# INSTALLATION OF A SECOND TRIP SYSTEM

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## ABSTRACT

Since its first criticality in 1957, the NRU reactor has been operating safely and efficiently supporting the CANDU reactor's research and development programs and producing radioisotopes for medical use. To ensure that the reactor continues to operate safely and effectively, Atomic Energy Of Canada Limited (AECL) commissioned a team in 1989 to conduct a systematic review and assessment of the reactor condition. The outcome of the study indicated that the overall condition of the reactor is good and that it is being operated safely. The study also produced recommendations as to where safety can be improved. These recommendations are the basis of the upgrade program currently being implemented in the reactor.

The Second Trip System (STS) is part of the upgrade program. It is a stand alone seismically qualified trip system that operates independently from the existing first trip system (FTS) to shutdown the reactor.

This paper discusses the design, installation and the inactive commissioning of the system, and the process used to ensure that the system can be retrofitted to the reactor without affecting its safety or its operational requirements.

## BACKGROUND

NRU is a thermal neutron, heterogeneous, heavy water moderated and cooled reactor (Figure 1). It was design for operation with natural uranium fuel rods and converted to operation with high enriched uranium fuel in 1964, and then to low enriched uranium fuel in 1993. The reactor operates at 130 MWTh to support the engineering experiments for the development of CANDU power reactor, fundamental research using neutron and the production of radioisotopes. A contractual agreement associated with the isotope production limits the downtime of the reactor for repair and maintenance to a maximum of five days.

Over the past four decades, the reactor operated safely and efficiently. To ensure that this will continue into the next century, AECL commissioned a team of experts to conduct a detailed systematic review and assessment of the NRU reactor. The primary objective of the assessment was to determine the physical condition of the reactor and to identify those systems where safety improvement is recommended.

The present control and shutdown system for the NRU reactor was identified as one of those systems requiring a safety upgrade. The upgrade is required because of lack of independence and separation between control and shutdown systems, lack of channel separation and insufficient system qualification for possible environmental effects.

Various options were examined to improve the shutdown system which included redesigning the existing shutdown system or the installation of a new shutdown system. These options were not practical with respect to schedule and cost. However, a third option that was acceptable and feasible, is to add a Second Trip System (STS).

The STS is a new independent set of trip chains containing a small number of critical trip parameters. These new trips act on the same control rod magnets as the existing trip system (now termed the First Trip System FTS). The addition of the STS significantly improves the overall safety and reliability of the reactor shutdown, with minimum interference or change to the FTS.

## EXISTING CONTROL AND SHUTDOWN SYSTEM

Figure 2 shows the schematic arrangement of the NRU existing control and shutdown system.

The NRU reactor is controlled and shut down by neutron absorbing control rods in the form of vertical tubes distributed at various location in the reactor core. The absorber section of each control rod is suspended vertically by an electromagnet from a driving head. With the magnet energized, the control rod serves as a regulating rod for power control. When the electric current to the magnets is interrupted by a trip signal, the absorbers are released and they fall under gravity, the rods then serve as a safety rods for rapid shutdown of the reactor. The reactor is equipped with 18 control rods.

The control system consists of 4 ion chambers located in reactor face E , and another 4 ion chambers located in face L. The four signals from face E are processed by the amplifiers into linear flux and linear rate measurements. The four linear flux measurements are compared to each other in a comparator unit then averaged and fed into three function generators. Linear rate measurements are also compared, averaged and fed to the three function generators. Similarly, the signals from face L ion chambers are processed to log and log rate measurements, compared in a comparator, averaged and fed to the function generators. The function generators compute the difference between the demanded values and the above received measurements (the log measurement is used for low power control only). The output of the function generators are compared and then used to drive the control rod head via the main drive magnetic amplifier.

The existing trip system interrupts the power supply to the control rod magnets upon detecting any safety parameter exceeding its predefined limit. The trip circuit is based on 2/4 logic for the main neutronic trips and 2/3 for all other trips.

For neutronic trips, the same 8 ion chambers and amplifiers that supply the control system are also used for the trip system. In addition, a set of three ion chambers located at face E provide an independent log rate trip signal, and another set of three ion chambers in face L provide excess neutron level trip signal. The three ion chambers for the log rate trip were originally located in face D, and were moved to face E to provide space for the new STS ion chambers as indicated in Figure 3.

Other trips are related to protection against failure of the control system such as comparative trip parameters, and special interlocking trip parameters. Numerous other trips are also available for shutting down the reactor should a key process failure occurs.

The FTS operated successfully and reliably covering over 2000 demanded rod releases. It is designed with high redundancy level and is provided with good provision for system testability. However, the system independence is compromised by the use of the same neutronic measurements for both control and safety, the lack of channel separation, and the vulnerability of the system against potential adverse environmental effects.

## KEY REQUIREMENTS FOR THE STS

The STS must be physically and functionally independent of the FTS and the control system. Where interfacing is necessary, interconnecting signals must be buffered to prevent cross-link failure. Both the FTS and the STS must be individually capable of shutting down the reactor on demand. In addition, the STS must be capable of tripping the reactor during adverse environmental conditions caused by internal or external hazards.

Due to practical and economical restrains, the STS should trip the same reactivity device (absorbers) as the FTS. The NRU reactivity device is a well-proven, highly reliable device, and has operated successfully for four decades without failure to actuate on demand to drop the absorbers into the reactor core.

Trip parameters for the STS should be limited to those parameters covering critical areas. The operator interface of the STS should blend smoothly with present systems.

The safety of the reactor and the integrity of the FTS must not be compromised at any time specially during the installation and commissioning phases of the STS. Due to isotope production requirements, which limit the down time of the reactor operation to a maximum of 5 days, all shutdown installation and commissioning work must be planned to meet this limitation.

## PROJECT STRATEGY

At the start of the project, it was recognized that operations involvement was necessary to ensure the successful integration of the new system with the existing reactor systems. This was accomplished by assigning a qualified Operations engineer to the project to liaise with the design, safety, and implementation teams. In addition, the STS was considered a modification to the operating reactor and therefore it was subject to the NRU change proposal and approval (CPA) process. Using this process, the NRU Change Control Committee (CCC ) ensures that changes are reviewed, assessed and categorized for their safety impact. Accordingly, the STS was classified as Category I change.

It was also realized that the Company's Safety and Review Committee (SRC) and the Atomic Energy Control Board (AECB) must be fully informed with the conceptual design of the new system and the progress of the work to facilitate approval and licensing of the system upon completion of its inactive commissioning. To this end, a preliminary safety note describing the STS and its benefits was submitted and accepted by the SRC and the AECB.

Quality assurance programs were applied throughout the activities to ensure that all deliverable meet the specified requirements for the system.

## SYSTEM DESCRIPTION

The overall arrangement of the upgraded NRU trip and shutdown system is presented in the block diagram Figure 4. Whereas Figure 5 shows the STS configuration. The STS has three trip channels (E, F, G). Its trip circuit is based on a two out of three general coincident logic. The system monitors four automatic trip parameters and two sets of emergency trip push buttons(P.B.'s). The auto trip parameters are: excess neutron linear power, excess neutron log rate, loss of Class 4 power, and excess seismic acceleration. One set of emergency P.B.'s is provided in the Control Room, and the other in the Qualified Emergency Response Center (QUERC which is a new seismically qualified room inside the reactor building). The main equipment is housed in three seismically qualified cabinets located in the QUERC, while the system's displays and controls are located in the Control Room. All sensing instruments, signal processors and cables associated with the STS are segregated from all other reactor systems as far as practically possible.

Figure 6 shows a simplified representation of Channel E trip logic. The four auto trips and the two manual trips are connected in series with the channel trip relay. Trips are sealed in a channel basis until reset by the operator. An arrangement of voting relays governs the final trip relays (SV). When two channels or more are tripped, the final trip relay contacts interrupt the power supply to the magnets of the absorbers allowing them to drop into the core.

The STS was design as a stand alone system that can be constructed in complete isolation from the reactor systems until its final commissioning. Some of the main system features are discussed below:

- Neutronic Trips: The neutronic trips are fed from three new ion chambers dedicated for the STS. The ion chambers are located in the reactor face D (FTS main ion chambers are in faces E &L) and their signals are transmitted to the main cabinets in the QUERC via seismically qualified conduits and trench. Each ion chamber signal is processed by an amplifier into linear neutron flux and log rate measurements.

The STS amplifiers are equipped with adjustable gain units which can be controlled remotely from the control Room. This enables the operator to boost the linear power for each channel by as much as 30% to overcome signal distortion caused by neutron flux tilt during refueling or control rod movements.

- Seismic Trip: seismic qualification of the NRU reactor was not a major consideration during its original design. Assessment and analysis indicated that the reactor structure and components have adequate strength to resist the seismic forces generated from a postulated Assessment Basis Earthquake (ABE = 0.07g). Therefore, a seismic trip was incorporated in the STS to ensure that the reactor is shut down and placed in a safe state at or below the ABE level. The trip is actuated if two-out of three accelerometers located in the QUERC, exceeded the trip set point of 0.06 g.

- Class 4 Trip: On average the NRU reactor experiences about 8 Class 4 power failure a year. It is by far the highest frequent event with potential sequence leading to core damage. The loss of Class 4 causes the FTS to trip due actuation of at least 5 process system trip parameters. However the addition of the STS Class 4 trip provides a dedicated direct reactor trip that ensures reactor shut down in this event.

- STS Main Cabinets: The three cabinets are located in a seismic qualified area, the QUERC. One of the cabinets was wired and equipped with the STS instrument, then subjected to a shake test up to the design base earthquake level for the NRU site (0.24g) using a shake table at Wyle Lab, Alabama. The cabinet passed the test after minor modifications which were also applied to the other two cabinets.

- Buffering of the STS: All connections between the STS main equipment in the QUERC and other systems in the reactor were buffered using relays, amplifiers or signal isolators to eliminate the possibility of cross links and common mode failures. In addition, all cables connected to the STS cabinets were provided with enough slack cables or passed through a reverse pull box to protect the cabinets against the pull forces from outside the QUERC during a seismic event.

- Testing: the STS is provided with an on-line testing facility which allow the testing of individual channels on power. Using a remote testing arrangement in the Control Room cabinet, the operator can place the channel in a test mode, then select each trip parameter (except the seismic) in turn for test including the testing the final trip rely contacts. Interlocks are provided to inhibit channel testing if another channel is already tripped or in the test mode.

## SYSTEM INSTALLATION

The Reactor Maintenance Branch (RMB) was assigned the installation responsibility of the system. An installation plan was developed in close consultation with the RMB planners, system designers and the commissioning engineer. The plan complies with the NRU Upgrade Project Overall Quality Assurance Plan which meets the requirements of the CAN/CSA-N286.0-92 standard.

Work was divided into work packages designated normal and critical (requiring reactor shutdown). Each critical work packages was examined closely to ensure that it can be completed within the maximum allowed shut down period of five days.

In all, twenty-seven work packages were created for the STS installation. All work packages were subjected to the CPA process, and were presented to the NRU CCC for approval. Some of the work packages were classified as Category I changes requiring further approval by the SRC and the AECB. Other packages were approved as either Category II requiring independent safety assessments and reporting to the SRC, or minor changes requiring only the approval of the CCC. At the completion of each work package, its associated CPA was close by the CCC. The closure of the CPA indicates that the job has been completed satisfactorily, its related documents are approved and issued, and that Operation personnel are well informed with the changes.

Procurement and installation activities were completed in accordance with the applicable QA requirements as specified in the system design manual. Route sheets were developed for installation work with appropriate hold points for inspection and acceptance. Normal NRU work control practices were applied throughout, to ensure that the installation work does not compromise the reactor safety or its operation.

At the end of the installation stage, a pre-commissioning function testing was successfully completed, then the system was turned over to the commissioning team.

# SYSTEM COMMISSIONING

Currently the system is being inactively commissioned in accordance with the Commissioning Plan which divides the activities into inactive and active commissioning work.

In the inactive state the system has been completely installed without the final tie-in to the magnet release circuit. Temporary 3 phase test power and a series of resistors have been used to simulate the missing magnet circuit. The STS in this configuration appears fully operational as it monitors and displays all its tripping parameters, alarms and prints out any detected fault on the system.

The inactive commissioning procedures have now been completed successfully as per the acceptance criteria for each test which is based on the design requirements and specifications.

The scope of the inactive commissioning also includes:

- Revising the NRU Handbook: the pertinent sections of the Handbook were revised to reflect the addition of the new system. This includes describing the system, its trip logic and its alarm and display functions.

- Preparation of periodic trip and alarm test procedures: All surveillance testing procedures for the STS were developed and performed during the inactive commissioning. Testing frequency was determined based on unavailability analysis of the system and were included in NRU surveillance testing program.

- Conducting operators' training: A training program was developed for three target groups: Senior Reactor Shift Engineers and supervisors, Nuclear Operators, and Maintenance personnel. The program consisted of classroom presentations and on-the-job training (OJT).
Classroom presentations were conducted in accordance with an approved Master Learning Directive. It introduced the trainee to the safety issues associated with the installation of the STS, described the system purpose, layout, trip parameters, trip logic and the system display function.
The OJT included walk-through the system main components, identifying normal and abnormal conditions and indications of the system, conducting the trip and alarm tests, responding to system faults and following the administrative rules associated with the system licensing and operating requirements.

- System Evaluation: As described previously, the STS is now fully operational except that it does not trip the reactor. Operations continuously monitor system indications, responding to alarms, and conducting periodic trip and alarm tests. The STS behavior is currently being monitored at different reactor operating modes. To date the system has met all its design requirements.

- Other tasks completed during the inactive commissioning include writing the maintenance and calibration procedures, developing the maintenance plan for the system, revising the NRU Operating Manual, and issuing the as-built drawings.

# CONCLUSION

The Second Trip System for the NRU reactor was designed, installed and inactively commissioned as part of a safety-related upgrade program for the NRU reactor. Close cooperation of the project, design, installation and operations teams ensured safe and efficient completion of the system with no negative impact on reactor safety. A safety note has now been submitted to the SRC and AECB for approval of the final hook-up of the STS to the NRU shutdown system. The active commissioning plan and procedures, also have been completed and are ready for implementation upon receiving the approvals.

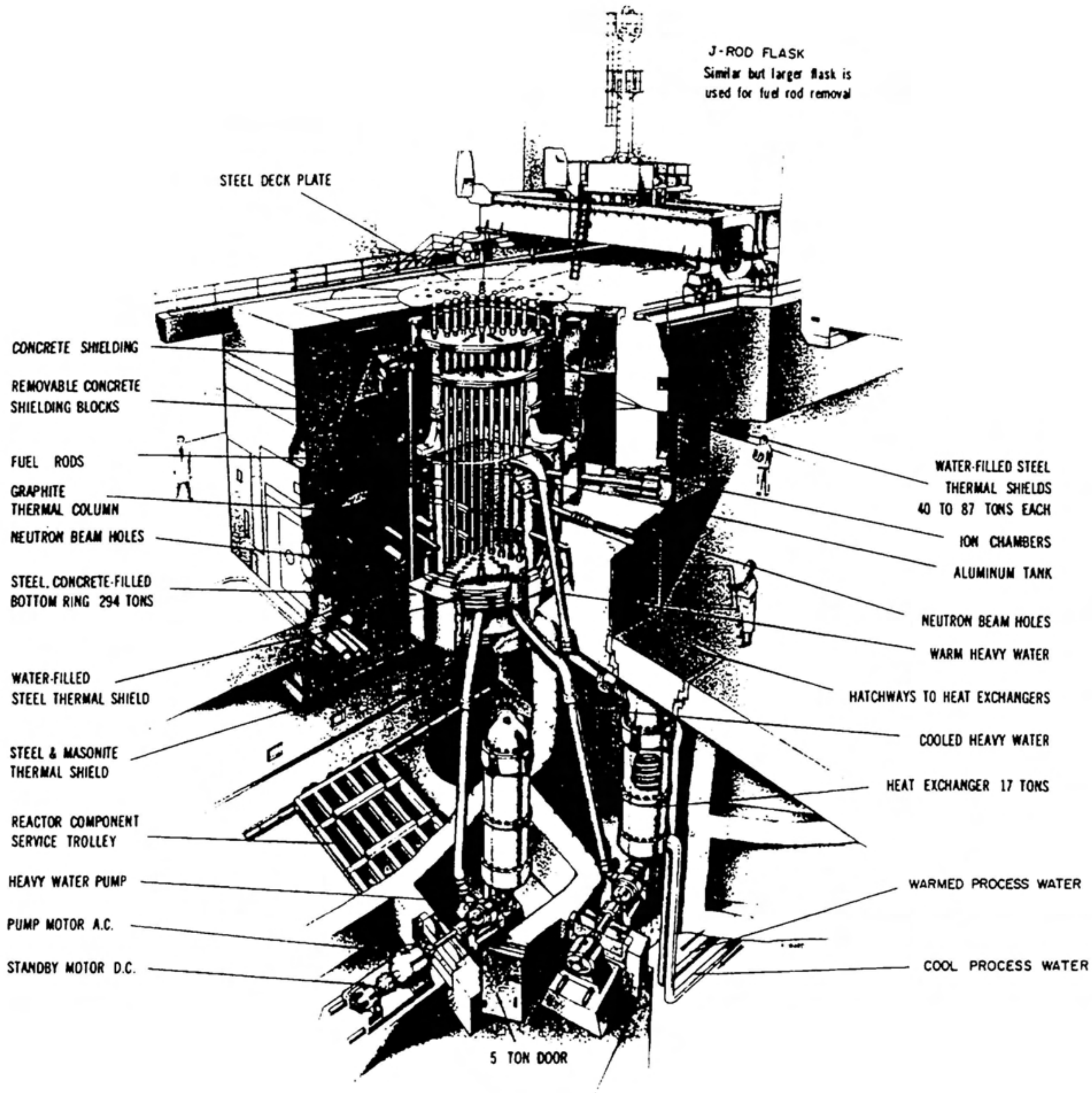


Figure 1 **NRU REACTOR**

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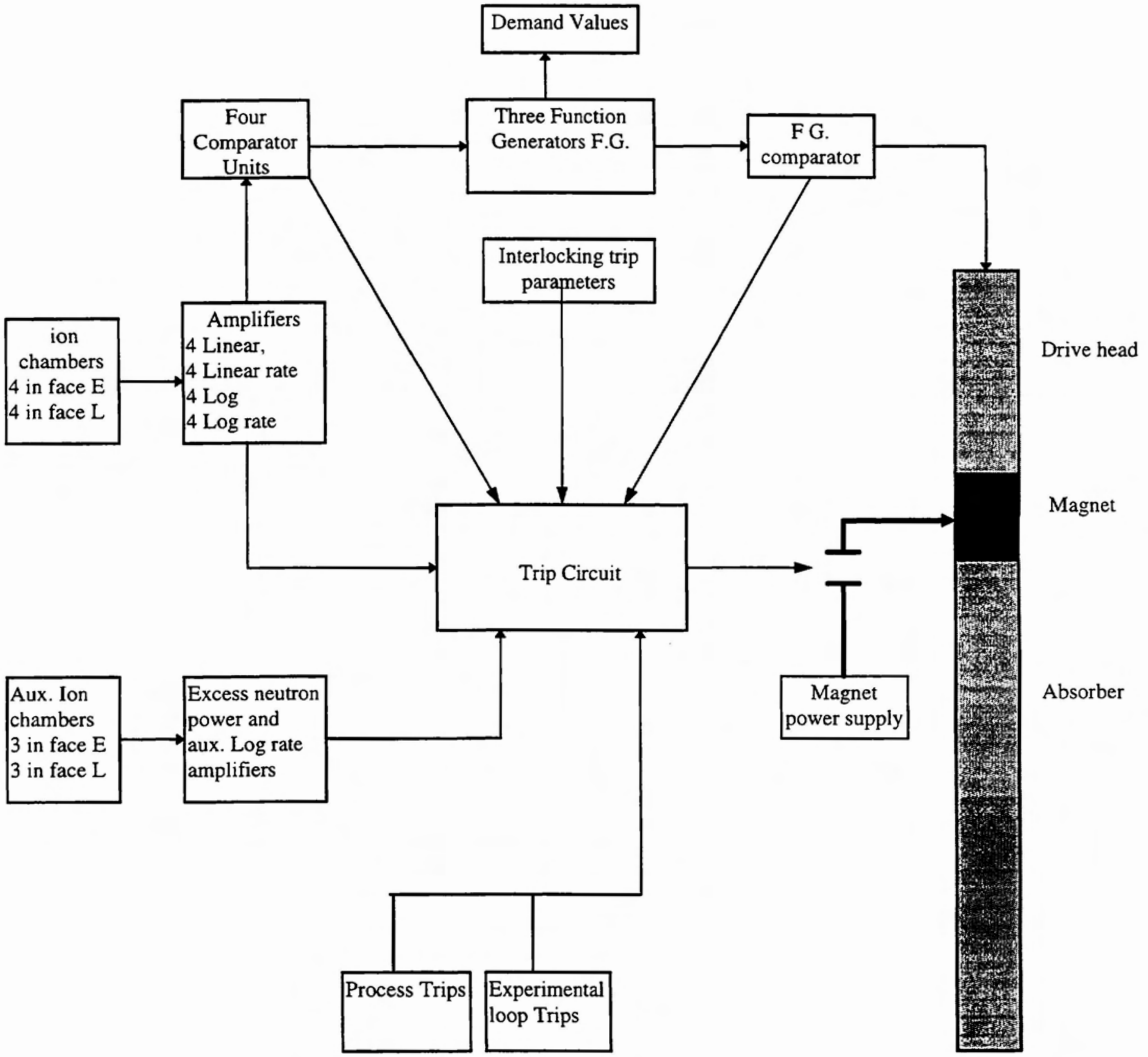


**Figure 2 Simplified Block Diagram for the Existing NRU control and Safety System**

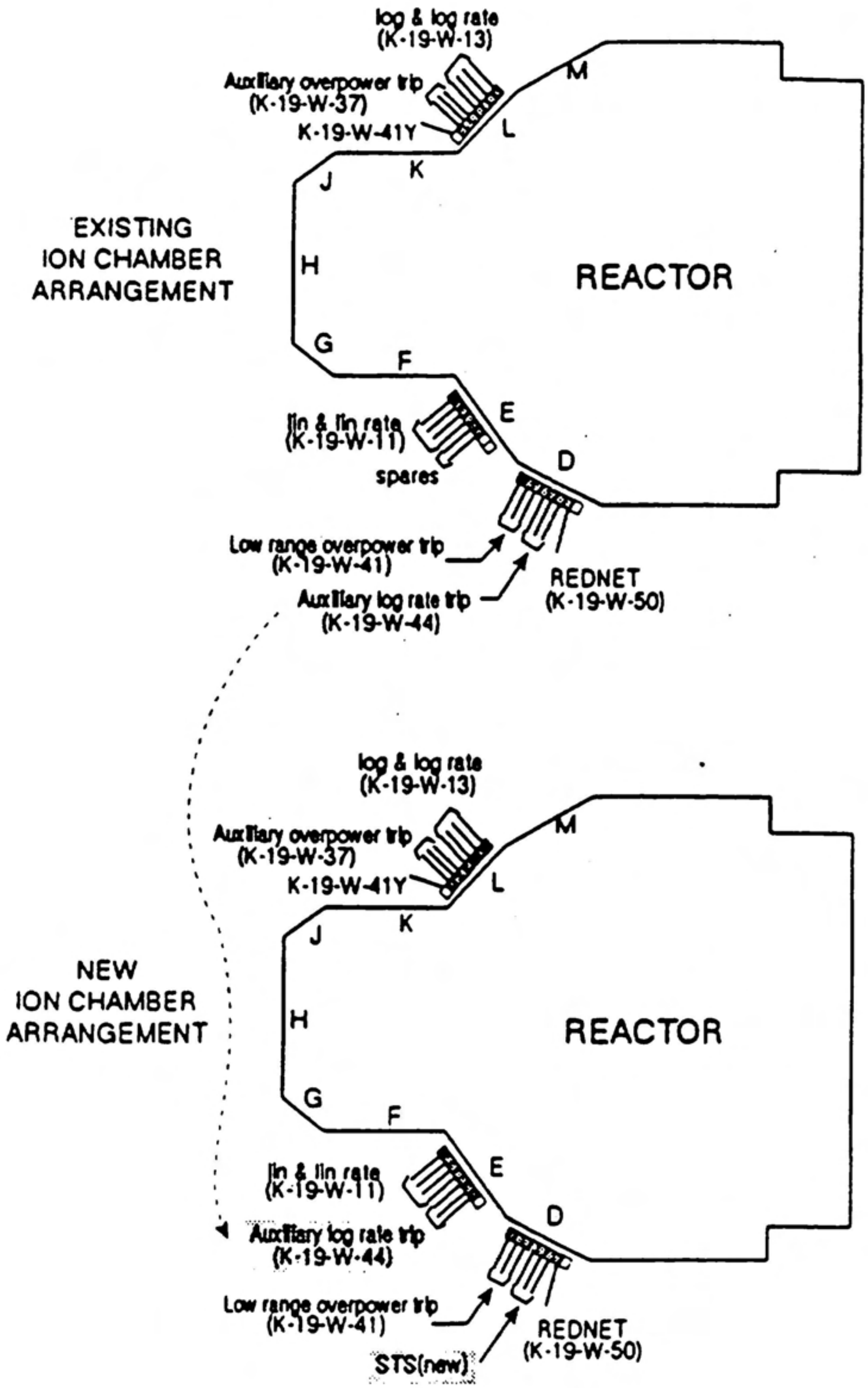


**Figure 3 Ion Chamber Arrangement For NRU**

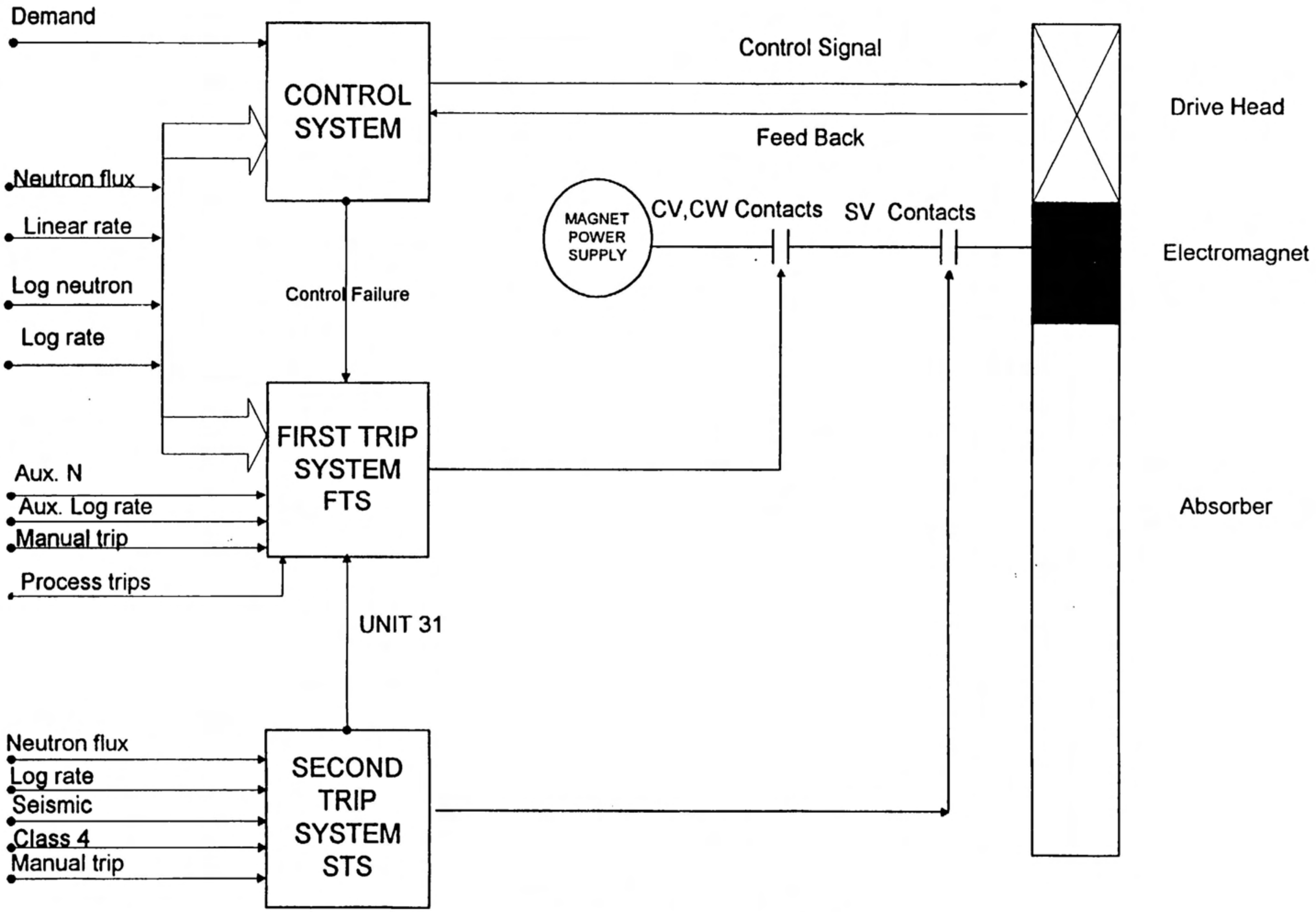


**Figure 4 Block Diagram of NRU Control, Trip And Reactivity Shutdown Systems**

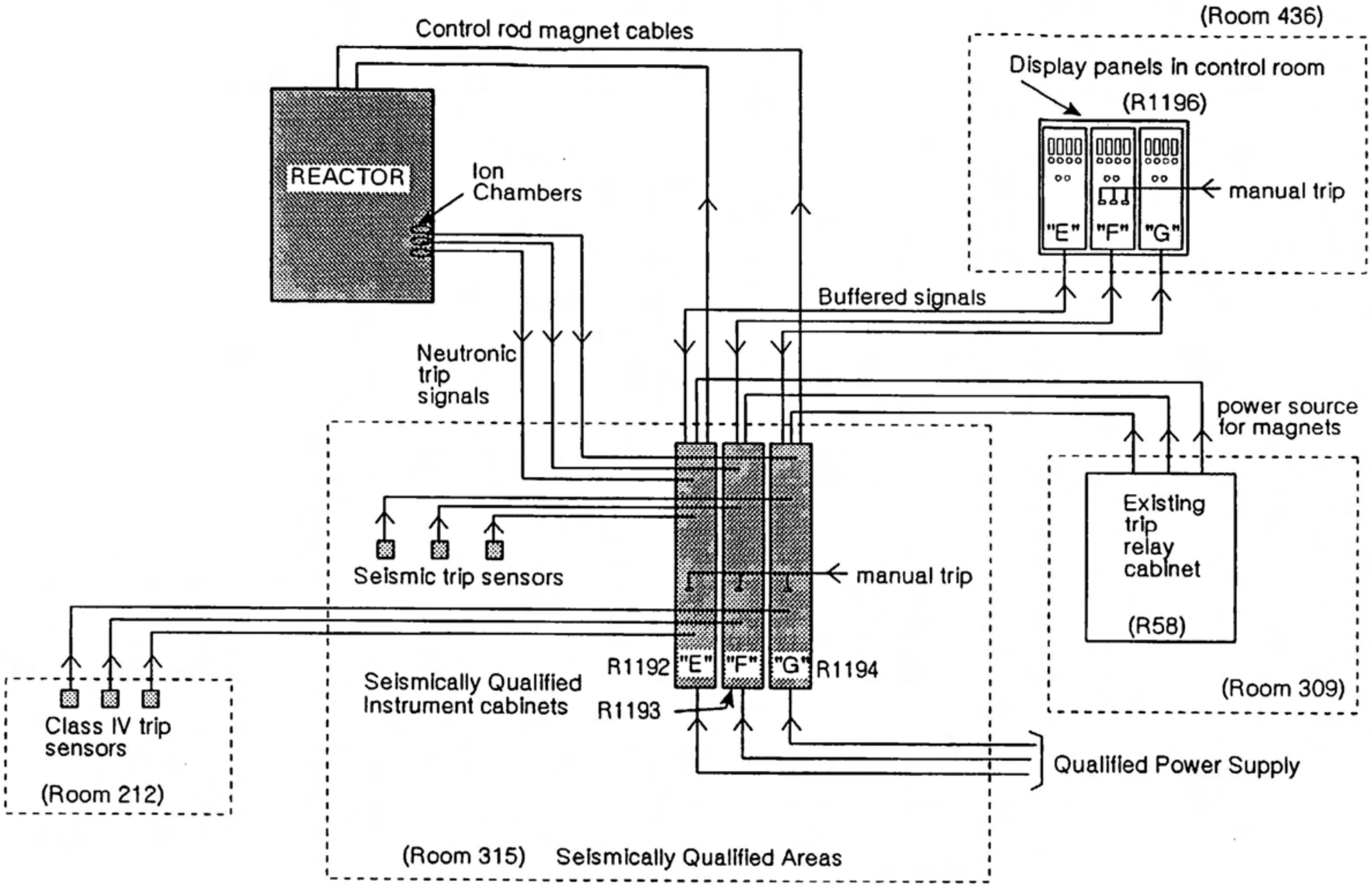


**Figure 5 STS System Configuration**

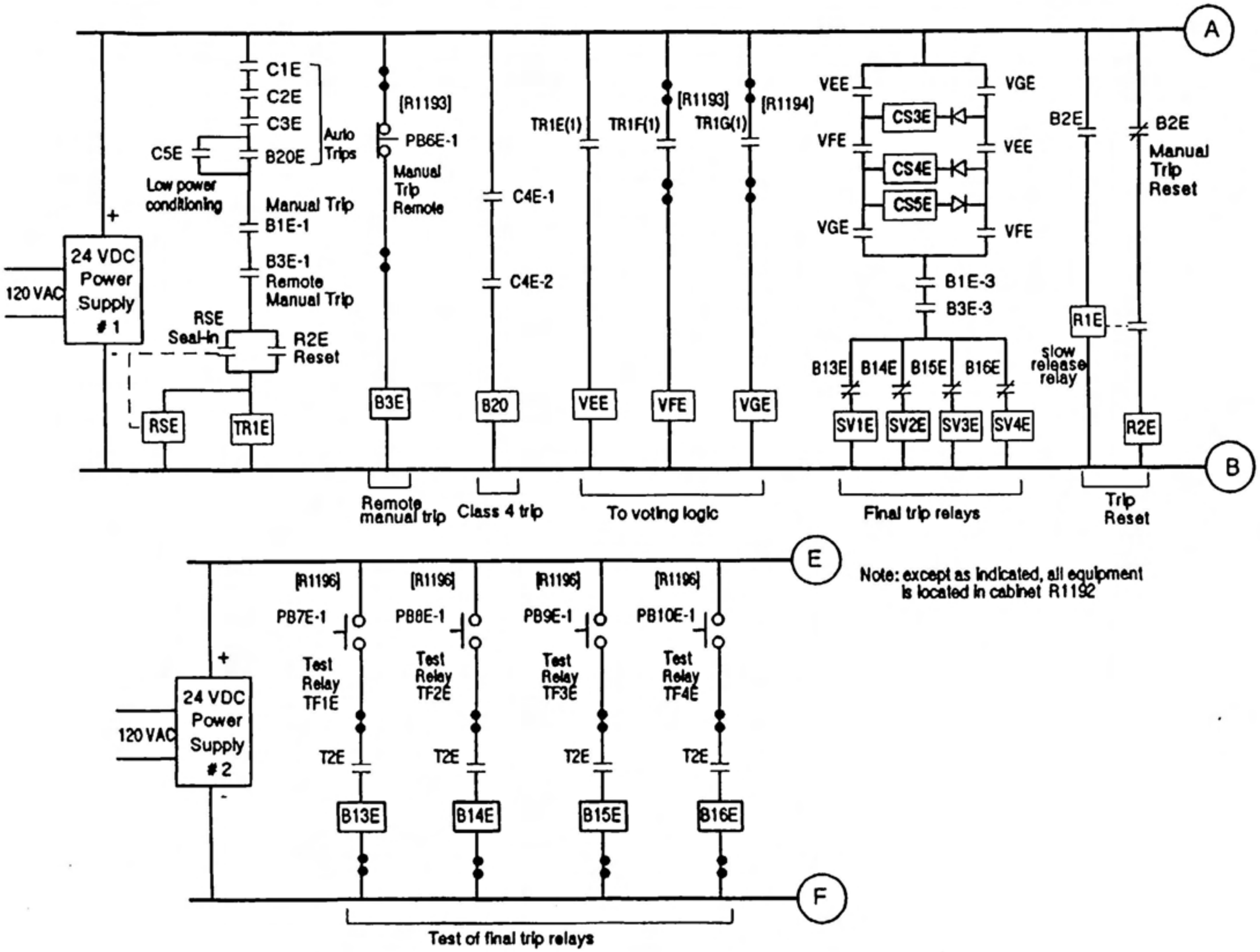


Figure 6 STS Trip Logic