amplifier.
12/24/60	0.083	Setback GCPR Experiment. Recorder failure.	Adjusted standardization mechanism.

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
1/15/61 to 1/21/61			Installed temporary fission chamber in pool. Initiated investigation regarding upscale drift of gamma monitors.
2/3/61	7.917	Scram. GCR Loop No. 1, MSR Experiment. Momentary loss of power.	Reason undetermined.
4/2/61 to 6/25/61	Total lost time 0 hrs.		Routine replacement of servo, No. 2 Nog N, and micromicroammeter amplifiers. Servo amplifier required re-zeroing. Reactor secondary by-pass valve controller required adjustment. Servo amplifier drift was caused by temperature shift due to loss of cabinet exhaust fan. Lost signal from fission chamber due to cable short. No. 2 Log N period amplifier tube failure. Both Log N channels were erratic due to faulty control room air conditioning. Drift in the count rate meter noted. Probably due to control room air conditioning. Replaced count rate meter on startup 6/25/61.
4/4/61	0.083	Setback. MSR Experiment. Recorder failure.	Replaced amplifier vacuum tube.
5/6/61	0.350	Scram. GCPR Experiment. Recorder short resulting in human error and safety circuit power loss.	Replaced balance motor.

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
6/1/61	0.017	Setback GCR Loop 1 Experiment. Differential pressure transmitter failure.	Replaced Δ P transmitter.
6/25/61	0.083	Setback MSR Experiment. Recorder failure.	Replaced amplifier vacuum tube. Initiated program for replacement of recorder amplifiers with a new model of lower heat generating capacity.
7/13/61	0.000	No. 1 Log N noise spikes.	Faulty compensated chamber. Chamber was changed out 8/3/61. Modifications were made to increase the reliability of the negative voltage contact in the chamber.
8/7/61	0.000	MSR Experiment. E-panel failure.	One scram relay was found to be faulty during checkout. Replaced same.
8/30/61	0.000		Shim rod magnet coils were coated with a thin film of silicon grease to prevent moisture absorption. Drain holes were drilled in the magnet keepers to prevent water buildup at the bottom of the magnet assembly.
9/5/61	0.000	No. 1 safety noise spikes.	Replaced both the recorder amplifier and standard cell.
9/11/61	0.000	Magnet amplifier No. 6A failed.	Replaced amplifier vacuum tubes.
9/21/61	0.000	No. 1 and No. 2 safety zero drift.	Adjusted preamp grid off-set during scheduled shutdown.

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
10/2/61 to 12/22/61	Total lost time 0 hrs.	No. 1 ΔT recorder erratic.	Replaced amplifier tubes. Installed modified PCP chambers to minimize radiation damage to connectors and cables.
		Gamma recorder failure.	Replaced amplifier fuse. Installed fission counting scaler audio detector at poolside to assist operations during fuel reloading.
		Compensated chambers checked outside of normal limits.	Routine compensation of all compensated chambers.
		Primary by-pass valve stuck in the open position.	Valve was pneumatically locked open. Then replaced at the next scheduled shutdown.
		No. 1 Log N. Period noise spikes.	Replaced amplifier tubes.
10/3/61	0.233	Scram. GCPR Experiment loss of control power.	Reason undetermined.
10/20/61	6.233	Scram. GCPR Experiment loss of control power.	Reason undetermined.
11/12/61	0.217	Scram. GCPR Experiment loss of control power.	Reason undetermined.
11/13/61	0.234	Scram. GCPR Experiment loss of control power.	Replaced sealed relay which was intermittently shorting to ground.
12/26/61	0.067	Setback B-9 Experiment. Recorder tube failure.	Replaced amplifier tubes.

Date or Period	Lost Operating Time - Hours	Malfunction	Repairs Initiated and Remarks
1/3/62	0.000	No. 2 Log N. Defective operate switch.	Replaced switch.
1/20/62	0.000	Reactor coolant activity monitor failure	Replaced monitor power transformer.
2/7/62	0.083	Setback MSR Experiment. Thermocouple failure.	Transferred to spare thermocouple.
2/18/62	0.000	No. 1 Log N Period erratic	Replaced amplifier tubes.
2/18/62	0.000	S.E. Gamma chamber failed.	Removed and replaced chamber due to water in chamber housing.
3/2/62	0.000	Auxiliary count rate channel failed.	Replaced A-1 amplifier and count rate meter.

SUMMARY

Period	Number	Lost Hours	Hours/failure
Reactor Controls Failures			
1958 (4 mo.)	4	116	29
1959	8	8.9	1.1
1960	3	26.8	8.9
1961	0	0	0
1962 (3 mo.)	0	0	0
Experiment Controls Failures			
1958 (4 mo.)	0*	0	0
1959	3*	0.833	0.28
1960	21	4.3	0.2
1961	10	15.4	1.5
1962 (3 mo.)	0	0	0

*Experiments being installed.

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