THE FORD NUCLEAR REACTOR
CONTROL SYSTEM

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Ann Arbor, Michigan

Fall Meeting--New York

October 28, 1957

American Nuclear Society

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INTRODUCTION

The one megawatt swimming pool type[1] research reactor at the University of Michigan recently (September 19, 1957) went into operation. At present, the reactor is operating at low power levels for the purposes of reactor and control system calibrations.

The Ford Nuclear Reactor[2] was designed to provide facilities for a broad comprehensive educational program in conjunction with a highly diversified research program. The control system for such a reactor must be characterized by simplicity and flexibility of operation while providing a high degree of safety, protection and reliability. The installed control system, designed in 1954, is similar to that for the original Bulk Shielding Facility[3] at the Oak Ridge National Laboratory.

DESCRIPTION OF THE CONTROL SYSTEM

There are four types of instrumentation channels that provide information about conditions within the reactor to the control system: namely, the pulse or start-up channel, the linear servo channel, the log N-period channel, and the safety channels. Fig. 1 shows the Instrument Block Diagram for the Ford Nuclear Reactor. These channels, designed by the Oak Ridge National Laboratory, are similar or identical to those used on other reactors, such as the MTR[4,5], ETR, LITR and GCR[8]. Since much has been written about these instruments elsewhere, there is little need to describe them here.

The safety actions initiated by the Ford Nuclear Reactor control system are, in order of importance:

1. Level Safety Scram

There are two level safety channels in the system which electronically decreases the currents to the three electromagnets, thus permitting the three shim-safety rods to be dropped into the reactor. These channels are the primary safety channels for the reactor and are independent of the rest of the control system. This independence prevents safety compromise due to control system interaction. The level safety channels are set to secram the reactor at a power level of 150 per cent of full power.

2. Period Safety Scram

The one period safety channel on the FNR receives its information from the log N channel. Since log N information is critically dependent on the degree of compensation of its detector and because the log N channel is not completely monitored for component failures as are the level safety channels, period safety can only be considered as secondary to the level safety channels. Control system interactions could conceivably compromise the protection offered by the log N channel, therefore cognizance of this fact must enter any discussion or establishment of period safety criteria. This channel will electronically reduce the magnet currents and hence, "scram" the reactor at periods of 5 seconds or less.

3. Automatic Interlock Scrams

Shutdowns from the interlock type of control system action are considered "slow scram" in that the power supplies for the electromagnets are turned off. This action is slower than the "fast" or electronic switching as described above and is, therefore, used to shutdown the reactor (or prevent the reactor from going into operation) when conditions exist requiring shutdown but not on an urgent basis. Action of this type in no way approaches the degree of safety protection provided by the level safety system. There are numerous interlocks thatperform this "slow scram" action on the FNR, such as high radiation level in the building, inadequate cooling, etc.

4. Automatic Rundown or Reverse

Driving the three shim-safety rods into the reactor by motor control is considered a mild form of safety action. The Automatic Rundown function adequately handles minor reactor excursions for which the more drastic action of scram is unnecessary and, indeed, undesirable. On the FNR, automatic rundown is initiated if the period becomes 10 seconds or less and/or the linear level reaches 135 per cent of the full scale value selected. The latter provides safety action over a wide range of reactor power levels.

5. Restriction of Control Rod Withdrawal

Should the reactor attain a period of 30 seconds or less, further withdrawal of the control rod by either manual or automatic servo control is prohibited. This feature provides reasonable assurance that the reactor, under normal conditions, will not be able to attain a period less than 30 seconds, the shortest permissible operating period. This action is desirable in that it provides a reminder for the "not-too-attentive" operator.

DISCUSSION OF CONTROL SYSTEM

Inasmuch as there were several delays before the reactor was put into operation -- due to the innate perversities of inanimate objects -- considerable time was available and devoted to testing and evaluating the control system performance. As a result of this pre-operational experience and our start-up and operating experience to date, several features of the control system were brought to light which require modification or correction.

ELECTROMAGNETS

As mentioned previously, the two level safety channels, in conjunction with the period safety channel which derives its signal from the log N-period channel, function to shut the reactor down by dropping all safety rods whenever the power level increases beyond a preset value and/or an abnormally short period occurs.

In each level safety channel, a PCP (Parallel Circular Plate) ionization chamber supplies a current proportional to the reactor power level to composite safety amplifiers whose components include a preamplifier, a sigma amplifier, and a magnet amplifier arranged on a single chassis. Since the current produced by neutron flux at high levels of operation is much greater than that produced by gamma radiation or other sources, this chamber is not compensated.

The output of the PCP chambers and the output of the log N channel are fed to preamplifiers in the composite safety amplifiers. The preamplifiers, in turn, feed into sigma amplifiers whose outputs are supplied to a bus, referred to as the sigma bus. This bus serves as the input to all three magnet amplifiers, each of which supplies the current to an electromagnet which holds a shim-safety rod.

When the signals from the two PCP ionization chambers or from the period channel are normal, the sigma amplifiers maintain the potential of the sigma bus at a prescribed level. However, if the positive period should become abnormally short, or if the power level should become dangerously high, the sigma bus potential is increased, which causes the magnet current in all three magnet amplifiers and, therefore, in the three electromagnets to be quickly reduced, thus dropping all three safety rods into the reactor.

The system is so designed that the same result is achieved if the sigma bus potential should decrease for any reason. Since the sigma bus is connected to the input of each magnet amplifier, a scram may be initiated automatically by any one of the three safety channels.

It is important to note that the magnet currents are reduced by a given amount under scram conditions of 150 per cent of full power or a 5 second period. To assure that the shim safety rods are released at these values, the reduced currents must be slightly less than the release or "drop" currents for magnet-rod combinations. Therefore, in setting up the safety system, synthetic scram signals are fed to the system and the magnet currents adjusted to their "drop values." Upon removal of the synthetic scram signals, the magnet currents will increase to values which are the maximum permissible values to assure a scram by the safety amplifier at the level and period intended. The maximum current is the "hold" current available for raising the rods during start-up and holding the rods during power level operation. Naturally, with a safety system of this type, it is absolutely necessary to have reproducible "drop currents" in order to scram at the specified level and/or period and, during normal operation, have a holding force considerably above that required to hold the rods reliably. If the holding forces are only slightly greater than that required to hold the rods, spurious shutdowns will occur because of vibration, slight misalignments of guide tubes and minor electrical power fluctuations. To date, we have experienced unnecessary shutdowns which we feel are attributable to the electromagnets. The "drop" currents vary as a function of the hold currents, implying that our electromagnets are not operating in the saturation portion of the hysteresis loop. What is needed, are magnets designed to operate at saturation -- to assure reproducibility of the drop currents -- and which would also have large holding forces for normal operation. Such magnets would then provide for continuity of normal power level operation and reliable shutdowns under certain abnormal conditions.

Another important feature of electromagnet performance in a reactor safety system that requires closer attention is the ability of the magnets to release the rods in a minimum time. Tests on the Ford Nuclear Reactor system indicate that if the magnet currents are rapidly reduced to well below the drop currents, the time required for the magnets to release the safety rods is about 50 milliseconds. This magnet-rod release time is many times greater than the total of all other safety system delays. Electromagnet-rod combinations having release times of about 10 milliseconds while retaining the advantages of high holding forces and reproducible drop currents are needed for reactor safety systems which employ safety concepts similar to those for the FNR.

The magnet-rod release time measurements were made using a technique developed by L. C. Oakes[6] of the Oak Ridge National Laboratory wherein a fixed amplitude, variable width voltage pulse is impressed on the sigma bus of the system. By slowly increasing the pulse width, a width is reached which raises the sigma bus to the scram level for a sufficient length of time that the electromagnets release the safety rods. This pulse width, at which the rods drop, then is a measure of the magnet-rod release time.

The measurement of magnet-rod release times as a function of rod positions proved very helpful in aligning our rod-magnet guide tubes. When the guide tubes were out of alignment, thus disturbing the air gaps between the magnets and rods, the release times were found to be small and variable with position. When properly aligned, however, the release times were independent of rod position. It should be noted that this alignment procedure would not be valid for electromagnets having large holding forces.

SAFETY SYSTEM INTERACTIONS

As mentioned earlier, the safety channels of the safety system are kept independent of the rest of the control system in order to prevent interactions. However, within the safety system itself there is interaction because the individual channels are all fed to a single point or bus. Thus, if only one channel, say the period channel, experiences an abnormal signal, this channel alone must drive the sigma bus potential to the scram level while the other level safety channels act as a load on the system. This means that the reactor period required to drive the system to the scram condition will be shorter than it would be if the other channels were also experiencing abnormally high signals. This argument can also be used for other cases such as a single level safety channel driving all the other channels. In the latter case, the reactor power level at which a scram would occur would be higher than when all the channels are driving the sigma bus. For the three channel system on the FNR, variations of scram levels and periods of 20 - 30 per cent have been observed.

Because of this interaction, the period and the level at which a reactor scram is required must be stated in terms of the safety system conditions. For the FNR, the safety criteria is stated on the basis of a single channel. Thus, the reactor is scrammed at a power level of 150 per cent of full power if only one level safety channel is driving the sigma bus and at a 5 second period if the period channel alone is driving the sigma bus. If two or three channels are driving the sigma bus simultaneously, scram will occur at less than 150 per cent of full power and for a period longer than 10 seconds. This safety system interaction does not compromise the protection offered the reactor but it does require that a more precise interpretation be placed on the level and period for which the reactor is protected. A more detailed investigation of this safety system interaction has been done by others[7], the results of which are expected to be published in the near future.

START-UP INSTRUMENTATION

During start-up from source level up into the range of the log N and linear instrumentation, the only information available is from the pulse or log-count-rate channel. At present, no control or safety action is provided on the FNR from this channel, hence, the full responsibility of control in this range falls to the reactor operator. Although this is not expected to cause any particular difficulty in the future, it is felt that some form of control and safety action, such as inhibiting safety and control rod withdrawal and automatic rundown, would be very desirable in this range. Then, instrument control and safety action would be available over the entire range or reactor operation from source level to full power. During start-up the most valuable information would be reactor period which would originate from the log-count-rate instruments. It is our intention to employ the ORNL Q-1881 Log Count Rate Meter for this purpose. During start-up, rod withdrawal will be inhibited for periods less than or equal to 30 seconds and rod insertion will be initiated for periods less than or equal to 15 seconds and automatic rundown, a safety action, will be initiated for periods of 10 seconds or less.

From our experience to date, wider range log-count-rate meters and log N amplifiers would be extremely helpful since the overlap of the log-count-rate meter and the log N channel is by no means a certainty. The ranges of the Ford Nuclear Reactor's log-count-rate meter and log N amplifier are 4 and 6.5 decades, respectively, and the range of operation from source to full power is expected to be between 10 - 11 decades.

INVESTIGATIONS AND MODIFICATIONS

As part of the nuclear engineering educational and research program at the University of Michigan, various investigations relating to reactor control are planned. At present, plans are underway for a thorough investigation of electromagnets in an effort to optimize their design in terms of the rather rigorous specifications placed on them as reactor safety system components. The statistical variations of neutron populations at low levels as related to the measurement of reactor periods will be investigated, both analytically and experimentally. The problems of gamma compensation of neutron detectors, as used on the FNR log N and linear channels will be studied to determine the best principles and techniques of compensation.

Minor modifications of the FNR control system were made prior to putting the reactor into operation. Others, such as the utilization of period information for start-up and servo control, will be made in the near future. The use of wider range instrumentation and dual-synchro rod position indicators (instead of potentiometric position indicators) will be investigated as will other details of the control system.

Because the FNR is used both as an educational and research facility, consideration is being given to the design of an instrument supervised start-up control system which will provide a greater degree of safety protection and minimize operational errors. With such a system, the reactor would always be safely brought up to power in an orderly fashion without needless delay. The design of a system of this type is now underway. After the usual system check-out, the start-up will be accomplished by (1) the selection of the desired power level for operation and (2) the selection of the instrument mode of operation by the reactor operator. The proposed system, similar to that used on the Geneva Conference Reactor (GCR)[8] is being designed using the following criteria:

a) No additional instrumentation channels are to be used. This means, of course, for the FNR only one pulse channel will be used instead of two as on the GCR.

b) A minimum number of components, such as relays, recorder contact switches and meters are to be used, thereby minimizing maintenance and other operational problems.

c) The primary and secondary safety functions of the FNR will not be compromised in any manner whatsoever. Thus, the instrument supervised start-up will use only the measuring channels, i.e., Log N, LCR and Linear Level.

d) There will be no automatic shim-rod control during power level operation. Shimming will be done manually by the reactor operator while the control rod is on servo control.

e) The instrument supervised start-up must provide a greater margin of safety than a manual start-up.

This will be the case since the instrument supervised start-up requires continuous automatic cross referencing of all the measuring channels. Further, by virtue of period control on the pulse channel, an additional safety function will be used. This is particularly significant since no safety action is initiated from the pulse channel on the present system.

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