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KSC-1037-1

RELIABILITY ANALYSIS OF AN HTGR SCRAM SYSTEM INCLUDING HUMAN INTERFACES

Final Report

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Date Published—March 1975

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Colorado Springs, Colorado (USA)

UNITED STATES ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION
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Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161

Price: Paper Copy $10.60
Microfiche $2.25 (domestic)
$3.75 (foreign)

Printed in the United States of America
USERDA Technical Information Center, Oak Ridge, Tennessee

KSC-1037-1
Distribution Category UC-77

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Prepared for the U. S. Energy Research and Development Administration, Division of Reactor Research and Development, under Contract No. AT(04-3)-1037.

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ABSTRACT

The SCRAM Protective System for Fort St. Vrain HTGR power plant has been reviewed in depth using the 'GO' reliability analysis technique developed by Kaman Sciences Corporation. A GO logic model of the SCRAM Protective System was created by referencing an intermediate set of logic schematics drawn from numerous detailed system drawings and procedures. Computer analysis of the model provided success probabilities for the various events. Time lines were constructed from the operational and surveillance procedures to define significant points of human interface. The results of the GO analysis indicate that the probability of SCRAM failure is small. Signals from individual SCRAM parameters were evaluated to determine those parameters which might be most effectively improved, if desired, in future reactors. A sensitivity analysis was performed to define the major contributors to system unreliability. Accident scenarios, as submitted by RRD, AEC (ERDA), were evaluated to show the improvement in SCRAM reliability resulting from functional diversity, and to rank the probabilities of successful SCRAM when initiated by the postulated accidents. In the most sensitive areas, results are presented parametrically for ease of extrapolation to newer HTGR designs.

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SUMMARY

The reliability of the SCRAM Protective System for the Fort St. Vrain High Temperature Gas Cooled Reactor (HTGR), which is designed to shut down the reactor whenever conditions have exceeded operational limits, has been analyzed.

The Fort St. Vrain HTGR was designed by General Atomic Corporation for the Public Service Company of Colorado. Kaman Sciences Corporation, under contract to the Reactor Research and Development Division of AEC (now ERDA), performed an analysis of the HTGR SCRAM Protective System. The analysis included identification of major components and subsystem elements, review of operational and test procedures, and application of the 'GO' methodology to the system model. The study was intended to provide information useful in improving the design of future gas cooled reactors.

Through the cooperation of General Atomic Corporation, and the Public Service Company of Colorado, copies of the principal documents and drawings associated with the Fort St. Vrain SCRAM Protective System and related interfacing systems were obtained and thoroughly reviewed.

The system surveillance and operational procedures were reviewed and points of interface for human elements within the SCRAM Protective System were identified. To document this phase of the review, and to provide a base for keying human interfaces into a logical model of the SCRAM Protective System, time line charts were compiled for each surveillance and operational procedure.

Concurrently with the development of the time line charts, an intermediate set of system logic schematics was constructed to allow a uniform level of modeling. The study was performed in two phases. The first phase included modeling of the main SCRAM sensor circuits. The second phase involved modeling the remainder of the SCRAM Protective System, starting at the Main SCRAM Gate, through selected parts of the Rod Control System, and into a detailed model of the Control Rod Drive mechanism.

The Fort St. Vrain SCRAM Protective System is basically a two-out-of-three system requiring the sensor inputs to any two-out-of-three channels, A, B, and C, to produce a SCRAM event which acts to release brake power on each of the 37 rod pairs in the reactor core, thereby resulting in all 74 rods falling into the core and stopping further generation of nuclear power.

The Main SCRAM System has 12 principal inputs feeding into a common gate. One of these inputs is known as the Two Loop Trouble input. Excluding the Two Loop Trouble input, the level of modeling used in this study resulted in approximately 3000 components for the Main SCRAM System.

The Two Loop Trouble system itself consists of 8 different types of sensor circuits, whose principal task is to detect problems and initiate SCRAM action or appropriate loop shutdown for any trouble detected in one or both of the two primary Helium Coolant Loops. One of the 8 inputs to this system is the Circulator Trip input. The Circulator Trip input has 10 major sensor circuits, any one of which can act to trip the Helium Circulators if circulator trouble is detected. The modeling of the Two Loop Trouble system, including Circulator Trip, required about 4000 components.

With this phase of the study completed, the 'GO' model for the SCRAM Protective System was exercised to determine the reliability and probabilistic relationships for the Main SCRAM, Two Loop Trouble, and Circulator Trip inputs to the final SCRAM event. Reliability of Loop Shutdown was not included in this study except for a single analysis conducted on the moisture monitor system.

Since the SCRAM system surveillance procedures indicate that most of the surveillance testing is to be accomplished on a monthly basis, the tabular results are generally based upon a component survival time of 720 hours, or 30 days, except where stated otherwise.

The SCRAM failure values obtained from this study for the constituent parts of the SCRAM Protective System represent the mean probability of failure at the end of a 30 day inspection interval and do not generally differentiate between those system elements which are alarmed or annunciated and those that are not. However, the component sensitivity studies do indicate which of the system sensitive components are alarmed or annunciated if a failure occurs. Contributions from these components can be subtracted from the total failure values to obtain covert failures. Premature events usually represent safe failures which will either spuriously SCRAM the reactor or trip an intermediate circuit.

The Phase 1 analysis of single parameter SCRAM probability showed that five inputs out of thirty-two had a relatively higher probability of failing than the balance of the SCRAM input parameters.

As might be expected, those parameters falling into this category were those which were part of the Two Loop Trouble or Circulator Trip inputs which are carried as dependent inputs into the three main SCRAM channels, and in addition, are inspected or monitored on a monthly basis rather than daily.

The five SCRAM Protective System inputs found to be relatively low in single parameter SCRAM reliability were as follows:

Moisture Detector Monitors
Steam Pipe Rupture Detectors
Steam Generator Penetration Overpressure
Circulator Penetration Pressure
Circulator Trip (Manual)

These parameters are used primarily for Loop Shutdown or Circulator Trip and serve as a backup for SCRAM whenever one loop is down and trouble develops in the second loop.

To improve the performance of any selected Main SCRAM input circuit, some measure of the sensitivity of the system output to each component in the sensor channel is needed. This data has been provided in the form of sensitivity tables for each of the Main SCRAM, Two Loop Trouble, and Circulator Trip input channels. These tables show sensitivity of system failure and system premature probabilities to small changes in any of the system components. The tables include only those components whose changes resulted in significant system output changes. This implies that the component reliability of all components not listed can vary over a small range and have no significant effect on the system output.

The second phase of this study involved two parts; (1) extending the SCRAM model from the Main SCRAM Gate to the Control Rod Brakes, through selected elements of the Rod Control system, and into a detailed modeling of the Control Rod Drive mechanism for each of the 37 rod pairs. This modeling phase increased the number of components in the model from 7000 to 13,000. An additional 2000 logic components were added to the model to incorporate a selective multiple rod output logic and indicate direct probabilities for multiple rods failing to SCRAM, or alternatively, to identify the probability of Spurious SCRAMS, (2) upon completion of this modeling task, the second phase was utilized to calculate probabilities for failure to SCRAM for scenarios of six low probability, but relatively high risk-consequence accidents. These accidents were specified by the Gas Reactor Safety Branch, RR&D, AEC (ERDA). The accident cases covered the following situations:

Depressurization (PCRV Penetration Breach),
Primary Coolant Leak (Into Steam System)
PCRV Overpressure,
Loss of Forced Circulation Cooling,
Control Rod Withdrawal Incident at Startup, and
Control Rod Withdrawal Incident at 100% Power.

The maximum probability of failure to automatically release the SCRAM brake power is conservatively estimated to be less than 4×10^{-6} for most of the accident cases.* This lower probability of SCRAM failure for the accident cases (compared to single parameter SCRAM failure) is due to the presence of independent SCRAM signals on more than one of the 12 Main SCRAM inputs (functional diversity). The result of the Loss of Forced Circulation Cooling accident illustrates what can happen if the number of trip channels is reduced. In this accident situation, there would normally be an independent Reactor Pressure Signal on channels A, B and C and a dependent signal on all 3 channels from the Two Loop Trouble input. Since the two-out-of-three

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*Manual SCRAM and the Reserve Shutdown System are not included in the failure probability given above. These features will improve the SCRAM success probability.

SCRAM brake circuit offers no advantage to dependent inputs,* the only SCRAM signal input which helped to reduce the probability of failure came from the Reactor Pressure signal. The probability of releasing SCRAM brake power during this accident was approximately 3×10^{-5}. If a Two Loop Trouble SCRAM signal had occurred by itself, the maximum probability of failure would have been approximately 1×10^{-3}.

At this point in the study, one major question remaining was the joint reliability of all 74 control rods dropping into the core upon receipt of a SCRAM brake power release signal. The portion of the GO model representing the Control Rod Drive mechanism was exercised to determine these values. The results were essentially independent of the input brake power release probabilities, except in isolated cases where the brake power release was low enough in reliability that it had an overriding influence on the rod drop results.

The individual rod drop results are sensitive to several factors, i.e., the reliability of the SCRAM Brake Mechanism (clutch), the assumed design load to actual load on Control Rod Drive system bearings, the average distance a control rod moves between SCRAMS, and the probability of experiencing individual or common mode failures. A set of parametric curves was constructed showing how the reliability of a single control rod drive pair varies with changes in these parameters.

A final set of curves was prepared showing the multiple rod SCRAM failure probability as a function of the reliability

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*The Two Loop Trouble System uses local coincidence and dual transmission logic with output fanned to all three SCRAM channels, since general coincidence is not appropriate to the system.

of a single control rod pair. For example, given an individual control rod drive failure probability of approximately 5.0×10^{-4} and a common mode failure probability of 10^{-5}, the following multiple rod failure probabilities will be realized:

Single rod pair:	.018
Two rod pairs:	.00018
Two adjacent rod pairs next to reflector, or any three adjacent rod pairs:	.000024
A third rod pair within one or two regions from the adjacent pair:	.000010

This report includes recommendations for future studies and possible changes in SCRAM systems of future reactors to increase SCRAM probability if an improvement is considered necessary due to increased power levels, or possible changes in safety requirements. The study also identifies areas of very high reliability where design trade-offs can be made without significant effect on safety.

I. INTRODUCTION

This report describes an analysis of the reliability of the SCRAM protective system of the Fort St. Vrain nuclear power plant. The purpose of the analysis was to determine the sub-systems or components and human interfaces which have the most significant effect on the reliability of the SCRAM system. Kaman's GO methodology (see Appendix A) was used to evaluate the reliability and sensitivity of the system elements used in the Fort St. Vrain plant. The analysis included those subsystems directly involved in SCRAM actions as well as those portions of the operating system which contribute to a reactor SCRAM. Human interface modeling was included to identify the steps in operational or maintenance procedures which could modify or impact SCRAM reliability. Loop shutdown was not included in this study except for a single analysis conducted on the moisture monitor system.

The Fort St. Vrain Nuclear Generating Station near Platteville, Colorado was build by the General Atomic Company (GA) for the Public Service Company of Colorado (PSCC). The station is a load following central station power plant using a high temperature gas cooled reactor (HTGR) to produce steam for the generation of electric power. Heat is produced by fission in an HTGR utilizing a uranium-thorium fuel cycle. Graphite is used for the moderator, fuel cladding, core structure, and reflector, with helium as the primary coolant. (See Figure 1-1).

The turbine plant design is conventional plant utilizing 1000°F superheated and 1000°F reheated steam.

The installation consists basically of a reactor building, a turbine building, cooling towers, and an electrical switch-yard. The reactor building houses a prestressed concrete

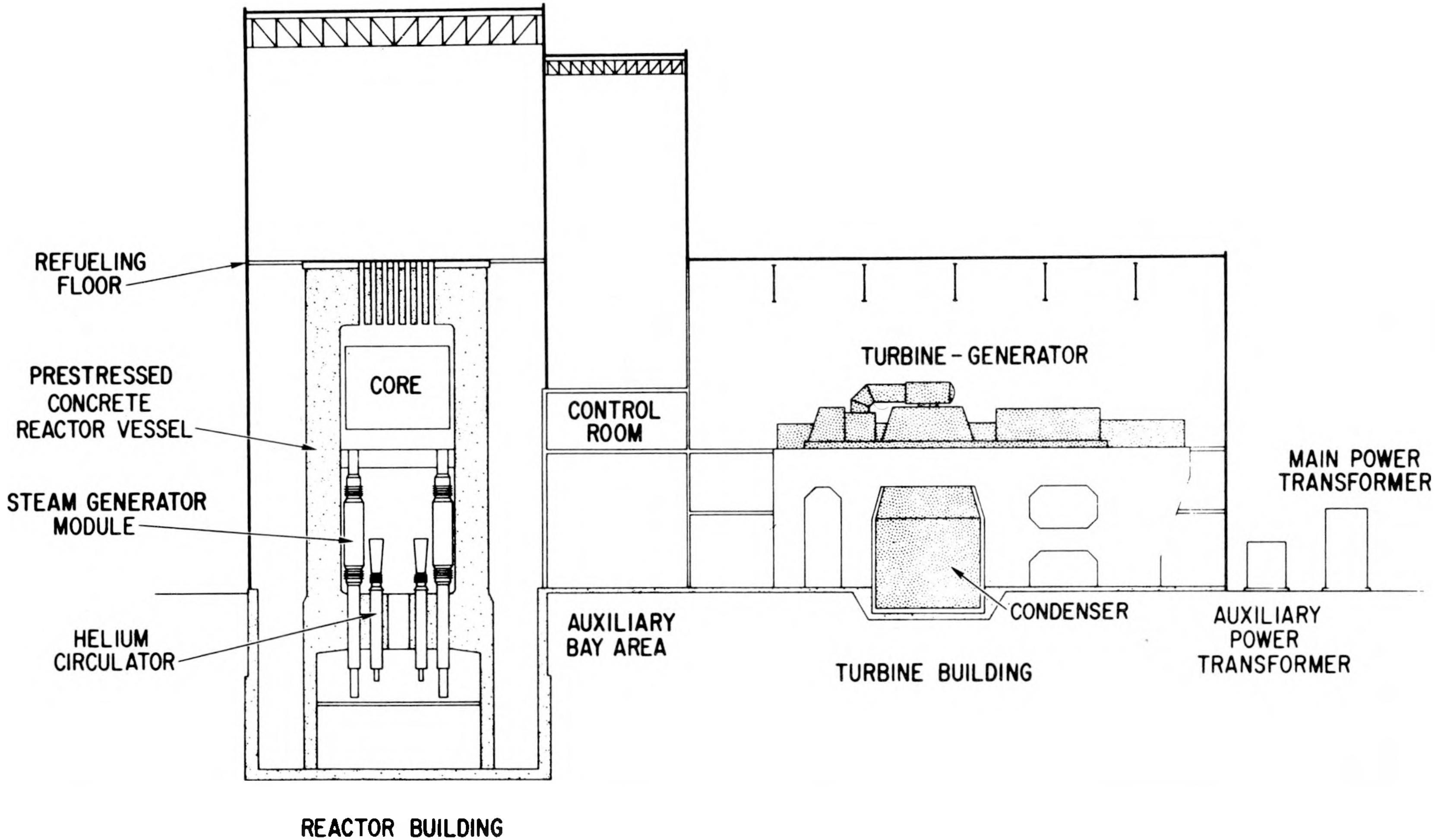


FIGURE 1-1 -Section through reactor building and turbine building

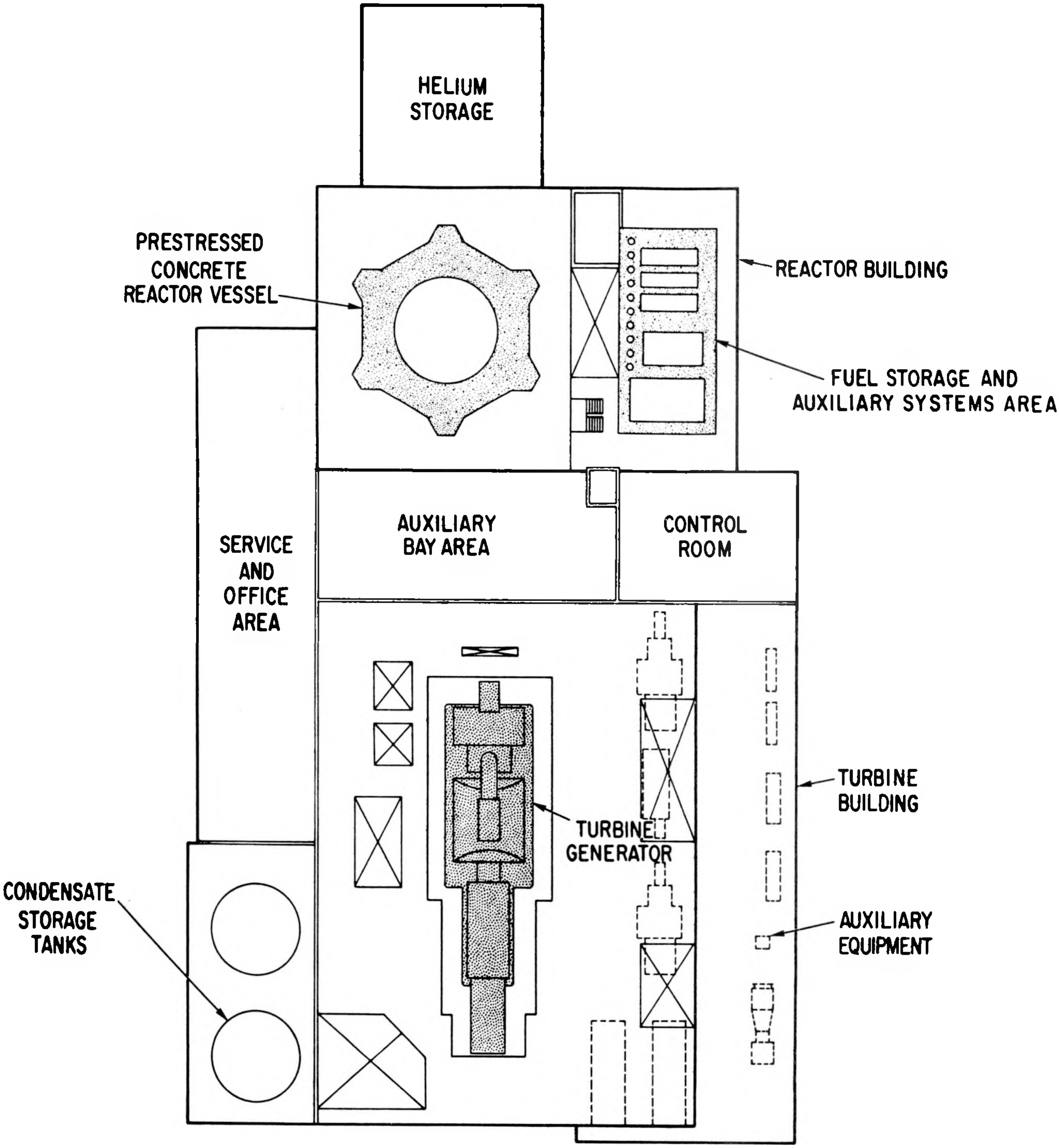


FIGURE 1-2 --Plan view of reactor building and turbine building reactor vessel, fuel handling area, fuel storage and shipment facilities, decontamination and radioactive waste disposal equipment, and all reactor plant process and service systems.

The building has been provided with a pressure relief system such that any large leak from the prestressed concrete reactor vessel or a steam line rupture will not cause significant damage to the structure.

The prestressed concrete reactor vessel (PCRV) is located in the west portion of the reactor building. In general, service facilities and auxiliary systems that are associated with the reactor plant are located in the reactor building. Positioned under the refueling floor level in the reactor building are the fuel storage area, storage facilities for various pieces of equipment, the loading port for the fuel shipping cask, and a hot service facility. The turbine building houses the turbine generator with condensers, feedwater, and other auxiliary systems and an auxiliary bay area housing the reactor plant ventilation equipment, the controlled personnel access to the reactor building, an area housing the control room, the miscellaneous electrical services, and a service and office area which provides space for the machine shop, auxiliary steam system, and administration. Areas not requiring radiological control or access are entered through the service structure adjacent to the turbine building (see Figure 1-2).

The active core is composed of 1482 hexagonal graphite fuel elements stacked in 247 vertical columns. The fuel elements in the core are grouped into 37 fuel regions.

The individual fuel elements are made of graphite and are hexagonal in cross section with dimensions approximately 14 inches across flats by 31 inches high. Vertical coolant holes within each element are aligned with coolant holes in elements above and below. The fuel is contained in an array of small-diameter holes, which are parallel with the coolant holes, and occupy positions in the triangular array of holes within the element structure.

The fuel is in the form of particles made of a mixture of the carbides of thorium and uranium which are coated with highly retentive coatings of pyrolytic carbon and silicon carbide; the particles are located within the fuel holes. The combination of a relatively large fuel particle (200-500 microns) and a three-layer coating gives the particle excellent fission product retention characteristics. All structural functions within the active core and reflector region are provided by graphite.

The high total thermal capacity of the core provides a very slow rate of fuel temperature rise in the event of an accident. The materials of core contruction permit a temperature rise to extend for a significant time without core damage.

The use of large thorium loadings in the fuel elements results in negative prompt and overall temperature coefficients at all times throughout the reactor life, for all temperatures throughout the normal operating range, and for all temperatures which might occur during accident conditions. These negative coefficients would ultimately limit the power transients that could be caused by accidental reactivity insertions.

The helium coolant transfers heat from the reactor core to the secondary coolant system. Helium is particularly desirable as a reactor coolant since it is chemically inert, is stable, has excellent heat transfer characteristics, does not undergo phase change and has zero neutron capture cross section. The coolant flow from the reactor core divides equally between two identical coolant loops; each loop consists of a six-module steam generator, a steam generator outlet plenum, and two helium circulators. The circulators of both loops discharge into a common plenum below the core support floor. All of the flow passes upward around the core support floor and the core barrel to the core inlet plenum above the reactor core.

The helium coolant, at a pressure of about 700 psia, flows downward through the reactor core where it is heated to a mean temperature of about 1403°F. The helium is then directed to the steam generators beneath the reactor core to produce superheated and reheated steam.

After passing through the steam generators, the coolant is returned to the reactor at about 760°F by four steam-turbine-driven circulators, operating on steam from the exhaust of the high-pressure element of the main plant turbine. Auxiliary water-turbine drives provide power to the circulators when steam supply is not available.

During periods when the plant is shut down and the primary coolant system depressurized for refueling or other maintenance, two circulators will be operated to remove afterheat from the reactor at relatively low helium temperatures, although one is sufficient for afterheat removal.

The prestressed concrete reactor vessel (PCRV) contains and shields the reactor and the entire helium coolant system. It is constructed of concrete reinforced with reinforcement steel and prestressed with steel tendons. Enclosing the entire system in the PCRV prevents sudden loss of primary coolant, prevents overheating of the core, and permits the leakage to be collected by conventional means, filtered, and discharged at roof level.

A core support floor is provided within the PCRV in the form of a water-cooled structure of steel and reinforced concrete supported by 12 water-cooled steel columns from the bottom of the PCRV cavity.

The reactor plant design does not require a separate system reserved solely for emergency cooling. Instead, the reactor cooling system normally in operation is enhanced by the provisions required for an emergency cooling system. These provisions include separate, independent circulator drives on common shafts, two separate coolant loops each with two independent heat transfer sections and two helium circulators, multiple cooling water supplies, and multiple power sources. The advantage of these provisions for emergency cooling over the usual "emergency cooling system" lies mainly in the fact that all parts of the system are continuously, or frequently, operated in the course of normal plant operations. This feature eliminates the question associated with seldom or never used systems as to adequate performance on demand.

A steam/water dump system is provided to minimize the amount of water that could leak into the primary coolant as a result of a steam generator tube or subheader rupture. On indication of high moisture level in the primary coolant, the plant protective system will act to scram the reactor, stop the helium circulators and the feedwater flow to the affected loop, dump water and steam from the leaking steam generator into a dump tank, and rapidly cool the core utilizing the intact primary coolant loop.

In order to limit the amount of water that could leak into the primary coolant system from steam generator failures before the steam/water dump system terminated the leakage, each steam generator is provided with feedwater flow limiters.

The reactor is controlled by the selective movement of 37 control rod pairs, each pair with an average reactivity worth of about 0.5% Δk; and a maximum worth of about 1.6% Δk in the normal operating mode. Interlocks are provided to prohibit rod withdrawal in the event of inadequate source neutron flux indication, short reactor period, high neutron flux level, or incorrect operator action regarding the sequencing of certain safety functions.

When the reactor is scrammed by a signal from the plant protective system or by the operator, all 37 control rod pairs are driven into the core by gravity.

In addition, a reserve shutdown system for emergency use is provided which is completely independent of the control rods and drives. It utilizes neutron absorbing material, containing boron, in spherical form. The approximately 1/2 inch diameter spheres are stored in a hopper in each refueling penetration from which they can be released, if required, by the operator and allowed to fall into channels in the core. This system can shut down the reactor from any credible operating condition and hold the reactor subcritical without any control rod insertion.

Fourteen channels of nuclear instrumentation are provided for neutron flux monitoring and control. Redundant channels are provided with individual indication and alarm. The plant protective system uses redundant nuclear and process inputs in coincidence and includes scram and automatic coolant loop shutdown.

The electrical system for an HTGR plant shares, along with similar systems of other nuclear power reactor concepts, the provision of an assured and adequate electric power supply to vital loads and instrument systems in the event of equipment malfunction or accident. Accordingly, the system has the following independent dependable sources of electricity, physically isolated so that any phenomenon causing one source to fail will not cause failure of other sources:

1. Main generator via a unit auxiliary transformer.
2. Four 230-kv transmission lines via a reserve auxiliary transformer.
3. Two standby generator sets.
4. Two DC batteries.

A number of auxiliary and emergency systems and facilities are provided to perform certain functions necessary for the operation and maintenance of the plant. Among these are the fuel handling and storage system, auxiliary handling equipment and facilities, the decontamination system, the helium purification system, the helium storage system, the nitrogen system, the reactor plant cooling water system, service water, domestic water, and fire protection systems, the instrument and service air system, and the building heating system.

During the design phase, GA calculated(1) the Mean Time Between Failure (MTBF) for selected modules in the system using MIL Handbook 217A failure rate data(2). The results were used to establish(3) a realistic test interval for each major item in the SCRAM protective system. As test data was not available for some of these items, conservative estimates were used by GA whenever necessary. The results of this study serve to verify or amplify the original reliability estimates and point out specific areas of concern from a safety standpoint as they are identified.

The following sections of the report cover the system description and functions, initial modeling, final modeling and evaluation, and conclusions. Detailed information is presented in the Appendices, including description of the GO methodology, test and surveillance procedures, time sequence charts, top level SCRAM system schematics, GO charts, component descriptions and associated probabilities and drawing references.

II. SCRAM SYSTEM DESCRIPTION

A. The subject of reactor safety involves those systems which are designed to protect the general public against the consequences of reactor accidents, primarily those involving release of radiation. Also included are systems which protect plant personnel and equipment against the consequences of accidents involving internal damage. The plant protective system consists of the instrumentation and controls required to initiate corrective actions upon onset of unsafe conditions. The plant protective system is used to mitigate the consequences of (1) equipment failures which require corrective action beyond the capability of the plant control system; (2) failure of the plant control system causing an abnormal condition; and (3) misoperation which has resulted in a potentially unsafe condition. The protective functions are related to conditions which might lead to (1) loss of core cooling; (2) power increase not matched by core cooling; (3) prestressed concrete reactor vessel (PCRV) pressure rise; or (4) core or major equipment damage.

The various systems for protection thus include protection of the general public and the plant itself. The current study is limited to analysis of one of the protective functions; namely, reactor shutdown, or SCRAM, upon occurrence of an unsafe condition. This includes those portions of the plant protection system which are necessary to initiate reactor SCRAM. In the Fort St. Vrain HTGR design a number of the systems which are used for reactor monitoring are also involved in reactor shutdown. Thus this analysis includes not only portions of the plant protection system, but also substantial portions of the plant operating system.

Since reactor shutdown is one of the primary defenses against radiation release and equipment damage, a high level of reliability must be designed into all subsystems and components. Some of the approaches used in this plant to achieve reliability are the use of redundancy and coincidence, derated components and modules, provisions for inservice testing and maintainability, and subsystem burn-in before operation to eliminate infant mortality.

The "single failure criterion" has been satisfied in the Fort St. Vrain design which means that the Reactor Shutdown System will attempt to perform its function in spite of the failure of any single channel or component. Some of the features included involve local two-out-of-three coincidence between sensors, one-out-of-two logic systems, generalized two-out-of-three coincidence in the SCRAM brake circuits, and the First In With Lock-Out (FILO) system for shutdown of a single cooling loop.

The FILO system is used because the reactor cooling system includes two operational cooling loops with engineered safeguards involving multiple backup systems, instead of a primary operational cooling loop and an emergency core cooling system in reserve. This concept is possible in the HTGR due to the use of high temperature materials throughout the core, so that temporary cooling failures will not result in melting of the uranium carbide fuel or the core components due to fission product after heat. Hence, the primary purpose for interim cooling is to prevent cracking of the fuel particles, distortion of the core geometry, and release of excessive quantities of fission products to the primary helium coolant. PCRV cooling is also available to maintain containment integrity and provide some shutdown cooling.

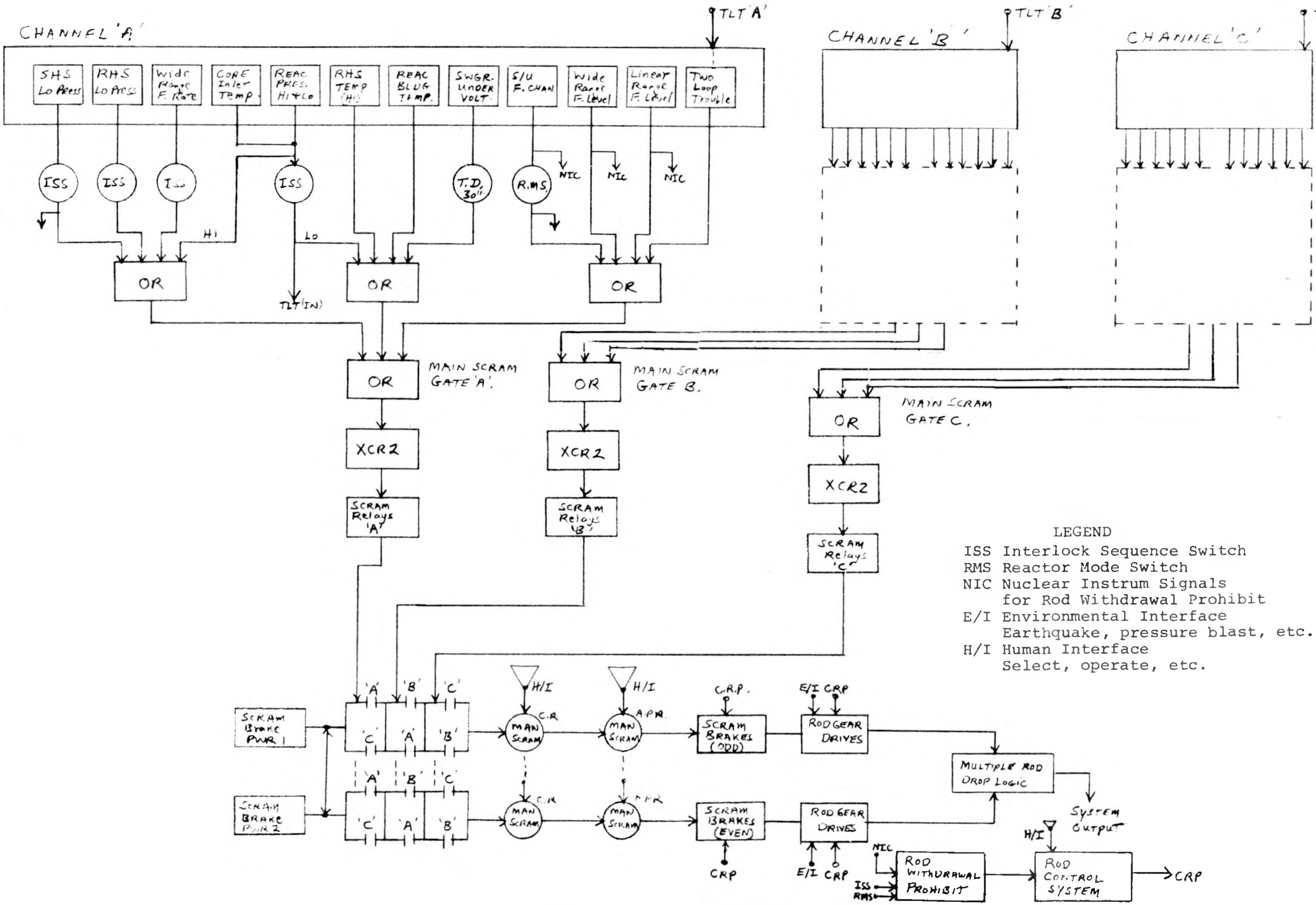
The primary helium coolant circuit normally contains substantial quantities of gaseous fission products. The system is designed with the entire primary coolant system self-contained inside of the prestressed concrete reactor vessel (PCRV). This means that the associated steam generators and helium circulators are inside the PCRV, and failure of a steam generator may result in moisture being released to the primary cooling system. Since the reaction of large amounts of steam with hot graphite is of concern, a substantial portion of the plant protection circuitry is devoted to detecting this problem and minimizing the consequences.

The primary coolant system includes two cooling loops, each with several steam generators and two helium circulators. The helium circulators are normally driven by steam with a water drive back-up. If one of the cooling loops develops a leak or a complete failure, this loop must be shut down, and the steam generators must have the steam and water removed to minimize the amount of steam that might leak into the primary coolant system. When this occurs the second cooling loop must continue in operation regardless of leaks or other weaknesses in order to provide some cooling to the reactor. This is the origin of the "First In With Lock-Out" concept. Basically, a detection of failure in the first loop results in locking out of the shutdown action in the second loop.

In the case of simultaneous initiation of loop shutdown signals for both loops, the system will not shut down either of the two loops. This system ensures that partial system cooling is maintained, thus reducing the potential damage due to total loss of cooling which could be much worse from a safety standpoint than damage caused by excessive moisture in the reactor core structure. Failure of a single loop generally results in a partial plant shutdown but not a reactor SCRAM. The plant load can be operated at half rated power while the faulty loop is being repaired. Half power operation is possible only if the shutdown loop has at least one good circulator and one good steam generator to provide shutdown cooling if the second loop develops trouble. Subsequent trouble indications in the second loop will usually result in a reactor SCRAM even though the loop shutdown function is locked out, so reactor cooling can be maintained.

The trouble sensors in the two-loop system are redundant and generally arranged in two-out-of-three local coincidence to initiate SCRAM or loop shutdown actions. The two loops are then combined in the final circuit to request a SCRAM whenever trouble occurs in both loops. This request is routed through the two loop trouble (TLT) input to the main SCRAM logic. A single transmission logic circuit for the TLT system would not satisfy the 'single failure criterion', so dual logic circuits are used with each loop to provide positive SCRAM requests.

An overview of the top level SCRAM circuitry is shown in Figures 2-1, 2-2 and 2-3. Figure 2-1 shows the main SCRAM circuitry with twelve inputs to each of the three SCRAM channels and the three main SCRAM Gate outputs which control power to the control rod brakes. The three SCRAM channels, A, B and C, feed in turn into a generalized two-out-of-three coincidence circuit with dual contacts which act to interrupt the SCRAM brake power. The mechanical relationships of the control rod gear drives are functionally indicated in Figure 2-1 and can act to inhibit a SCRAM even though the SCRAM sensors provide for loss of SCRAM brake power. The twelve SCRAM channel inputs are identified as follows: Super-Heat Steam Low Pressure, Reheat Steam Low

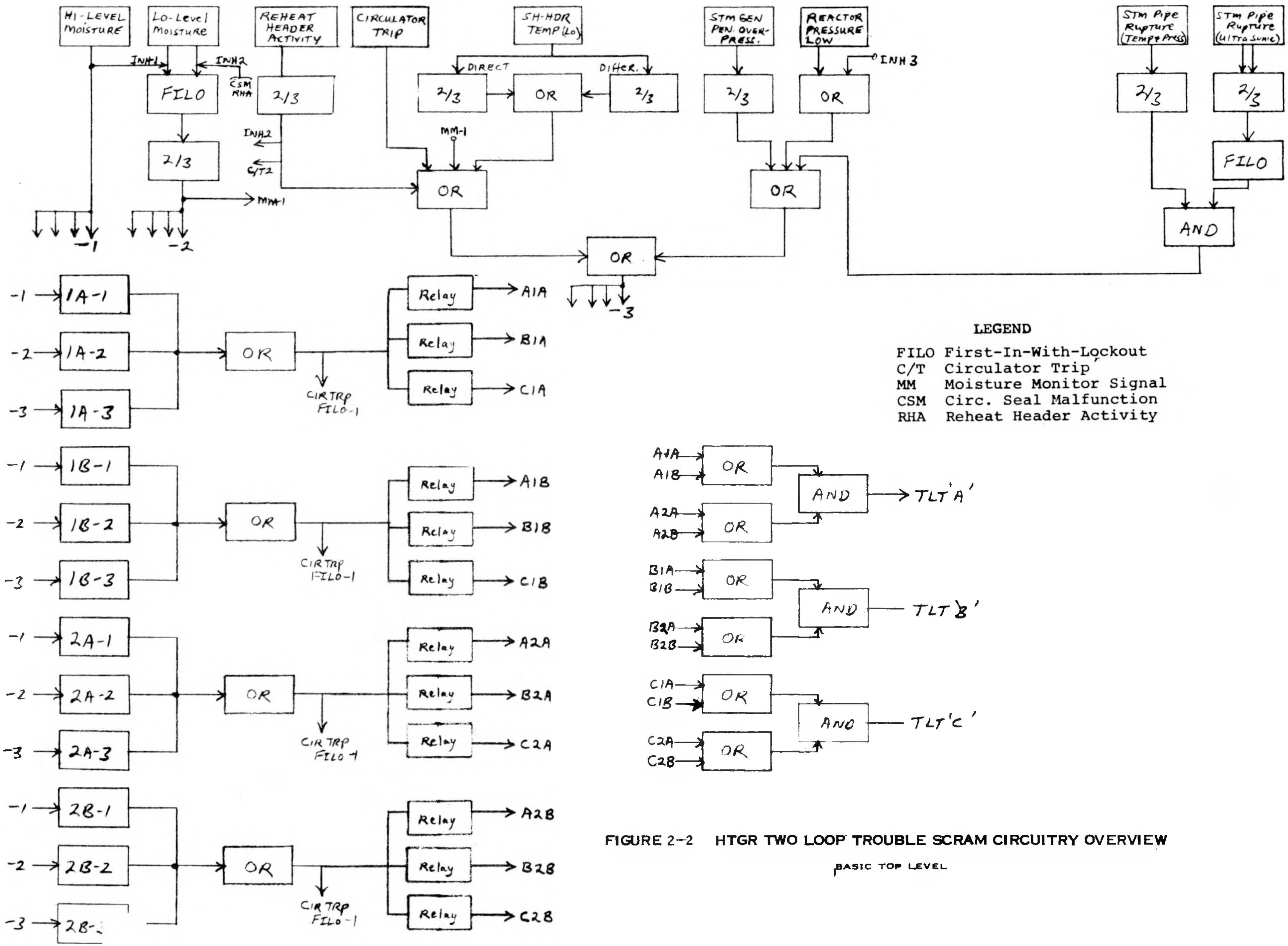


LEGEND

ISS Interlock Sequence Switch
RMS Reactor Mode Switch
NIC Nuclear Instrum Signals for Rod Withdrawal Prohibit
E/I Environmental Interface Earthquake, pressure blast, etc.
H/I Human Interface Select, operate, etc.

FIGURE 2—1 HTGR SCRAM PROTECTION CIRCUITRY OVERVIEW

BASIC TOP LEVEL

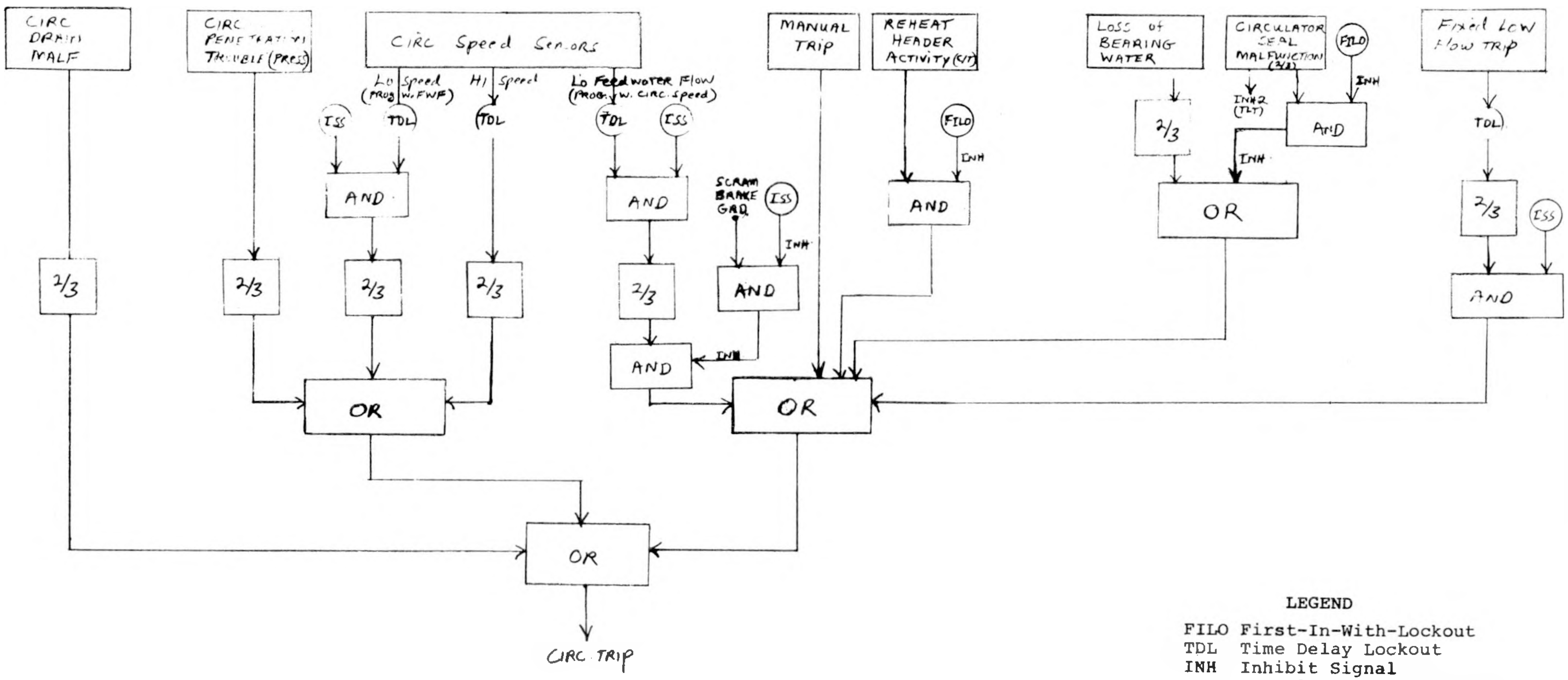


LEGEND

FILO	First-In-With-Lockout
C/T	Circulator Trip
MM	Moisture Monitor Signal
CSM	Circ. Seal Malfunction
RHA	Reheat Header Activity

FIGURE 2-2 HTGR TWO LOOP TROUBLE SCRAM CIRCUITRY OVERVIEW

BASIC TOP LEVEL



LEGEND

FILO First-In-With-Lockout
TDL Time Delay Lockout
INH Inhibit Signal
ISS Interlock Sequence Switch
TLT Two Loop Trouble

FIGURE 2–3 HTGR CIRCULATOR TRIP – SCRAM LOGIC OVERVIEW

BASIC TOP LEVEL

Pressure, Neutron Flux Rate Increase or Period (from the wide range nuclear channel), Core Inlet Temperature which is used to program the SCRAM trip levels for high or low Reactor Pressure, Reheat Steam Temperature High, Reactor Building Temperature High, Switch Gear Undervoltage (loss of power), Neutron Count Rate high (startup channel, used only in the refueling mode), Neutron Flux Level High (wide range channel), Neutron Flux level high (Linear Range Channel) and Two Loop trouble. These input channels usually include a signal sensor or transducer, signal conditioning electronics, analog recordings or indicating equipment, associated alarms or annunciators and an output Bistable trip unit.

Table 2-1 summarizes the trip conditions for each main SCRAM channel and indicates the number of sensors used for each SCRAM parameter.

The components indicated between the channel SCRAM inputs and the OR gate are the Interlock Sequence Switch (ISS), thirty second time delay (TD) and the Reactor Mode Switch (RMS). The Interlock Sequence Switch has three positions: Startup (power below 5% of rated output), Low Power (between 5 and 30% power), and Power (above 30% of rated output). The thirty second time delay lockout is used only in the Switch Gear Undervoltage trip and is provided to allow time for the Emergency Diesel Generators to come on line and to reduce the possibility that transients on the incoming power lines will trip the SCRAM outputs.

The Reactor Mode Switch has three positions: Off, Fuel Loading (used only at reloading or low level tests) and Run. The main function of the Reactor Mode Switch is to provide a count rate trip at 10^5 counts per second (through the dual

TABLE 2-1
SCRAM PARAMETERS

	Sensed Variable[a]	Type and Number of Input	Detector Location	Basic Logic	Normal Full Load Value	Approximate Trip Level
1a.	Manual	Hand switch (1)	Control Room Board (I-03)	1 of 1	--	--
1b.	Manual	Hand switches (3)	Control Board I-49	2 of 3	--	--
2.	Neutron countrate - high (use only at Fuel Loading)[a]	Nuclear Channels I, II	PCRV Well	1 of 2		10^5 counts/sec
3.	Rate of neutron flux rise - high (use only at Startup)[a]	Nuclear Channels III, IV, V	PCRV Well	2 of 3	< 2 decades per min	5 decades/min
4.	Neutron flux - high	Nuclear Channels III, IV, V, VI, VII, VIII	PCRV Well	2 of 3 2 of 3	100% power	140% power
5.	Primary coolant moisture - high	Dewpoint monitor[b] (8)	PCRV Penetration	2 of 3 plus 1 of 2 or 2 of 2 high level	< 1 vpm[d]	2000 vpm[d]
6.	Reheat steam temperature - high (4 thermocouples are averaged for 1 scram channel)	Thermocouples (12)	Turbine Building	2 of 3	1002°F	1075°F
7.	*Primary coolant pressure - low (use only at Power)[a]	Pressure Transmitters[b] (3)	PCRV Penetration	2 of 3	700 psia	50 psi below rated programmed with load
8.	*Primary coolant pressure - high (use only at Run)[a]	Pressure Transmitters[b] (3)	PCRV Penetration	2 of 3	700 psia	7-1/2% above normal pressure programmed with load
9.	Hot reheat line pressure - low (use only at Power)[a]	Pressure switches (3)	Turbine Building	2 of 3	610 psig	35 psig
10.	Superheat line pressure - low (use only at Power)[a]	Pressure switches (3)	Turbine Building	2 of 3	2500 psig	1500 psig
11.	Plant electrical system power - loss	Undervoltage relays (6)	480V SWGR No. 1 and No. 3	2 of 3	480 volts	60% rated voltage persisting for 30 seconds
12.	Two-loop trouble[c]	Loop shutdown logic	Control Room (Board I-10)	2 of 3 (both loops)	--	--

[a] Notation in parenthesis refers to Interlock Sequence Switch or Reactor Mode Switch positions.

[b] The same transmitters are used for steam/water dump.

[c] "Two-loop trouble" is a condition whereby one steam generator loop is shutdown and trouble that would normally cause a loop shutdown is sensed in the other steam generator loop.

[d] vpm: parts per million by volume.

*Primary coolant pressure is programmed by core inlet temperature. The thermocouples are physically located in the inlet plenums for each of four circulators. (two T/C per circulator) startup channels) at very low power operation. The positions of the reactor switches are detailed in Table 2-2 along with appropriate SCRAM inputs which operate under various conditions of these switches. Sensor Channels with Roman numerals I through VIII refer to the respective nuclear sensor channels and their SCRAM conditions. Sensors I and II are high sensitivity detectors which provide a count rate SCRAM during fuel loading but are disabled during normal operation. Sensors III, IV and V are wide range detectors with logarithmic and linear outputs. The log outputs are used to provide reactor period indications which then give a Rod Withdrawal Prohibit signal at two decades per minute (dpm) and a SCRAM at five dpm. The linear portion of the channel is used for high neutron flux level SCRAMS and Rod Withdrawal Prohibits. Sensors VI through VIII feed the linear range neutron flux channels providing high level flux trip and RWP's.

There is a ninth neutron flux channel (IX) which combines signals from six independent ion chambers to provide automatic control of the reactor when leveled off at power. These six chambers are independent of the safety channels except that each chamber can be used as a back-up if one of the six safety channels fails. The normal use is to provide an indication of power distribution around the edge of the core and to provide a means for automatic control. The last input to the main SCRAM Gate is the Two Loop Trouble input which is sufficiently complicated to be considered in further detail in Figures 2-2 and 2-3.

Following the main SCRAM Gate, an XCR2 (SCRAM relay driver) is used to drive the dual heavy-duty SCRAM relays. The SCRAM contactors are wired into the dual two-out-of-

TABLE 2-2

Reactor Switches

A. Reactor Mode Switch

Off--RWP and SCRAM

Fuel Loading--SCRAM above 10^5cps--I or II

Run--High countrate disabled.

Fuel loading in Run position prevented only by administrative action

B. Interlock Sequence Switch

Startup--RWP above 5% (III-VIII for 2 sets of 2 out of 3) and I and II below 5 cps

Low Power--RWP below 5% or above 30%

Power--RWP below 30%.

SCRAM on low main steam pressure, low reheat steam pressure and low primary coolant pressure.

SCRAM Inputs

A. All Conditions Of Mode And Interlock Switches

1. Manual Switch--Control Room
2. 2 out of 3 Manual Switches--Switchgear Room
3. 2 out of 3 SCRAM channels disabled or removed
4. Reactor Building above 325°F
5. Plant Electrical System (480V)-60% lasting longer than 30 seconds
6. 2-Loop Trouble (one loop down with trouble in second activating lockout). Includes Primary Coolant moisture above 2000vpm
7. Reheat Steam Temperature above 1075°F
8. Neutron Flux above 140% rated power

TABLE 2-2 (Continued)

B. Power Operation (Mode Switch in Run)

1-8. Same as A

9. Primary Coolant Pressure High (Reactor Pressure).

10. Primary Coolant Pressure Low (Reactor Pressure). Also, circulator (or core) inlet temperature programs set point to correspond to load.

11. Superheat Steam Pressure Low

12. Hot Reheat Steam Pressure Low

13. Mode Switch not in Run (SCRAM on I or II high count rate or Switch Off)

C. Low Power Operation (Mode Switch in Run)

1-9. Same as B

10. Mode Switch not in Run

D. Startup (Mode Switch in Run)

1-10. Same as C

11. Rate of flux rise above 5 decades/minute

E. Fuel Loading (Interlock Switch in Startup)

1-9. Same as A

10. Neutron Count Rate above 10^5 cps

11. Rate of flux rise above 5 decades/minute

12. Mode Switch Off (Fuel Loading or Run both permissible)

13. Interlock Switch in Power (SCRAM on low main steam pressure, low reheat steam pressure, and low primary coolant pressure). Low Power position causes RWP only.

TABLE 2-2 (Continued)

Other Protective Actions

1. Rod Withdrawal Prohibit
2. Single loop steam/water dump
3. Loop shutdown
4. Circulator Trip
5. Reserve Shutdown System--Manual
6. Emergency feedwater supply
7. PCRV Relief Valve

Radiation monitors--alarms plus loop shutdown.

RWP Inputs

1. Channel I or II below 5cps (no source or bad instrument)
2. Rate of rise greater than 2 decades/minute
3. Power greater than 120%--2 out of 3 for III, IV, and V, or VI, VII, and VIII
4. Flux level wrong (Channel III through VIII) for interlock sequence switch
   A. Above 5% in STARTUP
   B. Below 5% or above 30% in LOW POWER
   C. Below 30% in POWER
5. Rod Control Load Sensor--more than 1 rod being withdrawn.
6. Rod Withdrawal Sequencing--below 5% and attempted rod withdrawal out of prearranged group sequence
7. Power Range Downscale Failure--Channel III-VIII

three relay network in the main lines from the two SCRAM brake power supplies. The 28volt SCRAM brake power supplies are cross-connected before the two-out-of-three coincidence logic and then split with one line going to the odd numbered SCRAM brakes and the other line going to the even numbered SCRAM brakes. Either the odd or the even brakes are capable of shutting the reactor down from high power and high temperature to some intermediate temperature. The reactor power can be reduced drastically with half the control system, but complete shutdown requires most of the remaining rods to be inserted due to the negative temperature coefficient. Plenty of time is available for any required operator action to complete the SCRAM if necessary, since the reactor temperature has already been reduced substantially. Safe shutdown can still be achieved with a few of the rods out of the reactor, the number depending upon conditions of fuel loading and burn-up. As a final safety measure, a back-up emergency reactor shutdown system is available. This is a manually operated system which will drop boron carbide-graphite balls into the reactor core and provide a safe reactor shutdown.

Manual control rod drops are provided beyond the two-out-of-three logic with a single manual SCRAM switch in the control room and a set of two-out-of-three switches in the auxiliary switch-gear room, which serves as the emergency control room for the reactor. The symbol H/I on Figure 2-1 indicates a human interface for manual SCRAM.

It will be noted that the Control Rod Drive (CRD) power, normally under control of the reactor operator, interfaces both with the SCRAM brake/motor circuits and with the mechanics of the rod drop process; i.e., to physically insert or withdraw a control rod in the HTGR core, auxiliary a.c. power must be applied to the CRD and the brakes released from the rod to be driven. Conversely, if a short were to occur in the control rod drive unit, it is possible for power to be applied continuously to the rod brake unit which may inhibit the faulty unit from reacting to a system SCRAM. The rod drop mechanics include a modeling of the 3-phase rod motor drive, the rod gear mechanism, cable attachments, rod clearances, possibility of external forces acting to disrupt core and rod channel geometry, and consequences of human error during rod drive maintenance, such as forgetting to secure the penetration covers to the CRD's.

The logic involved in the Two Loop Trouble SCRAM circuit is shown in Figure 2-2. The inputs which will request the SCRAM are High and Low Level Moisture, Reheat Header Activity High (indicating radioactivity in the secondary coolant), Superheat Header Temperature Low, Steam Generator Penetration Overpressure, Steam Pipe Rupture (as detected by temperature and pressure or by ultrasonic noise detectors), Circulator Trip, and Low Reactor Pressure.

Table 2-3 summarizes the trip conditions for each of the Two Loop Trouble inputs and also lists the number and type of sensors required for each trip parameter.

The High Level Moisture Trip occurs at approximately 2000vpm (ppm by volume) and requests an immediate SCRAM because of the assumed presence of a large water leak. The Low Level Moisture detector trips at 100vpm and is used primarily to indicate which loop is starting to leak and to provide the means for determining a safe shutdown point for the faulty loop by tracking the rate at which the moisture

TABLE 2-3

LOOP SHUTDOWN PARAMETERS

(Typical Each Loop)

Sensed Variable[a]	Type and Number of Input	Detector Location	Basic Logic	Normal Full Load Value	Approximate Trip Level
1. Loop moisture - high	Dewpoint monitors[b] (4 per loop)	PCRV Penetration	2 of 3 plus 1 of 2	< 1 ppm	2000 ppm
2. Hot reheat header activity - high	Transmitters (3 per loop	Turbine Building	2 of 3	0	5 mr/hr or twice background
3. Steam generator penetration pressure - high	Pressure Switches (3 per loop)	Reactor Building	2 of 3	710 psia	800 psia
4. Superheat header temperature - low[d] (use only at power)[a]	Thermocouples (3 per loop)	Reactor Building	2 of 3	1000°F	800°F
5. Steam pipe rupture (under PCRV)	Ultrasonic Noise (2 per loop) Building Pressure (3 total for plant)	Under PCRV	1 of 2 and one 2 of 3	--- 0	Twice Background 5" H_2O
6. Steam pipe rupture (Reactor Building)	Ultrasonic Noise (2 per loop) Building Pressure (3 total for plant)	Reactor Building	1 of 2 and one 2 of 3	--- 0	Twice Background 5" H_2O
7. Primary coolant pressure - high[c]	Pressure Transmitters[b] (3 total for plant)	PCRV Penetration	2 of 3	700 psia	53 psia (7-1/2) above rated. Programmed with load
8. Circulator A and B tripped	Circulator trip circuitry	Control Room (Board I-10)	1 of 2 (A or B logic)	---	Tripped

[a] Notation in parenthesis refers to Interlock Sequence Switch positions.

[b] The same transmitters are used for scram.

[c] Shuts down only manually preselected loop.

[d] Trip occurs only if the difference in temperature compared to other loop is greater than 50°F.

level is increasing. A number of inhibits are provided for low moisture detection; i.e., the high level moisture circuits will normally inhibit the low level moisture system from tripping and creating additional steam dumps until the moisture level is high enough to trip the high level detectors. If High Reheat Header Activity or Circulator Seal Malfunctions are present, the Low Level Moisture detection system is inhibited from tripping. A malfunction in the Circulator Seal differential pressure usually indicates loss of helium pressure and possible introduction of moisture into the system. A shutdown in this case would result in a decrease of primary coolant pressure and a more rapid introduction of moisture into the system, hence the inhibit.

The Reheat Header Activity High indicates radioactivity detection in the secondary coolant which indicates a possible steam generator tube rupture resulting in leakage of reactor helium into the steam system. This requires loop shutdown to minimize the amount of activity introduced. However, it is possible that loop shutdown will result in steam leakage back into the helium. Thus, the inhibit output is introduced into the moisture monitoring system to inhibit loop shutdown and maintain the primary coolant pressure at a higher level than the steam pressure.

Low Superheat Header Temperature is an indication of either a feed water valve or control failure or deficiency of helium control which requires loop shutdown. The comparator circuits between the loops prevents loop shutdown in circumstances when the main steam temperature of both loops is being reduced, such as following a primary SCRAM.

Steam Generator Penetration Overpressure indicates a pipe rupture within the penetration. Loop shutdown is provided and the overpressure is handled by relief valves. Steam generator contents are also dumped. The Circulator Seal Malfunction provides an input to the circulator trips (see Figure 3) as well as an inhibit function into the Low Level Moisture detection, and feeds back through proper logic to the single loop trip as required. Steam Pipe Rupture is detected from pressure, temperature and ultrasonic noise detectors. Combinations of several sensors are used to indicate which loop to shut down and to provide a single channel trip signal to the SCRAM circuitry. Low Reactor Pressure is brought into the TLT section to signal that a probable penetration closure or major rupture has occurred and to initiate appropriate loop shutdown action and backup SCRAM functions. Circulator Trip can be initiated in a number of different ways and is described more completely in Figure 2-3.

The outputs from both cooling loops are fanned into dual A&B logic as shown on the left side of Figure 2-2. The single loop outputs are indicated by three types of output signals, i.e., -1 inputs (high level moisture), -2 inputs (low level moisture), and -3 inputs (which include all other trip parameters). These three outputs combine to provide trip signals for either of the two loops, 1 or 2, and with either A or B logic. These inputs are combined into four channels, each of which is fanned and combined into the final SCRAM logic to provide TLT outputs A, B and C to the three SCRAM channels. This logic results in a SCRAM request through all three SCRAM channels only when both loops are tripped and when either logic is activated.

Figure 2-3 shows the inputs to a typical Circulator Trip circuit and the logic resulting in circulator trip, which is also used as an input to the TLT circuit. The inputs are Circulator Penetration Pressure High, Circulator Speed Sensors (three types), Manual Trip, Reheat Header Activity High, Bearing Water Loss, Circulator Seal Malfunctions, Fixed Feedwater Low Flow, Circulator Drain Malfunction.

Table 2-4 summarizes the conditions required for a circulator trip. It also lists the type and number of sensors required for each trip parameter.

The Circulator Speed sensors include overspeed from the steam or water drives, low speed programmed by feedwater flow rate, and low feedwater flow rate programmed by circulator speed. Most of the circulator trip sensors incorporate a three to five second time delay lockout so that spurious noise or sudden transients in load will not cause a trip. The SCRAM brake input is an inhibit feedback from the final SCRAM logic into the Low Feedwater Flow Trip inputs. Whenever the reactor is scrammed or shut down, it is expected that feedwater flow will be drastically reduced or cut completely off, hence there is no need for a Low Flow Trip at that time.

Figure 2-4 is an overall plant control sketch showing the location and nature of all principal Scram and Loop Shutdown parameters.

From the above discussion, it can be seen that the SCRAM circuitry interacts in considerable detail with the plant operating system even though the operating system is concerned primarily with single loop shutdown. Thus it was

TABLE 2-4

PRIMARY COOLANT HELIUM CIRCULATOR TRIP PARAMETERS

(Typical Each Circulator)

Sensed Variable[a]	Trip[b]	Type and Number of Input	Detector Location	Basic Logic	Normal Full Load or Maximum Value	Approximate Trip Level
1a. Circulator Speed (Steam Drive) - High	S	Pulse Pickup Coil[c] (3 per circulator)	In Circulator	2 of 3	9550 rpm	11,000 rpm
1b. Circulator Speed (Water Drive) - High	W	Pulse Pickup Coil[c] (3 per circulator)	In Circulator	2 of 3	10,800 rpm with 12 psia primary coolant pressure	11,500 rpm
2. Circulator Speed - Low (use only at Power)[b]	S	Pulse Pickup Coil[c] (3 per circulator)	In Circulator	2 of 3	9550 rpm	1910 rpm (20%) below normal, programmed with feedwater flow
3a. Feedwater Flow - Low (use only at Power)[a] (Note d)	S	ΔP transmitters[e] (3 per loop)	Turbine Building	2 of 3	100%	20% below normal programmed with circulator speed
3b. Feedwater Flow - Low (use only at Power)[a]	S,W	ΔP transmitters[e] (3 per loop)	Turbine Building	2 of 3	100%	20%
4. Bearing Water - Loss	S,W	ΔP switches (3 per circulator)	Reactor Building	2 of 3	≈650 psi	550 psi
5. Circulator Seal Malfunction	S,W	ΔP switches (3 per circulator)	Reactor Building	2 of 3	+1/2 psi	--
a. Bearing Water Leakage to Primary Coolant - High	--	--	--	--	--	-1/2 psi
b. Labyrinth Helium Flow - High	--	—	--	--	--	+1 psi
6. Circulator Penetration Pressure - High	S,W	ΔP switches (3 per circulator)	Reactor Building	2 of 3	710 psia	800 psia
7. Circulator Steam/Water Drain - Malfunction	S	ΔP switches (3 per circulator	Reactor Building	2 of 3	45 psi	10 psi
8. Loop Shutdown (use only at Power)[c]	S	Loop Shutdown Logic (A&B)	Control Room (Board I-10)	1 of 2 ('A' or 'B' Logic)	--	Loop Shutdown
9. Manual (Separate for steam and water turbine)	S,W	Hand Switch (1 per circulator drive)	Control Rool (Board I-05)	1 of 1	--	--

[a] Notation in parenthesis refers to Interlock Sequence Switch Positions.

[b] Indicates trip: S = Steam Drive; W = Water Turbine Drive; S.W. = Both Drives.

[c] The same speed sensors are used for High and Low Speed Trip.

[d] Active only prior to scram.

[e] The same ΔP transmitters are used for both low feedwater flow trips on both circulators in the loop.

required to model those portions of the loop shutdown and related circuits which could have an evential influence on a SCRAM request. For these reasons, it was decided to modify the initial tasks previously defined for Phase 1 and Phase 2. Phase 1 was redefined to include modeling and evaluation of the St. Vrain SCRAM Protective System starting from the sensor inputs and terminating at the main SCRAM grate. This includes all SCRAM sensor circuits in the main SCRAM system, the Two Loop Trouble detection system, and the SCRAM portions of the Circulator Trip System. Phase 2 was redefined to include modeling and evaluation of the SCRAM system commencing with the main SCRAM gate input through control elements of the SCRAM brake power, selected parts of the Control Rod Drive System, and through a detailed modeling of the Control Rod Gear Drive mechanism for all 37 rod pairs. Phase 2 also includes an analysis of the total system response to a series of Simulated Accidents specified by the Gas Reactor Safety Branch of RR&D, AEC/ERDA. Failure data for Phase I were based on monthly systems testing. The effect of daily checks on the SCRAM Protective System sensors was evaluated in Phase 2. For convenience, the results of the daily checking has been included in the Phase 1 Summary Tables for those sensors used in the Main SCRAM, Two Loop Trouble, and Circulator Trip Circuits.

Top Level Logic Flow Diagram

Figure 2-5 is an abbreviated logic drawing of the complete SCRAM system modeled in this study. It includes the Main SCRAM circuit, the Two Loop Trouble circuits, and the Circulator Trip circuits. Figure 2-5 represents only a profile of typical circuits. Those circuits not detailed are referenced on the drawing.

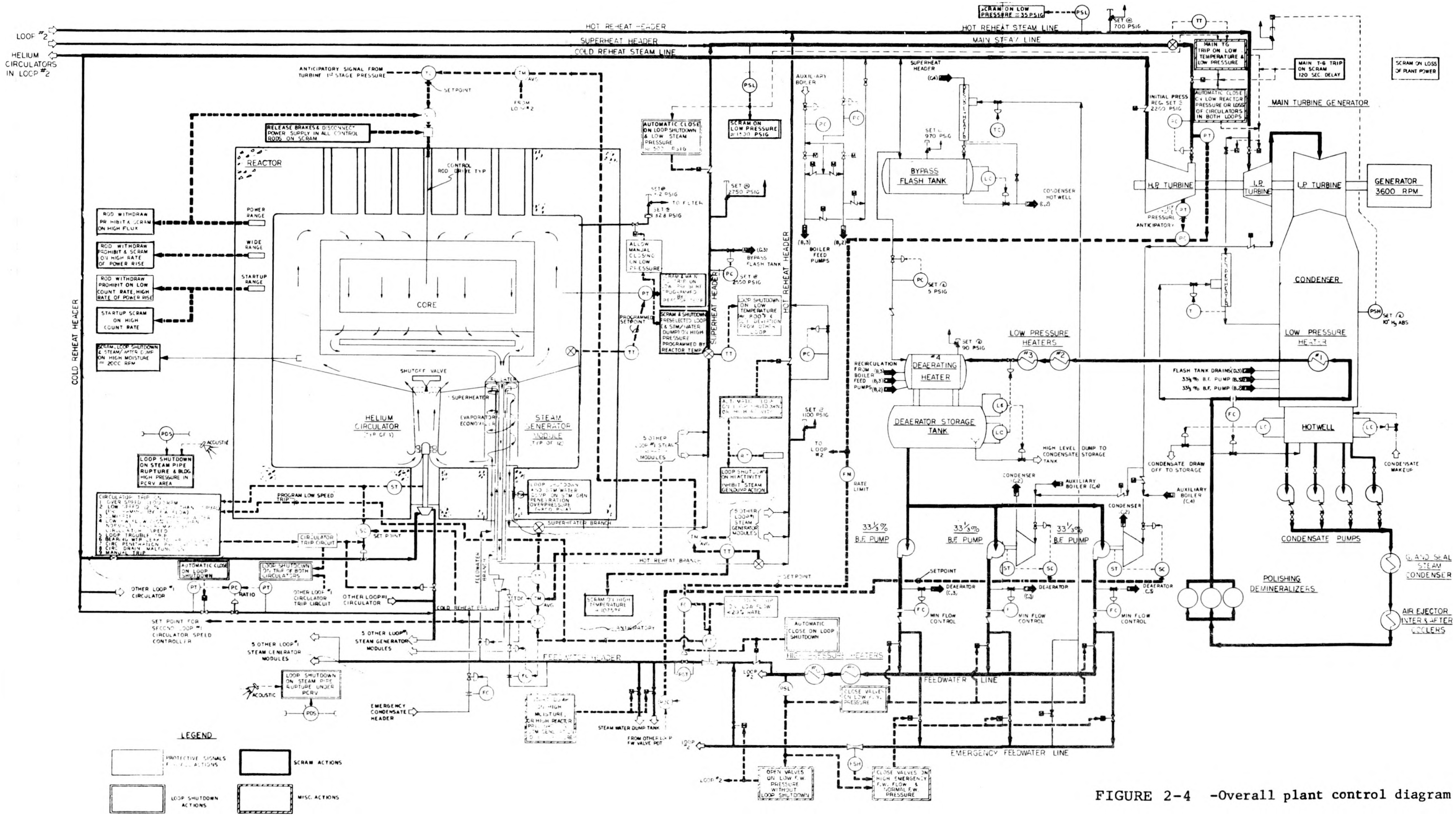
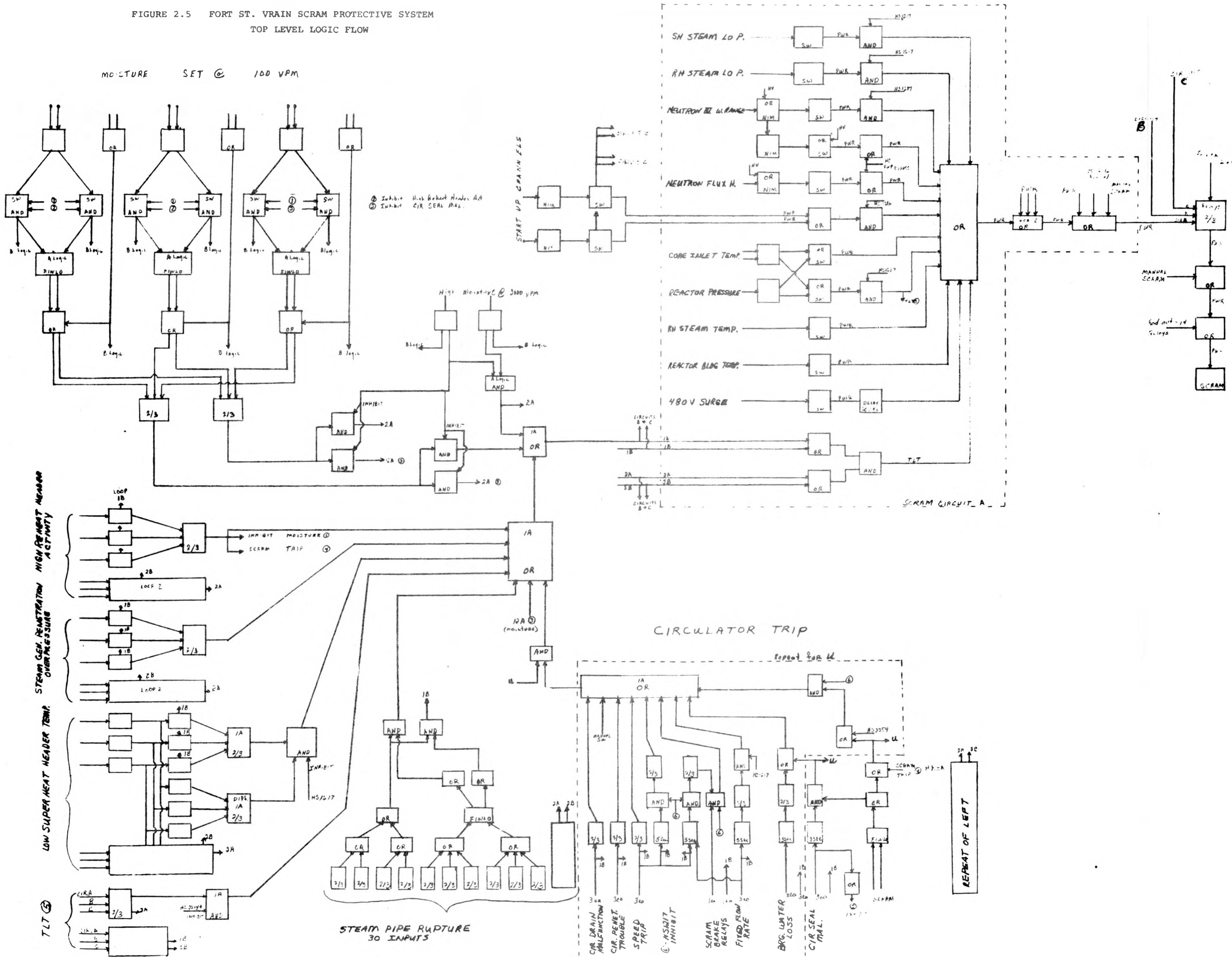


FIGURE 2-4 -Overall plant control diagram

NOTE: Circled Items represent controls initiating SCRAM action.

FIGURE 2.5 FORT ST. VRAIN SCRAM PROTECTIVE SYSTEM
TOP LEVEL LOGIC FLOW



B. Descriptive Material

A substantial number of manuals and drawings were obtained for reference or inspected at the Fort St. Vrain plant when copies were not available. The primary manuals were:

1. E-115-144: Operation and Maintenance Manual, Plant Protection System, Equipment No. I-9310. The primary manual describes the operation of the system in detail, the hardware supplied and some of the test and maintenance procedures. Appendix I, in 10 volumes, contains the operating manuals for the various modules used for input signal processing in the SCRAM channel. Appendix II is the collection of drawings and wiring lists for the system. Appendix III contains hardware adjustments.
2. E.115-265 Operation and Maintenance Manual, Rod Control System, Equipment I-903. The rod control system includes the controls and instrumentation to position the control rods in the reactor and read out their position. This includes the power supplies and circuitry used to drive the rods, switching circuits to select the rods that are to be controlled in groups or individually, and the various interlocks, switches, and relays involved with shut-down and rod withdrawal prohibit action.
3. GA-9806 Installation, Operation and Maintenance Manual for the Control and Orificing Assembly for the Fort St. Vrain Reactor. This manual describes the control rods, the control rod drive mechanisms, the orifice valve mechanism (an integral part of the assembly although not used for shut-down) and the various interlocks and alarms to indicate the status of the control rod system.

4. Final Safety Analysis Report, Fort St. Vrain Nuclear Generating Station, Public Service Company of Colorado, Denver, Colorado. (4 Vols. plus Attachments).

The above manuals describe the shutdown system in detail from the sensors through the logic to the control rods themselves. Detailed study of these manuals is required to understand the complete system and permit proper modeling with all of the various interactions.

Hundreds of drawings are involved in the systems contributing to reactor shutdown, but not all of these are needed for proper modeling of system operation. Those drawings involved in the system modeling, either modeled in detail or analyzed as an aid to modeling, are listed in Table I, Appendix E.

Additional descriptive material included Operational Procedures (OPOP'S) and Surveillance Procedures (SP's). These were converted to time lines for identification of human interfaces as discussed in Section III-C. The complete list of procedures modeled is also given in Section III-C.

III. INITIAL SYSTEM MODELING (PHASE I)

A. Delineation of SCRAM System Logic

System modeling and GO chart development depends upon several levels of detail, e.g. top level logic diagrams, system schematics, and subsystem or module detailed drawings. Drawings and manuals were obtained from GA and PSCC on the Plant Protection System and related systems, but the desired level of detail did not correspond to the levels of detail available, so information was extracted to the level considered necessary to meet problem requirements. Also the information contained on the schematics presents details relating to interfacing systems such as Loop Shutdown, Emergency Shutdown, Rod Control, Rod Withdrawal Prohibit, etc., which were defined to be outside the boundaries of the current task.

In order to allow uniform modeling within the problem scope, an intermediate set of working level logic schematics was developed from the above data. These schematics define the St. Vrain SCRAM Protective System within the specified boundary constraints. Their primary purpose is to serve as a guide for development of the associated GO charts from which the computer model of the SCRAM system is constructed.

Operation and maintenance manuals were examined to define modes of operation not fully defined by the schematics as well as human interfaces. In some cases detailed maintenance and test procedures had to be reviewed to define the human interfaces properly.

B. SCRAM Input Channels

Each of the three main SCRAM channels has 12 inputs which are initiated by the various plant parameters that have critical limits. The initial modeling was performed on these input channels in order to determine individual channel reliability. These channel inputs were then used in Phase II for modeling accident sequences involving different combinations of sensors for SCRAM reliability predictions.

In the St. Vrain SCRAM system, the 12 inputs are introduced to the Main SCRAM Gate which consists of three NAND type circuits, each with four primary inputs. The output of two of these NAND gates feed the third NAND gate as auxiliary inputs.

Preliminary estimates of the size of the GO model for all of the main SCRAM input circuits (except the Two Loop Trouble circuit) from sensor inputs down to the main SCRAM gate indicated about 3000 components. Estimates of the size of the Two Loop Trouble module including the SCRAM circuits in the Circulator Trip, came to about 4000 components. A sizing of the SCRAM system, starting from the main SCRAM gate through the SCRAM brakes, single rod control, and rod drop gear mechanism, gave an initial size of about 6000 components (160 components/rod pair x 37).

Due to the total number of elements involved, it was considered expedient to break the GO model into the three major segments described above. Phase I was defined to include the following:

- Segment 1 (All SCRAM inputs except 2-loop) to be completely modeled.
- Sensitivities of all components and human interfaces to be evaluated.
- Preliminary reliability of each main SCRAM input circuit to be determined.
- Segment 2 (Two-loop trouble input) to undergo initial modeling.

Completion of Segment 2 and Segment 3 (SCRAM system) was deferred for Phase II.

After the "GO" charts for Segment 1 were completed, it became apparent that the model could be conveniently constructed from three computer card decks. The contents of each deck were established as follows:

Deck I

Electrical Power Distribution System
Superheat Steam Pressure (Low)
Hot Reheat Steam Pressure (Low)
Plant Electrical Power Loss (480v Switchgear)
Reactor Building Temperature (High)
Reheat Steam Temperature (High)

Deck II

Startup Channels (Count Rate and Period)
Wide Range Channels (Period and Flux Level)
Linear Range Channels (Flux Level)

Deck III-A

Reactor Pressure (Primary Coolant), High & Low
Core INLET Temperature (High & Low)

Detailed modeling and explanation of the SCRAM input channels is presented in Appendix A-5.

The 8 nuclear channels provide 4 SCRAM inputs: Startup Count Rate High, Reactor Period High, Neutron Flux High (Wide-Range Channel), and Neutron Flux High (Linear Power Channel). The 8 channels include two low-level counting channels used at very low levels only, three wide-range logarithmic channels with both period and level trips, and three linear flux channels with level trips only.

Reactor Pressure (primary coolant) provides two SCRAM inputs for high and low pressure. The output is programmed by Core Inlet Temperature since these parameters are closely related. The trip occurs if reactor pressure goes outside of the range permitted by the associated inlet temperature.

The Two Loop Trouble system provides a single SCRAM input from either the A or B logic when moisture or various other parameters are outside allowable limits.

The remaining channels in the Main SCRAM System are simple process trips which are not directly interdependent, although more than one may trip as a result of trouble: Hot Reheat Steam Low Pressure, Superheat Steam Low Pressure, Reheat Steam Temperature High, 480v Surge Undervoltage, and Reactor Building Temperature High.

C. Time Sequence Flow

Human interfaces with the PPS were determined from the standard plant procedures. Surveillance Test Procedures describe the work performed on each of the SCRAM input channels (monthly, or prior to startup). In general, separate procedures are written for calibration and channel SCRAM test. These procedures were modeled in the form of a "time-line" with steps numbered and described along with appropriate numbers or identifiers for switches, lights, valves, sensors, etc. For those steps involving components modeled on Go logic system diagrams, the Go logic signal numbers were noted on the time lines. Then the human interfaces were added as initiators to the appropriate components (Reactor Mode Switch, Test/Operator Switches, Thermocouple Removal and Replacement, etc.). Reliability for proper performance of the function was assigned to the human operator for inclusion in the complete GO runs and sensitivity analysis.

The procedures modeled are listed in Table 3-1, which is an index to the tabulated time lines with detailed procedures. The time lines refer to the Surveillance Procedure numbers, drawings, and instrument numbers. A reference to the proper GO chart number is also given on each time line (FSV-1 through FSV-17). An index listing for all GO charts is given in Appendix C.

The time lines (Figures B.1 through B.28) are displayed in the Appendix B and an example (Figure B.1) is given on the following page.

TIME LINE FOR MANUAL (CONTROL ROOM) SCRAM TEST

SURVEILLANCE PROCEDURE # 5.4.1.1.1.a-R.P

References: 1) System operating Procedure 93-01 Control & Instrumentation: Plant Protection System 2) Drawing EL-169-2951
Frequency: Refueling and prior to startup.
GO Chart Reference No.: FSV-18
Instruments: HS-1216-Reactor Mode Switch (RMS)
HS-9330 Manual SCRAM Button (MSB)

Surveillance Events

1
- a) Verify Reset of SCRAM System
- b) Reset SCRAM System if Necessary (Sig. # 163)

2
- a) Prepare rod control system for W/D of first control rod group. Check Monitors
- b) Withdraw rod group 6 inches (Sig. # 210, 211)

3 Place MSB to SCRAM, then return to Normal (Sig. # 162)

4 Visual Verification

5 Reset SCRAM trip as in 1b (Sig. # 163)

6 Verify all trips in Event 4 are reset. (Sig. # 163)

7 Place RMS to OFF position and remove key (Sig. # 105)

8 Verify RMS will not move; make verification as in 6

9 Return RMS to the position desired for anticipated operation. Record Position (Sig. # 106)

(1a) Verify that XA-9319, XA-9320 and XA-9321 are all off. Verify that II-93177, II-93178, II-93179, II-93180 are all null (<3 amps). If any one of these is not true, reset SCRAM section according to (1b).

(1b) Proceed as follows:
α) Verify all SCRAM inputs are cleared:
XCR-93125, 301-P11, TRIP indicator out
XCR-93127, 201-P11, TRIP indicator out
XCR-93126, 101-P11, TRIP indicator out

β) Depress and release HS-93125, A LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-1, Alarm reset. Verify XI-93181 and 93235 are out.

σ) Depress and release HS-93126, B LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-2, Alarm reset, REACTOR on Lit, A-B SCRAM AUXILIARY RELAYS red lights out. Lights XI-93184, XI-93213, XI-93214, XI-93222 are out.

δ) Depress and release HS-93127, C LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-2, alarm reset. XI-93183, 93237 out, II-93177, 178, 179 and 180 all indicating null current (<3 amp).

(2a) Verify primary coolant moisture monitors MIS 1122, 1121, 1120, 1115, 1119, 1116, 1117, 1118 are reset and ready for sampling. If they are not, attempt to reset by pressing, then releasing red trip indicator.

(4) Verify that rod group in Event 2 returns to fully inserted position in approx. 6 sec. Verify REACTOR on light off and A-B SCRAM AUXILIARY RELAYS lights are ON. Verify I-03A, 5-1, 5-2, 5-3 alarm. Verify the following SCRAM trip outputs: XCR-93211A, + B, #1 red ON lit (2 min time delay). Also verify that XI-93235, XI-93181, XI=93237, XI-93183, XI-93236, XI-93182 are lighted.

FIGURE B 1

TABLE 3-1

TIME LINES FOR SURVEILLANCE PROCEDURES

Figure Number	Time Line Name
B.1	Manual (Control Room)SCRAM Test
B.2	Manual (I-49) SCRAM Test
B.3	Startup Channel SCRAM Calibration
B.4	Startup Channel SCRAM Test
B.5	Linear Power Channel SCRAM Test
B.6	Wide Range Power Channel SCRAM Calibration
B.7	Wide Range Power Channel SCRAM Test
B.8	Primary Coolant Moisture SCRAM Calibration
B.9	Primary Coolant Moisture SCRAM Test (Hi-Level)
B.10	Reheat Steam Temperature SCRAM Calibration
B.11	Reheat Steam Temperature SCRAM Test
B.12	Primary Coolant Pressure SCRAM Calibration
B.13	Primary Coolant Pressure SCRAM Test
B.14	Circulation Inlet Temperature SCRAM Calibration
B.15	Circulation Inlet Temperature SCRAM Test
B.16	Hot Reheat Header Pressure SCRAM Calibration
B.17	Hot Reheat Header Pressure SCRAM Test
B.18	Main Steam Pressure SCRAM Test
B.19	Main Steam Pressure SCRAM Calibration (Low Pressure)
B.20	Two Loop Trouble SCRAM Test
B.21	Two Loop Trouble SCRAM Test (Refueling)
B.22	Plant 480 V Power Low SCRAM Test
B.23	High Ambient Temperature SCRAM Calibration (Reactor Building Temp.), (Refueling)
B.24	High Ambient Temperature SCRAM Test (Reactor Building Temp.), (Monthly)
B.25	Reactivity Control System Control Rods

Figure Number	Time Line Name
B.26	Startup to 25% Load - Initial Conditions
B.27	Startup to 25% Load
B.28	Plant Operation Between 25% and 100% Load

Interfaces for reactor operation were determined by examining operating manuals and procedures. Many of these are not involved with the SCRAM System (load balancing, steam generation, etc). Those procedures that were directly involved with the SCRAM System are:

SOP 12-01, 12-02, 12-03: Reactivity Control
OPOP IIIB: Startup to 25% Load - Initial Conditions
OPOP III: Startup to 25% Load - Startup Procedures
OPOP IV: Plant Operation between 25% and 100% Load.

Detailed time lines were drawn for these procedures (Figures B.25 through B.28, Appendix B).

D. Component Reliability Values

NOTES

1. Initial estimates for component reliability were based on failures per 10^6 hours (λ) as compiled by General Atomic in Reference 1. The data in this report was estimated by GA using component failure rates given in MILHDBK 217, 217A, and AVCO data.

In this document it was assumed that:

(a) all circuit failures result from random component failures;
(b) during the operating time each component will have a constant failure rate; and
(c) part failures are effectively independent of each other, based on field experience.

The MILHDBK values are computed for operating electrical stresses and ambient temperatures for nominal or off nominal conditions as desired.

2. The values quoted by GA are intended to account for additional kinds of stresses, such as:

(a) Environmental
electrical surges
pressure surges (reactor malfunctions)
start/stop stress
radiation deterioration
moisture/oxidation effects
vibration or shock;

(b) Human errors - excessive heat from solder guns
errors in rewiring, etc.

(c) Non-normally distributed factory defects,

(d) Higher voltages, pressures and temperatures than rated, etc.

Since all protective systems are checked at least once a month and some elements of the system more frequently, it seemed appropriate to base the operating reliability on a 30 day period. (720 hours).

3. To provide initial estimates, one system element (the Bistable Trip Unit PT-3S) was selected as a reference upon which to ratio failure probabilities per 30 days for all of the remaining system elements and components. If the failure per 10^6 hours for this system element is used to compute the probability of failure in 30 days, the probability approaches 0.008. Using this philosophy, an initial estimate for each element in the attached tables was computed by comparatively adjusting its probability of failure by the ratio of the component failure rate at 10^6 hours to the value set for the bistable trip unit at 10^6 hours. Where failure probabilities were obviously meaningless or not available, the relative complexity of the system element in question was compared to similar elements for which values were available. It should be emphasized that for most of the system elements, the listed values can vary over a fairly wide range and affect their sensitivity on the system in only a very small degree.

During the development of surveillance testing and operational time lines for identification of human interfaces, it became evident that a large amount of the SCRAM protection circuitry and sensor status is inspected every 8 hours with routine testing scheduled at 30 day intervals. Those sensitive components which are inspected every eight hours are flagged in the sensitivity tables.

4. After Phase 1 was completed, it was found that, due to their insensitive nature, very few of the components required any adjustment to the values originally assigned.

The final component values assigned are listed in Appendix D. Some changes were introduced to the original component values listed in the table. Section IIIE of this report, the analysis of the initial GO system model, discusses some changes in components of the Electrical Power Distribution System. During Phase 2, it was discovered that values assigned to some of the mechanical components in the control rod drive were relatively critical. This is discussed in Section IVD under The Analysis for Final System Modeling.

E. Human Error Values

Human Error Rates utilized for all Human Interfaces in the system study have been maintained constant in this study for routine test, operation and surveillance.

The WASH-1400 Reactor Safety Study Report quotes general human error rates which were used as a basis for estimating initial values (Appendix 3, p.129, Table III-13).

Most of the Human Interfaces, concerned with the sensor systems, involve setting switches for initial turn on, surveillance or system check-out, and réinstallation.

WASH-1400 gives the following estimates (partial list only):

	FUNCTION	ESTIMATED FAILURE RATE
(a)	Selection of a switch dissimilar in shape or location to desired switch	.001

	FUNCTION	ESTIMATED FAILURE RATE
(b)	General error of commission, e.g., misreading (or ignoring) switch labels thus operating wrong switch.	.003
(c)	General error of omission when there is no display of status in control room or feedback status to operator, e.g., (status light burned out).	.01
(d)	Error of omission when items in procedure are embedded in text, rather than clearly listed at end.	.003
(e)	(Conditional) Error of commission when there are a number of similar switches in same location and the operator reaches for the incorrect switch. ("X" is equal to the number of similar switches up to 5 or 6).	1/X

These error rates assume no undue time pressures or stresses related to accidents.

Since most of the switches to be operated during surveillance procedures are similar in appearance and are located on a number of similar panels in back of the control room instrument console at St. Vrain, the error rate, according to this table, could be as high as .003 (Item 3). However, it is probable that an experienced technician may not bother to check switch status with operators at the console during frequent checks of a system with which he feels familiar. This has the effect of increasing the error rate to .01 (Item c). Using this value as a starting point, the human error rate was initially doubled to .02 for routine tasks on the St. Vrain SCRAM Protective System, to obtain an estimate of the importance of human errors on the overall system.

As discussed in Section IIIE of this report, this failure value for some of the critical Human Interfaces appears to be unduly high. Justification is given in Section 1.2, pages 3-16 of this report for revising the Human Interface failure probabilities from a value of .02 to .001.

F. Go Model Analysis

1.0 Channel Reliabilities

1.1 General

The reliability of each circuit feeding the main SCRAM gate was determined by making "GO" runs on decks I, II and IIIA. The circuits represented in these decks represent SCRAM channel 'A' inputs only. The SCRAM circuits in channels B and C are independent and identical to inputs in channel A with the exception of the Nuclear Startup Channels and the Two Loop Trouble input, which is contained in computer deck IIIB. The system reliabilities have been modified to correspond to probabilities during a 720 hour interval (30 days). No differentiation has been made for those system elements which are alarmed or annunciated and subsequently repaired during this interval. However, sensitive components falling into this category are flagged in the sensitivity tables. Referring to reference (4), a SCRAM system utilizing two-out-of-three general coincidence logic has an average failure probability (Q) as follows:

$$Q = \frac{N!}{(N-M+2)!(M-1)!} (\lambda t)^{N-M+1}$$

where λ = unsafe failure rate

t = inspection interval

N = number of redundant channels ($N = 3$)

M = Number of coincident channels required for action ($M = 2$)

$$\therefore Q_{Avg} = (\lambda t)^2$$

If t is changed, the value of Q changes by:

$$Q_1 \cong Q_2 (t_1/t_2)^2$$

The dependence of Q on the square of the inspection interval is of interest because the apparent estimated failure probability can be reduced if the inspection interval is reduced. In particular, a number of the instrumentation channels are checked for on-scale readings (although not tested) every 8 hour shift. For data of this nature, the inspection interval can be taken as 8 hours instead of 720 hours. This improves the estimated failure probability (for most of those channels inspected) by a factor of $(8/720)^2$ or 1.2×10^{-4}.

Component reliabilities used during Phase 1 and the rationale for their selection are listed in Appendix D and Section IIID of this report. Human error rates used and the accompanying rationale are given in Section IIIE of this report. Human error was assumed to have an initial probability of .02 for routine operations and surveillance testing. However, it became obvious from the initial sensitivity runs that this operator error was dominant and much too high for certain functions. This assumption is discussed below.

1.2 Electric Power Distribution System

Table 3F-1 and 3F-2 list typical results from initial and final runs on the Electrical Power Distribution System (EPDS). During the initial EPDS reliability analysis, the component reliabilities were estimated for 1000 hour intervals rather than 720 hours. Table 3F-3 lists sensitivities to the components and human interfaces in the Electrical Power Distribution System. As the Human/Environ part of the sensitivity table (Table 3F-3) indicates, the human interfaces depending on the reliability assigned to the human, may contribute 50 to 90% of the total unreliability. (Note particularly human interface tasks #23 and #131.). This prompted a more careful consideration of operational policies for operating the two hand switches involved.

(a) Task #23, involves switching of the 480 volt hand switches in the Electrical Power Distribution System. Once the switches are set there appears to be no occasion which would require changing their state except for major trouble in the switch gear yard, or distribution center. Because of this consideration, the probability of inadvertent switching of this component was changed from .01 to a more realistic value of .0001.

(b) Task #131 involves inadvertent turn off of the local Bin power supplies by operation of the on/off power switches or by removal of the power cables. Reference (5) indicates that whenever operations, maintenance or surveillance test procedures utilize redundancy in test personnel, e.g., the first person going through a complete checkout with the second person auditing and checking each operation, the joint probabilities for human error are lowered in the same way as the employment of redundant components.

A check with St. Vrain operational personnel indicated that the usual practice during systems testing is to use two personnel. For these reasons, it was decided to use a conservative redundant human error probability of .001 throughout the remainder of the SCRAM Protective System study. In addition to these two changes, the assigned failure probability of the power invertor, the most important contributor to failure among the hardware components, was felt to be too high. In subsequent runs the failure probability was changed from .01 to .001. Using the above criteria, the channel A circuit reliabilities for all SCRAM sensing circuits in Phase I were redetermined. Table 3F-2 lists the updated values for the Electrical Power Distribution System.

TABLE 3F-1

INITIAL RELIABILITY VALUES FOR ST. VRAIN
ELECTRICAL POWER DISTRIBUTION SYSTEM*

	PROBABLE SUCCESS (MIN)	PROBABLE FAILURE (MAX)
Essential Bus 1:	.9790	.0210
Essential Bus 2:	.9790	.0210
Essential Bus 3:	.9943	.0057
Bin Power Supply:	.9593	.0407

*Based on 1000 hour test intervals, human error probability of .02, and Power Invertor reliability of .01.

TABLE 3F-2

UPDATED RELIABILITY VALUES FOR
ST. VRAIN ELECTRICAL POWER DISTRIBUTION SYSTEM*

Essential Bus 1:	.9952	.0048
Essential Bus 2:	.9952	.0048
Essential Bus 3:	.9999	.0001
Bin Power Supply:	.9937	.0063
Motor Control Ctr. Bus 1A:	.9996	.0004
Motor Control Ctr. Bus 3:	.9996	.0004

*Based on 720 hour test intervals, human error probability of .001, and Power Invertor reliability of .001.

NOTE: Although the power distribution system operates continuously rather than on a "per-demand" basis, these values represent the probability of power being available when the demand occurs.

TABLE 3F-3

SYSTEM SENSITIVITY TO COMPONENT CHANGES

ST. VRAIN ELECTRICAL POWER DISTRIBUTION SYSTEM

COMPONENT TYPE	COMPONENTS	PROB. SUCCESS (MIN)	30 Day PROB. FAILURE (MAX)	FAILURE SENSITIVITY	MAX CONTRIB.
A.	Bin Power Supply				
*15	Bin Power Supply Electronics	.9996	.0003	1.0	.0003
204	Hand Switch Contacts	.9995	.0001	2.0	.0002
16	A/C Plug	.9995	.0004	1.0	.0004
1	Fuses	.9999	.00007	2.0	.00014
37	Multiconn Cable	.99995	.00004	1.0	.00004
3	Conn Pins	.99994	.00004	N/A	N/A
				Σ_F =	.00108
B.	Electrical Power Distribution				
3-109	Power Invertor	.98	.01(.001)	1.0	.0007
6-204	Hand Switch	.9995	.0004	1.0	.0003
7-309	Lightning Arrestor	.9998	.0002	1.0	.0001
1-13	Elec trans	.9998	.0002	1.0	.0001
1-14	Batt charger	.999	.001	N/A	NN/A
3-107	Battery	.990	.009	N/A	N/A
3-108	Motor Gen.	.950	.040	N/A	N/A
7-310	Air Ckt Breakers	.994	.002	N/A	N/A
7-311	Removable Elec. Links	.99999	.00001	N/A	N/A
7-312	Undervolt Switch	.997	.001	N/A	N/A
1-3	Connector Pins	.99994	.00006	N/A	N/A
				Σ_F Hardware =	.0012

Component Numbers

TABLE 3F-3 Continued

TASK/SIG. #	HUMAN/ENVIRON INTERFACES	PROB. SUCCESS (MIN)	**PROB. FAILURE (MAX)	FAILURE SENSITIVITY	MAX. CONTRIB.
A. Bin Power Supply					
Sig# 131	Turn on/off Pwr Switch	.98	.02(.001)	1.0	.02(.001)
				Σ =	.02(.001)
B. Electrical Power Distribution					
Type 11					
Sig#* 23	Turn on High Voltage Switch	.99	.01(.001)	1.0	.01(.001)
" 1	Lightning Interrupt	.98	.02	N/A	N/A
" 2	Environ Interrupt-Air Ckt Breakers (High Line Series)	.98	.02	N/A	N/A
" 3	Environ Interrupt-Air Ckt Breakers (Cross Tie Line)	.98	.02	N/A	N/A
" 13	Environ Interrupt-Air Ckt Breakers (Output Low Line Series)	.98	.02	N/A	N/A
" 20	Environ Interrupt-Air Ckt Breakers (Low Line Series)	.98	.02	N/A	N/A
" 21	Remove Elect. Link	.99	.01	N/A	N/A
" 22	Turn on Cross Tie High Voltage Switch	.99	.01	N/A	N/A
				Σ =	.01(.001)

		Percent of Total H/I~.01	H/I~.001
Bin Power Supply			
Hardware Failures	= .00112	5%	53.0%
Human/Envir. Error	= .02	95%	47.0%
Σ T	= .02112		
Electrical Power Distribution			
Hardware Failures	= .0012	10%	55.0%
Human/Envir. Error	= .01	90%	45.0%
Σ T	= .0112		

*Go Model Signal Numbers.

** Preliminary Human Error Values (.02 + .01) changed later to .001.

2.0 Maximum Unreliability (Main SCRAM Sensor Circuits)

Table 3F-4 tabulates the maximum single channel unreliability values for test intervals of 720 hours. The SCRAM brake failure column represents similar values adjusted for daily checking.

Table 3F-4 indicates that the individual sensor circuits feeding into a single channel of the main SCRAM gate have an estimated mean probability value of 3.2×10^{-2} of failing before the end of a 30-day period. If these signals are applied independently to all three channels A, B and C of the main SCRAM gate and subsequently to the two-out-of-three SCRAM brake release circuit, the maximum probability of any single SCRAM variable failing to release the SCRAM brake before the end of a 30-day interval is about 3.1×10^{-3}. However, for those variables which are inspected every 8 hours, except Two Loop Trouble and the Nuclear Start-up channels, the probability of any single SCRAM variable failing is improved by a factor of 1.2×10^{-4}. It should be noted that three of the twelve inputs are not subjected to daily checking.

Table 3F-4B depicts the current inspection/test frequency for each of the Main SCRAM System variables.

3.0 Sensitivity - Main SCRAM Sensor Circuits

An examination of the sensitive components in each SCRAM circuit provides an alternative method for evaluating individual circuit reliability.

Tables 3F-5 through 3F-15 depict the single channel sensitivity to component changes in each SCRAM circuit feeding into the main SCRAM gate. The table lists only those components which contribute <u>significant</u> changes to the system sensitivity. The

TABLE 3F-4

RELIABILITY VALUES FOR ST. VRAIN

PROTECTIVE SYSTEM CIRCUITS EVALUATED IN PHASE I

	SENSOR CIRCUIT	[2] SINGLE CHANNEL			[3] SCRAM BRAKE FAILURE
		PREMATURE	[1] SUCCESS (30 DAY TEST)	[2] FAILURE (30 DAY TEST)	
1	Reactor Bldg Temp (1806)	.00238	.97167	.02595	$2.4x10^{-7}$
2	Reheat Steam Temp (1803)	.00306	.96549	.03145	$3.6x10^{-7}$
3	(1) Superheat Stm Press, Low (1794)	.00127	.98230	.01643	$8.1x10^{-4}$
4	(1) Reheat Stm Press, Low (1797)	.00127	.98230	.01643	$8.1x10^{-4}$
5	(1) Undervolt Switch (1800)	.00454	.98019	.01527	$7.0x10^{-4}$
6	Core Inlet Temp (1242,1238)	.00144	.97218	.02638	$2.5x10^{-7}$
7	Reactor Pressure (1813, 1810) (Hi & Lo)	.00100	.97600	.02300	$1.9x10^{-7}$
	(TLT Input-Low)(841, 842)	.00028	.96934	.03038	--
8	Start-up Channels (5785)	.01555	.95875	.02570	$3.1x10^{-6}$
9	Wide Range Rate	.00842	.94384	.04774	$8.2x10^{-7}$
10	Wide Range Flux (5832)	.00785	.93815	.05400	$1.05x10^{-6}$
11	Linear Range Flux (5828)	.00641	.94053	.05306	$1.02x10^{-6}$
12	Two Loop Trouble	Dependent on Circuits Tripped		(See Table 3F-16)	

Human Error Reliability: .001 Mean: .0316

NOTE: Number in brackets after each sensor name indicates the GO model signal number for that output.

1 Checked monthly rather than daily.

2 Failure probabilities listed pertain only to the input to the main SCRAM gate for one channel of the three independent SCRAM channels. Furthermore, the failure probabilities listed are maximum and do not give credit for 'overt' type failures which may be subsequently repaired and returned to service during the 30-day period.

3 SCRAM brake release failure probabilities are adjusted for daily checking and for input to all three SCRAM channels.

reliability values of all other components were found to be relatively insensitive as far as generation of the SCRAM signal is concerned. The failure contributions from each component in the single channel sensitivity listings are based on a 720 hour interval between tests and do not account for daily checks. This does not change the relative sensitivities but does influence the maximum contributions from each component. It will be noted that in almost every case the component contributing the maximum unreliability is the Bin Power Supply. Since loss of power will trip the bistable output in every case, this component failure can be considered to be overt and will contribute more to spurious trips than to SCRAM failure, i.e., the covert failures can be estimated by subtracting the sum of all annunciated and alarmed failure probabilities from the total of the maximum contributions in the sensitivity tables.

Table 3F-4B depicts the current inspection/test frequency for each of the main SCRAM system variables.

TABLE 3F-4B

INSPECTION/TEST FREQUENCY

	MAIN SCRAM VARIABLE	Inspect (Hr)	Test (Days)	Calib.
1	Manual Trip (Control Room) (I-49)	None (None)	R (30)	None (None)
2	Start-up Channels	8	P	R
3	Linear Power Channels	8	30	8 hrs
4	Wide Range Channels	8	P	30 days + P
5	Reheat Steam Temperature	8	30	R
6	Reactor Pressure High (Primary Coolant)	8	30	R
7	Reactor Pressure Low (Primary Coolant)	8	30	R
8	Reheat Steam Pressure (Lo)	None	30	R
9	Superheat Steam Pressure (lo)	None	30	R
10	Undervoltage Switch	None	30	None
11	Reactor Building Temperature (Hi)	8	30	R
12	Two Loop Trouble		(See Page 44)	

R = each refueling cycle.

P = Prior to each start-up.

TABLE 3F-5

SYSTEM SENSITIVITY

REACTOR BUILDING TEMPERATURE (SN1806)

COMPONENT		TYPE/KIND	SINGLE CHANNEL FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply	(A)	1-60	.0063	2.0	.0126
*Bistable Trip Unit	(A)	6-210	.004	1.0	.0040
*Bus Supply	(A)	--	.0048	1.0	.0048
Connector/Pins		1-3	.00004	16.0	.00004
*Thermocouple Amplifier	(C)	6-207	.0015	1.0	.0015
*Test/Operate Switch (N/O)	(N)	6-202	.0003	5.0	.0003
*Thermocouple	(C)	1-17	.0007	1.0	.0007
*Switch Spring-loaded (N/C)	(N)	7-305	.0003	3.0	.0003
Logic Invertor		6-214	.0002	1.0 SCRAM Fail. (2.0 Alarm Failure)	.0002
Mechanical/Human Interface		1-65	0.001	1.0	.0010

Checked: Daily
Tested: Monthly

* Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift. Failures of these components usually result in spurious trips or deliberate trips when the module is removed for repair.

TABLE 3F-5 (Continued)

COMPONENT		TYPE/KIND	SINGLE CHANNEL PREMATURES (Spurious Trips) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
* Bistable Trip Unit	(A)	6-210	.004	1.0	.0040
Human/Operator		(11-35) (11-36)	.001	2.0	.0020
* T/C Amplifier	(C)	6-207	.004	1.0	.0040
* Test/Operate Switch (N/O)	(N)	6-202	.00004	5.0	.0002
Logic Invertor		6-214	.0001	1.0	.0001
* Switch, Spring-loaded (N/C)	(N)	7-305	.00004	3.0	.00012
Connector/Pins (Power Interlock)		1-3	0.0 0004	6.0	.00024

* Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

TABLE 3F-6

SYSTEM SENSITIVITY

REHEAT STEAM TEMPERATURE (SN1803)

COMPONENT		TYPE/KIND	SINGLE CHANNEL FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply	(A)	1-60	.0063	2.0	.0126
*Bistable Trip Unit	(A)	6-210	.004	1.0	.0040
*Bus Supply	(A)	--	.0048	1.0	.0048
*Auctioneer	(C)	6-208	.006	1.0	.0060
Connector/Pins		1-3	.00004	10.0	.0004
*Thermocouple	(C)	1-17	.0007	2.0	.0014
*Switch, Spring loaded (N/O)	(N)	6-202	.0003	3.0	.0009
Logic Invertor		6-214	.0002	1.0	.0002
*Switch, Spring-loaded (N/C)	(N)	7-305	.0003	1.0	.0003
Mechanical/Human Interface		1-65	0.001	2.0	.0020

Checked: Daily
Tested: Monthly

* Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

TABLE 3F-6 (Continued)

COMPONENT		TYPE/KIND	SINGLE CHANNEL PREMATURES (Spurious SCRAMS) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator		11-45 11-46, 11-47	.001	3.0	.0030
*Bistable Trip Unit	(A)	6-210	.004	1.0	.0040
*Auctioneer	(C)	6-208	.001	1.0	.0010
Connector/Pins (Power Interlock)		1-3	.00004	5.	.0002
*Switch, Spring-loaded (N/O)	(N)	6-202	.00004	3.0	.00012
Logic Invertor		6-214	.0001	1.0	.0001
*Switch, Spring-loaded (N/C)	(N)	7-305	.00004	1.0	.00004

*Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

TABLE 3F-7

SYSTEM SENSITIVITY

SUPERHEAT STEAM LOW PRESSURE (SN 1794)

COMPONENT		TYPE/KIND	SINGLE CHANNEL FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply	(A)	1-60	.0063	2.0	.0126
*Bus Power	(A)	---	.0048	1.0	.0048
Conn./pins		1-3	.00004	7.0	.00028
Switch Input Module		3-111	.0002	1.0	.0002
Pressure Switch		6-237	.002	1.0	.0020
Logic Invertor		6-214	.0002	1.0	.0002
*Switch, Spring-loaded (N/O)	(N)	6-202	.0003	1.0	.0003
Relay Contacts (N/O)		6-203	.00007	1.0	.00007
Mechanical/Human Interface		1-65	0.001	1.0	.0010

Checked: Monthly
Tested: Monthly

* Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

TABLE 3F-7 (CONTINUED)

COMPONENT	TYPE/KIND	SINGLE CHANNEL PREMATURES (Spurious SCRAMS) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator Test & Maint.	11-42	.001	1.0	.0010
Connector/Pins (Power Interlock)	1-3	.00004	4.0	.00016
Pressure Switch	6-237	.0007	1.0	.0007
Logic Invertor	6-214	.00011	1.0	.0001
* Switch, Spring-loaded (N/O) (N)	6-202	.00004	1.0	.00004
Relay Contacts (N/O)	6-203	.0001	1.0	.0001
Switch Input Module	3-111	0.0001	1.0	.0001

*Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

TABLE 3F-8

SYSTEM SENSITIVITY

REHEAT STEAM LOW PRESSURE (SN 1797)

COMPONENT	TYPE/KIND	SINGLE CHANNEL FAILURES		
		PROBABILITY	SENSITIVITY	MAX. CONTRIB.
* Bin Power Supply (A)	1-60	.0063	2.0	.0126
* Bus Power (A)	---	.0048	1.0	.0048
Connector/Pins	1-3	.00004	7.0	.00028
Switch Input Module	3-111	.0002	1.0	.0002
Pressure Switch	6-237	.002	1.0	.0020
Logic Invertor	6-214	.0002	1.0	.0002
Switch, Spring-loaded, (N/O)	6-202	.0003	1.0	.0003
Relay Contacts (N/O)	6-203	.00007	1.0	.00007
Mechanical/Human Interface	1-65	0.001	1.0	.0010

Checked: Monthly
Tested: Monthly

*Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

TABLE 3F-8 (CONTINUED)

COMPONENT	TYPE/KIND	SINGLE CHANNEL PREMATURES (Spurious SCRAMS) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator Test & Maint.	11-43	.001	1.0	.0010
Connector/Pins (Power Interlock)	1-3	.00004	4.0	.00016
Pressure Switch	6-237	.0007	1.0	.0007
Logic Invertor	6-214	.0001	1.0	.0001
Switch, Spring-loaded (N/O)	6-202	.00004	1.0	.00004
Relay Contacts (N/O)	6-203	.0001	1.0	.0001
Switch Input Module	3-111	0.0001	1.0	.0001

TABLE 3F-9

SYSTEM SENSITIVITY

UNDERVOLTAGE SWITCH (1800)

COMPONENT		TYPE/KIND	SINGLE CHANNEL FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
* Bin Power Supply	(A)	1-60	.0063	2.0	.0126
* Bus Power	(A)	--	.0048	1.0	.0048
Undervolt Timer (30 sec.)		3-120	.002	1.0	.0020
Connector Pins		1-3	.00004	6.0	.00024
Switch Input Module		3-111	.0002	1.0	.0002
Logic Invertor		6-214	.0002	1.0	.0002
* Switch, Spring-loaded (N/O)	(N)	6-202	.0003	1.0	.0003
Electric/Human Interface		1-75	0.001	0.0	.0010

Checked: Monthly
Tested: Monthly

*Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

TABLE 3F-9 (CONTINUED)

COMPONENT		TYPE/KIND	SINGLE CHANNEL PREMATURES		
			PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Undervolt Timer		3-120	.001	1.0	.0010
Human/Operator Test & Maint.		11-44	.001	1.0	.0010
Connector Pins		1-3	.00004	4.0	.00016
Switch Input Module		3-111	.0001	1.0	.0001
Logic Invertor		6-214	.0001	1.0	.0001
*Switch Spring-loaded (N/O)	(N)	6-202	.00004	1.0	.00004

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hour shift.

TABLE 3F-10

SYSTEM SENSITIVITY

START/UP CHANNEL (NUCLEAR), (5785)
(Both Sensors and Electronics)

COMPONENT	TYPE/KIND	SINGLE CHANNEL FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
* Bin Power Supply (A)	1-60	.0063	2.0	.0126
Low Volt Power Supply (A)/(N)	1-2	.0004	2.0	.0008
* Board Interlock (A)	1-4	.00004	7.0	.00028
Connector Pins	1-3	.00004	15.0	.00060
Human Test/Operator Switch (N)	11-51 11-59	.001	2.0	.0020
* Fuse (A)	1-1	.00007	2.0	.00014
Logic NAND	6-215	.0002	2.0	.0004
Capacitor	1-10	.0001	2.0	.0002
Human/Mechanical Interface	1-65	0.001	2.0	.0020

Checked: Daily

Tested: Prior to each startup

* Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

TABLE 3F-10 (CONTINUED)

COMPONENT	TYPE/KIND	*PROBABILITY	SENSITIVITY	MAX. CONTRIB.
		SINGLE CHANNEL PREMATURES (Spurious SCRAMS)		
*Bistable Trip Unit (A)	3-106	.004	2.0	.0080
*Linear Amplifier (C)	3-101	.001	2.0	.0020
*Nuclear Preamp (C)	3-103	.001	2.0	.0020
Human Test/Operator Function	11-58 11-60	.001	2.0	.0020
Logic NAND Gate	6-215	.0001	4.0	.0004
Connector Pins	1-3	.00004	2.0	.00008
*Rotary Switch (N)	6-204	.00007	2.0	.00014
Relay Contacts	6-203	.0001	2.0	.0002

TABLE 3F-11

SYSTEM SENSITIVITY

WIDE RANGE PERIOD (5824)

COMPONENT	TYPE/KIND	*PROBABILITY	SENSITIVITY	MAX. CONTRIB.
		SINGLE CHANNEL FAILURES		
*Bin Power Supply (A)	1-60	.0063	2.0	.0126
High Volt *Power Supply (C)	1-5	.0006	1.0	.0006
*Low Volt Power Supply (A)	1-2	.0004	2.0	.0008
*Nuclear Detector (Ion Chamber) (C)	1-6	.001	1.0	.0010
*Bistable Trip Unit (A)	3-106	.005	1.0	.0050
*Board Interlock (A)	1-4	.00004	9.0	.00036
Coax/Jacks	1-8	.0004	7.0	.0028
Connector/ Pins	1-3	.00004	17.0	.00068
*Nuclear Preamp (C)	3-103	.002	1.0	.0020
*Linear Amplifier (C)	3-101	.002	1.0	.0020
Rotary Switch (N/O) (N)	6-204	.0003	5.0	.0015
*Human Test/ Operator Function (N)	11-48 11-49	.001	2.0	.0020
*Fuse (A)	1-1	.00007	2.0	.00014
Logic NAND Gate	6-215	.0002	1.0	.0002
Capacitors	1-10	.0001	2.0	.0002

*Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

Checked: Daily
Tested: Prior to each startup

TABLE 3F-11 (CONTINUED)

COMPONENT	TYPE/KIND	SINGLE CHANNEL PREMATURES (Spurious SCRAMS)		
		*PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bistable Trip Unit (A)	3-106	.004	1.0	.0040
Human Test/ Operator Function	11-53 11-54	.001	2.0	.0020
*Nuclear Preamp (C)	3-103	.001	1.0	.0010
*Linear Amplifier (C)	3-101	.001	1.0	.0010
Connector/ Pins	1-3	.00004	2.0	.00008
Logic NAND Gate	6-215	.0001	1.0	.0001
Relay Contacts (N/O	6-203	.0001	2.0	.0002

TABLE 3F-12

SYSTEM SENSITIVITY
LINEAR RANGE FLUX LEVEL

COMPONENT	TYPE/ KIND	SINGLE CHANNEL FAILURES PROB-ABILITY	SENSI-TIVITY	MAX. CONTRIB.
*Bin Power Supply (A)	1-60	.0063	2.0	.0126
*Low Volt Pwr Supply (A)	1-2	.0004	4.0	.0016
*Nuclear Detector (Ion Chamber) (C)	1-6	.001	1.0	.0010
*High Volt Pwr Supply (A)	1-5	.0006	1.0	.0006
*Bi-Stable Trip Unit (A)	3-106	.005	1.0	.0050
Coax/Jacks	1-8	.0004	8.0	.0032
*Linear Amp (C)	3-101	.003	1.0	.0020
*Fuse (A)	1-1	.00007	4.0	.00028
Conn/Pins	1-3	.00004	7.0	.00028
*Board Interlock (A)	1-4	.00004	2.0	.00008
*Human Test/Operator Function (N)	11-64	.001	1.0	.0010
Toggle Switch (N/O)	6-201	.0003	2.0	.0006
Capacitors	1-10	.0001	4.0	.0004
*Rotary Switch (N/O) (N)	6-204	.0003	1.0	.0003
Logic NAND Gate	6-215	.0002	1.0	.0002

		SINGLE CHANNEL PREMATURES (Spurious SCRAMS)		
*Bi-Stable Trip Unit (A)	3-106	.004	1.0	.0040
*Linear Amp (C)	3-101	.001	1.0	.0010
Human Test/Operator Function	11-65 11-66	.001	1.0	.0010
Conn/Pins	1-3	.00004	2.0	.00008
Relay Contacts (N/O)	6-203	.0001	2.0	.0002
Logic NAND Gate	6-215	.0001	1.0	.0001
*Rotary Switch (N/O) (N)	6-204	.00007	1.0	.00007

*Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

Checked: Daily
Tested: Monthly

TABLE 3F-13

SYSTEM SENSITIVITY

WIDE RANGE FLUX LEVEL

COMPONENT	TYPE/ KIND	SINGLE CHANNEL FAILURES		
		PROB-ABILITY	SENSI-TIVITY	MAX. CONTRIB.
* Bin Power Supply (A)	1-60	.0063	2.0	.0126
* Low Volt Pwr Supply (A)	1-2	.0004	4.0	.0016
* Bi-Stable Trip Unit (A)	3-106	.005	2.0	.0100
* High Volt Pwr Supply (C)	1-5	.0006	1.0	.0006
* Nuclear Detec (Ion Cham) (C)	1-6	.001	1.0	.0010
Coax/Jacks	1-8	.0004	9.0	.0036
* Linear Amp (C)	3-101	.002	1.0	.0020
* Nuc. Preamp (C)	3-103	.002	1.0	.0020
Conn/Pins	1-3	.00004	11.0	.00044
* Fuse (A)	1-1	.00007	4.0	.00027
* Board Interlock (A)	1-4	.00004	2.0	.00008
* Human Test/Operator Function (N)	11-50	.001	1.0	.0010
Toggle Switch (N/O)	6-201	.0003	2.0	.0006
Capacitors	1-10	.0001	4.0	.0004
* Rotary Switch (N/O) (N)	6-204	.0003	1.0	.0003
Logic NAND Gate	6-215	.0002	1.0	.0002

COMPONENT	TYPE/ KIND	SINGLE CHANNEL PREMATURES (Spurious SCRAMS)		
* Bi-Stable Trip Unit (A)	3-106	.004	1.0	.0040
* Linear Amp (C)	3-101	.001	1.0	.0010
* Nuc. Preamp (C)	3-103	.001	1.0	.0010
Human Test/Operator Function	11-61 11-63	.001	1.0	.0010
Conn/Pins	1-3	.00004	2.0	.00008
Relay Contacts	6-203	.0001	2.0	.0002
Logic NAND CKT	6-215	.0001	1.0	.0001
* Rotary Switch (N/O)(N)	6-204	.00007	1.0	.00007

*Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

Checked: Daily
Tested: Prior to each startup

TABLE 3F-14

SYSTEM SENSITIVITY

CORE INLET TEMP. MODULE (1141, 1142, 1143)

COMPONENT	TYPE/ KIND	SINGLE CHANNEL FAILURES PROB-ABILITY	SENSI-TIVITY	MAX. CONTRIB.
* Bin Power Supply (A)	1-60	.0063	2.0	.0126
* Auctioneer (C)	6-208	.006	1.0	.0060
* Summer Amp (C)	6-209	.006	1.0	.0060
* Bus Power (A)		.0048	1.0	.0048
* Human Test/Operator Function (N)	11-27, 11-29,11-31 11-32,11-33	.001	3.0	.0030
* Switch, Spring Loaded (N/O) (N)	6-202	.0003	2.0	.0006
Conn/Pins	1-3	.00004	5.0	.0002
Human/Mech Inter	1-65	0.001	1.0	.0010

		SINGLE CHANNEL PREMATURES (Spurious SCRAMS)		
Human Test/Operator Function	11-27, 11-29,11-31 11-32,11-33	.001	3.0	.0030
* Auctioneer (C)	6-208	.001	1.0	.0010
* Summer Amp (C)	6-209	.001	1.0	.0010
* Switch, Spring Loaded (N/C) (N)	7-305	.00004	3.0	.00012
* Switch, Spring Loaded (N/O) (N)	6-202	.00004	2.0	.00008

*Components that are alarmed (A), annunciated (N), or checked (C) every 8 hour shift.

Checked: Daily
Tested: Monthly

TABLE 3F-15

SYSTEM SENSITIVITY

REACTOR PRESSURE (PRIM. COOLANT) (1810, 1813)

COMPONENT	TYPE/KIND	SINGLE CHANNEL FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
* Bin Power Supply (A)	1-60	.0063	2.0	.0126
* Bus Power (A)	--	.0048	1.0	.0048
* Bistable Trip (A) Unit	6-210	.004	1.0	.0040
* Human Test/Operator Function (N)	11-40 11-41 11-38	.001	2.0	.0020
* Switch, Spring-loaded (N/O) (N)	6-202	.0003	4.0	.0012
Connector/Pins	1-3	.00004	9.0	.00036
* Pressure Transducer (C)	1-19	.0004	1.0	.0004
* Pressure Amp (AGP-1) (C)	6-211	.006	1.0	.0060
Logic NAND Gate	6-215	.0002	1.0	.0002
* Fuse (A)	1-1	.00007	1.0	.00007
Human/Mechanical Interface	1-65	.001	1.0	.0010
		SINGLE CHANNEL PREMATURES (Spurious SCRAMS)		
* Bistable Trip Unit (A)	6-210	.004	1.0	.0040
Human Test/Operator Function	--	.001	3.0	.0030
* Pressure AMP (C)	6-211	.001	1.0	.0010
Logic NAND Ckt.	6-215	.0001	2.0	.0002
Connector Pins	1-3	.00004	6.0	.00024
Switch, Spring-loaded (N/O)	6-202	.00004	4.0	.00016
Switch, Spring-loaded (N/C)	7-305	.00004	4.0	.00016

Checked: Daily
Tested: Monthly

* Components that are alarmed (A), annunciated (N), or checked (C), every 8 hour shift.

4.0 Worst Case Reliability (Two Loop Trouble Circuits)

Table 3F-16A tabulates the maximum, single loop unreliability values at the end of 30 days for all of the main sensor circuits feeding inputs to the Two Loop Trouble (TLT) output circuit except for Circulator Trip. The single loop, thirty day mean value is 1.1×10^{-2}. The Circulator Trip outputs are covered in section 3F-5, pages 53 - 65. Table 3F-16A also lists single loop shutdown failures and Two Loop SCRAM brake failures adjusted for daily checking where appropriate.

Each sensor circuit in the TLT system has two lines going to the TLT SCRAM output. Loop 1 and loop 2 sensors each feed into an 'A' logic and 'B' logic circuit to satisfy single failure criterion. A loop shutdown is initiated in both logic 'A' and logic 'B' circuits whenever trouble is sensed in either loop. The shutdown is inhibited if one of the loops has been previously shutdown. (See overview Figure 2-2, or detailed logic drawings FSV-12E and G.) In addition, each of the four logic lines are fanned to the SCRAM channels A, B and C. To obtain a trip in any of the three SCRAM channels requires a signal from both loop 1 and loop 2 outputs and from either the A or B logic lines; i.e.:

Loop 1, Logic A and Loop 2, Logic A
or, Loop 1, Logic A and Loop 2, Logic B
or, Loop 1, Logic B and Loop 2, Logic A
or, Loop 1, Logic B and Loop 2, Logic B.

Since each of the sensors provide input to A and B logic, this dependency neutralizes any reduction in failure probability due to OR gating of the two logics but does reduce the effect of component failure in either logic. Similarly, the SCRAM requirement for trips from both loops effectively doubles the TLT single loop output failure probability.

From these relationships, we can obtain the failure equations which provide an estimate of the two loop SCRAM failure probability at the output of the TLT SCRAM circuits whenever a <u>single</u> TLT sensor variable is involved.

TABLE 3F-16A

RELIABILITY VALUES FOR TWO LOOP TROUBLE SENSING CIRCUITS IN THE SCRAM PROTECTIVE SYSTEM

SENSOR CIRCUIT (SIG #)	(1) SINGLE LOOP (SPURIOUS TRIPS) PREMATURE	SINGLE LOOP MIN. TRIP DEMAND	SINGLE LOOP MAX. FAILURE 30 DAY TEST	(4) SINGLE LOOP SHUTDOWN FAILURE (MAX)	(5) TWO LOOP SCRAM BRAKE FAILURE (MAX)
1. Steam Generator (2584,2592) Penetration Overpressure	Negl.	.9831	.0169	$1.69x10^{-2}$	$3.38x10^{-2}$
2. (2) Steam Pipe Rupture (3148,3151)	.0005	.9888	.0107	$1.07x10^{-2}$	$2.14x10^{-2}$
3. (3) Moisture Detection (1851,1852, Monitor 2518,2519,2530,2531)	.1779	.8121	.0100	$1.00x10^{-2}$	$2.00x10^{-2}$
4. Reactor Pressure (3182,3185)(Low)	.0012	.9879	.0110	$1.21x10^{-4}$	$2.42x10^{-4}$
5. Superheat Header (2353) Temperature (Low)	.0002	.9917	.0081	$8.9x10^{-5}$	$1.78x10^{-4}$
6. Reheat Header (2183) Activity (High)	Negl.	.9966	.0034	$3.7x10^{-5}$	$7.4x10^{-5}$
7. Circulator Trip	(See Section 3F-5)				
			Mean:	.0110	

(1) Based on 720 hour test intervals and human error reliability of .001. Failure probabilities listed pertain only to values for a single loop and single logic. The Two Loop combinatorial output logic has not been included in this Table. Furthermore, the failure probabilities listed are maximum and do not generally give credit for 'overt' type failures which may be subsequently repaired and returned to service during the 30-day period.

(2) Sensor Circuit is passed through a first-in-with lockout circuit.

(3) Nominal moisture monitor electronics reliability = .92. Failure Detector Efficiency: 0.80

(4) Maximum single loop shutdown failure probabilities adjusted for daily checking where applicable.

(5) Maximum two loop SCRAM brake release failure probabilities adjusted for daily checking. If one loop is down SCRAM failure probabilities can be halved. (The Two Loop Combinatorial output logic has been included in the latter column).

If Q = failure probability at output of the TLT SCRAM line for a 30 day test/inspection interval.

and p = probability of a failure at the end of a 30-day interval for any of the TLT input lines (sensor lines), we have

$$Q = 2p-p^2$$

and $Q \simeq 2p$, if $p \ll$ unity.

Using this approximation, the mean single loop TLT SCRAM failure probability at the end of 30 days for a SCRAM signal from a single TLT variable is 2.2×10^{-2}. For those parameters which are checked every shift, an improvement factor of $1.1 \cdot 10^{-2}$ can be assumed.

The mean value includes the Moisture Monitor Detection system. It should be noted that the basic electronics package for the moisture monitor system has an MTBF, quoted by GAC, of one year or an unreliability of about 10%. This is a magnitude higher than corresponding values for most of the other SCRAM protection system variables. However, the reliability of this system has been improved by designing a failure detection circuit into the electronics package. The failure detection circuit is designed to detect 60 - 90% of all failures which might occur in the electronics package. When a failure is detected, the system is either tripped or alarmed, thus providing a fail-safe or status-alert function. For purposes of this analysis, the total reliability of the moisture monitor electronics package was assumed to be .92, with a failure detector circuit efficiency of 80%. If the power supply fails in the moisture monitor system, a premature trip is initiated. The probability of the moisture monitor system failing with this fail-safe power supply and no allowance for Human Interfaces is approximately 2×10^{-3}.

Table 3F-16B presents a list of the inspection/test frequencies for each of the two loop trouble sensor circuits.

TABLE 3F-16B Sensor	TLT INSPECTION/TEST FREQUENCY Visible Check	 Circuit Test
1. Steam Generator Penetration Overpressure	Monthly	Monthly
2. Steam Pipe Rupture Detection		
Ultrasonic Detector:	Daily	Monthly
Pressure Detector:	--	Monthly
Temperature Detector:	--	Monthly
3. Moisture Detection		
Mirror Temperature:	Daily	--
Reflected Light Level:		Monthly
Moisture Injection	--	Refueling
4. Superheat header temp. (low)	Daily	Monthly
5. Reactor Pressure (low)	Daily	Monthly
6. Reheat Header Activity (high)	Daily	Monthly
7. Circulator Trip	(See Page 55)	

4.1 Sensitivity (Two Loop Trouble Circuits)

Tables 3F-17 through 3F-23 present the single loop sensitivity of the TLT output circuit to each of the six input sensor circuits. The failure contributions from each component in the single loop, single logic sensitivity listings were based on a 720 hour interval between tests and do not account for daily checks. This does not change the relative component sensitivities but does influence the values for the maximum contributions from each component. It will be noted that in almost every case, the component contributing the maximum unreliability is the Bin Power Supply. Since loss of power will trip the bistable output in every case, this component failure can be considered to be overt and will contribute more to spurious trips than to SCRAM failures, i.e., the covert failures can be estimated by subtracting the sum of all annunciated and alarmed failure probabilities from the total of the maximum contributions in the sensitivity tables.

TABLE 3F-17

SYSTEM SENSITIVITY

STEAM GENERATOR PENETRATION OVERPRESSURE (2584)

COMPONENT	TYPE/KIND	SINGLE LOOP FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply (N) & Essen Bus	1-60	.0111	1.0	.0111
Logic NAND Gate	6-215	.0002	1.0	.0002

COMPONENT	TYPE/KIND	SINGLE LOOP PREMATURES (Spurious Trips) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human Test/Operator Function (Not depicted)		.001	1.0	.0010
Logic Invertor	2-214	.0001	1.0	.0001

Inspected: ________

Tested: Monthly

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

TABLE 3F-18

SYSTEM SENSITIVITY

STEAM PIPE RUPTURE (3148)

COMPONENT	TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
		SINGLE LOOP FAILURES		
* Bin Power Supply (N) & Essen. Bus	1-60	.0111	1.0	.0111
First In With Lockout	1-22	.004	1.0	.0040
Logic NAND Gate	6-215	.0002	3.0	.0006
Logic Invertor	6-214	.0002	1.0	.0002
Connector/Pins	1-3	.00004	1.0	.00004
		SINGLE LOOP PREMATURES (Spurious Trips)		
Human Test/Operator Function (Not Depicted)		.001	1.0	.0010
Logic NAND Gate	6-215	.0001	1.0	.0001

	Noise	Press.&Temp.
Inspected	Daily	Monthly
and Tested	Monthly	Monthly

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

TABLE 3F-19

SYSTEM SENSITIVITY

MOISTURE MONITOR DETECTION SYSTEM (2030, 2531, 1851)

Low Level + One High SCRAM		Dual Loop Failures (SCRAM)		
Component	Type/Kind	Probability	Sensitivity	Max. Contrib.
* Power Supply	1-60 A,N	.0111	.88	.00977
Human Interface (Test)	1-65	.001	1.0	.0010
Human Interface (Calib)	1-75	.001	1.0	.0010
'NAND' Logic	6-215	.0002	2.26	.00045
Fail Detec	3-136 A,N	.18	.008	.00140
FILO	1-22	.004	.033	.00013
		Dual Loop Prematures (Spurious Trips)		
Invertor Logic	6-214	.0001	.19	.00019
'NAND' Logic	6-215	.0001	0.93	.00093
Moisture Mon	1-21	.08	.006	.00048
Fail Detec	3-136	.02	.31	.0062

* Power supply failure will trip circuit making this failure a spurious trip. Probability of SCRAM signal from two-out-of-three low level and one high level monitor failing with perfect power supplies from human interfaces is approximately: 2×10^{-3}.

Moisture monitor system includes failure detection circuits on all monitors.

Inspected: Daily
(Mirror temp. only)

Tested: Monthly

TABLE 3F-20

SYSTEM SENSITIVITY

MOISTURE MONITOR DETECTION SYSTEM (1851)

High Level SCRAM Only		Dual Loop Failures (SCRAM)		
Component	Type/Kind	Probability	Sensitivity	Max. Contrib.
* Power Supply	1-60	.0111	3.0	.0333
Conn/Pins	1-3	.00004	3.0	.00012
NAND Logic	6-215	.0002	1.0	.0002
Invertor Logic	6-214	.0002	2.0	.0004
Fail Detec	3-136	.18	.05	.0090
Human Interfaces	1-65	.001	2.0	.0020
Human Interfaces	1-75	.001	2.0	.0020
		Dual Loop Prematures		
NAND Logic	6-215	.0001	1.0	.0001
Moisture Monitor	1-21	.08	0.1	.008
Fail Detec	3-136	.02	.13	.0026

NOTE: Probability of SCRAM signal from two high level sensors failing with perfect power supplies and human interfaces is approximately 1×10^{-2}.

Inspected: Daily (Mirror temp only)

Tested: Monthly

* Power supply failure will trip annunciator and alarms; hence, this failure can be counted as a spurious trip when detected.

TABLE 3F-21

SYSTEM SENSITIVITY

REACTOR PRESSURE, LOW, TLT (3166)

COMPONENT	TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
		SINGLE LOOP FAILURES		
* Bin Power Supply (N) & Essen Bus	1-60	.0111	1.0	.0111
Human Operator Inhibit	11-72	.001	1.0	.0010
Logic Invertor	6-214	.0002	3.0	.0006
Logic NAND Gate	6-215	.0002	2.0	.0004
		SINGLE LOOP PREMATURES (Spurious Trips)		
Logic NAND Gate	6-215	.0001	5.0	.0005
Logic Invertor	6-214	.0001	5.0	.0005

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

Inspected: Daily
Tested: Monthly

TABLE 3F-22

SYSTEM SENSITIVITY

SUPERHEAT HEADER TEMPERATURE, LOW (2341)

COMPONENT	TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
		SINGLE LOOP FAILURES		
* Bin Power Supply (N) & Essen Bus	1-60	.0111	1.0	.0111
Human/Operator Inhibit	11-35	.001	1.0	.0010
Logic NAND Gate	6-215	.0002	3.0	.0006
Logic Invertor	6-214	.0002	2.0	.0004
		SINGLE LOOP PREMATURES (Spurious Trips)		
Logic NAND Gate	6-215	.0001	1.0	.0001

Inspected: Daily

Tested: Monthly

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

TABLE 3F-23

SYSTEM SENSITIVITY

REHEAT HEADER ACTIVITY, HIGH (2111)

COMPONENT	TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
		SINGLE LOOP FAILURES		
*Bin Power Supply (N) & Essen Bus	1-60	.0111	2.0	.0222
Logic NAND Gate	6-215	.0002	1.0	.0002
		SINGLE LOOP PREMATURES (Spurious Trips)		
Human Operator/Test	---	.001	2.0	.0020

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

Inspected: Daily
Tested: Monthly

TABLE 3F-23B

SYSTEM SENSITIVITY

TWO LOOP TROUBLE COMBINATORIAL

OUTPUT LOGIC (5355)

Component	Type/Kind	TWO LOOP FAILURE Probability	Sensitivity	Max. Contrib.
* Bin Power Supply (A,N) & Essen Bus	1-60	.0111	3.0	.0333
Logic NAND	6-215	.0002	3.0	.0006

* (A,N) Failure of the two loop trouble output power supplies will initiate a single channel trip into the Main SCRAM Bus, thus making failure of this component an overt event.

Since the two loop trouble output circuit may be used for scheduled testing of TLT parameters at least once per week, the estimated failure probabilities for the logic NAND component may be reduced by a factor of about 4.

5.0 Maximum Unreliability (Circulator Trip)

Table 3F-24A tabulates the maximum single loop, unreliability values at the end of 30 days for each of the ten sensor circuits feeding inputs to the circulator trip output logic.

The mean single loop, single logic, thirty day probability of failure is .0175. The circulator trip inputs usually originate from of of two circulators in each loop. When these lines are expanded to include A and B signal logic, we end up with eight output lines for each trip circuit. Two of the lines represent logic A from the first two circulators in loop 1. The next two lines represent logic B for the same two circulators. The remaining four lines are split in similar fashion to provide corresponding output logic in the second loop.

A circulator trip for shutdown is generated by either the logic A or logic B line from each circulator. However, for SCRAM purposes, a trip signal is generated whenever one loop is down and trouble signals are sensed in each of the two remaining circulators of the operating loop, or alternatively, whenever trouble is sensed in all four circulators.

From the SCRAM requirement we can calculate from failure equations that the average failure probability for any SCRAM initiating pair of signals at the circulator trip output will approach a value of 3.5×10^{-2}, e.g., $Q \approx 2P$, where P = 30 day probability of not receiving a SCRAM signal at the circulator trip output based on a 30 day inspection/test interval.

[1] TABLE 3F-24A

RELIABILITY VALUES FOR CIRCULATOR TRIP SENSING CIRCUITS IN THE ST. VRAIN SCRAM PROTECTIVE SYSTEM

SENSOR CIRCUIT	OR #	SINGLE LOOP, SINGLE LOGIC: Premature (Spurious Trips)	Min. Trip Demand	* Max. Failure	[2] Circulator Trip Failure (Max.)	[3] SCRAM Brake Failure (Max.)
Reheat Header Activity, High	(6)	.0004	.9768	.0228	2.5×10^{-4}	5.0×10^{-4}
Circulator Drain Malfunction	(9)	.0006	.9898	.0096	1.0×10^{-4}	2.1×10^{-4}
Circulator Penetration Pressure, High	(1)	.0009	.9890	.0101	1.0×10^{-2}	2.0×10^{-2}
Circulator Overspeed	(2)	.0005	.9741	.0254	2.8×10^{-4}	3.4×10^{-4}
Circulator Low Speed (Prog. by FWF)	(3)	.0005	.9729	.0266	2.9×10^{-4}	5.8×10^{-4}
Feedwater Low Flow (Prog. by Circ. Speed)	(5)	.0006	.9808	.0186	2.0×10^{-4}	4.1×10^{-4}
Loss Circ. Bearing Water	(7)	.0017	.9820	.0163	1.8×10^{-4}	3.6×10^{-4}
Low Fixed Feedwater Flow Trip	(8)	.0009	.9894	.0097	1.1×10^{-4}	2.1×10^{-4}
Manual Trip	(4)	.0005	.9883	.0112	1.1×10^{-2}	2.2×10^{-2}
Circulator Seal Malfunction	(7)	.0029	.9728	.0243	2.7×10^{-4}	5.3×10^{-4}
			Mean:	.0175		

(1) Based on 720 hour test intervals and human test reliability of .999.

(2) Maximum circ. trip failure probability adjusted for daily checking where appropriate.

(3) Maximum SCRAM brake release failures adjusted for daily checking where appropriate.

*Failure probabilities listed in this column apply to values for a single loop and single logic. The circulator trip combinatorial output logic is not included. Furthermore, the failure probabilities listed are maximum and do not generally give credit for 'overt' type failures which may be subsequently repaired and returned to service during the 30 day period.

Since most of the circulator trip inputs are inspected visually on a daily shift basis, the estimated failure rate for the sensors checked daily can be lowered by a factor of $1.1 \cdot 10^{-2}$.

Table 3F-24B depicts the inspection/test interval for each of the circulator trip inputs.

TABLE 3F-24B

CIRCULATOR TRIP INSPECTION/TEST FREQUENCY

	Sensor	Visual Check	Circuit Test
1.	Reheat Header Activity	Daily	Monthly
2.	Circulator Drain Malfunction	Daily	Monthly
3.	Circulator Penetration Trouble	--	Monthly
4.	Circulator Speed Over Speed Low Speed (Prog. with Feedwater) Low Feedwater Flow (Prog. with Circ. Speed)	Daily	Monthly
5.	Fixed Feedwater Flow (Low)	Daily	Monthly
6.	Loss Circulator Bearing Water	Daily	Monthly
7.	Circulator Seal Malfunction	Daily	Monthly
8.	Manual Trip	--	Refueling (Annual)
9.	Circulator Trip Output Circuitry	--	Monthly

5.1 Sensitivity - Circulator Trip Outputs

Tables 3F-25 through 3F-34 depict the single loop, single logic sensitivity values for each sensor circuit contained in the circulator trip SCRAM lines. The failure contributions from each component in the single loop, single logic sensitivity listings were based on a 720 hour interval between tests and do not account for daily checks. This does not change the relative component sensitivities but does influence the values for the maximum contributions from each component. It will be noted that in almost every case, the component contributing the maximum unreliability is in the Bin Power Supply. Since loss of power will trip the bistable output in every case, this component failure can be considered to be overt and will contribute more to spurious trips than to SCRAM failures, i.e., the covert failures can be estimated by subtracting the sum of all annunciated and alarmed failure probabilities from the total of the maximum contributions in the sensitivity tables.

TABLE 3F-25

SYSTEM SENSITIVITY

LOSS BEARING WATER (3532)

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply (N)	1-60	.0111	1.0	.0111
Logic Invertor	6-214	.0002	2.0	.0004
Logic NAND	6-215	.0002	2.0	.0004
Relay Contacts (N/O)	6-203	.0007	1.0	.0007
Connector Pins	1-3	.00004	2.0	.00008

COMPONENT	SINGLE LOOP AND SINGLE LOGIC PREMATURES Spurious Trips) TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human Operator Test		.001	2.0	.0020
Logic NAND	6-215	.0001	5.0	.0005
Logic Invertor	6-214	.0001	2.0	.0002

Inspected: Daily

Tested: Monthly

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hour shift.

TABLE 3F-26

SYSTEM SENSITIVITY

FIXED LOW FLOW TRIP (4078)

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply (N) & Essen Bus.	1-60	.0111	1.0	.0111
Logic Invertor	6-214	.0002	1.0	.0002
Logic NAND	6-215	.0002	1.0	.0002
Human/Operator Inhibit	ISS-1	.001	1.0	.0010

COMPONENT	SINGLE LOOP AND SINGLE LOGIC PREMATURES (Spurious Trips) TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator Test	-	.001	2.0	.0020
Logic NAND	6-215	.0001	5.0	.0005
Logic Invertor	6-214	.0001	2.0	.0002

Inspected: Daily

Tested: Monthly

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

TABLE 3F-27

SYSTEM SENSITIVITY

REHEAT HEADER ACTIVITY, HIGH (4936)

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply (N) & Essen. Bus.	1-60	.0111	2.0	.0222
Human Inhibits ISS	11-81 ISS-1	.001	2.0	.0020
Logic Invertor	6-214	.0002	6.0	.0012
Logic NAND	6-215	.0002	2.0	.0004
Resistor	1-9	.00007	1.0	.00007
Connector/Pins	1-3	.00004	2.0	.00008

COMPONENT	SINGLE LOOP AND SINGLE LOGIC PREMATURES (Spurious Trips) TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human Operator Test	11-82 SIB9	.001	2.0	.0020

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hour shift.

Inspected: Daily
Tested: Monthly

TABLE 3F-28

SYSTEM SENSITIVITY

CIRCULATOR DRAIN MALFUNCTION (3905)

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC FAILURES		
		PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply (N)	1-60	.0111	1.0	.0111
Logic NAND	6-215	.0002	1.0	.0002

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC PREMATURES (Spurious Trips)		
		PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator Test		.001	2.0	.0020
Logic NAND	6-215	.0001	4.0	.0004

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hour shift.

Inspected: Daily

Tested: Monthly

TABLE 3F-29

SYSTEM SENSITIVITY

CIRCULATOR PENETRATION PRESSURE, HIGH (3826)

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
* Bin Power Supply (N)	1-60	.0111	1.0	.0111
Logic NAND	6-215	.0002	2.0	.0004
Logic Invertor	6-214	.0002	1.0	.0002

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC PREMATURES (Spurious Trips) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Logic NAND	6-215	.0001	5.0	.0005
Human/Operator Test	S1A S1B	.001	1.0	.0010
Logic Invertor	6-214	.0001	1.0	.0001

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hour shift.

Inspected: ________

Tested: Monthly

TABLE 3F-30

SYSTEM SENSITIVITY

MANUAL TRIP (4884)

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
* Bin Power Supply & Essen. Bus.	(N) 1-60	.0111	1.0	.0111
Human/Operator Test	11-89	.001	1.0	.0010
Logic Invertor	6-214	.0002	1.0	.0002
Logic NAND	6-215	.0002	1.0	.0002
Relay Contacts	6-203	.0007	1.0	.0007
Connector/Pins	1-3	.00004	1.0	.00004

SINGLE LOOP AND SINGLE LOGIC PREMATURES (Spurious Trips)

COMPONENT	TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator Test	(S1B)	.001	1.0	.0010
Logic Invertor	6-214	.0001	1.0	.0001
Logic NAND	6-215	.0001	1.0	.0001

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hour shift.

Inspected: ________

Tested: Refueling

TABLE 3F-31

SYSTEM SENSITIVITY

CIRCULATOR OVERSPEED TRIP (4628)

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply (N) & Essen.Bus.	1-60	.0111	1.0	.0111
Logic NAND	6-215	.0002	1.0	.0002

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC PREMATURES (Spurious Trips) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator Test	--	.001	2.0	.0020
Logic NAND	6-215	.0001	4.0	.0004

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

Inspected: Daily

Tested: Monthly

TABLE 3F-32

SYSTEM SENSITIVITY
CIRCULATOR LOW SPEED,
PROGRAMMED WITH FEEDWATER FLOW (4758)

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply (N) & Essen. Bus.	1-60	.0111	1.0	.0111
Human/Operator Inhibitor	ISS-1	.001	2.0	.0020
Logic NAND	6-215	.0002	1.0	.0002
Relay Contacts	6-203	.0007	1.0	.0007

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC PREMATURES (Spurious Trips) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator Test	(S1A)	.001	2.0	.0020
Logic NAND	6-215	.0001	4.0	.0004

*Components that are alarmed (A),
annunciated (N), or checked (C),
every 8 hours shift.

Inspected: Daily
Tested: Monthly

TABLE 3F-33

SYSTEM SENSITIVITY

LOW FEEDWATER FLOW,
PROGRAMMED CIRCULATOR SPEED, (4382)

SINGLE LOOP AND SINGLE LOGIC FAILURES

COMPONENT	TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply (N) & Essen. Bus.	1-60	.0111	1.0	.0111
Human/Operator Inhibitor	ISS-1 S1A	.001	2.0	.0020
Logic NAND	6-215	.0002	3.0	.0006
Logic Invertor	6-214	.0002	1.0	.0002

SINGLE LOOP AND SINGLE LOGIC PREMATURES (Spurious Trips)

COMPONENT	TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator Test	S1A	.001	2.0	.0020
Logic NAND	6-215	.0001	4.0	.0004
Logic Invertor	6-214	.0001	1.0	.0001

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

Inspected: Daily
Tested: Monthly

TABLE 3F-34

SYSTEM SENSITIVITY

CIRCULATOR SEAL MALFUNCTION (2039)

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
*Bin Power Supply (N) & Essen. Bus.	1-60	.0111	2.0	.0222
Logic NAND Gate	6-215	.0002	1.0	.0002
Time Delay Lockout	6-234	.0002	1.0	.0002

COMPONENT	TYPE/KIND	SINGLE LOOP AND SINGLE LOGIC PREMATURES(Spurious Trips) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Human/Operator Test		.001	2.0	.0020

Inspected: Daily

Tested: Monthly

*Components that are alarmed (A), annunciated (N), or checked (C), every 8 hours shift.

TABLE 3F-35

SYSTEM SENSITIVITY

CIRCULATOR TRIP COMBINATORIAL OUTPUT LOGIC (5038)

COMPONENT	TYPE/KIND	PROBABILITY	SENSITIVITY	MAX. CONTRIB.
	SINGLE LOOP, SINGLE LOGIC FAILURES	30 DAYS		
*Pin Power Supply (A,N) & Essen. Buss.	1-60	.0111	1.0	.0111
Logic NAND	6-215	.0002	7.0	.0014
Logic Invertor	6-214	.0002	4.0	.0008
Conn./Pins	1-3	.00004	1.0	.00004

*(A , N) Failure of the circulator trip output circuit power supplies will initiate a trip signal into the TLT output module, thus making failure of this component an overt event.

Since the circulator trip output circuit may be used for scheduled testing of circulator trip parameters at least once per week, the failure probabilities for the Logic NAND and Invertor components may be reduced by a factor of about 4.

IV. FINAL SYSTEM MODELING - PHASE 2

A. GO Model Expansion

The GO model developed during Phase 1 represented a modeling of all sensor SCRAM circuits from the sensor input down to the main SCRAM gate. This model included all of the SCRAM circuits in the Two Loop Trouble Circuitry and in the Circulator Trip Circuitry. Original intent at the beginning of this program was to incorporate the Two Loop and associated Circulator Trip circuitry as a single black box in the SCRAM model. However, as the modeling proceeded it became evident that more than half of the Plant SCRAM Protective System would be included in the Two Loop and Circulator Trip Circuitry. For these reasons the definition of Phase 1 and Phase 2 were modified. Phase 2, as revised, involved modeling of the Rod SCRAM System starting from the main SCRAM gate down to the individual SCRAM brakes on each rod, through selected elements of the Rod Control System and a detailed modeling of the Control Rod Mechanical Drive. During the final stages of the model, selective output logic was incorporated to provide rod drop data for various numbers of rods in the core; i.e., up to 6 or more rods.

1. Rod SCRAM System

The Rod SCRAM system starts with the 12 main SCRAM parameters as inputs feeding an AND gate for each of the three SCRAM channels A, B, and C, and followed by SCRAM relay driver XCR2, which drives the dual heavy duty SCRAM contactors through the manual SCRAM switches, Reactor Mode Switch and a resettable latch in the main SCRAM contacts. The SCRAM contacts are combined in a dual two-out-of-three logic relay matrix on a cross strapped set of lines which feed power from the SCRAM brake power supplies to the even/odd set of rod brakes. Interlocks to and from the rod control circuit are included in the rod brake power lines. The logic diagram for the SCRAM circuit is shown in Figure FSV-18E. The equivalent GO chart is given in FSV-18G.

The control rod brakes are energized whenever rod brake power reaches the control rod brakes. A SCRAM occurs when rod brake power is interrupted. Since this is backwards from normal GO logic modeling techniques, in which a signal must pass through to succeed, the time sequence was inverted and the signal output of the main SCRAM circuit was defined as a NOSCRAM signal instead of SCRAM. This logic conversion can also be used to eliminate the need for separate fail-safe modeling, since the failure of any component will fail the NOSCRAM signal. In actual operation, the inputs to the main SCRAM gate must all be high for normal operation with the introduction of a low signal in any of the 12 inputs providing a trip in the appropriate SCRAM channel. This logic is inverted when using the NOSCRAM modeling, with a high input indicating NOSCRAM and low input interrupting the NOSCRAM signal, which signifies a SCRAM. Careful attention must be paid to the definition of time sequences and interpretation of the logic flow since the time sequence is inverted by the logic conversion.

The interpretation of various combinations of SCRAM signals on input channels A, B, and C when using NOSCRAM logic is as follows. At the start of the first time period, if all three channels contain a trip signal, they will have low inputs and the NOSCRAM signal should fail. The probability of NOSCRAM success during the initial time interval is then the probability of SCRAM failure or inhibit with all three channels tripped. If the A channel has all inputs high but the B and C channels are still tripped, the NOSCRAM signal should still fail. The probability of success at this time then indicates the probability of SCRAM failure with two-out-of-three channels tripped. If two channels have all inputs high the NOSCRAM signal should succeed since only one channel is tripped. If all three channels have their inputs high the NOSCRAM signal should again succeed with the highest probability. Finally, if the NOSCRAM signal has a high probability of occuring during the latest time period, this is equivalent to the probability of a premature or spurious SCRAM, since the last time period always corresponds to the signal never arriving.

2. Rod Control System

The rod control system receives three phase power from one of two Motor Control centers. The Motor Control centers step the incoming voltage down from 480V to 125V. This three phase power is transmitted directly to each rod drive motor through several sets of relay contacts. In case of shutdown or a SCRAM condition one pair of relay contacts is opened so that the rod drive motors cannot be energized. Upon startup, another set of relays provide capability to reverse two of the three phases depending on whether the rods are to be driven "in" or "out".

The Rod Control Drive Center receives power from the same source. The operator has a choice of three operational modes, individual rod control, group rod control, and automatic rod control. For modeling purposes, individual control of Rod #2 was selected. It was further assumed that Rod #2 was being withdrawn during the simulation of each accident case. Each individual rod drive has a set of Rod "in" and Rod "out" Limit switches plus a set of Slack Cable switches. A set of six digital position counters record the instantaneous position of any selected group of six rods.

3. Control Rod Drive Mechanism

The Control Rod Drive Mechanism was modeled in depth for several reasons, i.e.:

(1) The complexity of the Drive Mechanism suggests many possibilities for degraded operation depending on the accident postulates one may assume.

(2) Adequate reliability information for the Rod Drive Mechanism had not been found to be readily available

(3) The Rasmussen study (5) indicates that control rod failure is not negligible.

(4) Common mode failure of the control rods would negate the benefits of circuit redundancy and functional diversity except for the manual Emergency Reserve Shutdown System.

The control rod drives were modeled by starting with the primary three phase power, examining the possibilities for phase opening or shorting, drive motor freezing, etc. The availability and phase of the primary power is controlled by the presence or absence of a rod "in" or rod "out" command signal. SCRAM capability is also dependent on normal release of the SCRAM brake, proper operation of the drive motor and its associated gears and bearings. All of these items have been included in the model. In addition, the rods are attached to the rod drive assembly by means of steel cables, pulleys, bearings, etc. In order to SCRAM, the rods must be free in their guide channels, the channels must be aligned properly, and not be dislocated by external forces, such as earthquake, pressure blowout, etc. An attempt has been made in this model to incorporate the majority of these features. The modeling technique involved a detailed simulation of one rod drive assembly. This single rod pair assembly was then expanded 36 more times using computer techniques, and each new rod drive assembly properly phased into the group with its appropriate bus power, SCRAM brake power, and rod drive signal sources. This model permitted a detailed analysis of multiple rod failure probabilities.

B. Reliability Changes -- Final Model

The need for revising selected component reliabilities in the Final GO Model (Phase 2) is discussed in Section IVD under Analysis of SCRAM System Results.

C. SCRAM INITIATION - ACCIDENT SIMULATION

1. General

With the completion of Phase 1 and the first part of Phase 2, the GO model of the St. Vrain SCRAM protective system had been generally prepared for the task of evaluating plant SCRAM capability for a number of postulated accidents. The accidents selected have a very low probability of occurring, but are relatively high on a risk/probability plot due to their consequences.

The Gas Reactor Safety Branch of ERDA's Reactor Research and Development Division submitted a list of six accidents of interest with the associated normal plant protective system response for each postulated incident.

The accident scenarios are listed below. (The accidents are derived from FSV FSAR, Vol. 3, pp 14.2-5, 6).

2. Postulated Accident Scenarios with Normal Plant Protective System Action

CASE 1: DESIGN BASIS DEPRESSURIZATION ACCIDENT (DBDA)

Initiating Event: Simultaneous Failure at Both Closures in Largest PCRV Penetration (87 sq. in.)
Assume: Instantaneous Failure
Significance: Possible release of radioactivity.

Relative Time Periods	SCRAM CIRCUITS - PPS Response
2	Low Reactor Pressure - All Sensors.
3	High Core Inlet Temperature - All Sensors.
4	High Reheat Steam Temperature - All Sensors.
5	High Reactor Building Temperature - All Sensors.
6	Operator Manual SCRAM (Main Control Room).

CASE 2: RELEASE OF RADIOACTIVE PRIMARY COOLANT INTO SECONDARY COOLANT (STEAM) PLANT SYSTEM.

Initiating Event: Rupture in Steam Generator Reheat Section.
Significance: Possible Release of Radioactivity.

Relative Time Periods	SCRAM CIRCUITS - PPS Response
2	Reactor Pressure Low
2	High Reheat Header Activity (Loop 1)
3	Core Inlet Temperature High
3	High Reheat Header Activity (Loop 2)
4	Reheat Steam Temperature High (Channels A and B initially)
5	(Channel C)

CASE 3: PCRV OVERPRESSURE

Initiating Event: Steam Generator Superheater leak.
Significance: Possible Release of Radioactivity.

Relative Time Periods	SCRAM CIRCUITS - PPS Response
2	Low Moisture Level Detection. Loop 1; (Loop 2 locked out of shutdown)
3	High Moisture Level Detection.
3	Low Superheat Steam Pressure. Loop 1; initially - Loop 2 Time 4
5	High Reactor Pressure. (Assume no inhibits from RHA or CSM)

CASE 4: LOSS OF FORCED CIRCULATION COOLING (Temporary)

Initiating Event: Assume one Loop operation and loss of circulator bearing water to one of two operating circulators.

Significance: Possible release of radioactivity.

Relative Time Periods	SCRAM CIRCUITS - PPS Response
2	Circulator Trips (Loss Bearing Water) 1 operating loop).
3	Circulator Trips (Bearing Seizure-Circ. Speed Low) (1 operating Loop).
3,4	Superheat Header Temperature Low (one Loop tripped, and delayed response in second loop due to delayed operator response in balancing load).
3,4	Core Inlet Temperature High/Reactor Pressure High. (Channels A and B at first, C later due to delayed operator response).
7	(Second circulator in operating Loop has a Bearing seizure after SCRAM).

NOTE: This sequence is followed only to SCRAM. Forced circulation cooling is lost after SCRAM when second circulator in operating loop fails and if Loop 1, previously down, cannot be brought up.

CASE 5: CONTROL ROD WITHDRAWAL ACCIDENT AT STARTUP

Initiating Event:	Failure of Rod Withdrawal Prohibit System
Assume:	Startup condition (Run Mode-not Fuel Loading) Power less than 5% rated. Maximum worth rod (.05Δk) being withdrawn by operator
Significance:	Momentary Power excursion-some fuel and core components overheated

Relative Time Periods	SCRAM CIRCUITS - PPS Response
2	Rod withdrawal prohibit (RWP1) is initiated by startup or wide range nuclear channels when power increase is ≥2 decades/min. (Rods stopped 25.5 sec. after startup)
3	If RWP1 does not work, period SCRAM is initiated by wide range channels when period ≥5dpm (occurs ~63.6 sec.* after startup)
4	If RWP1 and the 5 dpm SCRAM do not work, RWP2 is initiated by the wide range or linear flux channels when power is 5% and ISS switch is in "startup" position. IF RWP1 does not work, another RWP is initiated at the 120% flux level. (5% occurs ~108.4 sec. after startup, 120%
5	If the previous constraints, RWP2, and the 120% RWP do not work. A 140% flux level SCRAM is initiated by the wide range and linear channels. (Occurs ~118 sec. after startup)

*Times and peak power were derived from a simple reactor physics model. More detailed calculations could be performed if important to consequence modeling.

Case 5 Continued

5	If the RWP2 does work, a 140% flux level SCRAM will occur ~118.5 sec. after startup. Peak power before shutdown will reach 3.3 times rated power.
6	If the RWP1 worked, the flux will build up to 5% of rated power in 243.7 sec. after startup, and to the 140% SCRAM level in 287.1 sec. after startup. Peak power before shutdown will reach 1.9 times rated power.
6	Manual SCRAM by operator from control room console. (Backup is available in manual actuation of Emergency Reserve Shutdown System - Boron Balls will be dropped into the core - this action takes 5-10 seconds after initiation.)

NOTE: Manual SCRAM or Emergency Reserve Shutdown Can Be Initiated At Any Time By The Operator.

CASE 6: CONTROL ROD WITHDRAWAL ACCIDENT AT POWER

Initiating Event: Failure of Rod Withdrawl Prohibit System.

Assume: Reactor at rated power. (Operator using individual rod control) Maximum worth rod being withdrawn. (.05Δk).

Significance: Momentary power excursion. Possible control rod linkage damage. Core Excessively overheated.

Relative Time Periods	SCRAM CIRCUITS - PPS Response
4	Rod Withdrawal Prohibit (RWP2) initiated by wide range or linear range channels. Power 120% rated power. (Time from start of rod motion 11.0 sec.)

5	If RWP2 does not work, a 140% level SCRAM will occur 14.9 sec. after start of rod motion. Maximum percent over power will reach 1.55 times rated power before shutdown.
5	If the 140% level SCRAM does not work, a SCRAM will be initiated when Reheat Steam Temperature reaches 1075°F. A delay time of 16 sec. is estimated between actual and indicated temperature. Peak power will reach 1.9 times rated power before shutdown.
6	IF RWP2 worked, a 140% level SCRAM will occur 15.6 sec. after start of rod motion. Peak power will reach 1.5 times rated power before shutdown.
6	Manual SCRAM initiated by operator. Estimated reaction time with failure of 140% level SCRAM approximately 5.0 sec. Time for rod drop 150 sec. Peak over power estimated 3.4 times rated power prior to shutdown. This action is backed up by Emergency Reserve Shutdown System. Peak power estimated at 9.8 times rated power before this system can shut the reactor down.

NOTE: Manual SCRAM or Emergency Reserve Shutdown can be initiated at any time by the operator.

3. Model Refinements for Accident Evaluation

a) All sensor circuits not listed in the accident sequence under consideration were inhibited from generating a SCRAM signal.

b) The SCRAM probabilities for each input of the main SCRAM gate were determined individually by making separate runs with inputs for the Two Loop and Circulator Trip logic respectively.

c) To reduce running time of the model, the control rod section was modified by using an equivalent simplified model of the rods. This allowed simulation of all 37 pairs and the formation of a combinatorial output logic which yielded NOSCRAM probabilities for one to six rods or more.

D. SCRAM System Results

1. Accident Simulations

Tables 4D-1 through 4D-6 describe the inputs required to simulate the SCRAM accident sequences. Independent values were prepared for all inputs except the Two Loop Trouble inputs and the Nuclear Startup channel which feeds all three SCRAM channels, A, B, and C from a single input in each case.

TABLE 4D-1 CASE 1. Design Basis Depressurization Accident - Input Signals

SINGLE CHANNEL MAIN SCRAM INPUTS	Relative Time Periods							
	0	1	2	3	4	5	6	7
1. Reactor Building Temperature	.00238					.97167		.02595
2. Reheat Steam Temperature, High	.00306				.96549			.03145
3. Reactor Pressure (Low) (High Core Inlet Temperature - Time 4)	.00010		.97531	.00071				.02388
4.*Two Loop Trouble	.00010		.98389	.00034				.01567
SINGLE LOOP <u>TLT INPUTS</u>								
a. Reactor Pressure (Low) Pressure Low (2) Core Temp. High (3)	.00086		.99109	.00017				.00788

*Computed from TLT Inputs

TABLE 4D-2 CASE 2. PRIMARY COOLANT LEAKAGE (RADIOACTIVE) - INPUT SIGNALS

SINGLE CHANNEL MAIN SCRAM INPUTS	Relative Time Periods 0	1	2	3	4	5	6	7
1. Reheat Steam Temperature (High)	.00306				.96549			.03145
2. Reactor Pressure (Low)	.00010		.97531	.00071				.02388
3. *Two Loop Trouble	.00010		.98876	.01114				.0000033
SINGLE LOOP TLT INPUTS								
a. Reactor Pressure (Low) (Both Loops)	.00086		.99109	.00017				.00788
b. Reheat Header Activity High, Loop 1 Time (2)	.00010		.99650					.00340
Loop 2 Time (3)	.00010			.99650				.00340
c. **Circulator Trip (Both Loops)	.00010		.00039	.95443				.04508
SINGLE LOOP CIRCULATOR TRIP INPUTS								
1. Reheat Header Activity High Loop 1 @ Time (2)	.0004		.9768					.0228
Loop 2 @ Time (3)				.9768				.0228

* Computed from Two Loop Trouble Inputs.

**Computed from Circulator Trip Inputs.

TABLE 4D-3 CASE 3. PCRV OVERPRESSURE - INPUT SIGNALS

SINGLE CHANNEL MAIN SCRAM INPUTS	Relative Time Periods							
	0	1	2	3	4	5	6	7
1. *Superheat Header Steam Pressure (Low)								
Channels A & B @ (3)	.00127			.98230				.01643
Channel C @ (4)	.00127				.98230			.01643
2. Reactor Pressure (High) (Core Inlet Temperature High - Time 5)	.00010					.97602		.02388
3.**Two Loop Trouble	.01935		.15903	.78711				.03451
SINGLE LOOP TLT INPUTS								
a. Low Moisture Detector Trip (See Note 3)	.01191		.16600	.81207				.01002
b. High Moisture Detector Trip (See Note 3)	.00812			.94735				.04453

NOTE:

*1. This variable inspected and tested at monthly intervals only.

**2. Computed from TLT Inputs.

3. All moisture monitor values assume a 720 hr. failure probability of 0.08 for the electronic circuits. The low moisture monitors assume the failure detection circuit picks up 80% of all possible failures.
A low level trip requires two-out-of-three low level monitors plus either one of the two high level monitors.
A high level trip requires both of the high level monitors.

TABLE 4D-4 CASE 4. LOSS FORCED CIRCULATOR COOLING - INPUT SIGNALS

SINGLE CHANNEL MAIN SCRAM INPUTS	Relative Time Periods 0	1	2	3	4	5	6	7
1. Reactor Pressure (High) (Core Inlet Temperature High-Time 4)								
Channels A & B, Time (3)	.00010			.97602				.02388
Channel C, Time (4)	.00010				.97602			.02388
2. *Two Loop Trouble	.00010			.00020	.98557			.01613
SINGLE LOOP TLT INPUTS								
a.**Circulator Trip	0.0		0.0	0.0				1.0
b. Superheat Header Temperature (Low)								
Loop 1, Time (3)	.00020			.99170				.00810
Loop 2, Time (4)	.00020				.99170			.00810

SINGLE LOOP CIRCULATOR TRIP INPUTS (one circ. only)

(1) Loss Bearing Water

(2) Low Speed Trip

(3) Programmed Feedwater Flow (Low)

(NO TRIP - ONLY ONE CIRCULATOR IN LOOP 1 INVOLVED)

* Computed from TLT Inputs.

**Computed from Circulator Trip Inputs.

TABLE 4D-5 CASE 5. CONTROL ROD INCIDENT @ STARTUP - INPUT SIGNALS

SINGLE CHANNEL MAIN SCRAM INPUTS	Relative Time Periods							
	0	1	2	3	4	5	6	7
1. Startup Channel	(See Note 2)		RWP_1 (2dpm)					
2. Wide Range Channel (Rate Output)			RWP_1 (2dpm)	SCRAM 1 (5 dpm)				
3. Wide Range Channel (Flux Level)					RWP2 (5%,30%)	SCRAM2 (140%)	SCRAM2 (140)	
4. Linear Range Channel (Flux Level)					RWP2 (5%,30%)	SCRAM2 (140%)	SCRAM2 (140%) (See Note 1)	

Note 1: Manual SCRAM 3 initiated at time period 6.

Note 2: Due to multiple time response requirements from the nuclear channels, a short GO startup model was coded to sequence the above inputs with the event initiating signals controlled by the probability of failure for the RWP1, RWP2 and SCRAM 1, SCRAM 2 signals. The RWP signals may fail due to imperfect components in the RWP logic circuit or lack of input from the nuclear channels. The SCRAM signals may fail due to imperfect components in the nuclear logic channels. Reliability of nuclear channels as computed by GO were used in the startup program.

TABLE 4D-6 CONTROL ROD INCIDENT AT POWER - INPUT SIGNALS

SINGLE LOOP MAIN SCRAM INPUTS	Relative Time Periods							
	0	1	2	3	4	5	6	7
1. Wide Range Channel (Flux Level)		(See Note 2)			RWP2 (120%)	SCRAM 2 (140%)		
2. Linear Range Channel (Flux Level)					RWP2 (120%)	SCRAM 2 (140%)		
3. Reheat Steam Temperature (High)	.00306				.97167	(See Note 1)		.02595

NOTE:

1. Manual SCRAM 3 initiated at time period 5.
2. Startup model was modified to sequence above nuclear channel signals.
   RWP2 signal reliability was made dependent on imperfection of RWP logic circuits.
   SCRAM 2 signals were made dependent on reliability of nuclear channel inputs.

Accident cases 2 and 4, called for preparation of Circulator Trip inputs. The necessary inputs were run concurrently in each case to obtain the overall output from Circulator Trip.

Accident cases 1 through 4 all required preparation of Two Loop Trouble inputs. The necessary inputs were run concurrently in each case to obtain the dependent inputs for main SCRAM channels A, B, and C.

The overall accident case response was concluded by preparing all inputs for the main SCRAM gate, including the TLT and circulator trip inputs mentioned above and making a final run for each case using these inputs. To simulate the multiple time phased outputs from the nuclear channels during accident cases 5 and 6, a special GO startup model was coded to run with or without inputs from the other main SCRAM channels. The startup model is explained in the following paragraphs.

2. Nuclear Instrumentation Model - (Startup Sequence)

A logic diagram of the GO startup model is shown in Drawing FSV-21G, Appendix C. The first signals to be developed in this model are the two Rod Withdrawal Prohibit Signals - RWP-1, RWP-2.

The generation of an RWP signal requires several conditions, i.e.,

(1) Either the RWP Logic A or RWP Logic B must be working.

(2) One of the three Linear Range Flux channels or one of the three Wide Range Flux channels must be working to generate RWP-2.

(3) One of the three Wide Range Period channels or an output from either of the two combined startup channels must be working to produce RWP-1.

(4) The last requirement is that the Control Rod Drive circuit must be working to initiate a change in power level. If these initial conditions are satisfied as represented by GO signal numbers 220-251, then RWP-1 will be generated at time period (2) to simulate the initial startup accident, and RWP-2 will be generated at time period (4). RWP-1 is generated when the neutron flux level is increasing by at least 2 decades/minute. RWP-2 represents a withdrawal inhibit whenever the current flux level exceeds the trip levels set for each position that the Interlock Sequence Switch can be in; i.e., 5%, 30%, or 120%.

In the next step, the model logic uses the Nuclear Instrument inputs to generate two SCRAM signals; i.e., SCRAM 1 and SCRAM 2. If the Wide Range Period channel is working and RWP-1 fails to arrive, a period SCRAM (SCRAM 1) will be generated at time period 3.

If the period SCRAM fails, due to possible failure in the Wide Range Trip circuit, and the Wide Range or Linear Range Flux channels are working, a 140% flux level SCRAM will be initiated at time period 5. (Still assuming RWP-1 is not working.)

If RWP-1 is working, the period SCRAM at time period 3 will be inhibited as well as the 140% flux level SCRAM at time period 5. However, a new 140% flux level SCRAM will occur at time period 6.

During the startup incident, RWP-2 has negligible effect on time of SCRAM whether it is working or not. Since the Nuclear Instruments in the model pass flux signals past the point where RWP-2 is applied, at time period (Ø), RWP-2 has no effect on the final results.

The component type (9) depicted in the startup model is used to convert real time periods generated in the model to reverse time logic to be compatible with the logic used in the top SCRAM model and Control Rod Drives.

This startup model was integrated into the St. Vrain SCRAM Protective System model at the input to the main SCRAM gate. All internal components except the Control Rod Drive unit and the two Rod Withdrawal Prohibit logic units were given a reliability of 1.0.

Table 4D-6B summarizes the time phasing discussed above for the Startup model.

TABLE 4D-6B

HTGR SCRAM STUDY

TIME PHASING FOR STARTUP MODEL

SCRAM EVENTS	*RELATIVE TIME	DESCRIPTION OF EVENTS
	0	Surveillance testing, maintenance and c/o. (completed by time period "1").
	1	Reactor critical - (zero to 1 watt power level) - *Max worth rod (.05ΔK) being withdrawn by operator.
	2	Period of 2 dpm reached-RWP_1 stops further rod withdrawal - 25.4 sec. after startup.
A	3	If RWP_1 does not work; a 5 dpm period SCRAM-1 will occur - 63.6 sec. after startup.
	4	If 5 dpm SCRAM does not work; a 5% RWP_2 will occur at - 108.4 sec. after startup. (If RWP_2 does not work-another RWP is generated at the 120% flux level)
B	5	If the 5% RWP_2 and the 120% RWP do not work, a 140% flux level SCRAM-2 will occur - 118.1 sec. after startup.
C	5	If RWP_2 works, a 140% flux level SCRAM-2 will occur - 118.5 sec. after startup.
D	6	If RWP_1 works, flux will build up to 5% level in 243.7 sec. after startup and to the 140% SCRAM flux level at 287.1 sec.

*HE Pressure and Temperature in this time span negligible.

3. SCRAM BRAKE POWER RELAY MATRIX

Table 4D-7 summarizes the probabilities for generating a SCRAM signal at the input to Channels A, B, and C of the two-out-of-three SCRAM brake power relay matrix as a function of time for each of the six SCRAM accident cases, plus a seventh case involving only Manual SCRAM. Since the two loop trouble Logic A and Logic B signal lines are fanned simultaneously into the input gates of each of the three SCRAM channels, probability distributions for Two Loop inputs are not independent.

There are 120 components, in channels A, B, and C between the main SCRAM gate and the SCRAM brake power relay matrix. The probability of failing to get a signal into the SCRAM brake power relay matrix depends on the probability of not getting a signal from any of the 12 main SCRAM inputs on two-out-of-three channels A, B, or C, and the probability of several relay coils shorting to power or several switch contacts welding or sticking closed on the two-out-of-three channels. The main SCRAM bus is a fail-safe bus which will SCRAM the Control Rod system if power is lost at any point along the main bus, or if an open line occurs. These failure modes are evidenced in the sensitivity analysis depicted in Table 4D.8A. The sensitivity table verifies that the majority of component failures will lead to premature or spurious SCRAMS. Table 4D.8A shows the relative sensitivities of a signal at the output of the SCRAM brake power relay matrix to each major component in the main SCRAM bus.

NOTE: The probability of failure of the main SCRAM bus to produce a signal at the output of the SCRAM brake power relay matrix is depicted in Tables 4D-9 and 4D-9B respectively, for each of the accident cases studied.

TABLE 4D-7

SCRAM BRAKE SIGNAL TO INPUT OF 2/3 RELAY CIRCUIT

(ACCIDENT SIMULATION)

CASE	Relative Time Periods 0	1	2	3	4	5	6	Worse Case Failure 7
1. Depressurization	1.056×10^{-2}		.98812	2.0×10^{-5}	3.6×10^{-4}	2.0×10^{-5}		$.920 \times 10^{-3}$
2. Primary Coolant Leak	7.752×10^{-3}		.99106	2.71×10^{-4}	negl.			$.917 \times 10^{-3}$
3. PCRV Overpressure	$5,97 \times 10^{-3}$		.956706	3.64×10^{-2}		9.0×10^{-6}		$.915 \times 10^{-3}$
4. Loss of Forced Circulation	4.7×10^{-3}			0.97060	2.34×10^{-2}			1.30×10^{-3}
5. Control Rod Incident (Startup)	4.012×10^{-3}			8.36×10^{-4}		2.6×10^{-5}	0.994468	$.658 \times 10^{-3}$
6. Control Rod Incident (Power)	6.68×10^{-3}					0.992523	1.91×10^{-4}	$.606 \times 10^{-3}$
7. Manual SCRAM (only)	2.8×10^{-2}			.97094				1.1×10^{-3}

NOTE: The failure probabilities listed are maximum and do not generally give credit for 'overt' type failures which may be subsequently repaired and returned to service during a 30 day period.

TABLE 4D-8

SYSTEM SENSITIVITY

MAIN SCRAM BUS

COMPONENT	TYPE/KIND	SINGLE CHANNEL FAILURES PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Scram Relay Coil	3-102	.0007 (short to power)	1.0	.0007
XCR2 Relay Drive	3-113	.0002 (short to power)	1.0	.0002
Relay Contacts (N/O)	6-203	.0001 (stuck closed)	$3\ 10^{-4}$	.000

Note: The failure mode for the above relay coils, is a short to power.

COMPONENT	TYPE/KIND	Single Channel PREMATURE (Spurious Trips) PROBABILITY	SENSITIVITY	MAX. CONTRIB.
Power Supplies/ Bus	1-60	.0111	2	.0222
Scram Relay Coil	3-102	.001 (open)	3	.0030
Connector/Pins (Cables)	1-3	.00004 (open)	15	.00060
Logic (NAND)	6-215	.0002 (open)	3	.00060
Switch Rotary (N/C)	7-302	.00007(open)	2	.00014
Relay Contacts (N/O)	6-203	.00007(Stuck open)	3	.00021
Switch (Spring Loaded)	6-202	.0003 (open)	1	.00030
Capacitor	1-10	.0002 (short)	1	.00020
XCR2 Relay Driver	3-113	.0001 (open)	1	.00010
Resistor	1-9	.00007(short)	1	.00007
XCR2 Rectifier	3-114	.001 (open)	1	.0010
Switch (Spring Loaded) (N/C)	7-305	.00004 (open)	1	.00004

Inspected: ____________
Tested: Monthly

Conventional failure equation analysis can be used to provide some insight and confirmation on the probability of a multiple SCRAM signal failing to occur at the output of the SCRAM brake power relay matrix, e.g.;

$$P = 3AT[2(F+R)+A]+3(F+R)^2+8R^3-3R^2$$

where A is the product of the failure probabilities for each independent input to the main SCRAM gate (except the Two Loop Trouble input), T is the probability of the Two Loop input failing, F is the probability of failure of a channel to transmit the SCRAM signal to the relay contacts, and R is the failure probability of each set of relay contacts.

Table 4D-9 contains the failure probability calculated from this relationship for each of the four SCRAM accident cases. Manual SCRAM, is not adequately represented by the failure equation because the power relay matrix is bypassed by a series of normally-closed contacts which open in the event of a manual SCRAM.

TABLE 4D- 9

PROBABILITY OF SCRAM FAILURE AT OUTPUT OF SCRAM BRAKE POWER RELAY MATRIX (FROM FAILURE EQUATIONS) FOR FOUR SCRAM ACCIDENT CASES EVALUTED IN THIS STUDY.

CASE	MODE	WORST CASE PROBABILITY OF FAILURE (FROM FAILURE EQUATIONS)
1. Depressurization,	unconditional failure:	3.5×10^{-6}
	Reheat steam temp., signal failure on one channel:	4.8×10^{-6}
	Reactor Pressure Signal failure on one channel:	5.2×10^{-6}
	One complete channel failure:	2.4×10^{-3}
2. Primary Coolant Leakage,	unconditional failure:	3.4×10^{-6}
	Reheat steam temp., signal failure on one channel:	3.4×10^{-6}
	Reactor pressure signal failure on one channel:	3.4×10^{-6}
	One complete channel failure:	2.4×10^{-3}
3. PCRV Overpressure,	unconditional failure:	3.6×10^{-6}
	Superheat steam pressure signals fails on one channel:	3.6×10^{-6}
	Reactor pressure signal failure on one channel:	3.6×10^{-6}
	One complete channel failure:	2.4×10^{-3}
	Moisture monitor inputs only (no diversity)	3.4×10^{-2}
4. LOSS OF FORCED CIRCULATION,	unconditional failure:	3.31×10^{-5}
	One complete channel failure:	3.14×10^{-3}

NOTE: Single channel failure assumes that one of the three SCRAM Channels A, B, or C has its relay contacts stuck or welded closed so that the SCRAM brake interrupt signal will have no effect on that channel. The resulting SCRAM network configuration under these conditions has now changed from a two-out-of-three system to a two-out-of-two system to initiate a SCRAM event.

Table 4D-9B lists the actual probabilities for SCRAM failure and success as a function of time for each of the six accident cases using the GO program.

It is apparent from Tables 4D-9 and 4D-9B that the probability of a SCRAM signal failing to occur (i.e., occuring in time period 7) at this point is greater for accident case 4 than for the other accident cases, except where one of the main SCRAM channels has malfunctioned. A short to power in the XCR-2 relay driver is capable of achieving this latter condition.

To gain insight into the reasons for the higher failure probability in case 4, consider the sequence of SCRAM input signals in accident case 3, (Table 4D-3). At time period (3) the two loop trouble circuit has a high probability of being tripped by the Low Level Moisture Monitor detectors. The cumulative probability is .96549. At the same time, there is a high probability of trip signals arriving from a low pressure condition in the Superheat Header Steam on SCRAM channels A and B. These two trip signals, plus the TLT trip raise the probability of a SCRAM at time period (3) to .998767. (See Table 4D-9B). The failure probability at this time is .001233. At time period (4), a third trip from the Superheat Header Steam pressure sensors is received on channel (C). This trip contributes .00119 to the probability of success, thus dropping the probability of failure to .000043. Finally at time period (5), the Reactor Primary Coolant Pressure sensors trip due to High Core Inlet Temperatures on all three SCRAM channels. These trip signals together contribute .00004 to success, thereby dropping the final SCRAM failure probability to 3×10^{-6}, or the cumulative SCRAM probability to almost 1.0.

TABLE 4D- 9B

SCRAM BRAKE SIGNAL AT OUTPUT OF BRAKE POWER SYSTEM

Relative Time Periods

CASE	0	1	2	3	4	5	6	7
1. a) Depressurization	$4.2x10^{-4}$		.999536	$1x10^{-5}$	$3x10^{-5}$			$4.0x10^{-6}$
b) One SCRAM channel malfunctioned	$2.9x10^{-4}$		.996420	$4.0x10^{-5}$	$7.1x10^{-4}$	$2.0x10^{-5}$		$2.52x10^{-3}$
2. a) Primary Coolant Leak	$2.75x10^{-4}$		.999700	$2.1x10^{-5}$				$4.0x10^{-6}$
b) One SCRAM channel Malfunctioned	$2.3x10^{-4}$		.996710	$5.4x10^{-4}$				$2.52x10^{-3}$
3. a) PCRV Overpressure	$1.94x10^{-2}$		$1.59x10^{-1}$	.820367	$1.19x10^{-3}$	$4x10^{-5}$		$3x10^{-6}$
b) Moisture Monitor (only active sensors)	$1.94x10^{-2}$		$1.59x10^{-1}$	.787100				$3.45x10^{-2}$
4. a) Loss of Forced Circulation cooling	$1.58x10^{-4}$			.950694	$4.9116x10^{-2}$			$3.2x10^{-5}$
b) One SCRAM channel malfunctioned	$1.60x10^{-4}$			.950670	$4.589x10^{-2}$			$3.2x10^{-3}$
5. Control Rod Incident (@ startup)	$<10^{-5}$					$8.6x10^{-4}$	.99914	$<10^{-6}$
6. Control Rod Incident (@ power)	$2.4x10^{-5}$					.999976		$<10^{-6}$
7. Manual SCRAM (only)	$1.166x10^{-2}$		.98834					$<10^{-6}$

NOTE: The failure probabilities listed are maximum and do not generally give credit for 'overt' type failures which may be subsequently repaired and returned to service during a 30 day period.

It is, therefore, highly likely that the SCRAM signal will finally occur in accident case 3, but it is significant that each of the two independent SCRAM signals contributed measurably to the success.

In accident case 4, however, only the Two Loop Trouble and the Reactor Pressure SCRAM signals occur. The absence of additional SCRAM signals and the fact that the Two Loop Trouble SCRAM signal cannot be improved by the two-out-of three logic results in the increased probability of SCRAM signal failure for accident case 4.

If the only contributor to SCRAM in accident Case 4 happened to be an output signal from Two Loop Trouble, it is estimated that the Brake Power SCRAM signal would fail with a probability of 1.6×10^{-2}. If only the Reactor Pressure SCRAM signal were present the estimated failure probability of the Brake Power SCRAM signal would be 1.7×10^{-3}. Thus, functional diversity plays a significant role in SCRAM reliability at St. Vrain.

4. Single Parameter SCRAM Analysis

While the probability of encountering a single parameter SCRAM trip is very small, the results of such an incident are of interest.

The SCRAM sensor parameters which will have the most impact on failure to SCRAM, will be those having the highest apparent probability of failure. Some of the SCRAM system parameters are inspected and tested only at monthly intervals, rather than daily. These parameters become likely candidates for single parameter SCRAM failures of interest especially so if they happen to be dependent parameters that make up the inputs to the Two Loop Trouble circuits.

Table 4D-9C summarizes the SCRAM parameters that fall into this category.

TABLE 4D-9C

CANDIDATES FOR SINGLE PARAMETER SCRAMS OF INTEREST IF THERE WERE NO FUNCTIONAL DIVERSITY

SENSOR PARAMETER	SYSTEM LOCATION	MAXIMUM PROBABILITY OF FAILING TO INTERRUPT SCRAM BRAKE POWER (30 DAYS)
Moisture Monitors	Two Loop Trouble	2.0×10^{-2}
*Steam Pipe Rupture Temperature Pressure	Two Loop Trouble	2.1×10^{-2}
*Steam Generator Penetration Overpressure	Two Loop Trouble	3.4×10^{-2}
*Circulator Penetration Pressure	Two Loop Trouble	2.0×10^{-2}
*Circulator Trip Manual	Two Loop Trouble	2.2×10^{-2}

*Failure to shutdown the affected loop will be approximately half of the values quoted above.

NOTE: Failure values shown are maximum and do not give credit for 'overt' type failures which may be subsequently repaired and returned to service during a 30 day period.
In almost every case the power supply contributes the dominant share of the values quoted for SCRAM brake failure. All power supply failures in the circuits above can be considered to be 'overt' and usually result in a single channel SCRAM or sensor trip. Removing the power supply failures will generally lower the expected SCRAM failure values by almost an order of magnitude.

4.1 Moisture Monitors

GAC has indicated that both the High Level and Low Level Moisture Monitors contain Failure Detection Circuits. The system schematics indicate that only the Failure Detection Circuits on the Low Level Monitors are tied to automatic trips. The Failure Detectors for the High Level Monitors are tied to alarms and annunciators. These will cause a delayed trip (when removed for service) and almost immediate repair (1-2 hours) when replaced with a spare module.

Figure 4-1 depicts the System Failure Probability as a function of the Moisture Monitor Unreliability. A review of the Moisture Monitor logic (FSV 11E and FSV 11G) indicates that the High Level Monitors maintain a SCRAM inhibit on the output of the Low Level Monitors until both High Level Monitors trip, or two-out-of-three Low Level Monitors in one loop - plus a single High Level Monitor trip.

Figure 4-1 depicts two types of failures, overt and covert. Overt failures are those which are usually caught by the Failure Detector and result in an automatic trip, audible alarm, or flashing annunciator light. It is presumed, in either of the above instances, that the operator will manually trip out the affected unit and replace it with a good spare unit.

Covert failures are considered to be unsafe failures since they are not usually detectable until the monthly test is initiated. If an MTBF of one year is assumed for the Moisture Monitor electronics, (FSAR, Vol II), the total probability of component failure by the end of 30 days without regard for overt failures or the presence of a Failure Detector is about 8%. If the Failure Detector circuits are assumed to have an operating efficiency of about 80%, and all other components in the Moisture Monitor System assumed to be perfect, it can be seen from Figure 4-1 that the covert failure probability is about .001.

If the power supply for the Moisture Monitor System is considered to be overt, the remaining components also contribute an additional failure probability of about .001. Similarly, it can be seen that the overt Failure Probability is about 0.16 at the end of 30 days.*

Figure 4-2 illustrates the effect that the Moisture Monitor System has on Loop shutdown. Using the same component parameters as above, it is seen that the covert probability of shutting down the wrong loop is about 0.0007, whereas the overt probability is approximately 0.045.

* The overt failure estimates do not include any credit for repair which will also reduce the overt system failure values.

FIGURE 4-1

SCRAM

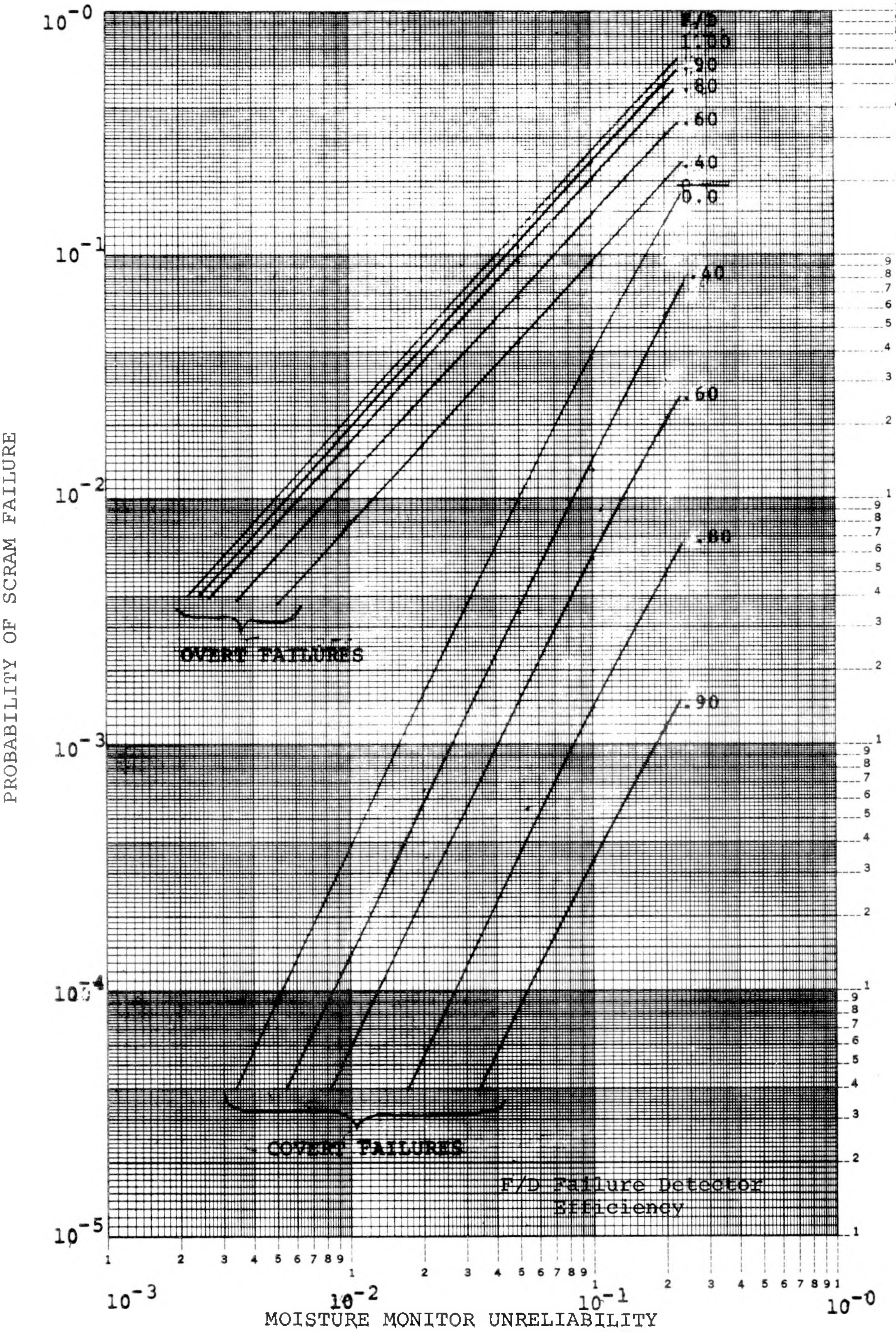
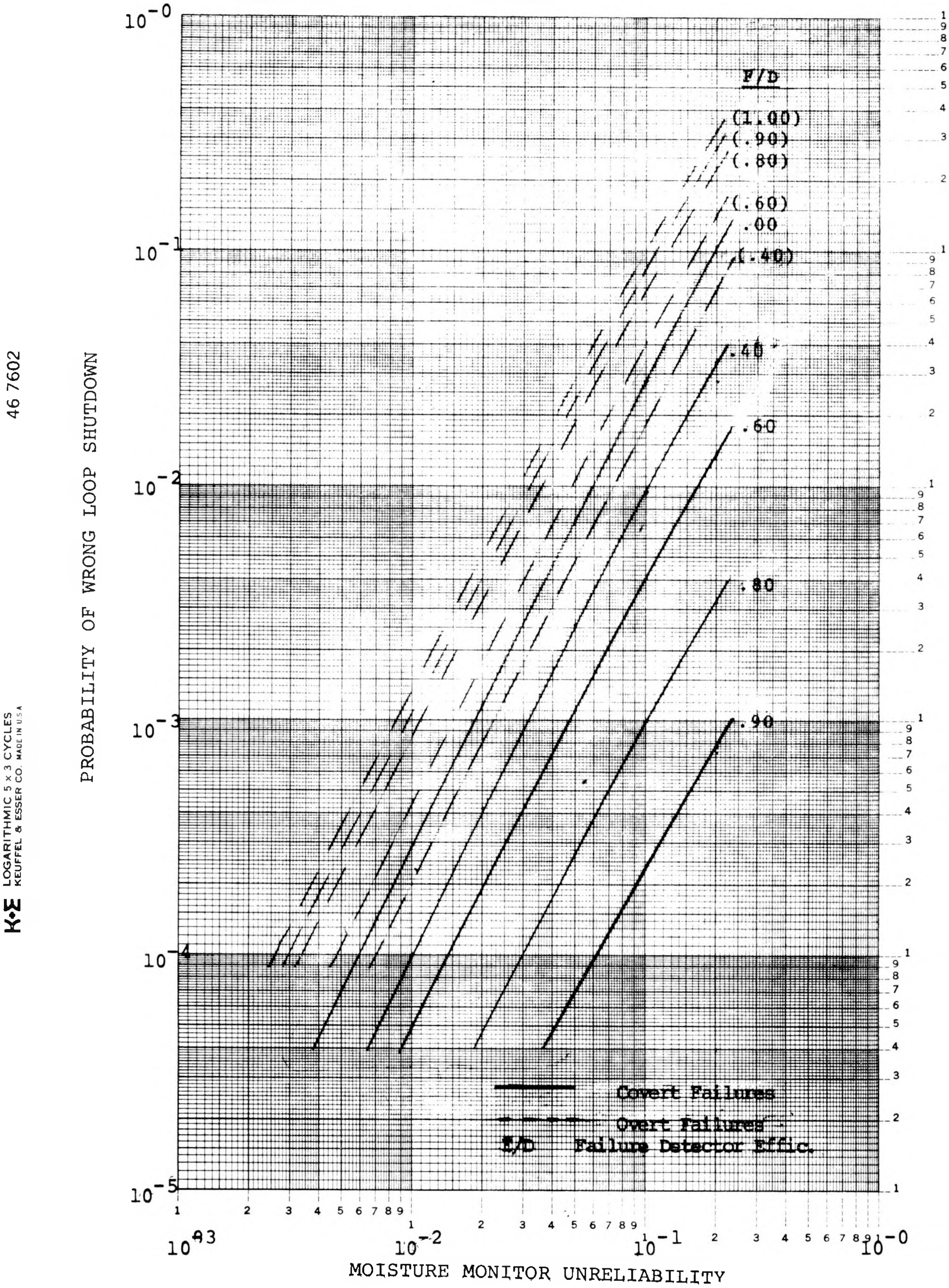


FIGURE 4-2 SHUTDOWN



4.2 OVERT/COVERT FAILURE CONTRIBUTIONS

Table 4D-10A has been prepared to show the maximum overt/covert contributions to SCRAM brake failure for all of the single parameters of interest discussed in this section assuming no functional diversity.

TABLE 4D-10A

MAXIMUM OVERT/COVERT SINGLE PARAMETER SCRAM BRAKE FAILURES WITHOUT FUNCTIONAL DIVERSITY

Sensor Parameters	Overt Failures	Covert Failures
Moisture Monitor System	1.9×10^{-2}	1.2×10^{-3}
Steam Pipe Rupture	2.2×10^{-2}	9.6×10^{-3}
Steam Generator Penetration Overpressure	3.3×10^{-2}	4.0×10^{-4}
Circulator Penetration Overpressure	1.9×10^{-2}	1.2×10^{-3}
Circulator Trip (manual) (For Loop shutdown only)	1.0×10^{-2}	1.1×10^{-3}

If a single parameter SCRAM fails, the operator still has recourse to two Manual SCRAM options plus the Emergency Reserve Shutdown System consisting of a large number of Boron balls which can be dropped into the reactor core to maintain the reactor subcritical.

5. CONTROL ROD SCRAM PROBABILITIES FOR ACCIDENT CASES

In order to determine the SCRAM probabilities for different numbers of control rods, a small, simple computer program, called SCRAM, was prepared to supplement GO. The SCRAM program is based upon combinatorial analysis of the different ways in which different numbers of rods can fail to SCRAM upon command. The program accepts as inputs the premature and failure probabilities for the control rod drive, for each of the two rods of a pair, and for the environmental common mode failure. These values were obtained from detailed GO runs of the control rod drive and the SCRAM program was validated by comparison with GO runs for identical cases. Other inputs to the SCRAM program are the joint premature and failure probabilities for the two SCRAM Brake Power signals to the odd and even numbered rod pairs. All of the SCRAM Brake Power signal probabilities are obtained from GO runs.

In order for all 74 control rods to SCRAM at the desired time, it is necessary that the common mode control rod failures not occur, that the individual failures of the SCRAM Brake Power signals not occur for both even and odd numbered control rod pairs, that the 37 control rod drives not fail, that the 37 individual control rods having only one cable pulley (called number 1 rods) not fail, and that the 37 control rods having two cable pulleys (called number 2 rods) not fail. If these do not all happen, then one or more control rods will not SCRAM at the proper time. The probability of one or more individual control rods failing to SCRAM is consequently approximated by

$$P_1 = 1-(1-P_A)\ (1-P_o)\ (1-P_e)(1-P_p)^{37}\ (1-P_1)^{37}\ (1-P_2)^{37},$$

where P_A is the probability of a common mode occurring which will prevent multiple control rods from scramming; P_o is the probability of the SCRAM signal failing to occur for odd numbered control rod pairs; P_e is the corresponding probability for even-numbered control rods; P_p is the probability of a failure affecting both rods of a pair, conditioned upon the occurrance of the SCRAM Brake Power signal; P_1 is the probability of a failure occurring which affects only rod 1 of a pair; and P_2 is the corresponding probability for rod 2 of a pair.

Using similar logic, in order for 73 control rods to SCRAM at the desired time it is necessary that the common mode failure for all rods not occur, the probability being $1-P_A$; that even and odd Brake Power SCRAM signals not fail, the probability being $(1-P_o)$ $(1-P_e)$; that the 37 control rod drives not fail, the probability of which is $(1-P_p)^{37}$; that no two number 1 rods fail, the probability of which is approximately $1-666P_1^2$; that no two number 2 rods fail, the probability of which is approximately $1-666P_2^2$; and that no combination of number 1 and number 2 rods fails, the probability of which is approximately $1-1369P_1P_2$. The probability of two or more rods failing to SCRAM is then approximately:

$$P_2 = 1-(1-P_A)\,(1-P_o)\,(1-P_e)\,(1-P_p)^{37}\,(1-666P_1^2)\,(1-666P_2^2) \times (1-1369P_1P_2).$$

Similar equations were developed for the probability of SCRAM failure of three or more rods, four or more rods, five or more rods, and six or more rods. The same approach was used to obtain corresponding relationships for premature SCRAM of from one or more rods to six or more rods.

Reference 14 states that there are 48 combinations of two rod pairs failing to SCRAM and 267 combinations of three rod pairs failing to SCRAM that can cause a reactivity problem. It is understood that the 48 combinations of two pairs include all combinations of two adjacent pairs which are next to the reflector. It is also understood that the 267 combinations of three pairs include all combinations of three adjacent pairs. 156 Of these adjacent triplets are also adjacent to the reflector and are, therefore, included in one or more of the 48 combinations of two rod pairs. Consequently, there are 111 combinations of three rod pairs in addition to the 48 combinations of two pairs the SCRAM failure of which could result in a reactivity problem. The probability of such a failure can be

$$P_g = 1-(1-P_A)\ (1-P_o)\ (1-P_e)\ (1-P_p^{\ 2})^{48}\ (1-P_p^{\ 3})^{111}$$

The Fort St. Vrain Technical Specification (Reference 13) contains a different description of the combinations of unscrammed control rod pairs which might cause reactivity problems. This source states that, with equilibrium concentrations of Pa-233, cold shutdown capability is retained if two adjacent rod pairs and a third rod pair that is at least 3 regions away from the adjacent pairs all remain unscrammed. By inference it can be suggested that cold shutdown capability may be marginal if two adjacent pairs and a third pair one or two regions away all fail to SCRAM. 969 such combinations have been identified. The probability of such a failure is approximately:

$$P_t = 1-(1-P_A)\ (1-P_o)\ (1-P_e)\ (1-P_p^{\ 3})^{969}$$

Since both P_g and P_t may be of interest, the SCRAM program computes both values.

TABLE 4D-10

PROBABILITY OF CONTROL ROD PAIRS FAILING TO SCRAM FOR SPECIFIED ACCIDENT CONDITIONS

CASE	1 or More Rod Pairs	2 or More Rod Pairs	3 or More Rod Pairs	P_g (SCRAM Failure per GAC Correspondence)	P_t (SCRAM Failure per Technical Specifications	18 or More Rod Pairs
1. Depressurization	1.84×10^{-2}	1.85×10^{-4}	1.90×10^{-5}	3.00×10^{-5}	1.81×10^{-5}	8.02×10^{-6}
2. Primary Coolant Leaks	1.84×10^{-2}	1.85×10^{-4}	1.94×10^{-5}	3.04×10^{-5}	1.85×10^{-5}	8.41×10^{-6}
3. PCRV Overpressure	1.84×10^{-2}	1.84×10^{-4}	1.81×10^{-5}	2.91×10^{-5}	1.72×10^{-5}	7.12×10^{-6}
4. Forced Circulation	1.84×10^{-2}	2.15×10^{-4}	4.93×10^{-5}	6.03×10^{-5}	4.84×10^{-5}	3.83×10^{-5}
5. Control Rod Withdrawal (Startup)	1.84×10^{-2}	1.77×10^{-4}	1.10×10^{-5}	2.20×10^{-5}	1.01×10^{-5}	$< 10^{-6}$
6. Control Rod Withdrawal (at Power)	1.84×10^{-2}	1.77×10^{-4}	1.10×10^{-5}	2.20×10^{-5}	1.01×10^{-5}	$< 10^{-6}$
7. Manual SCRAM (only)	1.84×10^{-2}	1.77×10^{-4}	1.10×10^{-5}	2.20×10^{-5}	1.01×10^{-5}	$< 10^{-6}$

TABLE 4D-11 PROBABILITY OF PREMATURE CONTROL ROD SCRAM FOR SPECIFIED ACCIDENT CONDITIONS

CASE	1 or More Rod Pairs	2 or More Rod Pairs	3 or More Rod Pairs	18 or More Rod Pairs
1. Depressurization	6.16×10^{-2}	2.49×10^{-3}	6.09×10^{-4}	5.71×10^{-4}
2. Primary Coolant Leaks	6.14×10^{-2}	2.30×10^{-3}	4.18×10^{-4}	3.80×10^{-4}
3. PCRV Overpressure	6.13×10^{-2}	2.20×10^{-3}	3.11×10^{-4}	2.73×10^{-4}
4. Forced Circulation	6.12×10^{-2}	2.13×10^{-3}	2.47×10^{-4}	2.08×10^{-4}
5. Control Rod Withdrawal (Startup)	6.10×10^{-2}	1.92×10^{-3}	3.82×10^{-5}	$<10^{-6}$
6. Control Rod Withdrawal (at power)	6.11×10^{-1}	1.95×10^{-3}	6.19×10^{-4}	2.35×10^{-5}
7. Manual SCRAM (Only)	6.11×10^{-1}	1.95×10^{-3}	6.19×10^{-4}	2.35×10^{-5}

The values of P_g, P_t and the probabilities of SCRAM failure of different numbers of control rod pairs are tabulated in Table 4D-10 for the accident cases. Table 4D-11 contains premature or spurious SCRAM probabilities for different numbers of control rod pairs. The probabilities presented in these tables are based upon the assumed success and failure probabilities of rod control and drive system components. The effect of changing these parameters is described in the next section of this report. Since the premature and failure probabilities differ little between the accident cases, subsequent discussions will consider the probability of a SCRAM occurring in response to a SCRAM signal occurring on the SCRAM Brake Power line, without regard for the cause of the SCRAM.

6. Control Rod Drives

In order to evaluate the control rod drives, the GO model was used to determine the sensitivities of premature SCRAM AND SCRAM failure to the corresponding probabilities for each of the control rod drive and rod control system components. These sensitivities are determined for a single control rod pair are shown in Table 4D-12. Components to which the control rod drive is insensitive are excluded.

Most of the components (and cause of failure) listed in Table 4D-12 are readily identifiable. Some explanation of "Environmental Effects" may be required, however. This heading is not intended to derate component reliability due to environmental stress. Instead it represents direct environmental interaction with the control rod drives. It includes such effects as intense gas flow through the control rod channels caused by failure of the Orifice and Control Assembly closure. It also inc udes the independent component of earthquakes or other such shocks. (The common mode components of such environmental effects are treated later.)

In addition to those components which affect the reliability of the rod pair, there are also components whose failure will affect a single rod of the pair. (See Table 4D-12) Sensitivities are listed separately for each of the two rods because the first rod of the pair has a single cable pulley, while the second rod has dual pulleys.

TABLE 4D-12

INITIAL ROD CONTROL AND DRIVE SENSITIVITY (1 Rod Pair)

COMPONENT	TYPE/KIND	FAILURES PROBABILITY	FAILURES SENSITIVITY	FAILURES MAX. CONTRIB.
Disk Brake (Sticking)	1-52	.0002	1.0	.0002
Mechanical Drive (Sticking)	1-53	.0008	1.0	.0008
Bearings	1-54	.00005	11.0	.00055
Drum Spindle	1-55	.00005	1.0	.00005
Disk Brake Actuator	3-124	.0001	1.0	.0001
Disk Brake Gear	3-125	.00001	1.0	.00001
Disk Brake Spider	3-126	.00001	1.0	.00001
Gear and Pinion	3-127	.0001	4.0	.0004
Environmental Effects (per rod pair)	11-311	.0001	1.0	.0001
				$\Sigma_F = .00222 \approx 2x10^{-3}$

COMPONENT	TYPE/KIND	PREMATURES PROBABILITY	PREMATURES SENSITIVITY	PREMATURES MAX. CONTRIB.
Fuse	1-1	.00007	1.0	.00007
Connector/pins	1-3	.00004	2.0	.00008
Relay Coil	3-102	.00072	1.0	.00072
Disk Brake Actuator	3-124	.0003	1.0	.0003
Disk Brake Gear	3-125	.00001	1.0	.00001
Disk Brake Spider	3-126	.00001	1.0	.00001
Gear and Pinion	3-127	.00001	4.0	.00004
Pin	3-128	.0002	2.0	.0004
Relay Contact (N/C)	7-303	.00007	2.0	.00014
				$\Sigma_F = .00177 \approx 2x10^{-3}$

TABLE 4D-13

INITIAL INDIVIDUAL CONTROL ROD SENSITIVITIES (Each Rod)

Component	Type/Kind	Probability	Sensitivity	Max. Contrib.
		FAILURE (First Rod of Pair)		
Bearing	1-54	.00005	1.0	.00005
Cable Pulley Shaft	1-57	.00002	1.0	.00002
Cable Pulley	1-58	.00005	1.0	.00005
Control Rod	1-59	.00002	1.0	.00002
			Σ_F =	.00012
		FAILURE (Second Rod of Pair)		
Bearing	1-54	.00005	2.0	.00010
Cable Pulley Shaft	1-57	.00002	1.0	.00002
Cable Pulley	1-58	.00005	2.0	.00010
Control Rod	1-59	.00002	1.0	.00002
			Σ_F =	.00022
		PREMATURE (Each Rod)		
Cable Anchor	3-130	.00001	1.0	.00001
Cable	3-131	.0001	1.0	.0001
			Σ_F =	.00011

The bearings and gears appear to be the most sensitive components in the determination of control rod drive failure and premature probabilities. Although they are not the major contributors to these probabilities, small errors in estimating their failure probabilities are greatly magnified. It is, therefore, necessary to verify that the failure probabilities of the sensitive components are sufficiently small so that even when multiplied by the sensitivities they are not dominant. For these reasons and because the initial estimates of these components were relatively rough, a more detailed examination was made of these parts. Information contained in Reference 8 indicates that the mean time between failure (MTBF) of typical bearings and gears might be approximated by:

$$\text{MTBF (bearings)} = 7 \times 10^6 (D/A)^3 \text{ cycles}$$

and

$$\text{MTBF (gears)} = 45 \times 10^6 (D/A)^5 \text{ cycles,}$$

where (D/A) is the ratio of design load to actual load. Although the validity of these relationships and their applicability to nuclear reactor components is open to question, they allow more realistic estimates to be made than are possible on intuitive grounds alone.

In the initial GO model of the control rod drives, the gears were all given the same characteristics and were represented by the same GO component (type 3, kind 127). Similarly, the bearings were all represented by a type 1, kind 54 GO component. Since the gear train causes the various bearings and gears to turn at different rates, and since the failure rate is proportional to the number of revolutions, it became necessary to represent each set of bearings and gears by a different GO component kind. At the same time, the use of GO component 1-53 representing mechanical drive friction which would be overcome if the system were powered but which would prevent an unpowered SCRAM, was discontinued. The unreliability represented by this component was distributed among the gears and bearings. Table 4D-14 illustrates the estimated failure probabilities for the bearings and gears between SCRAM demands. These probabilities reflect the gearing ratios in the control rod drive and are expressed in terms of the actual to design load ratio (A/D) and the average distance traveled by each control rod pair between SCRAMS.

Tables 4D-15 and 4D-16 contain the revised control rod drive and individual control rod sensitivities. The bearing and gear failure probabilities were arbitrarily based on a minimum design to actual load ratio of 5 and an average rod travel of one complete withdrawal (190 inches) and one insertion (an additional 190 inches) between SCRAMS. Increased load ratios or decreased control rod travel would further reduce the contributions of bearings and gears to control rod drive failure probabilities. However, the overall failure probabilities would not be significantly changed by this reduction. That these estimates of design to actual load ratio and control rod travel are conservative is supported by recent information (Reference 14) which gives values of 12.9 and 37.8 for the design to actual load ratio for two of the motor bearings. If these values are typical, the rod travel could increase considerably without significantly increasing the failure rate of the control rod drives.

TABLE 4D-14

ESTIMATED GEAR AND BEARING FAILURE PROBABILITIES

Component	Type/Kind	FAILURE (Per Control Rod Drive) Probability	Sensitivity	Max. Contrib.
1st Gear Bearings	1-61	$3.9x10^{-7}d(A/D)^3$	2.0	$7.8x10^{-7}d(A/D)^3$
2nd Gear Bearings	1-62	$4.7x10^{-8}d(A/D)^3$	2.0	$9.4x10^{-8}d(A/D)^3$
3rd Gear Bearings	1-63	$2.0x10^{-8}d(A/D)^3$	2.0	$4.0x10^{-8}d(A/D)^3$
Hub Bearings	1-64	$3.3x10^{-9}d(A/D)^3$	2.0	$6.6x10^{-9}d(A/D)^3$
Motor Bearings	1-66	$3.8x10^{-6}d(A/D)^3$	3.0	$1.14x10^{-5}d(A/D)^3$
Motor Pinion and Gear	3-132	$3.2x10^{-7}d(A/D)^5$	1.0	$3.2x10^{-7}d(A/D)^5$
2nd Gear and Pinion	3-133	$3.4x10^{-8}d(A/D)^5$	1.0	$3.4x10^{-8}d(A/D)^5$
3rd Gear and Pinion	3-134	$5.2x10^{-9}d(A/D)^5$	1.0	$5.2x10^{-9}d(A/D)^5$
Pinion and Ring Gear	3-135	$1.8x10^{-9}d(A/D)^5$	1.0	$1.8x10^{-9}d(A/D)^5$
				$\Sigma_F = 1.23x10^{-5}d(A/D)^3 + 3.61x10^{-7}d(A/D)^5$

Note: d is the average control rod travel, in inches, between SCRAM demands and (A/D) is the actual to design load ratio. For simplicity, it is assumed here that all components were designed to the same load ratio.

TABLE 4D-15

REVISED ROD CONTROL AND DRIVE SENSITIVITIES (Per Rod Pair)

Component	Type/Kind	FAILURES Probability	Sensitivity	Max. Contrib.
Disk Brake (Sticking)	1-52	.0002	1.0	.0002
Drum Spindle	1-55	.00005	1.0	.00005
Motor Bearings	1-66	.000012*	3.0	.000036
1st Gear Bearings	1-61	.000001*	2.0	.000002
2nd Gear Bearings	1-62	0*	2.0	0
3rd Gear Bearings	1-63	0*	2.0	0
Hub Bearings	1-64	0*	2.0	0
Disk Brake Actuator	3-124	.0001	1.0	.0001
Disk Brake Gear	3-125	.00001	1.0	.00001
Disk Brake Spider	3-126	.00001	1.0	.00001
Motor Pinion and Gear	3-132	0*	1.0	0
2nd Gear and Pinion	3-133	0*	1.0	0
3rd Gear and Pinion	3-134	0*	1.0	0
Pinion and Ring Gear	3-135	0*	1.0	0
Environmental Effects	11-311	.0001	1.0	.0001
			$\Sigma_F=$	.000508

*Bearing and gear reliabilities are conservatively based upon an assumed design/actual load ratio of 5 and average rod travel of one complete withdrawal and one insertion between SCRAM demands. The design/actual load ratio is known to be much larger than 5 in some cases. This would make the contribution of gears and bearings even smaller. (See Text)

TABLE 4D-16

REVISED INDIVIDUAL CONTROL ROD SENSITIVITIES (per Rod)

Component	Type/Kind	Probability	Sensitivity	Max. Contrib.
		FAILURE (First Rod of Pair)		
Cable Pulley Bearing	1-67	0*	1.0	0
Cable Pulley Shaft	1-57	.00002	1.0	.00002
Cable Pulley	1-58	.00005	1.0	.00005
Control Rod	1-59	.00002	1.0	.00002
				Σ_F = .00009
		FAILURE (Second Rod of Pair)		
Cable Pulley Bearing	1-67	0*	2.0	0
Cable Pulley Shaft	1-57	.00002	1.0	.00002
Cable Pulley	1-58	.00005	2.0	.00010
Control Rod	1-59	.00002	1.0	.00002
				Σ_F = .00014
		PREMATURE (Each Rod)		
Cable Anchor	3-130	.00001	1.0	.00001
Cable	3-131	.0001	1.0	.0001
				Σ_F = .00011

*Bearing reliabilities are conservatively based upon an assumed design/actual load ratio of 5 and average rod travel of one complete withdrawal and one insertion between SCRAM demands. (See Text)

Figure 4-9 illustrates the variation of control rod drive reliability with the design to actual load ratio (D/A) and the average rod movement between SCRAMS. The values in Figure 4-9 are shown parametrically as 3 different failure probabilities for the SCRAM brake mechanism or alternatively the probability of significant environmental inputs.

It should be noted that Figure 4-9 indicates that bearings and gears contribute little to the unreliability of a control rod drive if the control rod drive receives little usage and the design to actual load ratio is relatively large. If control rods were moved or SCRAMMED frequently, and if the load ratio were relatively small, then the bearings and gears could become the major contributors to the unreliability of the control rod drives. In the absence of valid reliability data, it is difficult to determine the full contribution of these components, but the routine drop tests on the control rods of the Ft. St. Vrain reactor may provide useful information in this regard.

In order to assess the effect of the reliability of the individual control rod drives on the probability of multiple rod SCRAM failures, the SCRAM program, described earlier, was run for very small brake power SCRAM failure probabilities (such as were experienced in accident cases 5, 6, and 7) and for different values of individual control rod drive failure probabilities and common mode failure probabilities. As discussed later, these common mode failures are most likely due to earthquakes larger than the Safe Shutdown Earthquakes. The results of the SCRAM runs are plotted in Figure 4-10.

The effect of different component failure probabilities may be assessed by using the sensitivities of Table 4D-15 to calculate a new value of Σ_F for the control rod drive failure probability. This value can then be used with Figure 4-10 to determine the probability of multiple rod pairs failing to SCRAM. The effect of bearing and gear load ratio and usage variations on multiple rod pair failure can be evaluated by joint use of Figures 4-9 and 4-10.

FIGURE 4-9. VARIATION OF CONTROL ROD DRIVE RELIABILITY WITH BEARING AND GEAR PARAMETERS

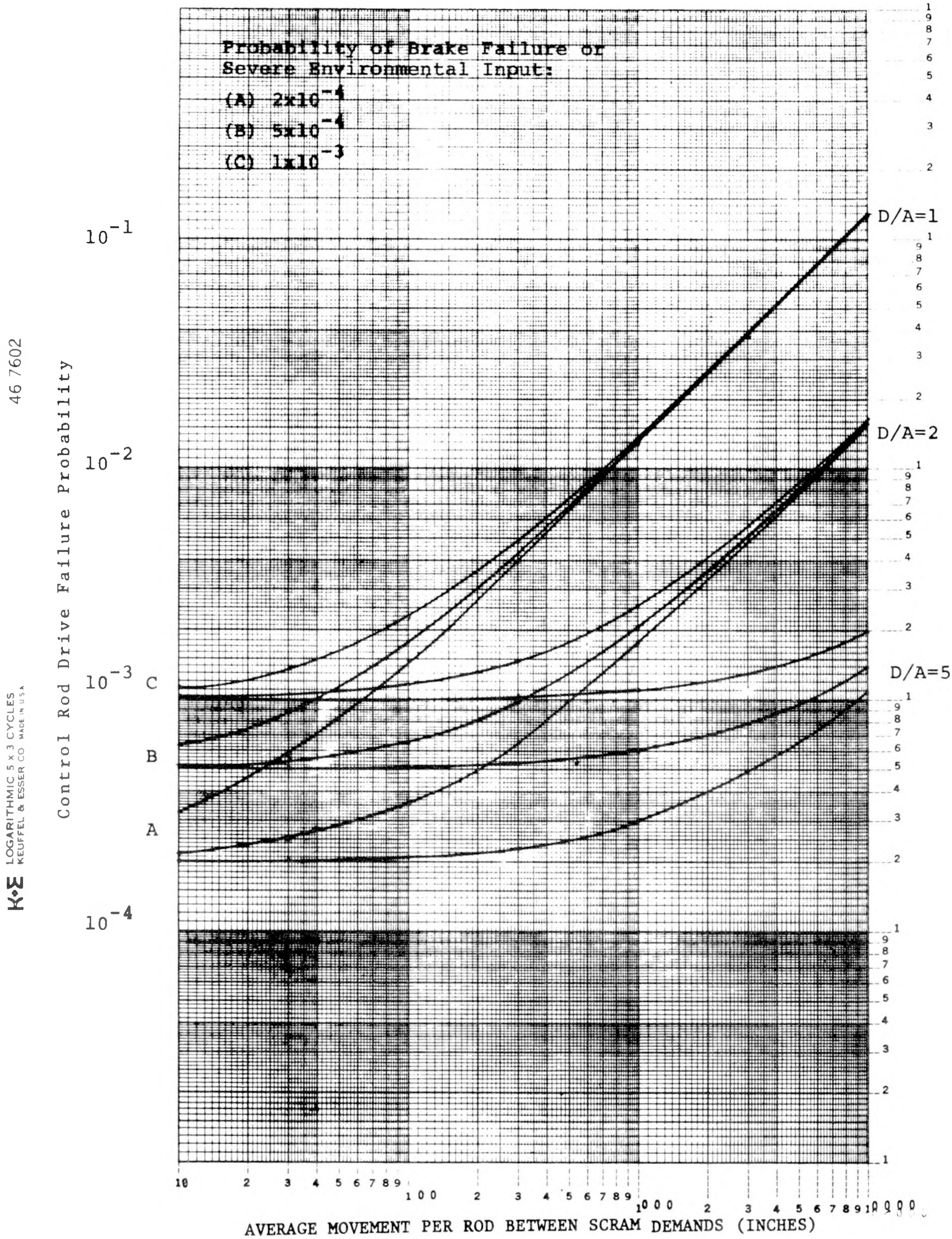
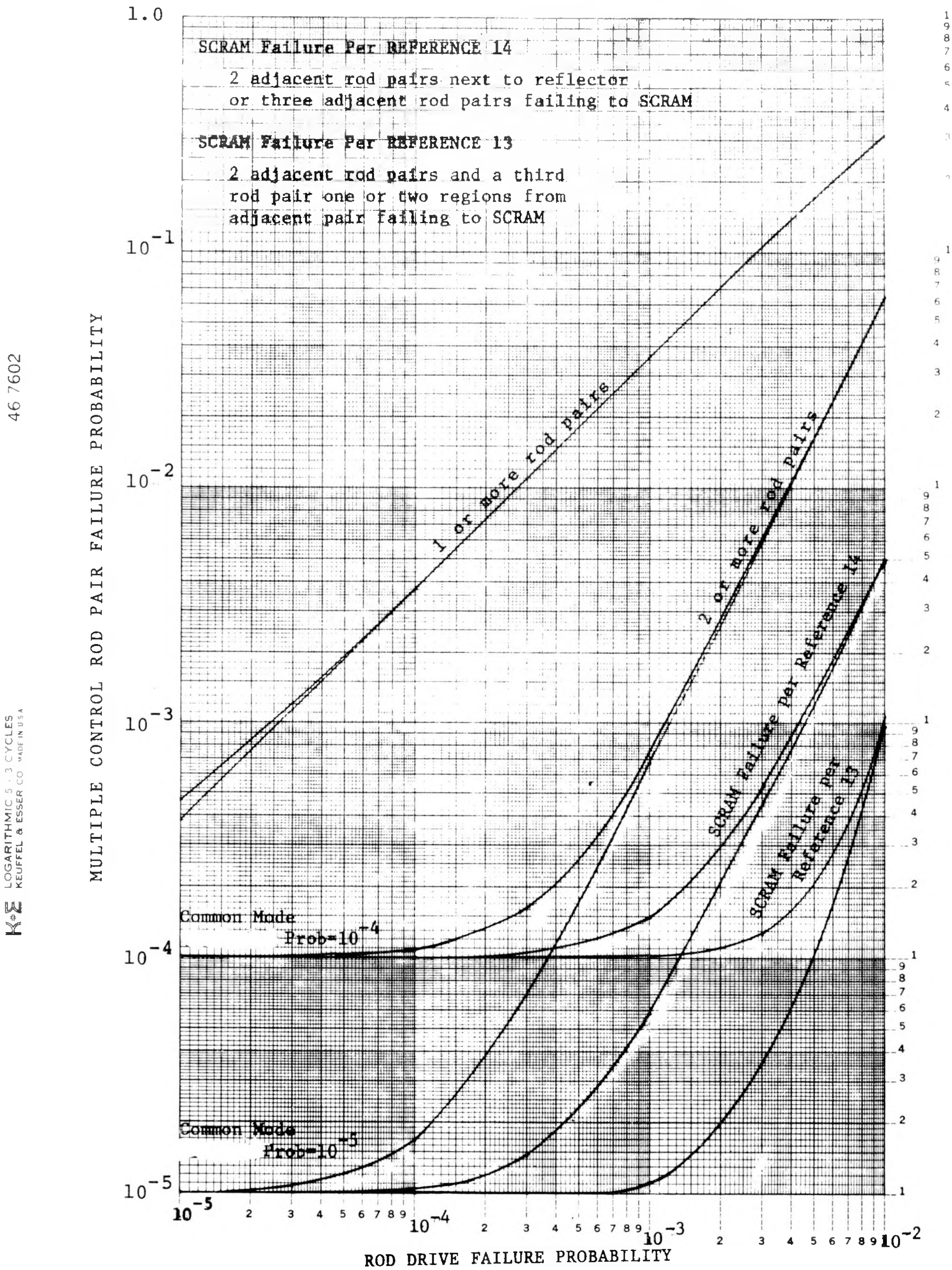


FIGURE 4-10. MULTIPLE ROD PAIR FAILURE PROBABILITY



As Table 4D-15 shows, the greatest contribution to control rod drive failure probabilities are the disk brake components with a total contribution of 3.2×10^{-4}. For comparison, Reference 5 reports electrical clutch failure probability from 10^{-4} per demand to 4×10^{-3} per demand with a best estimate of 3×10^{-4}. This indicates that the estimate of 3.2×10^{-4} appears to be reasonable.

Figure 4-10 demonstrates that the effects of control rod drive failure probabilities of approximately 5×10^{-4} would be overwhelmed by common mode failure probabilities of 10^{-4} and at least equaled by common mode failure probabilities of 10^{-5}. In using these SCRAM failure probabilities, it should be noted that even if SCRAM failure were to occur, a reserve shutdown system is available, which acts to reduce the reactivity to a safe level. The reserve shutdown system was not analyzed in this study.

7. Common Mode Control Rod Failures

Reference 18 states that nuclear power reactor operating experience (to 1973) has resulted in two instances of protection systems being in a condition where the primary SCRAM system was not operable. A light water moderated reactor was involved in one case while the other case involved a graphite moderated reactor. Each instance was the result of an unanticipated common mode failure. Statistical analysis of this operating experience in Reference 18 indicated that with 90% confidence, the probability of such a common mode failure occuring lies between 9×10^{-6} and 1.6×10^{-4} per reactor month.

Although the bulk of the power reactor operation experience does not apply directly to the HTGR at Fort St. Vrain, the HTGR SCRAM system seems to be of comparable complexity to those in other power reactors. Consequently, rounding to the nearest half-order of magnitude, it is estimated that like most other power reactors, the probability of an undiscovered common mode control rod drive failure lies between 10^{-5} and 10^{-4} per month.

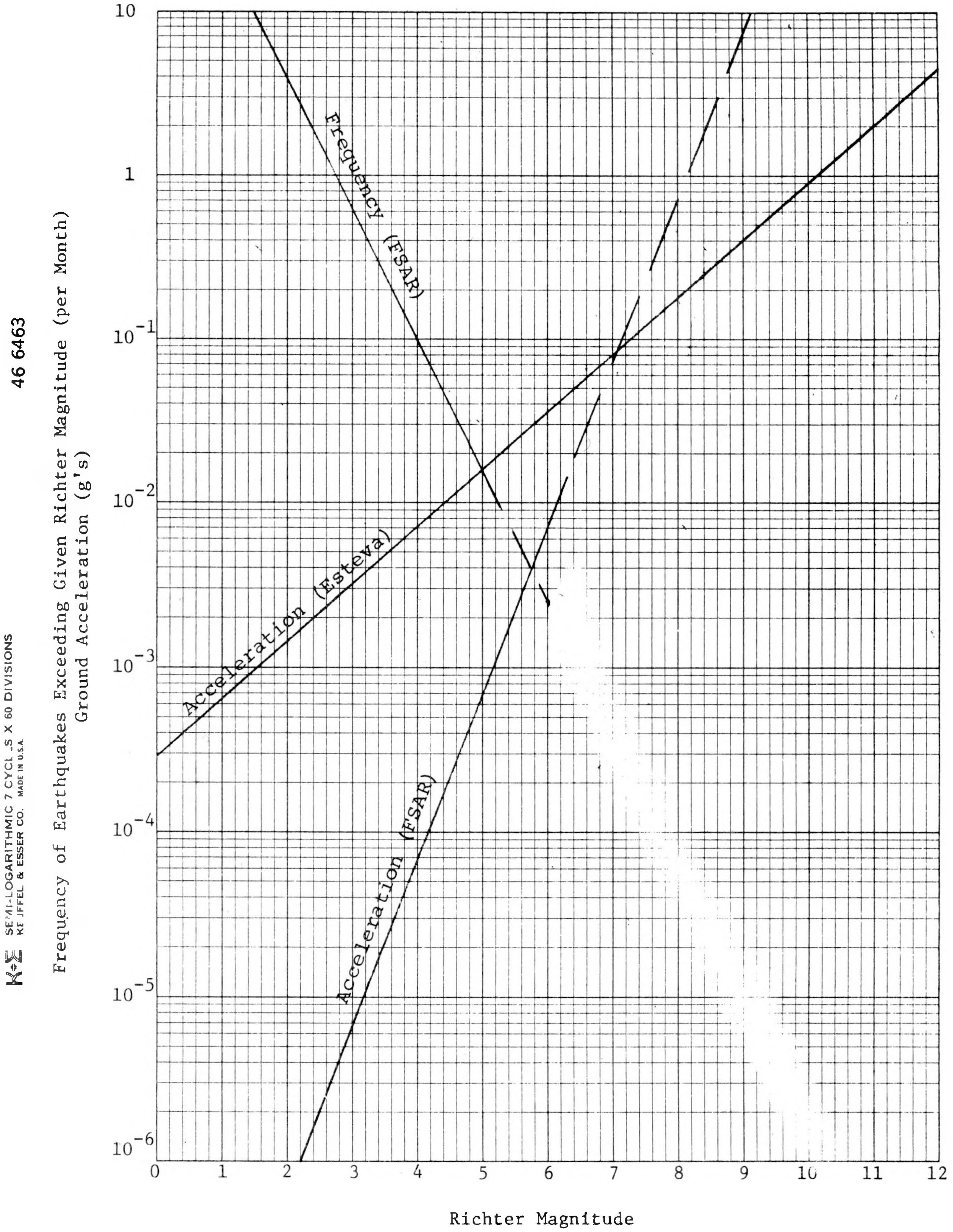
Earthquakes

In an attempt to further define the common mode control rod drive failure probability, an investigation has also been made of seismic disturbances which might contribute to such failures.

The nearest recent seismic activity to the Fort St. Vrain site is at Derby, 40 Km away. This region appeared to be inactive until 1962. It has been suggested, but not universally agreed (References 7, 11, 12), that the Derby earthquakes were activated by waste fluids pumped into the ground by the Rocky Mountain Arsenal. Although the disposal of waste in this manner was discontinued in 1966, the earthquakes continue. Three Derby earthquakes with magnitudes between 5.0 and 5.5 occurred from 14 to 21 months after the waste disposal stopped.

Figure 4-10a contains a plot of the frequency of occurrance of Derby earthquakes exceeding given Richter magnitudes. These frequency data were obtained from References 7 and 11 and were collected from 1962 through 1967. It should be noted that the use of data obtained during the injection of waste fluids may bias the frequency plot upward. On the other hand, more earthquake energy was released in 1967 after the waste water injection had ceased, than was recorded in all prior years. References 7 and 9 both caution against a reliance on extrapolated frequency versus magnitude data, because this approach overestimates the frequency of large magnitude earthquakes. Although Reference 16 suggests that such curves may remain linear at least as high as magnitude 7.5 or 8 in some areas, geological evidence (Reference 17) raises doubts

FIGURE 4-10a. EXTRAPOLATED EARTHQUAKE FREQUENCY AND INTENSITIES AT FORT ST. VRAIN



as to the probability of Derby earthquakes exceeding magnitude 6. Consequently, the frequency magnitude plot of Figure 4-10a is not extended beyon Richter magnitude 6.

Figure 4-10a also contains plots of the anticipated maximum acceleration at Fort St. Vrain as a function of Derby earthquake magnitudes. The acceleration plot labeled "FSAR" is from Reference 7 and the one labeled "Esteva" was computed from an approximation developed by Esteva (Reference 10). Although the two acceleration plots are significantly different, they intersect near the designated Safe Shutdown Earthquake intensity of 0.1 g's. This indicates that accelerations greater than this value would result from Derby earthquakes of Richter magnitude 7.3 or greater. Somewhat larger earthquakes would probably be needed if a common mode control rod failure were to result.

Additional insight might be gained by using the Modified Mercalli Scale (Table 4D-17) to estimate the point at which a common mode control rod failure would seem likely.

TABLE 4D-17. THE MODIFIED MERCALLI INTENSITY SCALE

1. Not felt. Marginal and long-period of large earthquakes.

2. Felt by persons at rest, on upper floors, or favorably placed.

3. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

4. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of 4, wooden walls and frames crack.

5. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

6. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, and so on, off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D* cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.

7. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D* including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, unbraced parapets, and architectural ornaments. Some cracks in masonry C*. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

8. Steering of motor cars affected. Damage to masonry C*; partial collapse. Some damage to masonry B*; none to masonry A*. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

9. General panic. Masonry D* destroyed; masonry C* heavily damaged, sometimes with complete collapse; masonry B* seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

10. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

11. Rails bent greatly. Underground pipelines completely out of service.

12. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

*Masonry A, B, C, D. To avoid ambiguity, the quality of masonry is specified by the following lettering (which has no connection with the conventional Class A, B, C construction).

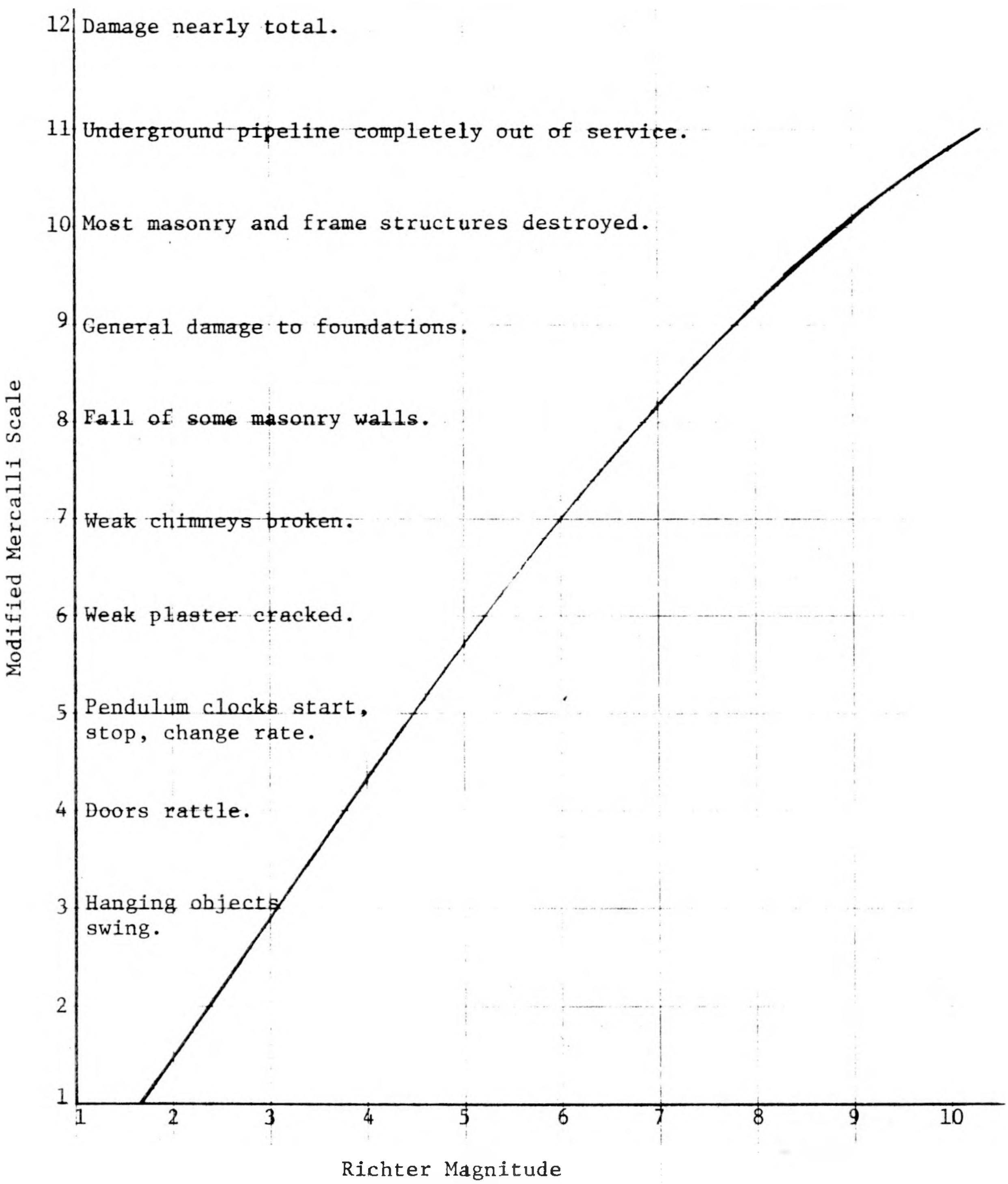
Masonry A. Good workmanship, mortar, and design; reinforced, expecially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

FIGURE 10b. APPROXIMATE CORRELATION BETWEEN RICHTER AND MODIFIED MERCALLI SCALES, 40 KILOMETERS FROM EPICENTER



Reference 9 contains an approximate relationship between the Modified Mercalli Intensity and the Richter magnitude as a function of the distance from the earthquake center. Evaluating this relationship for a distance of 40 Km (the approximate distance of Fort St. Vrain from the Derby activity) provides the curve shown in Figure 4-10b.

It seems reasonable to suppose that an earthquake of Modified Mercalli Intensity 9 or 10 could result in a multiple control rod SCRAM failure. At Fort St. Vrain this would be roughly equivalent to Derby earthquakes of magnitude 7.8 to 8.8. Since the shape of the frequency magnitude curve of Figure 4-10a is not known beyond Richter magnitude 6, the likelihood of such earthquakes cannot be estimated at the present time, but the probability of earthquake-induced common mode SCRAM failure does appear to be somewhat smaller than the total common mode failure probability estimate of from 10^{-5} to 10^{-4} per month.

V. CONCLUSION AND RECOMMENDATIONS

A. SCRAM RELIABILITY, SINGLE SCRAM PARAMETER RESPONSE

1. PHASE 1

Table 5-1 itemizes in ranking order the probability of SCRAM brake malfunction during a 30 day interval for each of the SCRAM parameters in the St. Vrain Plant Protective System (PPS). The failure probabilities are listed at both the input and output of the SCRAM Brake Relay Matrix. The table does not indicate any distinction between overt and covert malfunctions. However, the sensitivity tables in Section III of this report itemize the significant components in each SCRAM parameter circuit for which failures may be annunciated. Those component failures which may result in a trip have been built into the model and contribute to spurious trips and/or SCRAMS. These trips are almost always alarmed and are indicated as such on the Sensitivity Tables. Some of the SCRAM parameters are monitored and logged on a daily basis. This has been taken into account in the final SCRAM Brake Output Column.

The exceptions to this rule are indicated in the table listings. Since the start time for a thirty day test and inspection interval is distributed weekly among the various SCRAM parameters, the PPS system is not uniformly degraded at the end of each 30 day interval.

The table also indicates that all of the SCRAM Protective system sensors will trip on loss of power, and all main SCRAM parameters will trip on a line open condition. Human error probability for each of the SCRAM studies was arbitrarily set at .001.

The combination of daily monitoring and the improvement for independent SCRAM parameters obtained by driving through the two-out-of-three SCRAM relay matrix will tend to drive the SCRAM parameter malfunction probabilities to the appreciably lower values indicated in the output columns of Table 5-1.

TABLE 5-1

*PROBABILITY OF MALFUNCTION FOR EACH PPS PARAMETER CAPABLE OF INITIATING SCRAM BY RANK ORDER AT THE INPUT TO THE SCRAM BRAKE RELAY MATRIX

		MAXIMUM 30 DAY PROBABILITY OF MALFUNCTION @ SCRAM BRAKE RELAY MATRIX	
SCRAM PARAMETER DESCRIPTION	SECTION	INPUT	[4]OUTPUT
1. [3]Wide Range Flux	M.S.	.0540	1.05×10^{-6}
2. [3]Linear Range Flux	M.S.	.053	1.02×10^{-6}
3. [3]Wide Range Rate	M.S.	.0477	8.2×10^{-7}
4. [3]Circulator Low Speed (Prog. by Feedwater Flow)	C/T	.0532	5.8×10^{-4}
5. [3]Circulator Overspeed (High)	C/T	.0308	3.4×10^{-4}
6. [3]Circulator Seal Malfunction (I)	C/T	.0486	5.3×10^{-4}
7. [3]Reheat Steam Temperature (High)	M.S.	.0314	3.6×10^{-7}
8. [3]Reheat Header Activity (C/T) (High)	C/T	.0456	5.0×10^{-4}
9. [3]Reactor Pressure (Low)-TLT Input	M.S.	.0230	1.9×10^{-7}
10. [3]Core Inlet Temperature	M.S.	.0264	2.5×10^{-7}
11. [3]Reactor Building Temp. (High)	M.S.	.0259	2.4×10^{-7}
12. [3]Feedwater Low Flow (Prog. by Circulator Speed)	C/T	.0372	4.0×10^{-4}
13. [3]Startup Nuclear Channels	M.S.	.0257	3.1×10^{-6}
14. [3]Reactor Pressure (High)	M.S.	.0230	1.9×10^{-7}
15. [3]Loss Circulator Bearing Water (Low)	C/T	.0326	3.6×10^{-4}
16. [3,1]Steam Generator Penetration Overpressure (High)	TLT	.0338	3.4×10^{-2}
17. [1,3]Superheat Header Steam Pressure (Low)	M.S.	.0164	8.1×10^{-4}
18. [1,3]Reheat Header Steam Pressure (Low)	M.S.	.0164	8.1×10^{-4}
19. [3,2]Moisture Detection Monitors	TLT	.0200	2.0×10^{-2}
20. [3,1]Circulator Trips (Manual) (Loop shutdown only)	C/T	.0112	1.1×10^{-2}
21. [1,3]Undervoltage Sense Switch (Low)	M.S.	.0153	7.0×10^{-4}
22. [1,3]Circulator Penetration Pressure (High)	C/T	.0202	2.0×10^{-2}
23. [3]Fixed Feedwater Flow Trip (Low)	C/T	.0194	2.1×10^{-4}
24. [3]Circulator Drain Malfunction (Low)	C/T	.0192	2.1×10^{-4}
25. [3]Reactor Pressure (TLT Output)	TLT	.0220	2.4×10^{-4}

TABLE 5-1 (Continued)

*PROBABILITY OF MALFUNCTION FOR EACH PPS PARAMETER CAPABLE OF INITIATING SCRAM BY RANK ORDER AT THE INPUT TO THE SCRAM BRAKE RELAY MATRIX

		MAXIMUM 30 DAY PROBABILITY OF MALFUNCTION @ SCRAM BRAKE RELAY MATRIX	
SCRAM PARAMETER DESCRIPTION	SECTION	INPUT	OUTPUT
26. [3,2]Steam Pipe Rupture	TLT	.0214	2.1×10^{-2}
27. [3]Superheat Header Temperature (Low)	TLT	.0162	1.8×10^{-4}
28. [3]Reheat Header Activity TLT (High)	TLT	.0068	7.4×10^{-5}
29. [1,3]Manual SCRAM (Control Room)	M.S.	.0011	1.2×10^{-6}
30. [1,3]Manual SCRAM (I-49)	M.S.	<.0011	$<1.0 \times 10^{-7}$

NOTES:

1--Parameters subject to 30 day monitoring only.

2--Partially monitored on a daily basis.

3--Trips on Loss of Power, (or line open condition for all main SCRAM parameters).

4--Output adjusted for monitoring frequency.

*Malfunction values given are maximum and do not generally give credit for 'overt' type failures which may be subsequently repaired and returned to service during a 30 day period.

It will be noted that some SCRAM protective system sensors in the TLT and Circulator Trip sections which are not monitored on a daily basis have apparent total failure probabilities in the range of one to two percent, i.e.;

	MAXIMUM FAILURE PROBABILITIES	
	Total	Covert
Moisture Detection Monitors	.020	.0012
Steam Pipe Rupture	.021	.0096
Steam Generator Penetration Overpressure	.034	.0004
Circulator Penetration Pressure	.020	.0012
Circulator Trip (Manual for Loop shutdown only)	.011	.0011

However, in every case, the estimated covert failure probability is at least a decade lower.

The above parameters are used principally to initiate Loop shutdown or a Circulator Trip which may precede a Loop shutdown. The probability of failing to perform the Loop shutdown or Circulator Trip functions is about one-half the SCRAM values listed above. If one primary coolant Loop happens to be down these five parameters plus others in the two Loop and Circulator Trip protective circuits provide a back up SCRAM function if trouble should develop in the remaining operating Loop. With one Loop down, the SCRAM failure probabilities would again be about half of the values listed above. Since most all SCRAM initiating events will require the trip of more than one different SCRAM parameter, i,e,; introducing functional diversity the probability of not getting a SCRAM becomes very small. Thus, the relatively lower probabilities of success encountered in these five parameters are more of academic interest for improving overall SCRAM protective circuitry in future designs.

MAIN SCRAM BUS

Between the main SCRAM input GATE and the SCRAM Brake Relay Matrix, there appears to be only one significant possibility for a circuit malfunction that could result in a SCRAM inhibit from the sensor inputs. That is the probability of a short to power within two of the XCR2 SCRAM Relay Drivers or equivalently a short to power within three or four of the six heavy-duty SCRAM contactor relays. The probability of either of these two things happening without outside interference is of the order of 10^{-6} or less.

Finally the presence of two Manual SCRAM capabilities plus Reserve Shutdown (Injection of Boron balls) provide a second and third line of defense against failure of the automated SCRAM Protective System.

Thus, even the weakest parts of the system have only a small effect on SCRAM reliability, due to extensive use of redundancy and functional diversity.

2. PHASE 2

During Phase 2 of this study the GO model was extended from the main SCRAM gate through the control rod brakes and the 37 control rod drives. This extended model and a simplified multiple rod model were used to evaluate the response of the SCRAM system to six high risk accidents. The accident cases revealed the following:

a. The SCRAM system from the main SCRAM gate to the control rod brake power signal reduces the SCRAM failure probability (P) of independent SCRAM channel inputs (i.e., all inputs except the Two Loop Trouble input) to approximately $3P^2 - 2P^3$. In addition, the internal components from the main SCRAM gate to the control rod brake power signal contribute a failure probability to the SCRAM brakes of approximately 3×10^{-6} for each of the accident cases.

b. The SCRAM system from the main SCRAM gate to the control rod brake power signal reduces the premature SCRAM probability (p) for the independent SCRAM channel inputs to $3p^2 - 2p^3$. However, the intervening internal components introduce an additional maximum premature SCRAM probability* of approximately 1.0×10^{-2}.

c. The two-out-of-three logic following the main SCRAM gate does not improve the reliability of fully correlated inputs to the main SCRAM gate such as the Two Loop Trouble input (which does use local coincidence and dual logic).

d. For those accident cases in which multiple independent SCRAM signals were present, their contribution to the SCRAM failure probability at the input to the two-out-of-three relay matrix was smaller than subsequent component failure probabilities from the main SCRAM gate to and including the relay matrix.

*Annunciation and repair of single channel failures will substantially reduce the premature SCRAM probabilities.

e. Accident case 4 resulted in a larger SCRAM brake release failure probability than the other accident cases (approximately 4×10^{-5} vs. 8×10^{-6}), because a minimum number of SCRAM parameters contributed to the SCRAM signal.

The control rod drives were studied, using the GO model, to determine their effect upon SCRAM reliability. Evaluation of the control rod drives resulted in the following conclusions:

(1) SCRAM failure probability is insensitive to the reliability of the rod control system components.

(2) Control rod drive SCRAM reliability depends in large measure upon the reliability of the disk brake components and upon the probability of severe environmental factors involving common mode failure. The SCRAM reliability of an individual control rod drive is sensitive to the reliability of gears and bearings, especially the shim motor bearings. It is, therefore, important that the gears and bearings be highly reliable.

(3) The unreliability of gears and bearings is proportional to the amount of use they receive and is strongly dependent upon the ratio of actual load to design load. While the "conservative design" of the gears and bearings apparently result in sufficient reliability, the relatively high sensitivity of SCRAM reliability to these components suggests a need for their reliability to be fully verified. The three shim motor bearings require the greatest attention, not only because they are the most sensitive components, but also because the control rod drive gearing causes them to experience more motion (and possibly more wear) than the other bearings. Because of the gearing, the effect of friction in the shim motor bearings on the control rod motion is greatly multiplied and might be expected to increase with time as the bearings wear.

(4) With the relatively higher sensitivity to bearing motion frequent premature SCRAMS might contribute to an increased probability of SCRAM failure.

(5) If the estimated probability of SCRAM failure is 5×10^{-4} for each control rod drive, the joint probability of SCRAM failure becomes approximately 2×10^{-2} for one or more of the 37 control rod pairs, 2×10^{-4} for two or more rod pairs, and 2×10^{-5} for two adjacent rod pairs next to the reflector or any three adjacent rod pairs. The probability of two adjacent rod pairs and a third rod pair one or two regions from the adjacent pair failing to SCRAM would be approximately 1.0×10^{-5}. This latter value is dominated by an assumed common mode failure probability of 10^{-5}.

B. Human Interface Effects

The effect of Human Interfaces on the operation of the SCRAM sensor channels appears to have a tendency to cause more prematures than failures. If the surveillance and operational procedures are carefully followed with a team of two operators or technicians each checking the other, the impact of the Human Interface can be kept acceptably low. However, if this dual checking concept is not followed, the Human Interface effects can increase by better than an order of magnitude. Table 5-2 summarizes the contribution of Human Interfaces on single channel, single loop sensor system performance. The Wash 1400 value of .01 was used for an estimate of the probability of single human operator failures for this table.

As indicated in the Table Notes, many of the Human errors which might be executed result in annunciator trips which are quickly detected and corrected. It is estimated that this has the effect of reducing the impact on single channel, single Loop failures by about one order of magnitude from the values listed in the table.

The main SCRAM sensor circuits in which human intervention seem to have the most impact appear to be the Core Inlet Temperature and Reactor Pressure circuit, due primarily to the greater number of in-line operator/test switches. The portion of the system in which the human appears to have a minimum of effect is in the Two Loop Trouble circuits which are tested in logic parallel with the main trip circuit rather than in-line. All of the system sensor circuits seem equally prone to prematures when human actions are involved.

C. System Redundancy

The large amount of redundancy used in the design of the Fort St. Vrain SCRAM Protective System has been very instrumental in reducing the sensitivity of most all the SCRAM sensor elements, i.e., the detecting sensors, their preamplifiers, signal conditioning equipment and Bistable trip units. The most sensitive portion of the sensor system is, as expected, concentrated in the in-line SCRAM logic elements after emerging from the two-out-of-three voting circuits. This would include the Motorola Gating circuits, Invertors, Time Lock Out Units, etc. However, the design of the SCRAM system has taken this into account by providing parallel output lines in the areas of possible vulnerability.

It should be noted that the presence of 37 control rod drives in the SCRAM system does not necessarily imply a great deal of redundancy. For example, there are 37 different ways in which one control rod pair can fail, 666 ways in which two control rod pairs can fail and 7770 ways in which three control rod pairs can fail. If the criterion for success were the SCRAM of all 37 rod pairs, there would be no redundancy at all.

TABLE 5-2

HUMAN INTERFACE CONTRIBUTIONS

Single Channel/Single Loop

System	Probability Failure		Probability of Premature (Spurious Trips)	
	Mean	High	Mean	High
Main SCRAM	.015	.030	.018	.030
Two Loop Trouble	.003	.010	.011	.020
Circulator Trip	.009	.020	.018	.020

NOTE: Above values for Human Interfaces were evaluated by using pessimistic Wash 1400 values of 0.01 for Human operator failure to correctly perform normal monthly testing, checkout, and circuit restoration procedures. Many of the errors which might occur are annunciated which has the effect of lowering the effective operator failure probabilities from .01 to the values used in the analysis of the sensor hardware, i.e.; .001, or alternatively of lowering the single channel, single loop failure values listed above by one order of magnitude.

D. Recommendations

1. The preceding analysis has shown that the probability of SCRAM failure is small. In fact, unidentified common mode failures will probably be dominant. The largest contributors to SCRAM failure have been identified to indicate possible improvements in future reactors, if these improvements are considered to be worthwhile.

2. Test, maintenance, and pre-startup procedures should insure that the above operations are carried out by a minimum of two people each independently checking the work of the other. This will not only reduce the number of possible SCRAM failures but will help to increase plant availability by reducing the tendency toward spurious SCRAMS.

3. Design of SCRAM protective systems in future HTGR's could incorporate built-in automatic testing provisions similar to that used the St. Vrain Two Loop Trouble System to enable automatic circuit and SCRAM parameter testing logically in parallel with the main SCRAM line; i.e., without switching or inhibiting the main SCRAM line functions. This would reduce the impact of maintenance errors on both reliability and availability.

4. The reliability of the mechanical components in the control rod drive mechanism should be reviewed in detail. This is especially true of the brake components and the gears and bearings. The SCRAM system reliability is dependent upon the reliability of the shim motor bearings and the reliability of these bearings is dependent upon the amount of use the control rod drives experience. These factors should be considered in conducting an extensive review of control rod drive reliability.

Recommendations (Continued)

5. The design of SCRAM systems for future HTGR's might consider the possibility of (a) using independent SCRAM rods to avoid the complexity introduced by the use of mechanical rod drives, or (b) decoupling the rods from the mechanical drive during a SCRAM.

APPENDIX A

GO METHODOLOGY AND SCRAM PROTECTIVE SYSTEM DESCRIPTION

APPENDIX A-1

1. <u>GO Methodology</u>

a. General

The Kaman Sciences GO methodology and computer code have been developed over a period of years as part of a procedure for analyzing the reliabilitis of complicated systems. The primary motivation was to produce a computer routine which could, with a minimum of scientific labor, quickly, economically and comprehensively analyze the reliability and safety of complex hydraulic, pneumatic and electromechanical networks involving hundreds of components having two and often three or more modes of operation.

The GO methodology, which is a refinement of the classical approach to reliability, has been used extensively for several years. The modeling required corresponds in a natural way to the functional drawings or schematics. Attention is focused individually on constituent subsystems or piece-parts identifying all possible operational modes, as differentiated from the fault-tree method which constrains the documentation to operational modes causing the defined event of interest.

Using this generalized approach the computer program, rather than the analyst as in the fault-tree or equation writing techniques, systematically creates and retains the various event combinations bearing on both the central problem and all other significant system operational modes. Because the logic, other than the component interactions, is handled automatically, significant savings in scientific labor are achieved, and increased knowledge of system responses is obtained as contrasted with either the classical equation writing or the fault-tree approaches to reliability assessment.

b. Description

The GO program is a probabalistic combinatorial analysis procedure. Components are identified by their input signals, output signals, and probabilities of operation in different modes (success, premature and failure). The GO chart is a diagram of component interactions through the signal paths. The modeling required includes selection of the proper standard GO component to represent the physical components and the identification of signal paths. This modeling is direct and simple, since the chart can be drawn in one-to-one correspondence with the schematic, almost as an overlay.

The heart of the method is the computer program which follows all signal paths and combines probabilities from initial components to end results. Thus, the analyst need not concern himself with finding failure paths, identifying common mode failures, computing redundant or voting logic probabilities (parallel paths or m-out-of-n coincidences), etc., since the computer does this naturally. Sequential events can be included since the logic includes distinct time intervals (usually 8, although more can be used), for which probabilities can be assigned. In general, time period 0 is used to indicate the presence of input signals at the start of the problem (power on, water tank full, completion of maintenance, etc.), or for premature operation with regard to components or output signals. Time period 7 (if 8 periods are used) indicates 'never,' which means a failure since the output signal never arrived. Time 7 can also be used for input initiators which indicates that the input being represented never came. In some cases a system has several auxiliary circuits and the analyst may wish to examine the primary circuit only, even though the total model is available. The model and input deck could be modified, but in many cases it is easier to put perfect initiators at time 7 on the auxiliary circuits for early runs and change them to real times and probabilities later for complete system runs.

The probabilities of one or many events occurring as a function of time can be determined by selecting the desired signals to be retained as outputs. The code will retain a signal until it has been used for all necessary following inputs. Then the signal will be deleted from the problem (unless required as an output) in order to keep the array as small as possible. This deletion is one of the keys to the speed and economy of the method, since array size partly determines computer cost.

Another technique for improving speed and economy is the elimination of signal paths which lead to a failure probability less than a specified constant (perhaps 10^{-8} for a problem where the important events have failure probabilities 10^{-5}). These paths are deleted and not followed further, but all deleted probabilities are summed and the final sum of the "throwaway" is printed. Comparison of this value with the output for desired events will assure that an unusual comtination of multiple events has not caused a significant error.

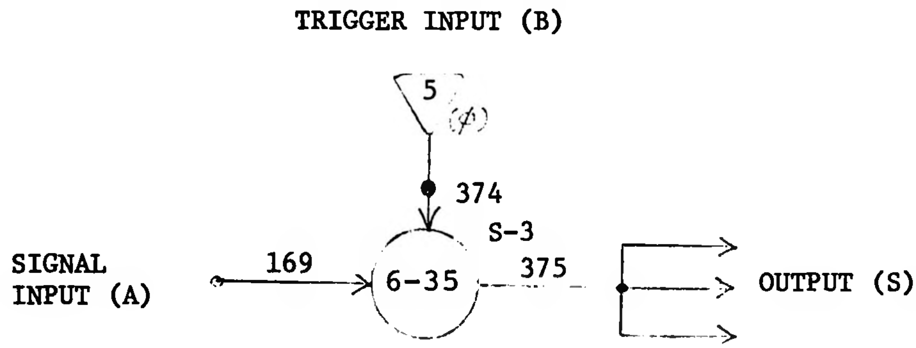
APPENDIX A-2

2. GO Modeling Techniques

a. Signals

The concept of a "signal" is basic to the sequential analysis and combinatorial processes of the GO methodology. Components are identified by signal numbers, as are computations and results. However, the term "signal" is not constrained to current in a wire as in the electrical sense, or even to informational content as in logic flow diagrams. The "signal" could be water in a pipe leading to a valve, pneumatic pressure in an instrument air system, torque on a shaft, mechanical pressure on a lever or gear, or even the absence of a true signal. The code simply combines input probabilities (in the manner specified by the GO Type component used) with the component probabilities to determine the output probabilities in the discrete time periods allowed.

The use of a GO "signal" to represent the absence of a signal deserves more consideration. Many circuits in safety systems are designed to be fail-safe; i.e., the presence of power is used to prevent a trip (SCRAM, Rod Withdrawal Prohibit, Loop Shutdown, etc.). Thus, an initiating signal requesting a trip actually removes the physical signal (power) to cause a trip. An open circuit also removes power and causes a trip, which is the desired fail-safe result. This logic could be modeled by converting the GO code, essentially into a STOP code, but there are easier ways to handle the required logic. One of these is to invert the signal logic so that the transmitted signal becomes "NOSIGNAL". A certain amount of caution must be exercised with this technique, because the time sequences are also inverted. Thus, prematures occur in time 7 and failures occur in time 0. This technique was used on the main SCRAM logic in this study and will be discussed in more detail in that section. Inverse logic is especially appropriate for the SCRAM system because the SCRAM signal



169, 374, 375 : SIGNAL NUMBERS

6 : TYPE NUMBER (NORMALLY OPEN CONTACTS)

35 : KIND NUMBER

$T_S = \text{MAX}(T_A, T_B)$: NORMAL

$= T_A$: PREMATURE

$= \infty$: FAILURE

FIGURE 1

COMPONENT IDENTIFICATION

removes control rod brake power from the rods, allowing them to fall into the reactor. Thus, the signal is defined as "NOSCRAM", which is equivalent to control rod brake power being present.

b. Components

Although many types of components exist in the various mechanical, hydraulic and electrical circuits of interest, it has been found that all of them can be modeled by proper application of only 11 types of components. These 11 have been chosen as standardized components and modeled in the code. They include components with a single input (Types 1 and 3), normally open and normally closed switches or contacts (Types 4, 6 and 7), perfect OR and AND gates (Types 2 and 10), perfect and probabilistic initiators (Types 5 and 11), and time generators (Types 8 and 9). The complete description of these components is given in the Appendix.

The nomenclature for a typical component is shown in Figure 1. The components are represented by circles for all components except the initiators (5 and 11) for which triangles are used. The type number is the first number in the circle. For imperfect components a second number (kind number) is used to distinguish between various kinds (rotary switch, toggle switch, relay contacts, etc.) which have different reliabilities.

The output signal number (375) is the unique identifier for this specific component. This output may go to several other components as indicated by the multiple arrows. The inputs A and B are the primary signal and the "trigger" (denoted by the small circle on the input arrow) which closes the contacts. These signals may come at different times and the output signal is not produced until both input signals arrive. Premature closure of the contacts will give an output at the time of Signal A. An additional identifier may be used by the analyst to help tie the GO chart to the logic diagram or schematic. In this case S3 is the identifier (for switch number 3), which is usually the same as the nomenclature on the schematic or an easily recognizable abbreviation thereof. This identifier is not used anywhere in the code - it is only a convenience for the analyst.

Each component kind has its own set of probabilities. For the type 6, the probabilities to be entered are:

P1: Premature

P2: Success

The failure probability is computed internally as 1-P1-P2. A 6-35 type component will carry the same probabilities throughout the model. If a different kind of component type 6 is used elsewhere with different probabilities, it is given a new kind number (perhaps 6-36) and the appropriate probabilities are entered for 6-36.

c. GO Chart

Development of the GO chart consists of matching the circuit components with GO components and connecting them with signal arrows to correspond to the logic flow diagram or schematic. Occasionally, pseudo-components are added to correctly represent the logic of the physical system. A simple example is given in Figure 2. The circuit consists of a Bistable trip (circuitry simplified) with relay output and a manual switch. This unit is normally operated with the relay energized and contacts closed with low input. When the signal goes high or a failure opens the circuit driving the relay, the relay is de-energized and the contacts open. The circuit following the Bistable may be normally biased high but its input is held low by the ground through the relay contacts. When the ground is removed by

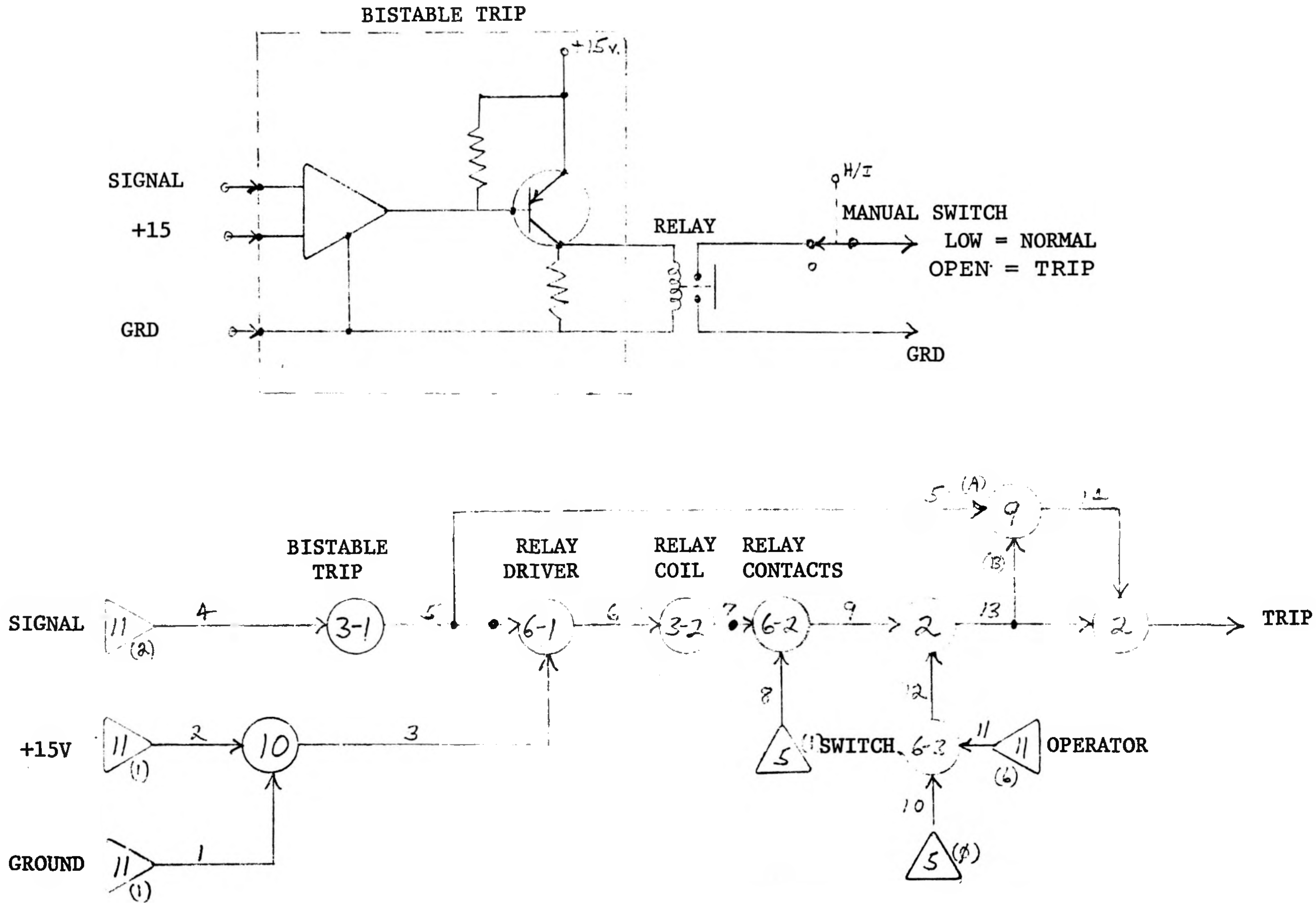


FIGURE 2

EXAMPLE OF GO CHART DEVELOPMENT

the contacts or the manual switch opening, the following input goes high initiating a trip. The circuit is "fail-safe" from the relay driver forward since an open line will cause a trip in the following logic.

The GO chart shown below in Figure 2 starts with Type 11 initiators for the signal, +15V, and ground inputs. The numbers in parentheses (2 for signal and 1 for +15V and ground) are the time intervals when these signals have high probability for occurrence, although the Type 11 can be given probabilities for all time intervals used in the model to indicate probability of improper operation. Ground and +15V are combined in a perfect AND gate (type 10) to feed the relay driver. Electrically, this output (number 3) would be combined with the signal (number 4) into the Bistable trip, since the circuit requires power to operate. However, this combination is not logically required, and, in fact, its inclusion would negate the operation of the fail-safe logic discussed below. Basically this means that power loss should cause a trip, rather than power presence being needed to operate the trip circuit. The signal input goes directly to the Bistable trip, type 3-1, which feeds the relay driver. The relay driver is called a type 6-1 since it is basically a switch. The output signal drives the relay coil type 3-2 which closes contacts type 6-2. A perfect type 5 initiator at time 1 is used as the signal to be transmitted through the contacts.

At this point it should be noted that the relay contacts are normally closed and are opened for trip condition which would seem to require a type 7. However, the GO methodology operates with transmission rather than hindrance logic, so a type 6 is sometimes necessary to model normally closed contacts. When this is done, the failure probability of the type 6 should be the probability of stuck contacts for a normally closed relay. Another problem requiring care in the use of the type 7 is the so-called "race" phenomenon. In the GO methodology if the signal input to the type 7 occurs at the same time as the trigger, the signal will pass through, even though the physical circuit may require that the circuit be interrupted. It would be possible to use another component type such as a type 8 or 9 (time delay components) to eliminate the problem, but it is usually simpler to use the type 6 instead, as long as the proper logic is retained.

The manual switch is normally closed and opened by the operator to cause a trip. This switch cannot be modeled by a type 7 since the operator would then open the circuit and inhibit the trip instead of causing it. Instead the model uses a type 6-3 with a perfect initiator (type 5 at time 0) as the signal to be transmitted with the operator (type 11 at time 6) serving as the trigger input to the normally open switch. The switch output is combined with the main signal line through a type 2 OR gate so that either can cause a trip.

At this point the fail-safe nature of the circuit needs to be considered. The actual circuit will trip if an open circuit occurs anywhere from the relay driver input forward. It would be possible to use the inverse logic mentioned earlier, but this is normally convenient only for major subsystems where the entire subsystem can be inverted. For smaller circuits it is possible to use the type 9 time generator to accomplish this task. The type 9 is a "time machine" which produces output at a time which is a user-specified function of the time difference between the A and B inputs. This function is then added to the time of the A input. Many complex output functions can be handled with this component, but the function for the fail-safe model is quite simple.

The A and B inputs are taken from the input and output, respectively, of the fail-safe portion of the circuit (signal number 5 from the Bistable trip and number 13 from the output OR gate). If the signals come at the same time (as they will normally if the circuit is intact), the time difference is 0, and the delta time (or output function) to be added to the time of arrival of input A is specified as 7 (output times greater than 7 are automatically converted to time 7). Thus, the output of the type 9 component (signal 14) produces no output if the circuit works normally and the normal trip output is produced by signal 13 at the time of B. If B arrives later than A (indicating a failure or open in the main line), the new delta time (or output function) is defined as 0 to be added to the time of arrival of signal A. Thus a fail-safe trip output is provided on signal line 14 at the time the trip signal arrives at the input to the relay driver. The operation of the type 9 is expressed as a set of values of the output function for input to the code. This example is shown in the table below where the first line is the time difference between A and B, and the second line is the time to be added to the time of A.

Time of B signal minus time of A signal (N)	0	1	2	3	4	5	6	7
F(N): Time periods added to time of A	7	0	0	0	0	0	0	0

Output signals 13 and 14 are combined in an OR gate to produce the final trip output, signal 15. The circuit will also fail-safe on loss of power since under these circumstances signal 3 will not reach the relay driver. Thus, the B signal to the type 9 will never arrive and the circuit will produce a fail-safe trip output when the main input signal arrives.

Normally, signal 15 output data will not indicate any distinction between a normal SCRAM and a SCRAM due to component failures between signals 5 and 13. If this information is desired, signals 3 and 13 should be called for output data along with signal 15.

The only situation not included with this model is simultaneous loss of power <u>and</u> signal failure, which should cause a trip. Although the probability of this dual failure is extremely small, it could be modeled in the power supply circuitry by using a type 9 whose A input is switchyard power (or a perfect initiator) with the B input originating at the power supply output. Alternatively, the input and output of signal 3 could be monitored with a type 9 component and its failure probability could be added in as a premature SCRAM.

APPENDIX A-3
GO TYPE DEFINITIONS

1. INTRODUCTION

The basic document describing the GO methodology is "GO, A Computer Program for the Reliability Analysis of Complex Systems", (Reference A), Kaman Sciences Corporation, Colorado Springs, Colorado, April 1968. This document discusses in detail the meaning of the GO symbology and the mathematical manipulations of the program and it is recommended to the serious reader. However, the degree of detail contained in the basic document is not essential to an understanding and use of the GO symbology in developing GO charts. The following descriptions provide additional information on the GO symbology.

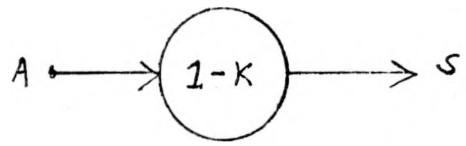
2. GO TYPE DEFINITIONS

To understand the functioning of GO it is necessary to become familiar with the components modeled logically in the program and the physical analogs they may be used to represent. There are 11 types of components modeled. Some types are further defined by the addition of a kind description. Thus one type may have several kinds, e.g., resistors are Type 1 components but differing failure rates may require one kind for each rate. The following paragraphs will describe each of the 11 types, provide physical analogs where applicable and specify the symbols used for GO charts. For details on the signal flow logic see Reference A.

Type 1. Two State Component

This component either passes or does not pass the single input signal.

GO Chart Representation



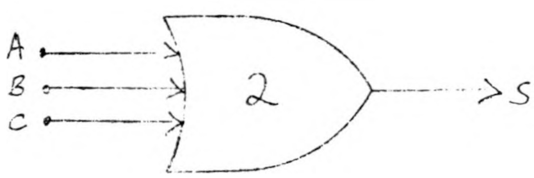
Analogs:

Resistors, diodes, connector pins, wires, vents, pipes, etc. This component also has an application as a potential short circuit.

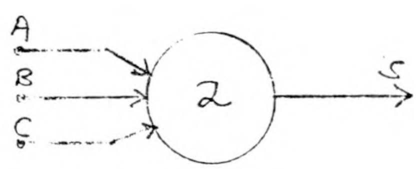
Type 2. Perfect OR.

This component is a pseudo component which is represented by the disjunction of two or more (up to 11 without cascading) signals - that is, an output will occur if any or all inputs occur. This pseudo component is perfect and is not given a kind number or associated probabilities.

GO Chart Representation



OR,



Type 3. Triggered Generator

This particular component was devised to simplify inclusion of electro-explosive devices which commonly have a sequence

* When K is used in the symbols it indicates kind number.

of a resistor, a normally closed contact, and an explosive actuator (which opens the series contact as well as actuating other contacts). The resistor and/or the series contact may be deleted, logically, by making them perfect.

GO Chart Representation

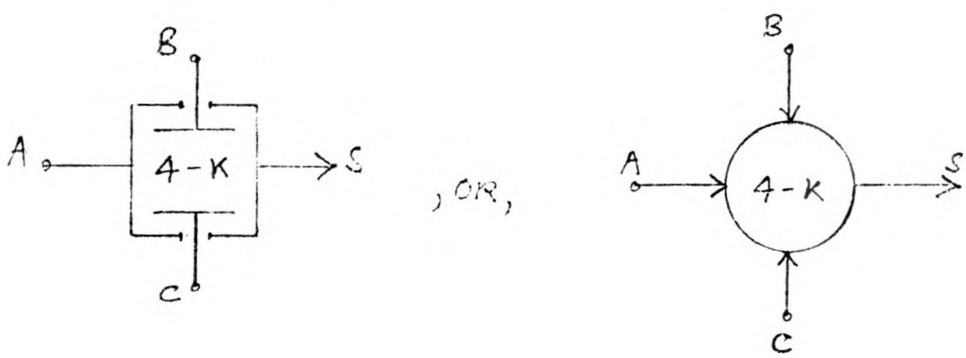
Analogs:

Explosive actuators, relay coils or solenoids, actuating sensors such as accelerometers, actuating motors for pumps or control rods, etc.

Type 4. Normally Open Parallel Contact Pair.

This type may be replaced by two Type 6 components joined by a Type 2, but it occurs often enough to justify separate definition.

GO Chart Representation



A is the main signal to be transmitted requiring the arrival of either secondary signals B or C or both.

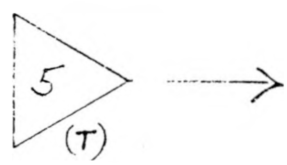
Analogs:

Any of the analogs of a Type 6 in parallel.

Type 5. Non-stochastic Generator

This type generates a signal at a time specified. It is used to provide inputs to the sequential machine. The triangular symbol for this type is also used for a Type 11. These two types are the only ones which have no inputs and every problem must begin with one or more of them.

GO Chart Representation



Where (T) represents the time period signal is initiated.

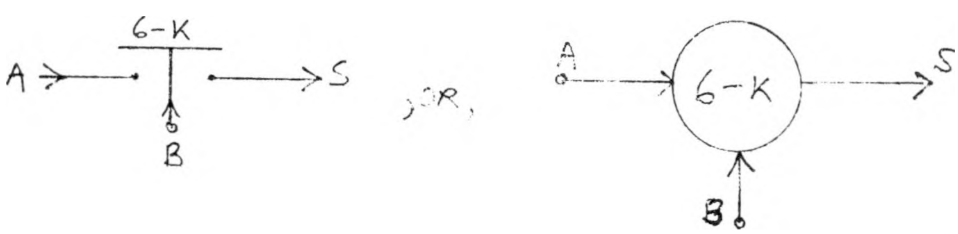
Analogs:

Operator pushes start/stop button, start/stop signal is received, power available, etc.

Type 6. Normally Open Contact

The normally open contact is normally disconnected and then connected for signal flow. A is the main signal to be transmitted when signal B closes the contacts.

Go Chart Representation



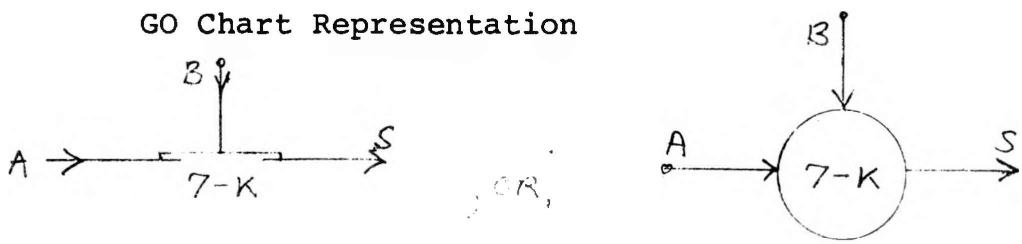
Analogs:

Normally open electrical relay/switch actuated by a solenoid (Type 3 output) or human operator, a normally open hydraulic valve which is closed by an actuating signal, a normally disengaged clutch/gear which engages upon an actuating signal, etc.

Type 7. Normally Closed Contact

Normally closed, permits signal flow unless interrupted. A is the signal to be interrupted upon the arrival of signal B.

GO Chart Representation



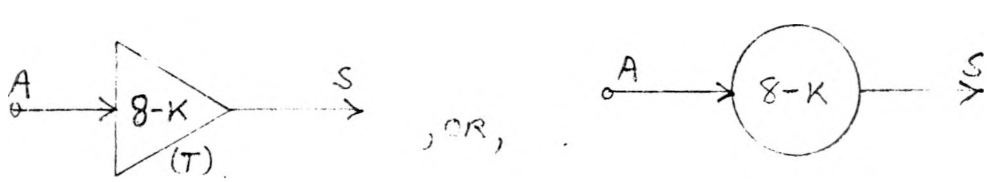
Analogs:

The analogs are the opposite of Type 6. i.e., Normally closed relays, normally closed valves, or normally engaged clutches.

Type 8. Triggered Delay Generator

This perfect type produces a signal T time periods after the arrival of the input.

GO Chart Representation



Where T is the number of time periods of delay.

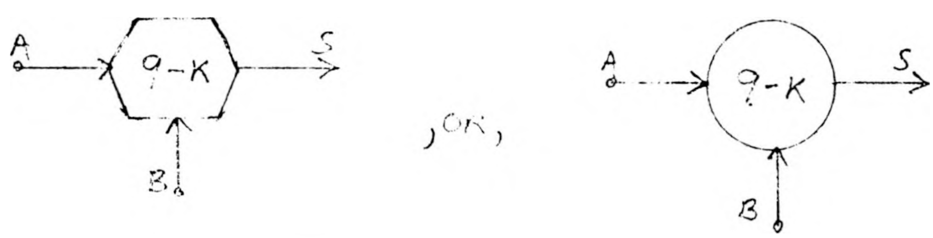
Analogs:

Mechanical or electrical timers, delay lines, powder trains, operator delay approximations, etc.

Type 9. Functional Delay Generator

This type can be used to represent rather complicated timing sequences. No particular physical device is suggested by this type, but it has proven convenient in many instances requiring synchronization. This type - like 2 and 10 - is perfect. In general, signal A arrives first, and signal B arrives N time periods later. The output signal S will then appear F(N) time periods after the arrival of A where the values of F(N) are input.

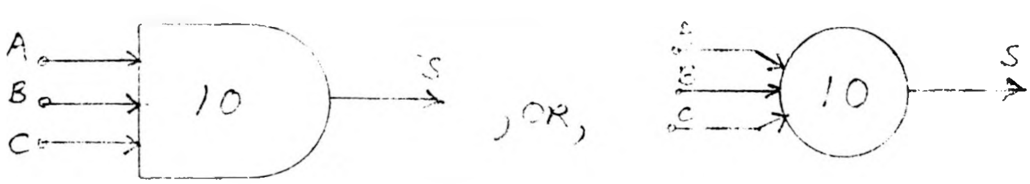
GO Chart Representation



Type 10. Perfect AND

This is a perfect logical device and is used to generate a signal when the last of 2 to N (N=11 without cascading) signals arrives.

GO Chart Representation



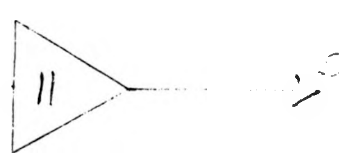
Analogs:

If an "AND" gate is physically present, a Type 1 or some other type may be used in series with the Type 10 to introduce imperfection.

Type 11. Stochastic Generator

This type generates a signal at time instants 0 through M according to the probability distribution defined. It is used to simulate noise (which might actuate an explosive switch, for example) or to provide a normal input which occurs randomly. The values of P(T), the probability of a signal being generated at time T, are input.

GO Chart Representation



Analogs:

The Type 11 signal generator has been used to represent human operator, environmental or mechanical interfaces, clogging of pipes or filters with time, radio frequency interference, and similar basically random events. The requirement that the values of P(T) must sum to unity does not imply large probabilities of occurrance in time periods of interest as the final time period, i.e., never, can contain the bulk of the value.

APPENDIX A-4
SENSITIVITY ANALYSIS

1. INTRODUCTION

If systems were perfect, reliability studies would not be required. Reliability studies do have a part in the attempt to achieve near perfection of the system. Pointing out those components, which, if made more reliable, contribute most to the improvement of system reliability is the purpose of the sensitivity analysis.

2. THEORY

Consider the total reliability R_o of the system with all components considered at their nominal reliability values. Selecting a single component of nominal reliability r_o, assume it is improved to reliability r_1 and determine the new system reliability R_1. Then

$$\frac{R_1 - R_o}{r_1 - r_o} = \frac{\Delta R}{\Delta r} \approx \frac{\partial R}{\partial r}$$

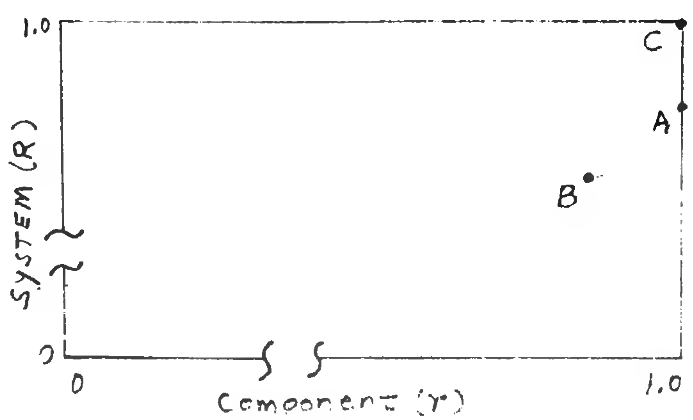
This process can conceptually be repeated for each component until the improvement in system reliability is known with respect to each component. Ordering this list of approximate partial derivatives from the largest to the smallest will provide a list of priorities for obtaining maximum system reliability improvements by component changes.

3. IMPLEMENTATION

GO can be used to implement sensitivity analysis directly as described above. In the analysis at hand, about 15,000 signals are utilized, each implying a component. Assuming about 400 seconds per run to establish system reliability for each imperfect component and 150 components, about 17 hours of computer time would be required. Significant savings in computer time and cost can be achieved through a two stage sensitivity analysis procedure adapted to capitalize upon GO's internal mechanization and the nature of the curves from which the partials are taken.

The bulk of the processing time in GO is utilized in manipulating large bookkeeping arrays of probability distributions. These arrays become single values for a perfect system and thus the run time is significantly decreased.

Several things are known about the general shape of the curve of system reliability vs a specific component reliability. Consider the set of broken axes shown below.



It is known that if r=1.0, R≠1.0 as the system has other imperfect components. It is not known that R=0 if r=0. It is also known that R increases monotonically as r increases. Consider point A to be the system reliability if r=1.0. Consider point B to be system reliability if r=nominal value. The basic question is, "What is the shape of the curve between points B and A"? Now consider the other components. As more and more components are made perfect in the system, both points A and B will move upward. Moreover, the displaced curve will be very nearly parallel to the original. (It must be remembered that the range of r is very small, say from 0.999 to 1.0, in the discussion, which is the reason for the broken axes.) Finally when all components are perfect, system reliability is 1.0 and will be at point C of the figure. Point B will have moved upward also, but now some observations can be made about the shape of the curve between the upwardly displaced point B & point C. If there is only a single component in the system of the kind represented, the curve must be a straight line of slope 1. If there are two components in series in the system, the curve will be concave upward with slope 2 at point C. If the two components are in parallel the curve is concave downward with slope 1/2 at C. (At this time it should be pointed out that the terms series and parallel are being used in the sense of failure only. Prematures behave in series as operational failures behave in parallel and vice versa.) Generally the slope at C will be very nearly an integer reflecting the number of series components of the kind. With a large mixture of series and parallel representations, the slope generally will be very near zero as it represents a high order polynominal constrained to be monotonically increasing in the interval.

A first approximation for the desired partial derivatives may be achieved by making the system perfect and degrading each Kind of component and Type 11 input from perfect by a fixed amount, say by 1×10^{-5}. A common decrement from perfection is utilized to reduce the probability of error in forming the partial, i.e., the decimal point is moved to the right five places in each ΔR. There are only about 150 Kinds in the system. The run time for varying each Kind and Type 11 is minimal as only one set of probability distributions must be manipulated. Only about 75 minutes of computer time is utilized to achieve the first approximations for all 150 components.

Determining the approximate partials accomplishes two purposes:

1) it serves to eliminate from consideration those Kinds of components and Type 11 inputs which have only minimal impact on system reliability; and

2) it serves to order the relative importance of those Kinds of components which may have significant impact upon system reliability.

The ordered list is then screened to consider both the reliability of the Kinds, the Type 11 inputs and their arrangement in the GO chart.

The actual reliabilities are important with respect to the decrement assumed. For example, relays have a probability of failure of .0005 to .002. By using a decrement from perfection of .001, the reliability of the relays has been degraded from actual by an order of magnitude. The same reasoning must also be applied in reverse, specifically in the case of the operator when operator reliability of .98 is assumed to be 0.999.

After minimal rearrangement of order resulting from the reliability considerations above, the GO charts are examined to identify those components of the Kind under consideration which contribute the most to the system unreliability. The examination basically considers whether the components of the Kind are in parallel or series. Those components in series are expected to have the major impact, again allowing for the nature of the failure, i.e., premature or operational.

After the components to be examined are identified, the necessary runs are then made with all other components returned to their nominal reliability values with the single components made perfect. The resultant list of partials, when ordered, then provides the list of components, which if improved, can contribute most to improving system reliability for a constraint improvement in component reliability. System redesign to achieve parallel (series for premature) redundancy of these components can achieve the same objective.

APPENDIX A-5

DETAILED MODELING

A. Nuclear Channels

The eight neutron flux channels in the SCRAM Protection system include two low-level counting channels (primarily for fuel loading) with both neutron count rate and period trips, three wide range logarithmic channels with both flux level and period trips, and three linear flux channels with flux level trips only. A similar set of six linear range flux instruments constitute a ninth channel which is used for flux balancing and power level control. The latter channel is used only for controlling and not for protection functions, so this channel was not modeled as part of the SCRAM system. It serves only as a back-up in the sense that the detectors for this channel can be connected into the protection system by cable changes if any of the sensors in the protection channels fail.

The initial logic diagram for the nuclear channels (Figure 1) were taken from ELJ169-3111 (System Schematic - Nuclear Channels) and ELJ169-3109J (Sytem Schematic - SCRAM Channel). Additional details were needed so more detailed logic diagrams (Figures 2,3 and 4) were developed from the complete schematic in the PPS Instruction Manual.

(1) Start-up Channel Logic DWG No.: FSV 4E

The interconnection schematic for the start-up channel is number ELJ194-0010E. Each of the two start-up channels consist of a B^{10}-lined proportional counter mounted in a shield well, a preamplifier mounted near the detector and a linear and log count rate drawer in the control room. The linear circuitry contains a conventional pulse amplifier, discriminator, driver, and a diode pump circuit. The output from the diode pump feeds the linear trips as well as a rate of change amplifier for period trips which has a range of -1 to +7 decades per minute. Calibration switches and test switches are provided for both linear and logarithmic signals. The calibration switch is designed to trip the channel since it disables the signal input. The test switches do not trip the channel (except for the low count rate rod withdrawal prohibit) since these switches add a signal to the existing signal and will not prohibit a normal SCRAM request.

The low voltage power supplies are contained in the drawer and supply power through drawer and board interlocks so that if some of these elements are out of position, the +15 volt power is not available. The low voltage power supplies are fed out of the drawer to the wide range channel and then returned as inputs to the high voltage power supply for the detectors. This is done to provide a disconnect of the detector high voltage when the power level (as sensed by the wide range channel) is greater than 10^{-3}% of total power. This disconnect prevents damage to the sensitive start-up channel detectors at high flux levels.

A low count rate trip is provided (rod withdrawal prohibit only) which basically indicates that the channel is not operating. The source neutron background level in the reactor is high enough to provide a count rate of several counts per second. Thus a low count rate trip indicates channel failure. This trip is inhibited by the high voltage power supply disconnect in order to bypass the RWP that would otherwise occur at higher levels.

The period trip is set at two decades per minute and provides a rod withdrawal prohibit. This output affects the

SCRAM function only through the human interface, since the operator is presumably warned to be more alert and careful when the RWP occurs. The SCRAM output occurs when the count rate exceeds 10^5 counts per second, but is only used during fuel loading operations or low power tests.

The trip relay supplies +15 volts in the normal condition to all three SCRAM channel inputs A, B and C. The trip relays are energized in the normal condition, so that either a high count rate trip or loss of +15 volt power to the bistable will de-energize the relay and open the trip contacts removing the +15 volts from the SCRAM line. The following circuitry recognizes +15 volt input as the high (or normal) signal and an open circuit (from a true trip or a broken wire) as the low logic (or trip) condition. The outputs from channels I and II are combined and fanned to the A, B, and C SCRAM channels so that either channel will trip the "Start-up Count Rate High" input to all three SCRAM gates. This input is automatically inhibited if the reactor mode switch is in the "Run" position instead of "Off" or "Fuel Loading", since the high sensitivity channels are only for use at very low levels.

(2) Start-up Channel - GO Model DWG No.: FSV 4G

The GO model of the start-up channel is shown in Figure 5 and is patterned after the logical schematics of Figures 1 and 2 as well as the wiring schematic. The power supply starts with SN819* which is main power from essential bus 1. The components shown in this line are primarily fuzes, pins, capacitors and low voltage power supplies (PS-2 and PS-1, SN1416 and SN1417). The two switches shown (SN1478 and 1499) are the calibration switches for level and period calibration. These switches trip the channel by inter-

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* SN refers to the output signal number which is the unique identifier in GO modeling for each component.

rupting the interlocked +15 volt line, which provides power to all bistables. The type 11's which operate these switches represent the human operator. The initial model assumes that the operator closes the switches (to the operate position) at time 0 and operates only by accident thereafter.

The neutron signal portion of the channel starts with the ion chamber (ND-1, SN1572). Signals 1415, 1553 and 1556 represent low-voltage power to the ion chamber high voltage power supply (HV-5) and are followed by the cable plugs leading to the ion chamber. In the initial model of the start-up channel, SN1553 and 1556 are type 5's (perfect initiators) at time 1. In the full interactive model, these inputs are replaced by Signals DS2 and DS4 from the wide-range channel, since the ±15 volt supplies go to the HV disconnect bistable in the wide-range channel and return to HV-5 through SN1553 and 1556.

NF-1 (SN52) is the initiating signal representing the neutron flux going high. Signal 1572 from the detector goes through the preamplifier and plugs to the start-up drawer (SN1583) after picking up DC power to the preamp (SN1575), DC power in the start-up drawer, input-output jacks and the level calibrate switch. M/I (SN340 and 337) represent mechanical interfaces involving the maintenance procedure of removing connectors for channel calibration. The model includes a perfect initiator (type 5 at time 0) with the probability of failure to replace the connector included in the probability values assigned to the element representing the mechanical interface (1-65).

SUC (SN1583, type 3, kind 101) includes the electronics in the start-up drawer except for the switches and bistables which are modeled separately. Output 1583 goes to the high and low count rate bistable inputs (SN1588) through the level trip test switch (SN1587). The level trip test logic (OP2, S8A, R1) indicates an operator turning the switch to test and rotating the potentiometer to simulate a higher flux level than normal. The trip test also trips the low count rate bistable through SN1589. Signal 1583 also goes to the period trip through the period calibrate (S2) and period trip (OP4, S9, R2) test switches.

The output Bistable trips (BT8 and BT9) include an amplifier, latching circuit, driver for both logic and relay outputs, two relays, a trip indicator light and trip reset button. All of the trip circuit up to the output logic signal is modeled as component type 3-106. Inputs are the interlocked +15 supply (1499), ground (1415), and the signal input. In the 10^5 cps SCRAM trip, SN1588 is a signal input and SN1619 is the logic output. Component 6-206 (SN 1620) is a perfect switch indicating an output from the relay driver. Component 3-105 (SN 1621) is the relay coil and component 6-203 (SN 1622) is the relay contact which provides a SCRAM signal. R27 is a current limiting resistor and P-J is the output pin.

The actual logic of the bistable is such that the logic output is high and the relay coils are energized when the system is in normal or untripped condition. The relay contacts are closed at this time so that a low logic (equivalent to ground) signal is supplied through the SCRAM line to the following logic. When the trip signal arrives the relay is de-energized and the contacts opened. The following logic is biased high so that either a high signal or open circuit is recognized as a SCRAM request.

This logic is different from the modeling normally used in the GO methodology where the presence of a signal is used to indicate the need for an output. In order to model this logic properly, a probabilistic time delay generator (type 9) is used in the output circuit. The normal SCRAM output (SN 1624) feeds logic inverter MI (type 6-214, SN 1540) as well as the second input to the type 9. The normal SCRAM request will come through this line. The time relationships of the time generator (SN 5815) are such that if both A and B signals arrive at the same time, the output appears in time 7 (or never). Thus this output is not active and the system operates normally. However, if the A and B signals do not arrive at the same time, an output is generated at the time of the A signal. If signal 1619 arrives (say in time period 2) but fails to reach SCRAM line 1624 due to failed components in the line, the signal at B will not arrive at the same time as signal A and this will generate an output from the type 9 component. Thus, the SCRAM will occur through signal 5815 instead of 1624 at the time of arrival of signal 1619.

Either SCRAM line, 5780 or 5817, will request a SCRAM through OR Gate 5781. At this point, the SCRAM request from startup channel II also enters the OR Gate through signals 5787 and 5820. MA (type 6-215) is a logic NAND Gate and represents the imperfect part of the preceding OR Gate.

The next major component is the Reactor Mode Switch which bypasses the startup channel in the "Run" position, since the high count rate SCRAM is used only for fuel reloading. This switch is modeled with three perfect initiators for the "Reload," "Off" and "Run" conditions. The initiator for Run (SN 106) is shown at time zero to indicate that the normal position of the switch would be Run. However, these initiators can be changed for modeling of different conditions. Component MA (SN 5785) is a logic NAND Gate used to indicate the imperfect part of the preceding perfect type 10 AND Gate. SN 5785 is the high count rate SCRAM line which is fanned to feed the three SCRAM channels A, B and C. An alarm output is also provided which can be used for a later human interface study if desired.

The low count rate bistable provides a trip whenever the count rate drops below 5 cps. This trip produces a Rod Withdrawal Prohibit. The internal logic in the bistable is reversed so it trips at low level instead of high. The purpose is to indicate that the channel is not working, since the count rate on the source will normally provide more than 5 cps in the startup channel. The period circuitry (SN 1595) feeds a bistable trip which provides a Rod Withdrawal Prohibit if the rate of power increase is greater than two decades per minute (dpm). These two bistables use the logic output instead of relay output. The high voltage disconnect bistable is used only as a monitor to indicate the high voltage has been removed from the startup channel detectors as a result of the signal from the wide range channel indicating $>10^{-3}\%$ of full power.

(3) Wide Range Channel Logic DWG No.: FSV 4E

The interconnection schematic for the wide range log power channel is number ELJ195-0010. Each of the three wide range channels (III, IV, V) includes a fission chamber detector mounted in a shield well, a preamplifier mounted near the detector and log power circuitry in the control console. An output from the preamplifier for each channel is fed to one of the linear power sub-channels. The three linear power channels (VI, VII, VIII) each include two sub-channels A and

B. The A sub-channel of channel VI receives its signal from the detector in wide range channel III. The B channel includes its own detector. The detector high voltage power supply for both sub-channels A and B is contained on the corresponding wide range channel. Thus, there are actually six linear power sub-channels, although there are some dependencies between the sub-channels and the wide range log power channel.

The wide range log power channel combines pulse counting and mean square techniques to determine the logarithm of the reactor power over approximately 10 decades of power. The circuitry includes an amplifier, discriminator, driver, and log diode pump (for the lower 5 decades) in parallel with the Campbell rectifier for the upper 5 decades of reactor power. Both feed a log amp and summer which provides an electronic transition between the count rate and mean square signals to avoid mechanical switching between the lower and upper ranges.

Output from the log amp and summer goes to a period circuit, a log power meter and a bistable trip to disconnect the high voltage to the startup channel detector when the reactor power is above 10^{-3}% of full power. The period circuit goes to bistable trips set at two dpm for Rod Withdrawal Prohibit and five dpm for SCRAM, as well as the period meter. A high voltage supply is provided which powers the detectors for both the wide range and linear power channels and includes a bistable which will trip the linear power channel if the high voltage is too low.

The channel includes calibration switches (and a signal generator) and test switches for both level and period. The calibrate switches automatically trip both period outputs, but the test switches add a signal to the existing signals so these switches trip the period outputs only when the test signal is large enough to reach the trip level. Low voltage power supplies are connected through board and drawer interlocks to the two period bistables and will trip these two bistables if any interlock is not intact. The calibrate switches are also included in this interlock line to trip the period bistables.

The high voltage monitor bistable operates through the K2 relay which is energized if the high voltage is above the required set point. Interlocked +15v from the corresponding linear power channel is brought to this relay and back out through the normally open contact back to the linear power channel bistables. If the high voltage is low, the relay is de-energized, opening the interlocked +15v line which removes power from the 120% and 140% power bistables in the linear channel to provide a trip. The high voltage disconnect bistable is inverted so that the relays are de-energized until the power reaches 10^{-3}% of full power. Above 10^{-3}% the contacts on the K51 relay are closed to supply -15v to the high voltage disconnect relay (K2). This disconnects the ±15v supplies to the chamber high voltage supply in the startup channel.

The 2 dpm bistable uses the relay contacts to provide power to an alarm, and the logic output goes to the A and B lines of the Rod Withdrawal Prohibit logic. The 5 dpm bistable provides the SCRAM signal through relay contacts. Relays are energized below 5 dpm and provide a low logic (or equivalent ground) signal to the SCRAM line through closed relay contacts. When the bistable trips the contacts are opened which is equivalent of a high logic signal out since the following logic input is biased high and recognizes the high input as a SCRAM request. The output line goes through an inverter before reaching the SCRAM inputs, since the main SCRAM inputs require a high logic level for normal and a low logic level for SCRAM. The same line also goes to an alarm through another inverter.

(4) Wide Range Channel GO Model DWG No.: FSV 5G

The GO chart for wide range channel III, which feeds SCRAM channel A, is shown in Figure 6. Channels IV, and V, which feed SCRAM channels B and C, are identical and independent, so they are not modeled separately.

The power supply is initiated by SN 819 from main power bus number 1. Channels IV and V are powered from buses 2 and 3. The power supply is essentially the same as that on the startup channel including board and drawer interlocks, as well as disconnects in the +15v line for the level calibrate and period calibrate switches. The interlocked +15v line feeds the two period trips but not the other bistables. The detector high voltage supply (SN 1459) is HV5 which also feeds out through SN 1512 to the detector in the linear power channel. ND3 (SN 1504) is the detector and its signal goes to the preamp PA-3 through the level calibrate switch. Low voltage power to the preamp comes through the preceding AND gate (SN 1510). The preamp signal output through J4 (SN 1512) goes to J6 and J10 on the wide range channel chassis. The signal through J10 goes back through J3 to subchannel A of linear power channel VI.

The main signal continues through another bank of the level calibrate switch picking up power and ground, then going to the electronics on the wide range channel chassis (LGA-SN1518). The unreliability of the channel electronics except for the bistables, pins and switches is lumped into component 3-101 (LGA). The signal continues through the level trip test switch, period calibrate switch and period trip test switch to become the input to the period trips (SN 1527).

The trip test switches are modeled the same as those on the startup channels. The bistable trips are also the same as those on the startup channels. Interlocked +15, ground and input signals are combined in the AND gate (SN 1558) to the bistable trip BT10B, type 3-106. Output signal 1559 drives the output relay driver type 6-206 (1560), which is modeled as a perfect transistor switch, since the electronics unreliability is already contained in type 3-106. The K52 output relay is modeled with coil type 3-105 (1561) and contacts type 6-203 (1562). The contacts supply a low logic signal (ground) through output jack J2 (SN 1563) to the following SCRAM logic. Logic inverter MI (type 6-214, SN 615) inverts the signal to high normal and low SCRAM for the main SCRAM input gate. Another logic converter powers the alarm circuit. The type 9 (SN 5821) is included as in the startup channel to provide a fail safe circuit beyond the input to the bistable relay driver so that an open circuit will provide a SCRAM request through SN 5823. Timing of the type 9 is the same as for the startup channel.

The bistable for the 2 dpm Rod Withdrawal Prohibit trip is similar to the SCRAM bistable except that the logic output (SN 1532) is used instead of relay output. The A and B RWP lines are fed through current limiting resistors R28 and R29. SN 1532 also drives a relay (coil 3-105, contact 6-203) to provide power to an alarm output SN 1542.

The high voltage interlock bistable (input SN 1459) uses relay output (SN 1464) to provide continuity in the interlocked +15v line from the linear power channel low voltage power supply. The interlocked +15 from the linear range low voltage supply comes in as SN 1473 and is fed out as SN 1476 back to the 120% and 140% power bistables on the linear range channel. If the high voltage on the wide range channel detector is high enough the bistable will close the K2 relay (SN 1464) but low high voltage will interrupt the linear range interlocked +15v supply and trip the 120% and 140% bistables.

The startup channel high voltage disconnect bistable uses the main logic signal 1522 as input and trips when reactor power is 10^{-3}% of full power. The K52 relay (coil SN 1547, contacts SN 1549) is not energized at low power and the contacts are open. One of the contacts receives -15v through the level calibrate switch. When the contacts close at 10^{-3}% power, the K2 high voltage disconnect relay is energized and contacts C1 and C2 (SN 1552 and 1555) are opened. These contacts receive ±15v from the DS1 and DS3 outputs of the startup channel. These voltages return through SN 5834 and 5835 to DS2 and DS4 on the startup channel which provide low voltage power to the detector power supply in the startup channel.

(5) Linear Power Channel Logic DWG No.: FSV 4E

There are three dual linear power channels VI, VII, VIII (with A and B subchannels). The A subchannel receives its signal from the detector and preamp in the corresponding wide range channel. The B subchannel has its own detector. Detector high voltage for the B subchannel is obtained from the corresponding wide range channel. Each subchannel includes a linear amplifier and four output bistables (140%

power-SCRAM; 120% power-RWP; 30% power-RWP and 5% power-RWP). The low voltage power supplies are common to both subchannels.

Each subchannel contains independent trip test and calibrate switches. Sensitivity and rod withdrawal prohibit bypass switches are common to both subchannels. The sensitivity switch allows the linear power channels to be used at lower power level, if desired, through the x10 feature. The RWP bypass switch trips the 140% power-SCRAM line when activated so it can be used on only one SCRAM channel at a time.

A high sensitivity switch is mounted on the chassis with access only by pulling the drawer out. This switch increases the gain of the amplifier enough so that alpha pulses from the detector can pass the discriminator level. This switch allows testing all the way from the detector through the channel output. It is used prior to start-up to indicate that all six linear power subchannels are in operation, since otherwise an open circuit could leave one of these channels dead at start-up.

One leg of the +15V supply goes to the high voltage trip on the wide range channel and returns to power dual pilot lights to provide a positive indication that detector high voltage is present. Another leg of the +15V goes through a board interlock on the linear amplifier, the calibration switch and out to the high voltage trip on the wide range channel, returning as interlocked +15V to supply the 120%-140% bistable trips. The high voltage interlock is provided only in subchannel A, since only a single detector high voltage supply is used.

Each bistable includes a trip indicator light and trip reset button, connected to an SCR latch. The trip lights remain on until the reset button is depressed, even though the bistable itself may have changed state due to a change in the input level. The 120% RWP bistable also latches the input when tripped, so that the RWP signal remains until the trip is manually reset. The 140% bistable SCRAM does not use this feature because the SCRAM channels are individually latched in the main SCRAM logic. The 30% power and 5% power bistables provide Rod Withdrawal Prohibit outputs to correspond with the positions of the Interlock Sequence Switch.

The three positions of the ISS are Start-up (less than 5% power), Low Power (5 to 30% power) and Power (above 30% power). These bistables will cause a Rod Withdrawal Prohibit if the power level is outside the range required by the ISS. Thus, the 5% power bistable amounts to a downscale interlock when the reactor is out of the Startup mode. The 30% bistable trips at 30% as the power increases, but includes hysteresis so that it trips at 10% as the power decreases. This eliminates the need for frequent switching of the ISS due to power level variations near the 30% level as the plant is being brought up to power.

The output from the 5% bistable is +15V through a relay to the A and B RWP logics. A bypass switch is provided so that this bistable trip can be bypassed, but operation of the switch trips the 140% power single channel SCRAM. The 30% and 120% power bistables use the logic output with low level indicating RWP and high level being normal or untripped. A relay in the 120% power bistable provides power to an alarm. The output from the 140% power bistable to the SCRAM circuit is normally grounded through a relay with open circuit or +15V indicating SCRAM request. This output is followed by an inverter to change the logic to high-normal and low-SCRAM for the main SCRAM OR gate input. An additional inverter feeds the alarm circuit.

(6) Linear Power Channel GO Model DWG No.: FSV 6G

The GO chart for linear power channel VI, which feeds SCRAM channel A, is shown in Figure 7. Channels VII and VIII, which feed SCRAM channels B and C, are not shown separately. Main power bus 1 (SN819) provides power to this channel. The power supply is essentially the same as in the other nuclear channels, except that no drawer interlock is included. PS1 and PS2 (SN1430 and 1429) are the low voltage power supplies and B/I-3 (SN1466 for subchannel B and 1470 for subchannel A) is the board interlock. OP2 and OP6 (SN50 and 64) are part of the calibrate switch to interrupt the +15V supply to the high power bistable when the channel is placed on calibrate. Subchannel A (from the wide range channel detector) also includes the high voltage interlock (SN1473) out to the wide range chassis and 1476 back in. The input to subchannel A (SN1514) comes from the wide range channel detector preamp. The level calibrate switch S2 (SN1716) will interrupt the channel if activated by OP6 (SN64). This switch also grounds the input, and the possibility of an accidental short is modeled with N/O component 1714 and N/C component 1715. The sensitivity switch S6 (SN1718) is activated by OP3 (SN61). The level trip test switch and potentiometer S4 and R1 (SN1720 and 1721) are activated by OP9 (SN66). Either of these switches can activate the channel through the OR gate (SN1719). LA2 (SN1726) is the linear amplifier in subchannel A.

The bistable trips are the same as those used in the other nuclear channels. The bistable logic is component type 3-106 (SN1772, 1760, 1749 and 1732). Type 6-206's (SN1773, 1761, 1750 and 1733) are the logic or relay driver outputs. The 140% SCRAM bistable uses the K51 relay output (coil SN1774 and contacts SN1775). This channel is also tripped when the RWP bypass switch (SN1776) is activated by OP7 (SN67). Logic inverter MI (SN5790) inverts the high SCRAM-low normal logic to the high normal required by the SCRAM input through SN5832. Another logic inverter SN5791 drives the alarm circuit. A type 9 (SN5829) is again included to model the fail safe feature from the output of the bistable to the SCRAM line (SN5831). The 120% power and 30% power Rod Withdrawal Prohibit bistables both use the logic output (SN1761 and 1715) to drive the A and B RWP lines through current limiting resistors (SN1765, 1763, 1752 and 1754). The 5% power RWP bistable uses the K2 relay output (contacts type 6-206, SN1735) and passes through the RWP bypass switch (SN1736) to drive the A and B RWP lines. The bypass switch is shown as normally closed since operation of this switch inhibits the RWP signal and thus prevents an output from this line.

Subchannel B is essentially the same, except that it has its own detector type 1-6 (SN1641). The channel initiators are the high voltage from the wide range channel (SN1512) and the flux signal (SN52).

b. Non-Nuclear Channels DWG No.: FSV 3E/G

(1). Hot Reheat Steam Low Pressure and Superheat Steam Low Pressure

These channels are identical so only the hot reheat steam channel will be defined. The channel includes a pressure switch, PSL2269, which opens on low pressure, a test/operate switch, a single switch module, (SW-2S) and power supplies. The logic chart is on Figure 8 and the GO chart is on Figure 9.

The pressure sensing switch is represented by GO component 6-237 (SN1297) with a type 5 initiator which simulates the environmental interface at time period 4. The time period for initiation can be varied according to the user's wishes. The pressure switch logic has been inverted to be compatible with logic internal to GO. Human interfaces (SN323 and 324) indicate successful completion of maintenance operations and removal of calibration equipment from the channel. Power (SN1008) feeds through the test/operate switch (SN1293) where OP-3 (SN43) represents the human interface and is modeled to leave the switch closed at time period Ø.

The pressure amplifier and MP unit is represented by component 3-111 (SN1301) with output contacts type 6-203 (SN1304). The signal output is high normal with the pressure switch closed and switches to low when the pressure switch opens on low pressure, however, the output logic is inverted in the model to be compatible with GO. The output signal then goes through an AND gate with the interlock sequence switch, which by-passes the channel for Start-up and Low Power operation. From the AND gate the signal is passed directly to SCRAM logic module SL8A. From this point, the output signal (SN1797) is routed to SCRAM logic module 2A. A type 9 component is included to model the fail-safe output which is necessary due to the inverted logic. The fail-safe circuit provides an automatic SCRAM signal if the output lines for this SCRAM circuit are opened or removed. The final signal is identified as output SN1797 for the Hot Reheat Steam line, and SN1794 for the Superheat Steam line.

(2) Reheat Steam Temperature High DWG No.: FSV3E/3G

This channel is described on Figures 8 and 9. The channel includes four thermocouples connected in pairs, with each pair feeding an ATC3A thermocouple amplifier module through test/operate switches. The thermocouple modules provide inputs to an auctioneer circuit which accepts the higher of the two signals to provide an output. The output goes through another test/operate switch to a process trip bistable amplifier PT-3S, followed by an inverter to the SCRAM logic and inverter to the alarm circuit.

The channel is initiated by environmental interfaces 2 and 3 (SN1330 and 1393) at time period 6 indicating the temperature going high at that time. The thermocouples are represented by a component type 1-17. This is followed by an AND gate with human interfaces at time 0, component type 1-65, indicating the probability that the thermocouples were successfully replaced after calibration. The cold junctions are also component types 1-17 (SN1342 and 1405). The test/operate switch is OP-5 (SN45). The test signal from the Master Test Unit, component type 1-18, is initiated by a component type 5 at time 1 (SN1349 and 1410). The thermocouple amplifier modules, TT22135A & B are represented by component types 6-212 (SN1361 and 1420) with power supplied through SN1008. The outputs go through the second test switch, human interface (SN46), to the auctioneer, component type 6-208, (SN1369). The second test switch allows either input of the auctioneer to be tested separately. A third test switch, OP-7, with human interface number (SN47) controls the output of the Master Test Unit (SN1383) into the bistable trip TSH22135 (SN1389). An interlock from power SN1008 to the bistable trip is also provided to trip and alarm on power failure or board removal. Two of the test/operate switches interrupt this line to provide a single channel trip in the test position. The channel output is inverted in the SCRAM logic by component type 6-214. A failsafe circuit (type 9, SN1801) and initiator F/S-1 (SN 1792) is included to provide immediate SCRAM signal (SN1803) if the output line is opened or removed.

(3) Reactor Pressure Programmed By Core Inlet Temperature — DWG No.: FSV 2E/2G

The reactor pressure sensors will produce a SCRAM on either high or low pressure if the pressure is outside of the limits programmed by the core inlet temperature. The logic chart for this circuitry is Figure 10 and the GO chart is Figure 11.

The Core Inlet Temperature, uses two thermocouples in each of the three SCRAM channels with associated thermocouple amplifiers, and an auctioneer circuit to compare the two channels. The output from the auctioneer feeds two Summer Modifiers MS-1 which determine the trip points for reactor pressure. Each channel also has a process trip unit PT-3D to drive the associated alarm circuitry. The reactor pressure channel contains the pressure sensor, a pressure amplifier and two bistable trips for high and low pressure. Test/operate switches are included, interlocked and alarmed. The bistable trips receive signal from the outputs of the Summer Modifiers in the temperature channel to determine the variable trip point for the reactor pressure channel. The high pressure trip goes through inverters to the SCRAM logic and alarm circuits. The low pressure trip goes through the Interlock Sequence Switch in order to bypass this trip when the reactor is in Startup or Low Power operation.

The pressure sensor is represented by component type 1-19 (SN1197). The initiators are high pressure (SN212) or low pressure (SN211). SN325 and 326 represent mechanical interfaces and indicate that the pressure sensor has been correctly replaced after calibration and all valves left in their proper states. The other input to the AND gate driving the pressure sensor is power interlocked through the test/operate switch. OP1 and OP2 are the human interfaces which activate the Master Test Unit and the test channel to the pressure amplifier, type 6-211 (SN1215). At this point, the signal is routed to both the high and low bistable trip unit through test/operate switches which are activated by human interfaces designated OP4 and OP3. The signals from the core inlet temperature SN1141 or 1143, and 1142 are brought in through OR gates 21 and 22 respectively to the bistable trip units BS-4 and BS-5 (type 6-210, SN1245 and 1268). The high level trip feeds circulator logic outputs 1246 and 1248 as well as the main SCRAM output through SN837. A type 9 component with its initiator F/S-1 are included to model the fail-safe output which provides a SCRAM through SN1813 if output continuity is broken. The SCRAM output is inverted and is routed to SCRAM logic 4A as SN1813. An alarm output (SN838) is also provided.

The low pressure output signal is similar, including fail-safe logic, except that it can be inhibited by the Interlock Sequence Switch (SN100, 101 and 102), so that a low pressure SCRAM is sensed only while operating in the power mode. The power supply interlocks including operator interfaces and output alarms are also shown on the GO drawing.

The core inlet temperature channel is initiated by environmental interfaces SN201 and 202, indicating low temperature or high temperature respectively. The theromocouples are represented by component type 1-17, (SN332 and 335).

SN331 and 334 are mechanical interfaces indicating successful completion of maintenance, including proper calibration and replacement of thermocouples. Test switches activated by human interfaces OP-1 and OP-2 are provided to bring in signals from Master Test Unit, component type 1-18. The output of the temperature amplifiers TA1 and TA2 are represented by SN1031 and 1080. Both channels provide alarm outputs interlocked with Bin power supplies and test switches. To provide programming outputs for the Reactor Pressure SCRAM circuit, the two channels are combined in OR gate, SN1112, routed through a test switch activated by Human interface OP-5 and into the auctioneer unit AU-1 (output signal SN1120). Signals from the auctioneer go either to the high or low temperature channels and are fed through test switches activated by human interfaces OP-5 and OP-6 to the Summer Modifiers TM1 and TM2 (output signals SN1136 and 1138). The outputs then go to process indicating circuits as well as to the Reactor Pressure channels previously described.

(4) 480V Surge Undervoltage DWG No.: FSV 1E/1G

The trip circuit for the 480V surge undervoltage contains two field switches (one for each of the essential instrument buses 1 and 2), a switch module SW-2S, a 30-second time delay unit (to prevent trip on fast transients), and a SCRAM logic inverter to feed main SCRAM logic 3A. The logic diagram is on Figure 12 and the GO chart is on Figure 13.

The channel is initiated by a signal in either SN313 or 314. The initiation time can be varied for different accident simulations. The initiation signal logic is inverted for GO logic from actual conditions. A push button switch is included in each channel, initiated by type 5 components feeding into human electrical interface components, type 1-75. Power from SN1008 comes through several pins, a fuze and the test/operate switch with Human interface OP-4 (SN44). The switch module XSL93362 is represented by component type 3-111 (SN1324). The time delay is represented by component type 3-120 (SN836). A failsafe circuit is included on the output with the final signal number 1800 going to the multiple SCRAM logic gate 3A, after inversion by the SCRAM logic inverter, SN1329.

(5) Reactor Building Temperature DWG No.: FSV 1E/1G

The reactor building temperature channel includes a thermocouple, thermocouple amplifier and bistable process trip. The output goes through an inverter to multiple SCRAM logic gate 3A, and another inverter to the alarm circuits.

The environmental interface (E/I-1, SN34) is the channel initiator indicating the time period for high temperature. The high temperature signal is routed to thermocouple TE93472 (SN329). A mechanical interface component type 1-65, is also included to show the probability of successful maintenance and proper replacement of the thermocouple in its well. The signal proceeds through the test switch (actuated by Human interface OP-1) to the thermocouple amplifier TT93472. The signal proceeds through another test switch (actuated by Human interface OP-2) to the process switch TSH93472. Both test switches also include the Master Test Unit which provides a temperature test tripping signal. The +15V power (SN1008) goes through both test switches to an alarm circuit and then provides the power to the bistable trip through SN1178. Components type 9 and 6 provide a fail-safe circuit for output signal 1806 to the multiple SCRAM logic gate SL3A. Alarms are provided with SN834.

(6) Plant Electrical Service DWG No.: FSV 1E/1G

The Plant Electrical Service originates with 230KV in the switch gear yard or from 22KV provided by the inplant generator. This voltage is stepped down to 4KV by transformers then cross-tied and fanned to feed three main buses. A second set of transformers step the voltage down to 480V to feed the plant Motor control centers. Power at this point can also be provided by the stand-by generators if main power fails. From here, two of the lines go to a third set of transformers which step the voltage down to 120/208V three phase power. Instrument bus 3 is driven directly from these transformers. Instrument buses 1 and 2 go through battery chargers which maintain 125V DC to a bank of storage batteries floating on line, and power two DC/AC invertors which furnish 120V AC, single phase, power to Instrument buses 1 and 2.

The initial GO model shows the plant running from off site power. Initiators SN750 (off-site power) occurs at time 0, and initiator SN755 (for the plant generator) is shown time 7 representing never. The removable link in the plant generator line is shown as a human interface H/I-1 (SN21). The lightning arrestor in the switch gear yard is initiated by E/I-1 and shown by component type 7-309. Transformers are represented as component types 1-13. Air circuit breakers are shown as component types 7-310 with the actuators as environmental interfaces. The main line feed splits to all three 480V transformers (SN767, 770 and 775). The lines are cross-tied with SN774, 769, 773 and 778 through air circuit breakers initiated by environmental interfaces SN 8 and 9. At this point the three line signals (E1, E2 and E3) are combined through AND gates 780 and 785 to initiate switches SN783 and 788 if any one of the 3 lines drop low. This will start the emergency diesels (MG1 and MG2, shown as component type 3-108, SN784 and 789). The diesels receive their startup power through batteries SN782 and 787 at time 1, unless power at time Ø has opened switches SN783 and 788. Power to the motor control centers is taken off at signals SN772 and 790. Signal SN790 and 791 go through transformers to the battery chargers, component type 1-14, (SN798 and 804). These lines are also combined through transformers TFM6 and 7 and air circuit breakers to instrument bus number 3, 120V, 3 phase AC (SN821). Beyond the battery chargers the signals are 125V DC with crossties through air circuit breakers and manual switches. H/I-2 is a manual switch which can select either line to power both buses 1 and 2. H/I-3 and H/I-4 are manual switches in each line. DC/AC inverters SN816 and 818 supply 125V single phase AC power to instrument buses 1 and 2, with one more set of air circuit breakers forming the final in-line components. SN819, 820 and 821 represent the final power outputs. The numbers (100, 200 etc.) indicate the respective instrument bays fed from each main power bus.

c. Two Loop Trouble Inputs DWG No.: FSV 12E/12G

One of the most important inputs to the SCRAM function in the SCRAM Protective System at St. Vrain is the input identified as the Two Loop Trouble SCRAM circuit. The various sensors which may originate as SCRAM signals within the Two Loop Trouble circuit perform major protection functions. The following sections briefly describe the general logic flow and typical GO model signals (SN X) for each of the Two Loop Trouble detection systems.

Moisture Detection System DWG No.: FSV 11G/E

The moisture detection system has 8 moisture detection sensors, two of which operate at a high level (SN1802, 1819), i.e., the detectors will cause an immediate SCRAM of the HTGR system if the moisture level reaches 2,000 to 4,000 parts per million by volume. The remaining six sensors (SN1862, 1871, 2401, 2421, 2452, 2466) are low level sensors which will trip at 100 parts per million by volume and are arranged so that there are three sensors to each loop. Human interfaces have been provided in each sensor circuit to measure the impact that human actions such as Reset, Calibration, and Testing have on the operational reliability of the sensor systems (typical SN7011, 1865).

The moisture detection system consists of the moisture detector (SN1862, typical), a preamplifier section with photocells and a mirror temperature controller (SN1863), a temperature indicating unit with its electronic section (SN1864) and finally a mirror temperature trip unit (SN7003, 1866, 1868). Since the trip Bistable has two independent outputs, the Bistable was modeled in three parts, i.e., an input part and two output parts). The signals coming from the moisture detectors are fed downstream through an inverter (SN1888) and into a double inhibit gate (SN5108, 1889). The inhibit gate prevents the moisture detector from providing a trip signal further down the line, if either of two conditions have been sensed. If High Reheat Header Activity has been identified or if there has been a malfunction in the Circulator Seals. The output of the inhibit gate is fed into a FILO, or first-in-with-lock-out circuit (SN1896, 1897). Upon exiting the FILO circuit the moisture signals are fed into a second inhibit circuit (SN2507) which provides an automatic inhibit action if a high level moisture signal has already been detected. After this inhibit, the moisture detection signals are fed into the output of the Two Loop Trouble circuit. At this point, the moisture detection signals split two ways, one going directly to the loop output which initiated the trouble to effect loop shutdown (SN2530), and the second signal feeding back into the Two Loop system in the opposite loop (SN2531) to effect a trip signal for SCRAM purposes only.

Steam Pipe Rupture System — DWG No.: FSV 8E/8G

The Steam Pipe Rupture System is divided into two parts. Steam Pipe Rupture underneath the PCRV and Steam Pipe Rupture outside the PCRV. Steam Pipe Ruptures under the PCRV require a rapid shutdown of the leaky loop in order to minimize pressure and temperature buildup within the PCRV support ring area as well as to minimize loss of steam. A combination of ultrasonic noise sensors, pressure, and temperature sensors are used to indicate pipe ruptures. Steam Pipe Rupture outside the PCRV, or in the reactor building, serves a similar purpose to the Steam Pipe Ruptures under the PCRV. Its purpose is to monitor the status of the loop piping for all areas outside of the PCRV. The ultrasonic sensors which are used for both Steam Pipe Ruptures under PCRV and outside the PCRV are routed into two-out-of-three circuits (SN2713, 2900 typical) and from there in the case of ultrasonic sensors into a first-in-with-lock-out circuit (SN3129, 3131 typical) to prohibit shutdown of the second loop after trouble has been detected in the first loop. The temperature and pressure sensors which are used in Steam Pipe Rupture system are combined with the ultrasonic detectors (SN3133) and are then fed directly to the Two Loop Trouble output. The sensors in the Steam Pipe Rupture system are allocated as follows: under the PCRV, there are three ultrasonic detectors for each of the two loops (SN2847, 3876, 3879) plus three pressure sensors (SN2724, 2731, 2738) and three temperature sensors (SN2655, 2662, 2693). The pressure and temperature sensors are physically located in the reactor building basement. Outside of the PCRV there are six microphone sensors, three temperature sensors, and three differential pressure sensors for each loop.

<u>Reactor Pressure System (TLT)</u> DWG No.: FSV 11E/11G

Whenever the main SCRAM system detects low primary coolant reactor pressure, an auxiliary output is fed to the Two Loop System. Within the Two Loop System, the Low Reactor Pressure signal (SN5766, 5768, 5764) from the three SCRAM channels A, B and C are fed into a two-out-of-three voting logic (SN3160) and from there through an inhibit switch (SN3165) to the SCRAM output (SN3166) of the Two Loop Trouble module. The inhibit switch is used during startup so that low reactor pressure will not cause a trip in the Two Loop System. Low primary coolant pressure is indicative of helium leakage from the reactor system. A SCRAM is required at this point because the reactor is in danger of being inadequately cooled. The low primary coolant pressure signal is brought into the Two Loop system for purposes of tripping the turbine generator, anticipating a drop in the main steam temperature, and to back up the main SCRAM signal.

Reheat Header Activity DWG No.: FSV 9E/9G

Detection of Reheat Header Activity is an indication that there is a rupture of one of the reheater tubes resulting in leakage of the primary coolant into the steam system. This requires a shut-off of the Reheat outlet stop check valves and a loop shutdown to minimize the amount of activity introduced into the steam system.

High Reheat Header Activity is detected by six monitors, three in each loop (SN2041, 2048, 2071), which form part of the radiation detection package. These sensors are mounted near the Reheat Header and serve to initiate a SCRAM if radioactivity is detected in that region. Following a loop shutdown, equalization of pressure in the Reheater with the primary coolant may permit steam to leak back into the primary system; therefore, an inhibit (SN2095, 2167) is introduced into the moisture monitoring system whenever High Reheat Steam Activity is detected. The output of the Reheat Header Activity sensors are brought into a dual trip switch (SN2043, 2045) and from there are fed into a two-out-of-three voting circuit (SN2091) and then routed directly to the Two Loop Trouble output (SN2092, 2111).

Steam Generator Penetration Overpressure

A Steam Generator Penetration Overpressure is indicative of a Steam Pipe Rupture within the penetration. This requires a loop shutdown to prevent moisture backflow into the primary coolant. There are three sensors assigned to each loop (SN2541, 2548, 2571) for the Steam Generator Penetration Overpressure system. The output of each of of these sensors is fed into amplifiers (SN2542), through a pressure switch (SN2543, 2545) and finally into a two-out-of-three voting circuit (SN2583) which feeds directly into the Two Loop Trouble output (SN2584).

Low Superheat Header Temperature DWG No.: FSV 10E/10G

Low Superheat Header Temperature in either loop is indicative of a feed water valve or controller failure. Comparative circuits are built between the two loops to prevent loop shutdown when the main steam temperature of both loops is being reduced. The output of the Low Superheat Header Temperature detectors (SN2185, 2195, 2205) is amplified and fed directly to a temperature trip switch (SN2188, 2187). Outputs are also taken off to provide the comparative temperatures between loops (SN2187, 2197, 2207). The primary outputs (SN2191, 2193, etc.) are fanned out and fed to two-out-of-three voting circuits (SN2221) which in turn are fed directly to the Two Loop Trouble output (SN2341). There is an inhibit switch built into the final output of this system (SN2337). This inhibit switch is the Interlock Sequence Switch which disables the circuit when in startup or low power phases. The final circuit in the Two Loop Trouble module is the Circulator Trip circuit. If either one of the four circulators is tripped for various reasons, a SCRAM is introduced at the output of the Two Loop Trouble circuit. These SCRAM signals are fanned out by the time they reach the Two Loop Trouble output so that they will be found to be present on both the A logic (SN5255, 5267) and B logic lines (SN5261, 5273) for both loops 1 and loops 2. As a signal is propagated down each of these four lines, the SCRAM signals are phase locked (SN5276-5279) just prior to leaving the Two Loop Trouble output (SN5355). At this point, the output of each of the four SCRAM lines are fed to all three channels A, B and C of the main SCRAM system (SN5282). The Two Loop Trouble circuit is devised so that SCRAM signals must be present from loop 1 and loop 2 to initiate a Two Loop Trouble SCRAM, but may be present in either A logic or B logic lines.

Circulator Trip

A Circulator Trip input to the Two Loop Trouble Module has nine distinct types of sensors which can initiate a trip on the Circulator Trip line. These are Loss Of Bearing Water to the circulator bearings, excessive Reheat Header Activity, trouble in the Speed Trip Monitors of which there are three different types, Overspeed Trip (for both water drive and steam drive), Low Speed Trip, and a Programmed Low Feed-water Flow, programmed by the circulator speed. In addition to these trips, there is Fixed Low Feed Water Trip, a Manual Trip, which is under the control of the reactor operator, a Circulator Drain Trip whenever the circulator steam/water drain pressures are indicative of instrumentation or system failure, a Circulator Seal Malfunction Trip and lastly, there is a trip available for Circulator Penetration Overpressure. Each of these tripping circuits will be discussed individually.

Loss Of Bearing Water and Circulator Seals DWG No.: FSV 13E/13G

Bearing water leakage past the helium/water drain indicates a possible failure of the seal system between the circulator and the reactor, which if not taken care of, may lead to water entering into the primary coolant system. This possible malfunction of the Circulator Seals is monitored by differential pressure switches, three per circulator

(SN1901, 1918, 1935) which trip whenever the differential pressure exceeds one half to one psi. The signal which is generated by a malfunction in the Circulator Seals (SN1966, 2003, 2023, 2032) is also fed to the Low Level Moisture detector system to block inadvertent loop dumping, due to the presence of moisture from the leakage. The loss of bearing water is monitored within the circulators by three differential pressure switches (SN3466, 3474, 3482) which are set to trip at 550 psi. The nominal pressure is approximately 650 psi. Loss of Bearing Water is potentially damaging to the helium circulator and requires that a trip be introduced immediately if this condition is detected. The signals from the Loss of Bearing sensors and the Circulator Seal Malfunction sensors are individually fed into time delay lockouts (SN3470, or SN7210) of approximately 3-5 seconds to prevent spurious changes in pressure from tripping the system. Any signals existing after the lockout are then introduced into a two-out-of-three voting logic circuit (SN3521) and passed directly to the circulator trip outputs (SN3532, 3582, etc.).

Reheat Header Activity (Circulator Trip) DWG No.: FSV 13E/13G

The Reheat Header Activity signals (SN2092, 2164, etc.) are routed from the Two Loop Trouble System to the Circulator Trip circuitry. It is combined with a first-in-with-lockout signal (SN4922) which prevents a loop shutdown if there has already been a SCRAM in the Two Loop system. From there it is fed directly out to the Circulator Trip output (SN4936, 4943, etc.) with the only inhibit being through an Interlock Sequence Switch (SN3336), so that in startup or low power the Reheat Header signal is inhibited.

Circular Speed Trips DWG No.: FSV 17E/17G

The next group of sensors which are important in initiating a circulator trip are the Circulator Speed Trip sensors. There are three types of speed trip functions which serve each one of the four circulators. Each circulator has 3-speed sensors (SN4264, , , etc.). The Speed Trip sensor signals are fed into a network of amplifiers and tripping switches with some of the signals being programmed by feedwater flow. There are three major outputs from the Speed Trip sensors. The first output is an Overspeed Trip (SN4628, 4689, etc.) for both steam drive and water drives The second output signal is a Low Speed Trip (SN4758, 4833, etc.) which is programmed by the feedwater flow (SN4024, 4036, 4048, etc.). The third output is a variable Low Feedwater Flow signal (SN4382, 4557, etc.) which is programmed with the circulator speed (SN4022, 4034, 4046, etc.) The programmed Low Feedwater Flow trip output is inhibited by the status of the control rod brakes (SN4377, 4552). If the reactor has SCRAMMED so that the brakes have been released, an inhibit signal is supplied to the programmed Low Feedwater Flow output circuitry. The three speed trip signals are fed over to the trip output logic and include a five second time delay lockout (SN4277) to inhibit transient changes from initiating a trip signal. At this point, the signals are passed into a two-out-of-three voting logic circuit (SN4367) and from there directly into the circulator trip output circuits (SN4628, 4758, 4382, etc.). The programmed Low Feedwater Flow trip prevents prolonged operation in the region of speed versus flow, which may cause excessive Reheat Steam temperatures. The programming signal is Circulator Speed and two such programmers are required, because the correct circulator speed to feedwater flow relationship depends upon whether one or two circulators from the loop are operating.

Fixed Low Feedwater Flow DWG No.: FSV 15E/15G

A trip from Fixed Low Feedwater Flow is included in Circulator Trip functions to avoid unstable steam generator flow conditions. Six additional sensors (SN4020, 4032, 4044, etc.), three in each loop, are used to provide the input data for the Fixed Low Flow trip. The output of the six Low Flow sensors are likewise fed into a time delay lockout unit (SN4028) and thence into a two-out-of-three circuit (SN4070), the output of which is fed in through an inhibit gate (SN4074). The inhibit (SN3336) is controlled again by the Interlock Sequence Switch. From the inhibit gate, the signal flows directly into the Circulator Trip output circuitry (SN4078, 4082, etc.).

Manual Circulator Trip DWG No.: FSV 16E/16G

This circuit provides the reactor operator with the option of manually tripping (SN89, 90, 91, 92) any one of the four circulators. The output from these switches feed directly to the Circulator Trip output circuitry (SN4884, 4888, etc.).

Circulator Drain Malfunction DWG No.: FSV 14G/13E

If the steam pressure is allowed to exceed the bearing water pressure a Circulator Drain Malfunction signal is generated by a set of differential pressure sensors. Three sensors in each circulator (SN3880, 3886, 3892, etc.) are used to measure the differential pressure between the steam pressure and the bearing water drain pressure. The normal pressure between the two systems is 45psi. If this pressure drops to the neighborhood of 10psi, the differential pressure, trip is initiated. The output of the Circulator Drain Malfunction is fed directly to a two-out-of-three voting logic (SN3900) and from thence directly to the Circulator Trip output (SN3905, 3940, etc.).

Circulator Penetration Overpressure DWG No.: FSV 16E/16G

The Circulator Penetration Overpressure is indicative of a pipe rupture within the penetration. Under these circumstances, a circulator trip is required. Three differential pressure sensors (SN3798, 3804, 3810, etc.) are used in each circulator to detect Circulator Penetration Trouble. If these sensors detect a pressure about 100psi above nominal, which is 710psi, a circulator trip is initiated. The output of the Circulator Penetration Trouble sensors are fed into a two-out-of-three voting logic (SN3822, etc.) and from there directly into the output circuitry of the Circulator Trip (SN3826, 3867, etc.).

Circulator Trip Output DWG No.: FSV 13E/14G

The output circuits for the Circulator Trip function collect all of the Circulator Trip initiation signals from both A and B logic lines for each of the four circulators and use these lines to obtain a trip signal for each circulator in the system, i.e., the circulators in Loop 1 (SN5038, 5061) and the two circulators in Loop 2 (SN5084, 5107). Provision is made for checking out the circulator trip logic by using a combination of dc and pulse testing. The testing is initiated by manually tripping one of the Two Loop sensors and by sending a test pulse throughout the remainder of the system to trip the second input of the two-out-of-three logic. The test pulse results in a rapid switching on and off of the output relay drivers with the energy imparted to the relay coils being insufficient to pull up the relay and produce a physical SCRAM. However, a test pulse light is utilized to indicate a potential SCRAM. The test light receives its signal from a pulse transformer which is in series with the relay coils. As long as the test pulse push button is depressed, the test light will be on. By sequentially checking each of the various input channels, all of the Bistable trips may be checked along with the associated wiring and the various logical combinations which are possible in both the A and B logic systems. The switch selection modules for this testing are incorporated in the TLT output circuits (SN7201-7204). The logic associated with circulator trip is normally de-energized during plant operation, and safety action is initiated upon energization of the output signals. For this reason, dual A and B logic is provided to ensure system reliability. Either output can actuate the final control elements.

d. Rod SCRAM System DWG No.: FSV 18E/18G

On the logic diagram and GO chart only channel A is shown up to the SCRAM contactors since channels B and C are identical. The 12 SCRAM inputs are combined in three AND gates, component type 10, and the three type 6-215's which represent initial SCRAM logic leading to SN6006, the channel A SCRAM line. SCR-2 (type 3-113, SN6011) represents the SCRAM line Bistable. There are two outputs from the XCR-2 (SN6015 and 6014). SN6014 is a relay contact which when activated, feeds 115V AC to the line driving relay CRK-A (SN6030) with contacts (SN6031 and 6032) which represent the SCR drawer interlock and interrupt the main SCRAM line just before channel reset. SN6015, the second SCR relay contact feeds 115V AC to a rectifier to provide 110V DC through three manual switches, i.e., single channel SCRAM (OP1), (SN160); Reactor Mode Switch (OP2), (SN106); and the main manual SCRAM (OP3), (SN162). The single channel reset for the main SCRAM relays is modeled by (OP4), (SN163) and RS1A (SN6034).

The signal then splits into two lines going through resistors and capacitors for arc suppression to energize the dual SCRAM relays KR2 and KR1 (SN6039, 6040, 6044, and 6045). The even and odd control rod brakes each use contacts controlled by the dual relays KR1 and KR2 to drive a dual two-out-of-three voting matrix circuit. Outputs A1-1, A1-2, A2-1 and A2-2 are then combined with the B and C relays in the following type of combinatorial logic.

Instrument Buses 1 and 2 each drive identical 28V SCRAM power supplies (component type 1-38, SN6151 and 6099) into the two-out-of-three logic matrix for the odd and even control rod brakes. The power supplies are cross connected so that (SN6151 and 6099) the output of either can drive both sets of brakes. The components modeled in the two-out-of-three logic matrix are shown as a component type 6 or a component type 2 corresponding to the actual circuitry. The NOSCRAM signal to the SCRAM relays must succeed to close the normally open component type 6 and allow SCRAM brake power to proceed to the rod brakes. The component type 1-9 represents the meter shunts in the cross connections between the dual logic. These meters read zero unless one of the channels has opened, so a non-zero reading indicates a single channel trip. The outputs to the odd and even rod brakes are represented by output lines SN6169 and 6193. The manual SCRAM switch (SN162) has dual contacts in these same output lines (SN6196, 6197, 6172 and 6173) as a backup to relay contacts in the main line to the SCRAM contactor relays. Outputs SN6202 and SN6178 split to the individual circuits for each control rod brake. These signals are also interlocked with the rod control system through test switches TS1, TS2, TS3 and TS4 (SN6427, 6433, 6447, and 6453) and interlock relays K49, K51, K48 and K50 (coils SN6430, 6436, 6450 and 6456).

e. Rod Control System — DWG No.: FSV 19E-1, E-2

The rod control system for the St. Vrain Nuclear Power Plant receives all of its power for the rod control drive motors from two three-phase lines originating in the plant Electrical Distribution Center. These lines are 480V lines and are routed directly to Motor Control Center 1A and Motor Control Center 3. At the motor control centers, the high voltage is passed through stepdown transformers and reduced to three-phase 125V. The 125V lines are brought into a three pole transfer switch which allows the operators to switch from the power source from one Motor Control Center to the other in case one of the two power sources is not working properly. From the transfer switch the power is fed through a set of dual relays which are held normally closed as long as SCRAM brake power is available. If a SCRAM has been initiated or the reactor has been shut down these relay contacts are open and prohibit power from reaching the control rod drive motors. At this point, the power is fed to an auto-transformer. At a junction just prior to entering the auto-transformer two of the phases are tapped to provide 125V power to the control rod drive selection circuitry. This circuit is fused. After leaving the auto-dyne transformer the power from each of the two Motor Control Centers is combined and fed through a circuit breaker, from thence, through a set of relay contacts which are energized by rod "in" or rod "out" signals from the control rod drive center. These relay contacts serve to reverse the phase of the control rod drive motors depending on whether the rods are to be driven "in" or are to be driven "out". After passing through this set of contacts, power goes through a set of thermo-overload breakers and directly to the motor windings. Just before going into the motors, there is a set of three heavy duty capacitors across each of the three phases. These capacitors serve to provide dynamic braking as the rods are dropped during a SCRAM.

The rod "in" and rod "out" signals originate in the Rod Control Drive Center. The Rod Control Drive Center provides the reactor operator with an option of three modes of operation, i.e., individual rod control, group rod control, and automatic rod control. The manner of providing rod "in" or rod "out" information to the phase controlling relays is practically identical for each of the three modes of operation. For this purpose the model was constructed using the individual rod control mode as typical. As previously discussed, the power for any one of the three modes of rod control comes from the Motor Control Center. This 125V is passed through an Interlock Sequence Switch which provides power for rod control only in Refueling or Run modes of operation. After leaving the Interlock Sequence Switch, the 125V splits into two paths; one path going to the rod "in" circuitry, the second path going to the rod "out" circuitry. Since the two circuits are almost identical, only the rod "out" circuitry will be discussed at this point. The rod drive signal in the rod "out" circuitry passes through a set of normally closed contacts which are energized by the Rod Withdrawal system and from there directly to a Mode switch which indicates whether the rod is to be driven "out" or "in" or not at all. At this point, the drive signal passes into two selection switches, the first switch giving the operator an opportunity to select any of four groups or rods. The second switch allows the operator to pick out which specific rod in that group he desires to move. From here the drive signal is routed directly to the rod that was selected to be driven.

Upon reaching the designated control rod, the rod drive signal passes through a slack cable switch which is normally closed, but which has a reset switch mounted in parallel with it. At this point the rod drive signal goes through a set of rod "out" relay contacts, which are opened only if the rod has been pulled all the way out. From thence, through an overload fuze and back into the Control Rod Drive Center. In the Control Rod Drive Center, the signal is passed through two sets of contacts normally energized by the rod "in" relay. These contacts are normally closed unless the rod "in" mode has been selected, in which case the opening of these contacts would prohibit the operator from driving the rod out. From here, the rod drive signal is passed through the K2 rod "out" relay and through a third set of rod "in" relay contacts. Finally, the rod drive power goes through a set of three overload breakers and terminates in a rod counter circuit to indicate the number of inches that the rod has been withdrawn. For the purposes of the SCRAM model evaluation, a rod "out" command was selected for controlling rod 2.

GO Logic Circuitry for Rod Control DWG No. FSV 19G

The electrical and GO logic circuitry for the functions just described are modeled in Drawing FSV19G/E. Motor Control Center signal SN6500 is shown after coming through the three-phase transformer and represents power into Motor Control Center 3. In a similar manner, SN6501 represents three-phase power source for Motor Control Center 1A. A description of the GO modeling logic for Motor Control Center 3 will be given. After passing through the 480/125V step-down transformer the power is fed through identical channels in all three phases. SN6505, 6510 and 6515 represent passage of the three-pahse 125V through the transfer switch which is under control of the human operator, (OP1). The signal next encounters a set of relay contacts which act to inhibit progression of the power if rod brake power has been interrupted. The outputs of these contacts are identified as SN6540, 6546 and 6550. The relays controlling this action of these contacts are K48, K49, K50 and K51. The three-phase lines are brought through the auto-transformer and sent to the individual rod control drive motors, SN6690, 6691 and 6692. Phases 2 and 3 are tapped (SN6548 and 6553) to provide power for the Control Rod Drive Center. In Motor Control Center 3, relay K56 will insure that any drive power coming from Motor

Control Center 1A will be inhibited unless Motor Control Center 3 loses power, in which case the K56 contacts will be closed, and drive power can be provided from Motor Control Center 1A to the Control Rod Drive Center and to the selected control rod drive motors. In parallel with the signal paths just discussed, three-phase power can be provided by Motor Control Center 1A. This power is identified on the GO schematic as SN6693, 6694 and 6695. The Motor Control Centers also incorporate an Emergency set of relays which are used only if a control rod becomes stuck during a SCRAM request. These relays insure that drive power can be delivered to the stuck rod, even though the rest of the rods are scrammed through a set of manually controlled switches. This is indicated on the GO charts by the Hand Switches (OP3-6). Closure of these switches will provide bus power through relays K61, K62, K63 and K64 to bypass the K48, K49, K50 and K51 relays, if they had been previously opened by a SCRAM action and if it is necessary to apply emergency power to remove the rods. The emergency signals coming into these relay contacts are identified as SNK6524, K6535, K6528 and 6676. In the Control Rod Drive Center the power coming from SN6601 and 6602 is first passed through a type 7 component representing a Rod Withdrawal Prohibit relay contact which is normally closed and from thence through the Reactor Mode Switch (SN6604). At this point the signal splits into two paths to furnish power for the rod "in" or the rod "out" control lines. In the rod "out" line, the signal is passed through several transfer points, one of the transfer points representing a current transformer sensor which indicates whether more than one rod is being pulled. In a case such as this, a Rod Withdrawal Prohibit will be implemented. The drive signal is directed through a set of normally closed run-back contacts (SN6627) and finally to an operator actuated mode switch which indicates that the operator wants to drive the rods "out" (SN6628). This switch has been set to be operated at time period 2 in the current GO model. At this point, the 125V power passes into a set of rod selection switches which provide the operator with the capability of deciding which rod he wants to drive out. The first bank of switches give him an option to choose any one of four rod groups and the second set of swtiches give him the option of picking out a specific rod in that group which he wants to apply power to. Following the line for rod number 2 in the first bank, which is GO SN8126, the power passes through the cable slack switch and the reset switch exiting as SN6659, through the rod "out" limit switch SN6661, and through 1-3 type connectors back into the Control Rod Drive Center to operate the rod "in"/rod "out" relays and the associated counters. The rod "out" relay which is used to control the phase of the voltage applied to the rod drive motors is designated by SN6299. The rod "in" signal, if the operator wishes to drive the rods in, is designated by SN6298. The signal going to the rod position counter is SN6677 or SN6668, depending on whether the rod is being driven in or out. SN6299 and SN6298 are also applied back in the SCRAM brake line to release the control rod brakes whenever it is desired to move the rods.

The relay contacts which are opened up in the rod brake lines whenever drive power is applied for each of the 37 rod brakes are represented in the GO diagram as being the same signal for all rods, except the rod "out" signal for control rod number 2. SN6300 has been used as the common signal for all rods not being moved. Signal number 6299 has been used to designate a normally open set of contacts for the rod brake line on control rod number 2 when it is being driven out.

f. Control Rod Drive Mechanism DWG No.: FSV 20E/20G

GO drawing FSV-20G illustrates the control rod drive mechanism for one pair of control rods. It has been repeated 36 more times in the GO model to represent all of the control rod drives. There are three major inputs to this model. The first is represented by three phase power, SN6690, 6691 and 6692 for one half of the control rods, and SN6693, 6694 and 6695 for the other half. The second input comes from the K2 "in" relay (SN6298) or the K2 "out" relay, (SN6299). The third input is SCRAM Brake Power.

Phase Information

If the K2 "in" relay is actuated and if three phase input power is present, output signals SN8004, 8005 and 8006 will exist. Similarly, if the K2 "out" relay is actuated with the presence of three phase power, signals will appear on SN8001, 8002 and 8003. It will be recalled that the purpose of the K2 "in" and the K2 "out" relays is to reverse two of the input phases on the control rod drive motor depending on whether the control rod is to be driven "in" or "out". The third phase remains the same in either case so SN8002 and SN8005 are OR'd together to provide SN8009, which will be present if either K2 "in" or K2 "out" relays have been actuated. If K2 "in" and K2 "out" relays are both actuated simultaneously, signals will appear on SN8001 and SN8004, which indicates that these two phases are shorted together. At the same time, signals will appear on SN8003 and SN8006 which will verify the shorting of these two phases. In this event, signals will appear at SN8007 and at SN8008 simultaneously. If either or both signals appear, OR gate SN8010 appears. This indicates a short between two phases of the power supply, and consequently, it will activate their respective circuit breakers.

Power Interruption

If the circuit breaker, CB1, has been actuated, it will in turn actuate relay contacts CB1A, B and C. The combination of type 3's and type 9's are used here for the circuit breaker contacts to disrupt the three phase signals at the time that the short occurs. In a similar manner, thermo-circuit breaker, CB2, which is energized by the load environment is represented by a type 3 as a driver and three other pairs of 3's and 9's representing the circuit breaker contacts. If the phase signals to the motor have survived to this point, we have signals present at SN302, SN304 and SN306. In the physical circuitry several dynamic breaking capacitors are found to be bridging the three phase lines at this point. These capacitors have not been put into the current GO model, however, because the effect of a short in one or more of these capacitors is uncertain. Preliminary analysis indicates that a short in at least two capacitors would be required in order to affect the SCRAM system. A short occurring in these capacitors while the motor is being operated would almost certainly throw one of the circuit breakers and lead to repair action being taken. It was decided that if the rod drop action turned out to be sensitive to this particular part of the system that a closer look would be taken at these capacitors. That has not proved to be the case.

Rod Motion

Three phase power is transmitted through connectors and power cables resulting in signals at points 8025, 8028 and 8031. If any two of the three phases are powered a signal will appear at SN8118. If the selected rod is to be driven "in" and if power appears at all three phases, there will be a signal at 8035, indicating a power insertion signal. The presence of this signal will inhibit a signal on SN307. In the absence of such an inhibit, the signal at this point indicates that all three phases are powered in relationship which will create a powered withdrawal of the rods. Rod insertion and power withdrawal depend upon the performance of the motor. If the motor functions properly, the signal will appear at SN8037 at time zero. If the motor does not work properly, this signal will not appear. If power appears on only two of the three phases of the shim motor and if the motor is not already actuated, it is possible that the resulting AC magnetic field within the three phase induction motor will cause the motor to freeze preventing a SCRAM. If the motor is functional and a powered withdrawal signal is present, the signal appears at SN8039. This signal will prevent a SCRAM from occurring on the rod that is being withdrawn. Similarly, if the power insertion signal appears at the SN8035 and if the motor functions properly, a signal will appear at SN8038. This signal will act to drive the rods in. Up to this point in the control rod drive model, all time has been reverse time. Consequently, the signals at SN8038 and at SN8039 indicate the complement of the time at which powered insertion and powered withdrawal stop. At this point the drive signals are fed through type 9 operators which function to reverse the time, so that the signals at SN309 and SN312 are in forward time. These signals represent the time at which powered withdrawal or powered insertion stop.

SCRAM Brake Power DWG No.: FSV 20G

At the left side of Figure FSV-20G, the SCRAM Brake Power signal comes in at the point indicated by (6). The brake power passes through a fuze and two cable connectors before reaching the K2 rod "in" relay contact or the K2 rod "out" relay contact. At SN8131, brake power is in reverse time just before being applied to the SCRAM brake. Again, we go through a time reversal with a type 9 component, generating SN308. This signal is now the time at which brake power ceases to be applied, or in other words, the time at which SCRAM would normally occur. The SCRAM signal then passes through component 3-124 representing the brake soloniod, component 3-125 representing the brake gear and component 3-125 representing the brake spider. It is necessary for all these components to work properly in order for the SCRAM to occur. A SCRAM in the rod under evaluation will not normally occur if the brake release reprsented by component 1-52 sticks, or if the mechanical drive sticks (component 1-53). Depending upon the time at which power insertion stops, the SCRAM signal may bypass a stuck brake release or a stuck mechanical drive. In the physical situation, this situation is represented when the force of the shim motor overcomes the sticking brake or the residual friction in the mechanical drive. The powered insertion is fed to control component 7-307, which is a perfect, normally closed, switch. This switch allows the SCRAM signal to bypass the sticking brake release or a sticking mechanical drive if the power insertion is active. A signal at SN8046 will occur if the brake release and the sticking mechanical drive have been bypassed or if they function properly. If withdrawal has stopped before the SCRAM signal occurs, a signal at SN8204 will appear otherwise, it will not appear until power withdrawal ceases.

Component Reliability Changes

It was discovered after a few computer runs with the above model that the system was relatively insensitive to inputs from either powered insertion or powered withdrawal. This is primarily because multiple mode failures are required in order for these signals to be present at the same time as a SCRAM signal. Consequently, the sticking mechanical drive, component 1-53, was considered to be perfect and the mechanical drive friction was distributed throughout the bearings and gears of the mechanical drive itself. During the early computer runs of this model, all of the bearings were treated as identical type components. Consequently, all bearings were represented by a component type 1-54. After a few runs, it was discovered that the system was highly sensitive to bearing failure. Estimates were made of the failure rates of bearings in different places in the drive mechanism, and the type 1-54 components were replaced by six different component types, i.e., component types 1-61, 1-62, 1-63, 1-64, 1-66, 1-67.

Friction Paths

SN8036 is a perfect signal occurring at time zero. This signal is transmitted through the three bearings type 1-66, representing the motor bearings up to the type 10, which generates SN8050. The SCRAM signal at this point occurs only if the bearings do not create excessive friction. In a similar manner, when the model demonstrated that it was sensitive to gear and pinion friction, or failure, the gear and pinion component (3-127) was replaced by four new component types, i.e., 3-132, 3-133, 3-134 and 3-135. If the pinion and the gear driven by it functions properly, signal SN8051 will appear. This is coupled through pin type 3-128 to generate a signal at SN8052. The type 3 component used to represent the pin may premature, representing a pin shearing, but it is not given any probability of causing a failure. Conversely, the gears are more likely to cause a failure to SCRAM than to have the teeth stripped completely from them thereby allowing the rod pair to SCRAM prematurely. From this point, the signal is passed through two bearings, types 1-61, on the first motor drive gear to an AND gate which generates signal SN8055 if the bearings function properly and if all prior components function. The SCRAM signal is then transmitted through another gear and pinion type 3-133 to form SN8056. This gear and pinion is fastened with three bolts types 3-129. If these bolts premature they could cause a premature operation of the system. A signal at SN8062 will occur if all three of these bolts were to shear off if the system functions properly. Initiation signals are now fed through two bearings, type 1-62, on the second motor drive gear. This signal is ANDED with the previous SCRAM signal idnicating that successful operation of these bearings is required for a SCRAM. At this point, the signal is routed through component type 3-134, representing the third gear and pinion combination, with component 3-128 representing the pin. This brings the SCRAM signal to SN8067. Here the signal is ANDED with the signal coming up through the two bearings on which the third gear and pinion are supported. If these bearings function properly and if previous indications indicate a SCRAM, then the SCRAM signal SN8070 is generated. The signal is now fed through component type 3-135 representing another gear and pinion combination. This component represents the ring gear which is mounted to the drum of the control rod drive. The ring gear is fastened to the drum by six bolts represented by components 3-129. If all of these bolts were to premature, a premature SCRAM would occur. The drum, in turn, is supported by six other bolts represented by type 1-56 components. If all of these bolts were to fail then it is believed that the drum would lock up and the system would not SCRAM. The drum is supported on the drum spindle by two bearings types 1-64. If the drum spindle (component 1-55), the bearings and one or more of the supporting bolts function then a SCRAM signal will appear at SN8098, assuming of course, that nothing has gone amiss in the SCRAM signal up to this point.

Rod/Cable Assembly (Type 2)

The rods are supported by cables passing over the drum. At this point, GO models each of the control rods separately. Choosing the type 2 rod, we note that SN8098 passes through the control rod cable anchor, component 3-130, and terminates at a type 10 component. Here we recognize that the cable passes over two pulleys (1-58), each supported on a bearing (1-67) and each bearing on a common shaft (1-51). If all of these function properly, then a SCRAM signal will appear at SN8105. If the cable does not function prematurely, i.e., break, then signal SN8106 occurs at the proper time. A low possibility exists, of course, that the control rod may be hanging up somewhere within the control rod guide hole. This is represented by component 1-59. A successful SCRAM will be represented by a signal at SN8116, if environmental effects have not caused it to hang up.

It should be noted that the signal SN310 represents common environmental effects to all rods. The purpose of this signal is to represent such things as seismic shock which may affect all rods equally. SN311 represents an individual environmental effect for each pair of rods such as might occur if a rod assembly penetration cover were to suddenly be breached and cause a rapid decompression. If either of these environmetal effects occur, signal SN8114 will prevent a successful SCRAM of the rod.

Rod/Cable Assembly (Type 1 Rod)

In a manner analogous to the path followed for a type 2 rod, signal SN8098 is fed through components representing the cable anchor, shaft, bearing and cable pulley. It should be noted that in a type 1 rod there is only one cable pulley (1-58) and one bearing (1-68), which passes through a component type 3-131, representing the cable, and another component type 1-59, representing the possibility of the rod sticking. The signal then passes through another perfect type 7 switch which is opened only if the environmental input may inhibit the SCRAM.

SCRAM Outputs

A successful signal at SN8201 occurs only if both rods of the pair SCRAM. This signal is ANDED in the model with signals from all previous rod pairs to generate the probability of all rods successfully SCRAMMING.

APPENDIX B

TIME LINE SEQUENCE CHARTS

TIME LINES FOR SURVEILLANCE PROCEDURES

TIME LINE FOR MANUAL (CONTROL ROOM) SCRAM TEST

SURVEILLANCE PROCEDURE # 5.4.1.1.1.a-R.P

References: 1) System operating Procedure 93-01 Control & Instrumentation: Plant Protection System 2) Drawing EL-169-2951
Frequency: Refueling and prior to startup.
GO Chart Reference No.: FSV-18
Instruments: HS-1216-Reactor Mode Switch (RMS)
HS-9330 Manual SCRAM Button (MSB)

Surveillance Events

- 1 (a) Verify Reset of SCRAM System
- 1 (b) Reset SCRAM System if Necessary (Sig. # 163)
- 2 (a) Prepare rod control system for W/D of first control rod group. Check Monitors
- 2 (b) Withdraw rod group 6 inches (Sig. # 210, 211)
- 3 Place MSB to SCRAM, then return to Normal (Sig. # 162)
- 4 Visual Verification
- 5 Reset SCRAM trip as in 1b (Sig. # 163)
- 6 Verify all trips in Event 4 are reset. (Sig. # 163)
- 7 Place RMS to OFF position and remove key (Sig. # 105)
- 8 Verify RMS will not move; make verification as in 6
- 9 Return RMS to the position desired for anticipated operation. Record Position (Sig. # 106)

(1a) Verify that XA-9319, XA-9320 and XA-9321 are all off. Verify that II-93177, II-93178, II-93179, II-93180 are all null (<3 amps). If any one of these is not true, reset SCRAM section according to (1b).

(1b) Proceed as follows:
α) Verify all SCRAM inputs are cleared:
XCR-93125, 301-P11, TRIP indicator out
XCR-93127, 201-P11, TRIP indicator out
XCR-93126, 101-P11, TRIP indicator out

β) Depress and release HS-93125, A LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-1, Alarm reset. Verify XI-93181 and 93235 are out.

σ) Depress and release HS-93126, B LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-2, Alarm reset, REACTOR on Lit, A-B SCRAM AUXILIARY RELAYS red lights out. Lights XI-93184, XI-93213, XI-93214, XI-93222 are out.

δ) Depress and release HS-93127, C LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-2, alarm reset. XI-93183, 93237 out, II-93177, 178, 179 and 180 all indicating null current (<3 amp).

(2a) Verify primary coolant moisture monitors MIS 1122, 1121, 1120, 1115, 1119, 1116, 1117, 1118 are reset and ready for sampling. If they are not, attempt to reset by pressing, then releasing red trip indicator.

(4) Verify that rod group in Event 2 returns to fully inserted position in approx. 6 sec. Verify REACTOR on light off and A-B SCRAM AUXILIARY RELAYS lights are ON. Verify I-03A, 5-1, 5-2, 5-3 alarm. Verify the following SCRAM trip outputs: XCR-93211A, + B, #1 red ON lit (2 min time delay). Also verify that XI-93235, XI-93181, XI=93237, XI-93183, XI-93236, XI-93182 are lighted.

FIGURE B.1

TIME LINE FOR MANUAL (I-49) SCRAM TEST
SURVEILLANCE PROCEDURE #5.4.1.1.2.a-M-p

References: 1. System Operating Procedure 93-01; Control & Instrumentation: Plant Protective System.
2. Drawing EL-169-2951.

Instruments: HS-93372
HS-93373
HS-93374

GO Chart Ref: FSV-18

Frequency: Monthly and Prior to Startup.

Surveillance Events	
1	Reset all scrams. (Sig. #163)
2	Depress and release SCRAM CHANNEL A push button. (Sig. #160)
3	Visual verification.
4	Reset Channel A Scram. (Sig. #163)
5	Visual verification as in (3).
6	Depress and release SCRAM CHANNEL B push button. (Sig. #161)
7	Visual verification.
8	Reset Channel B Scram. (Sig. #163)
9	Visual verification as in (7).
10	Depress and release SCRAM CHANNEL C push button. (Sig. #159)
11	Visual verification.
12	Reset Channel C Scram. (Sig. #163)
13	Visual verification as in (11).

(1) α) Verify all scram inputs are cleared.
XCR-93125,301-P1 TRIP indicator out.
XCR-93127,201-P1 TRIP indicator out.
XCR-93126,101-P1 TRIP indicator out.

β) Depress and release HS-93125, A LOGIC SCRAM/ANNUNN RESET. Verify I-03A,5-1, alarm reset. Verify XI-93181 and 93235 are out.

σ) Depress and release HS-93126, B LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-2, alarm reset, REACTOR ON light, A-B SCRAM auxiliary relays, red lights out. Lights XI-93184, XI-93213, XI-93214, XI-93222 are out.

δ) Depress and release HS-93127, C LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-2, alarm reset. XI-93183, 93237 out, II-93177, 178, 179, 180 all indicating null current (<3 amp).

(3) XI-93181 light on.
XI-93235 light on.
I-03A, 5-1, alarm tripped.

(7) XI-93182 light on.
XI-93236 light on.
I-03A, 5-2, alarm tripped.

(11) XI-93183 light on.
XI-93237 light on.
I-03A, 5-3, audible alarm.

FIGURE B.2

TIME LINE FOR STARTUP CHANNEL SCRAM CALIBRATION
SURVEILLANCE PROCEDURE #5.4.1.1.3.c-R

Reference: Drawing EL-169-3111
Frequency: Refueling (once yr)
GO Chart Reference No.: FSV-4
Instruments: NIM-1131
NIM-1132

Surveillance Events	
1	Disconnect high voltage cable connected to J7 (Sig. #340)
2	Make voltage test and adjustment
3	Reconnect high voltage cable on SUC (Sig. #340)
4	On SUC connect oscilloscope to A1-TP2
5	Verify oscilloscope wave form is 10V peak to peak
6	Remove card box cover and adjust A1-R34 if oscilloscope wave form is unsatisfactory
7	Replace cover on SUC and repeat events 4 thru 6 until oscilloscope wave is satisfactory
8	Remove coax cable connected to J5 (Sig. #337)
9	Connect frequency counter to J8
10	Rotate operate switch to 10^2 position. Frequency counter should indicate 50 counts/sec. (Sig. #51)
11	Adjust A2-R10 until counts PER SECOND meter shows 10^2
12	Rotate operate switch to 10^5 position. Frequency counter should indicate 50000 counts/sec. (Sig. #51)
13	Adjust SPAN until meter indicates 10^5
14	Repeat events 10-13 until no zero or span adjustments are required
15	Return all connections to normal on SUC (Sig. #337)
16	Connect DVM to A1-TP1

Surveillance Events	
17	Connect frequency counter to J8
18	Make plot of discriminator voltage vs. count rate, using R8
19	Set R8 to value that cuts off the extrapolated steep portion of the curve
20	Install coaxial "TEE" on J5 on SUC back (Sig. #337)
21	Reconnect coaxial cable on SUC (J5) (Sig. #337)
22	Connect oscilloscope to A1-TP1. Connect second channel of oscilloscope to coaxial "TEE". Verify all high amplitude pulses are counted
23	Return all connections to normal (Sig. #337)
24	Disconnect high voltage cable connected to J7 (Sig. #346)
25	Connect DVM to high voltage output connector. Record DVM reading. Adjust voltage if not 607 volts. Disconnect DVM
26	Reconnect high voltage cable (Sig. #346)
27	Connect oscilloscope to A1-TP2
28	Verify oscilloscope wave form amplitude is 10V peak to peak
29	Remove card box cover and adjust A1-R34 if oscilloscope wave form is unsatisfactory
30	Replace cover on SUC and repeat events 27 thru 29 until oscilloscope wave is satisfactory
31	Remove coaxial cable connected to J5 (Sig. #343)
32	Connect frequency counter to J8

FIGURE B.3

TIME LINE FOR STARTUP CHANNEL SCRAM CALIBRATION
SURVEILLANCE PROCEDURE $5.4.1.1.3.c-R

Surveillance Events

33 Rotate operate switch to 10^2 position. Frequency counter should indicate 50 counts/sec
(Sig. #51)

34 Adjust A2-R20 until COUNTS PER SECOND meter indicates 10^2

35 Rotate operate switch to 10^5 position. Frequency counter should indicate 50000 counts/sec
(Sig. #51)

36 Adjust SPAN until meter indicates 10^5

37 Repeat events 33-36 until no zero or span adjustments are required

38 Return all connections to normal
(Sig. #343)

39 Connect DVM to A1-TP1

40 Connect frequency counter to J8

41 Make plot of discriminator voltage vs. count rate, using R8

42 Set R8 to the valve that cuts off the extrapolated steep portion of the curve

43 Install coaxial "TEE" on J5
(Sig. #343)

44 Reconnect coaxial cable on SUC (35)
(Sig. # 343)

45 Connect oscilloscope to A1-TP1. Connect second channel of oscilloscope to coaxial "TEE". Verify all high amplitude pulses are counted

46 Return all connections to normal
(Sig. #343)

Note: Events 24-46 are a repetition of events 1-23 for SUC-2.

FIGURE B.3(Continued)

TIME LINE FOR STARTUP CHANNEL SCRAM TEST (SUC 1 + 2)

SURVEILLANCE PROCEDURE # 5.4.1.1.3.b-P/5.4.1.4.1.b-P

References: EL-169-3111
EL-169-3109

Frequency: Prior to startup

GO Chart Reference: FSV-4

Instruments: NIM-1131
NIM-1132

Startup Channel Check, SUC 1

Surveillance

Events	
1	Place RMS HS1216 to FUEL LOADING (Sig. #104)
2	Set or verify SUC switches
3	Place level operate/test switch to 10^2, 10^4, 10^5, and operate. Observe counts per second for each reading and record (Sig. #51)
4	Visual Verification
5	Reset all trips on SUC 1 (Sig. #51)
6	Reset SCRAM trips (Sig. #163)
7	Turn level TRIP TEST CW until HI Level trip indicator is on. Record level indication (Sig. #60)
8	Visual Verification
9	Return level TRIP TEST to OFF (Sig. #60)
10	Reset HI Level trip Reset RATE 1 if tripped (Sig. #60)
11	Reset SCRAM Trip (Sig. #163)
12	Reset any RWP trip by placing HS-1217 (ISS) to startup (Sig. #100, 101, 102)
13	Visual Verification
14	Disconnect P4 from back of SUC drawer (Sig. #337, 343)
15	Visual Verification
16	Rotate Level TRIP TEST until LO LEVEL trip can be reset. Rotate level TRIP TEST CCW until LO LEVEL trip indicator trips (Sig. #60)

Surveillance

Events	
17	Visual Verification
18	Place TRIP TEST to OFF (Sig. #60)
19	Place rate made switch to CALIBRATE (Sig. #59)
20	Verify rate meter reads 7.0 DPM ± 0.1 DPM
21	Return rate mode switch to OPERATE (Sig. #59)
22	Verify rate meter reads 0.0 DPM ± 0.1 DPM
23	Reset RATE 1 trip (Sig. #59)
24	Slowly turn rate TRIP TEST CW until RATE 1 trip is on. Record rate meter indication (Sig. #58)
25	Visual Verification
26	Return rate TRIP TEST to OFF (Sig. #58)
27	Reset Rate 1 trip indication (Sig. #59)
28	Reconnect P4 to J4 (Sig. #337, 343)
29	Reset LO LEVEL trip
30	Visual Verification
31	Return RMS H51216 to RUN (Sig. #106)

FIGURE B.4

SURVEILLANCE PROCEDURE # 5.4.1.1.3.b-P5.4.1.4.1.b-P

NOTE: Procedure for SUC 2 is identical to that for SUC 1 provided SUC 2 is substituted for SUC 1.

(2) Verify operate/test switch to OPERATE, Level TRIP TEST to OFF, rate switch to OPERATE, and rate TRIP TEST to OFF. Verify green pilot light on. Record CHAMBER VOLTAGE and verify its correctness according to latest calibration procedure.

(4) Verify that level/operate test switch positions 10^2, 10^4, 10^5, are within red calibration marks.

(8) Verify I-03B, 4-4, 5-4, 6-4 alarms tripped. Verify reading in event 7. Verify I-03 Reactor SCRAM shows: REACTOR ON light is OFF SCRAM AUX. Relays A-B on I-03A, 5-1, alarm I-03A, 5-2, alarm I-03A, 5-3, alarm FACILITY HAZARD alarm tripped on FHM console.

(13) Verify I-03A, 2-2, alarm reset Record SUC count rate indication. and verify this indication > 2.5 cps.

(15) Verify I-03A, 2-2, alarm tripped.

(17) Record level indication in event 16 and verify that reading is 2.5 cps ± 0.5 cps.

(25) Verify reading in event 24 is 2.0 DPM ± 0.1 DPM. Verify I-03A, 1-1, alarm tripped.

(30) Verify level indication. Verify I-03A, 2-2, alarm reset.

(6) & (11)) Verify all SCRAM inputs are cleared:
XCR-93125, 301-P11, TRIP indicator out
XCR-93127, 201-P11, TRIP indicator out
XCR-93126, 101-P11, TRIP indicator out

) Depress and release HS-93125, A LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-1, alarm reset. XI-93181 and 93235 out.

) Depress and release HS-93126, B LOGIC SCRAM/ANNUN RESET. Verify I-03 A, 5-2, Alarm reset, REACTOR on lit, A-B SCRAM AUXILIARY RELAYS red lights out. On I-10, XI-93184, XI-93213, XI-93214, and XI-93222 lights are out.

) Depress and release HS-93127 C LOGIC SCRAM/ANNUN RESET. Verify I-03 A, 5-3, alarm reset. XI-93183 and 93237 lights out, II-93177, 178, 179, 180 all show null current (<3amps)

FIGURE B.4(Continued)

TIME LINE FOR LINEAR POWER CHANNEL SCRAM TEST (& WIDE RANGE CHANNELS)

SURVEILLANCE PROCEDURE # 5.4.1.1.4.b-M-P/5.4.1.4.2.b-M-P

References: SOP-93-01
Drawings 169-3109, 169-3110,169-3111
GA Manual, O & M for Nuclear Instrumentation
GO Chart Reference: FSV-6
Frequency: Monthly & prior to startup.
Instruments: NIM-1133 NIM-1134 NIM-1135 NIM-1136 NIM-1137 NIM-1138

Power Range Channel Check, PRC 3 and PRC 6

Surveillance Events	
1	Preliminary verification
2	Place ROD WITHDRAWAL PROHIBIT switch to NORMAL
3	Visual verification
4	On PRC 3, place mode switch to Zero. Verify PER CENT POWER reads 0.0 ± 0.5. Release mode switch (Sig. #64)
5	On PRC 3, place mode switch to CALIBRATE. Verify PER CENT POWER reads 150.0 ± 0.5. Release mode switch (Sig. #64)
6	On PRC 6, place mode switch to ZERO. Verify PER CENT POWER reads 0.0 ± 0.5. Release mode switch (Sig. #50)
7	On PRC 6, place mode switch to CALIBRATE. Verify PER CENT POWER reads 150.0 ± 0.5. Release mode switch. (Sig. #50)
8	Skip to event 17 if reactor power level is 30% or greater.
9	Slide drawer out of I-9310. Depress S13, record PRC 3 PER CENT POWER reading release S13. Verify reading. (Sig. #61)
10	Depress S14, record PRC 6 PER CENT POWER reading release S14. Verify reading. Slide drawer in and secure. (Sig. #61)
11	Reset all trips on PRC 3 and PRC 6 (Sig. #61)
12	Reset all SCRAM trips (Sig. #163)
13	On PRC 3, slowly increase level TRIP TEST until LLT 1 is on. On PRC 6 slowly increase Level TRIP TEST until LLT 1 is on (Sig. #63, 66)
14	Verify readings in event 13 are 5.0% ± 0.5%.
15	On PRC 3, increase level TRIP TEST until LLT 2 is on. On PRC6 increase level TRIP TEST until LLT 2 is on (Sig. #63, 66)
16	Verify readings in event 15 are 30.0% ± 0.5%.
17	On PRC3 increase level TRIP TEST until HLT 1 trip indicator is on. On PRC 6, increase level TRIP TEST until HTL1 trip indicator is on (Sig. #63, 66)
18	Visual Verification
19	On PRC 3 increase level TRIP TEST until HLT 2 trip indicator is on. On PRC 6 increase level TRIP TEST until HLT 2 trip indicator is on (Sig. #63, 66)
20	Visual Verification
21	Return both level TRIP TEST pots to OFF (Sig. #63,66)
22	Visual Verification
23	Reset HLT1 and 2 on both PRC 3 and PRC 6 (Sig. #63, 66)
24	Visual Verification
25	Reset SCRAM Trips (Sig. #163)
26	Place RWP bypass switch to BYPASSED (Sig. #67)
27	Visual Verification
28	Return RWP bypass switch to NORMAL (Sig. #67)
29	Visual Verification
30	Reset SCRAM Trips (Sig. #163)

FIGURE B.5

SURVEILLANCE PROCEDURE # 5.4.1.1.4.b-M-P/5.4.1.4.2.b-M-P

NOTE: The procedure for Power Range Channel Check, PRC 4 & 5, and PRC 7 & 8 is identical to the procedure shown on the above time line provided
   a) PRC3, PRC6 are replaced by PRC4, 5 & PRC 7, 8 respectively
   b) In event 24, I-03B, 1-1, 1-2 is replaced by I-03B, 2-1, 2-2, respectively.
   c) In event 27, I-03B, 1-1, 1-2 is replaced by I-03B, 2-1, 2-2 respectively. Also, I-03A, 5-1 is replaced by I-03A, 5-2, respectively.

(1) on both PRC 3 and PRC 6 verify preliminary setup:
  Mode switch to OPERATE
  Level TRIP TEST to OFF

(3) Verify green POWER ON pilot light is on. Verify red GAIN x 10 is off.

(18) Verify readings of event 17 are 120.0% ± 0.5%. Verify I-03A, 1-3, alarm tripped. Verify I-03A, 1-4, alarm tripped

(20) Verify readings of event 19 are 140.0% ± 0.5%. Verify I-03B, 1-1, alarm tripped. Verify I-03B, 1-2, alarm tripped.

(22) Verify both HLT 1 trip indicators remain lit. Verify I-03A, 1-3, 1-4 alarms have not cleared.

(24) Verify all alarms I-03A, 1-3, 1-4, I-03B, 1-1, 1-2, are reset.

(27) Verify I-03A, 5-1, alarm tripped
  Verify I-03B, 1-1, alarm tripped
  Verify I-03B, 1-2, alarm tripped

(29) Verify reset of alarms in event 27.

(12)
(25)
(30)
α) Verify all SCRAM inputs are cleared:
  XCR-93125, 301-P11, TRIP indicator out
  XCR-93127, 201-P11, TRIP indicator out
  XCR-03126, 101-P11, TRIP indicator out

β) Depress and release HS-93125, A LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-1, alarm reset. XI-93181 and 93235 out.

γ) Depress and release HS-93126, B LOGIC SCRAM/ANNUN RESET. Verify I-03A, 5-2, alarm reset, REACTOR on lit, A-B SCRAM AUXILIARY RELAYS red lights out. Verify lights XI-93184, XI-93213, XI-93214, and XI-93222 are out.

δ) Depress and release HS-93127, C LOGIC SCRAM/ANNUM RESET. Verify I-03A, 5-3, alarm reset. XI-93183 and 93237 lights out, II-93177, 178, 179 and 180 all indicating null current (~ 3 amps)

FIGURE B.5(Continued)

References: 169-3109,3110,3111
Instruments: NIM-1133-1
NIM-1134-1
NIM-1135-1
GO Chart Ref: FSV-5
Frequency: Monthly

TIME LINE FOR WIDE RANGE POWER CHANNEL SCRAM CALIBRATION

SURVEILLANCE PROCEDURE #5.4.1.1.5.c-M/5.4.1.4.3.c-M

NOTE: This procedure calibrates power only -- Does Not Test Scram Levels.

Surveillance Events	
1	Dial function 016 on data logger.
2	Push selector button on data logger.
3	Record or calculate reactor power level.
4	Record reading on NIM-1133-1.
5	Verify differences.
6	Record reading on NIM-1134-1
7	Verify differences.
8	Record reading on NIM-1135-1.
9	Verify differences.
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

(3) Record reactor power level indicated by data logger. If data logger is not functioning use calculational procedure outlined in Appendix 1 attached to description of this surveillance procedure.

(5)
(7)
(9) Verify that instrument value does not differ from reactor power level (read from logger or calculated) by more than 10%.

FIGURE B.6

References: SOP 93-01,
GA Drawing: 169-3109,3110,3111
Frequency: Prior to each reactor startup.
GO Chart Ref #: FSV-5
Instruments: NIM-1133,NIM-1134, and NIM-1135(WRC 3,4,5).

TIME LINE FOR WIDE RANGE POWER CHANNEL TEST

SURVEILLANCE PROCEDURE #5.4.1.1.5.b-P/5.4.1.4.3.b-P

Surveillance Events	
1	On WRC 3, verify initial set up; i.e., level calib on OPERATE, level trip test on OFF, rate MODE switch on OPERATE, rate trip test on OFF.
2	Reset all trips.
3	Verify indicators.
4	Rotate level calib switch to positions 1 thru 6. (Sig. #48)
5	Verify % PWR indic.
6	Return level calib to OPERATE. (Sig. #48)
7	Verify Indic. and chamber volt on SUC-1.
8	Increase level TRIP TEST until level 1 indic. is on. (Sig. #53)
9	Verify and record readings on SUC-1.
10	Place level TRIP TEST to OFF and verify readings. (Sig. #53)
11	Place Rate Mode Switch to calibrate and verify rate meter readings. (Sig. #49)
12	Return rate mode switch to OPERATE and verify indicators. (Sig. #49)
13	Reset rate 1 and 2.
14	Increase rate trip test until rate 1 trip is on. (Sig. #54)
15	Verify indicators and record.
16	Increase rate trip test until rate 2 trip is on. (Sig. #54)
17	Verify Indicators and Record.
18	Return rate trip test to OFF. (Sig. #54)
19	Verify all readings and indicators.
20	Reset scram trip. (Sig. #163)

NOTE: This procedure - steps 1-20 is repeated identically for each of the three wide-range channels WRC3, 4, & 5, except for WRC5 which has no high voltage interlock with the SUC; hence Events 7-10 are omitted.

(3) Verify green pilot lamp on. Chamber voltage on meter and correct per most recent calibration.

(9) Verify power reading is $1 \cdot 10^{-3}$% nominal.

(11) Verify rate meter reads 7.0 Dpm ± 0.1 Dpm.

(15) Verify rate meter reading is 2.0 Dpm ± 0.1 Dpm. Verify I-03A, 1-2 alarm is tripped.

(17) Verify rate meter reading is 5.0 Dpm ± 0.1 Dpm. Verify alarm I-03B, 4-3 alarm is tripped.

FIGURE B.7

TIME LINE FOR PRIMARY COOLANT MOISTURE SCRAM CALIBRATION

SURVEILLANCE PROCEDURE # 5.4.1.1.6.C-R

References: Drawings EL-J169-3107
EL-R265-5020
EL-J123-2000

FSV-11

Surveillance Events	
1	Verify reactor pressure is 700 psia ± 50 psia and record.
2	Remove penetration cover (Sig. #229-236)
3	Close Valves (B 5) (Sig. #229-236)
4	Connect sample helium bottle to traceable standard moisture element and determine its moisture content.
5	Connect sample helium bottle to valve (A)
6	Set moisture instrument to TRIP INDICATE Mode.
7	Open valves C_i and start stop watch with 15cc/sec flow through moisture element
8	Observation and visual verification of trip
9	Close valves (C_i) (Sig. #229-236)
10	Disconnect Test Gas (Sig. #221-228)
11	Open valves (D_i) (Close penetration cover) (Sig. #229-236)
12	Reset Moisture Instrument (Sig. #221-228)
13	Final verification

FIGURE B.8

SURVEILLANCE PROCEDURE # 5.4.1.1.6.C-R

PROCEDURES	EVENT 2 Penetration Cover Designation	EVENT 3 Valve (B_i) Designations		EVENT 5 Valve (A) Designation	EVENT 6 Moisture Instrument	EVENT 7 Valve (C_i) Designations
1	B-6	V-11994-1 V-11882 V-11884	V-11994-2 V-11883 V-11885	V-11888	MIS-1115, 703, P6	V-11888 V-11994-1 V-11994-2
2	B-3	V-11971-1 V-11860	V-11971-2 V-11861	V-11892	MIS-1116, 703, P6	V-11892 V-11971-1 V-11971-2
3	B-5	V-11875 V-11986-1	V-11876 V-11986-2	V-11894	MIS-1117, 703, P6	V-11894 V-11986-1 V-11986-2
4	B-6	V-11868 V-11979-1	V-11869 V-11979-2	V-11893	MIS-1118, 703, P6	V-11893 V-11979-1 V-11979-2
5	B-1	V-11964-1 V-11845 V-11847	V-11964-2 V-11846 V-11848	V-11852	MIS-1119, 703, P6	V-11852 V-11964-1 V-11964-2
6	B-1	V-11871 V-11981-1	V-11872 V-11981-2	V-11774	MIS-1120, 703, P6	V-11774 V-11981-1 V-11981-2
7	B-2	V-11854 V-11968-1	V-11855 V-11968-2	V-11782	MIS-1121, 703, P6	V-11782 V-11968-1 V-11968-2
8	B-3	V-11864 V-11973-1	V-11865 V-11973-2	V-11773	MIS-1122, 703, P6	V-11773 V-11973-1 V-11973-2

(8) Observe that moisture instrument trips and stop the stop watch. Record time required to trip. Observe moisture instrument tracking the sample moisture and record mirror temperature. Verify lights as indicated in table for event 8 are lit.

FIGURE B.8(Continued)

PROCEDURES	EVENT 8 Moisture Instruments and light designations	EVENT 9 Valve (C_i) Designations	EVENT 11 Valve (D_i) Designations	EVENT 12 Moisture Instruments	EVENT 13 Light Designations
1	MIS-1115 XCR-93216A XCR-93216B	V-11888 V-11994-1 V-11994-2	V-11882 V-11883 V-11884 V-11885	MIS-1115	XCR-93216 A & B
2	MIS-1116 XCR-93195A XCR-93195B	V-11892 V-11971-1 V-11971-2	V-11971-1 V-11971-2 V-11860 V-1184	MIS-1116	XCR-93195 A & B
3	MIS-1117 XCR-93197A XCR-93197B	V-11894 V-11986-1 V-11986-2	V-11875 V-11876 V-11986-1 V-11986-2	MIS-1117	XCR-93197 A & B
4	MIS-1118 XCR-93199A XCR-93199B	V-11893 V-11979-1 V-11979-2	V-11868 V-11869 V-11979-1 V-11979-2	MIS-1118	XCR-93199 A & B
5	MIS-1119 XCR-93217A XCR-93217B	V-11852 V-11964-1 V-11964-2	V-11845 V-11846 V-11847 V-11848 V-11964-1 V-11964-2	MIS-1119	XCR-93217 A & B
6	MIS-1120 XCR-93200A XCR-93200B	V-11774 V-11981-1 V-11981-2	V-11871 V-11872 V-11981-1 V-11981-2	MIS-1120	XCR-93200 A & B
7	MIS-1121 XCR-93198A XCR-93198B	V-11782 V-11968-1 V-11968-2	V-11854 V-11855 V-11968-1 V-11968-2	MIS-1121	XCR-93198 A & B
8	MIS-1122 XCR-93196A XCR-93196B	V-11773 V-11973-1 V-11973-2	V-11773 V-11973-1 V-11973-2	MIS-1122	XCR-93196 A & B

(13) Verify lights as indicated in table for event 13 are not lit. Verify that time required to trip in event (8) is 15 sec ± 5 sec. Verify that moisture content of gas as measured by both instruments does not differ by an amount greater than 25 pp mv.

FIGURE B.8(Continued)

TIME LINE FOR PRIMARY COOLANT MOISTURE SCRAM TEST (HI-LEVEL)

SURVEILLANCE PROCEDURE #5.4.1.1.7.a-M

References: EL-169-3107,
EL-169-3108,
EL-169-3104,
EL-169-3109.
Instruments: MSH-1115,
MSH-1119
GO Chart Ref: **FSV-11**
Frequency: Monthly

Surveillance Events	
1	On LOGIC COMMON TO ALL CIRCULATORS, CC-1A, move toggle switch to center position.
2	On CC-1A, set rotary switch to 13.
3	On CC-1A, move toggle switch to A.
4	Visual verification.
5	On CC-1A, move toggle switch to center position.
6	On CC-1A, set rotary switch to 14.
7	On CC-1A, move toggle switch to A.
8	Visual verification.
9	On CC-1A, move toggle switch to center position.
10	On CC-1A, set rotary switch to 15.
11	On CC-1A, move toggle switch to A.
12	Verify TEST light XCR-93197A is on.
13	On CC-1A, move toggle switch to center position.
14	On CC-1A, set rotary switch to 16.
15	On CC-1A, move toggle switch to A.
16	Verify TEST light XCR-93196A is on.
17	On CC-1A, move toggle switch to center position.
18	On LOGIC COMMON TO ALL CIRCULATORS, CC-1B, move toggle switch to center position.
19	On CC-1B, set rotary switch to 13.
20	On CC-1B, set toggle switch to A.
21	Visual verification.
22	On CC-1B, move toggle switch to center position.

Surveillance Events	
23	On CC-1B, set rotary switch to 14.
24	On CC-1B, move toggle switch to A.
25	Visual verification.
26	On CC-1B, move toggle switch to center position.
27	On CC-1B, set rotary switch to 15.
28	On CC-1B, move toggle switch to A.
29	Verify TEST light XCR-93197B is on.
30	On CC-1B, move toggle switch to center position.
31	On CC-1B, set rotary switch to 16.
32	On CC-1B, move toggle switch to A.
33	Verify TEST light XCR-93196B is on.
34	On CC-1B, move toggle switch to center position.
35	On LOGIC COMMON TO BOTH LOOPS, CC-1A, set toggle switch to center position.
36	On LOGIC COMMON TO BOTH LOOPS, CC-1B, set toggle switch to center position.
37	On CC-1A, set rotary switch to 14. On CC-1B, set rotary switch to 14.
38	On MOISTURE DETECTOR LIGHT DRIVER, MSH-1115, rotate switch to GND and release. (Sig. #222)
39	Verify XA-9323, audible alarm.
40	On MOISTURE DETECTOR LIGHT DRIVE, MSH-1117, rotate switch to GND and release. (Sig. #226)
41	On CC-1A, set toggle switch to A. On CC-1B, set toggle switch to A.

FIGURE B.9

Surveillance Events	
42	Visual verification.
43	Reset moisture instruments MSH-1115, MSH-1117. (Sig. #222, 226)
44	On CC-1A, move toggle switch to center position. On CC-1B, move toggle switch to center position.
45	Verify loss of events 39 and 42 indications.
46	On LOGIC COMMON TO BOTH LOOPS, CC-1A, set toggle switch to center position.
47	On LOGIC COMMON TO BOTH LOOPS, CC-1B, set toggle switch to center position.
48	On CC-1A, set rotary switch to 13. On CC-1B, set rotary switch to 13.
49	On MOISTURE DETECTOR LIGHT DRIVER, MSH-1119, rotate switch to GND and release. (Sig. #221)
50	Verify XA-9324, audible alarm.
51	On MOISTURE DETECTOR LIGHT DRIVER, MSH-1122, rotate switch to GND and release. (Sig. #223)
52	On CC-1A, set toggle switch to A. On CC-1B, set toggle switch to A.
53	Visual verification.
54	Reset moisture instruments MSH-1119, MSH-1122. (Sig. 221, 223)
55	On CC-1A, move toggle switch to center position. On CC-1B, move toggle switch to center position.
56	Verify loss of events 50 and 53 indications.

(4) Verify test lights XCR-93165A, XCR-93161A, XCR-93195A, XCR-93199A are on. Also, for TLT-2A: 1A, 1B, 1C, 2A, 2B, 2C test lights are on.

(8) Verify test lights XCR-93166A, XCR-93162A, XCR-93198A, XCR-93200A are on. Also, for TLT-2A: 1A, 1B, 1C, 2A, 2B, 2C test lights are on.

(21) Verify test lights XCR-93165B, XCR-93161B, XCR-93195B, XCR-93199B are on. Also, for TLT-2B: 1A, 1B, 1C 2A, 2B, 2C test lights are on.

(25) Verify test lights XCR-93166B, XCR-93162B, XCR-93198B, XCR-93200B are on. Also, for TLT-2B: 1A, 1B, 1C, 2A, 2B, 2C test lights are on.

(42) Verify red lights XCR-93197A, XCR-93197B, XCR-93216A, XCR-93216B are on. Verify test lights XCR-93200A, XCR-93200B are on; test lights XCR-93198A, XCR-93198B are not on.

(53) Verify red lights XCR-93196A, XCR-93196B, XCR-93217A, XCR-93217B are on. Verify test lights XCR-93199A, XCR-93199B are on; test lights XCR-93195A, XCR-93195B are not on.

FIGURE B.9(Continued)

References: 1) ELJ-169-3109
Frequency: Refueling (once/year)
GO Chart Reference No.: FSV-3
Instruments:

TIME LINE FOR REHEAT STEAM TEMPERATURE SCRAM CALIBRATION

SURVEILLANCE PROCEDURE # 5.4.1.1.8.C-R

Surveillance

Events

1. Remove reheat steam thermocouples and calibrate (Sig. #306, 308, 310, 312)
2. Reinstall calibrated reheat steam thermocouples (Sig. #306, 308, 310, 312)
3. Calibrate TT (Sig. #46)
4. Return TT from calibrator to operate position (Sig. #46)
5. Set MTU-1, B Gen.
6. Rotate Test/Oper. Switch on TSH 22136 to test and hold (Sig. #47)
7. Visual Verification of SCRAM
8. Reduce level on MTU-1 until red light on TSH goes out
9. Return T/O Switch to operate (Sig. #47)
10. Reset TSH Module
11. Verify reactor oper. resets hand switch HS-93126 (Sig. #163)

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NOTE: Since this is a calibration procedure considerable lumping was done in obtaining events. Events 3, 4, 5 apply to each of the temperature transmitters TT-22136, TT-22137, TT-22135.

(7) See procedure writeup for various light combinations that have to be verified for the three different temperature transmitters.

FIGURE B.10

References: Drawings
E1-169-3109 EL-169-3296
EL-169-3297 EL-169-3298
Frequency: Monthly
GO Chart Reference No.: FSV-3
Instruments: TSH-22135, TSH-22136, TSH-22137, TT-22135, TT-22136 and TT-22137

TIME LINE FOR REHEAT STEAM TEMPERATURE SCRAM TEST
SURVEILLANCE PROCEDURE # 5.4.1.1.8. b-M

Surveillance Events	
1	On MTU-1 set RANGE A and B to 100 MV
2	On MTU-1 set LEVEL A and B to 50 MV
3	Connect DVM to TT
4	Set toggle switches to center positions on TLT-1A & TLT-1B
5	On TLT-1A and TLT-1B set rotary switches to 2
6	On TLT-1A and TLT-1B set toggle switches to A
7	Rotate and hold test switch to TEST on Reheat Steam Temperature Transmitter (TT) (Sig. # 45)
8	Visual Verification of SCRAM
9	On MTU raise level A Until red trip light on TSH is lighted - lower level until light goes off
10	Repeat Event 9 for level B on MTU
11	On TT release switch to operate (Sig. # 45)
12	Reset TSH yellow trip
13	Verify reactor operator resets channel SCRAM Verify loss of all event (8) indications/alarms (Sig. # 163)
14	On TLT-1A and TLT-1B set toggle switches to center positions
15	Remove test leads and equipment

Note: The above time line holds for all 3 channels except for positions and instruments. The following table shows differences per event for the 3 channels.

Event 1 Position on MTU	Event 3 DVM Connection	Event 5 Rotary Switch Positions	Event 7 TT Number	Event 8 Indications/ Alarms	Events 9,10,12 TSH Numbers	Event 11 TT Numbers	Event 13 Channel SCRAMS
MTU-1, 305, P6	TT-22135 TP6(+), TP10(-)	2	TT-22135	TAH-9333, audible alarm XI-93235, lighted XI-93181, lighted XCR-93125, lighted XA-9319, audible alarm XCR-93234A, lighted XCR-93234B, lighted	TSH-22135	TT-22135	A
MTU-1, 105, P6	TT-22136 TP6(+), TP10(-)	3	TT-22136	TAH-9345, audible alarm XI-93236, lighted XI-93182, lighted XCR-93126, lighted XA-9321, audible alarm XCR-93234A, lighted XCR-93234B, lighted	TSH-22136	TT-22136	B

FIGURE B.11

Event 1 Position on MTU	Event 3 DVM Connection	Event 5 Rotary Switch Positions	Event 7 TT Number	Event 8 Indications/ Alarms	Events 9,10,12 TSH Numbers	Event 11 TT Numbers	Event 13 Channel SCRAM
MTU-1, 205, P6	TT-22137 TP6(+), TP10(-)	1	TT-22137	TAH-9357, audible alarm XI-93237, lighted XI-93183, lighted XCR-93127, lighted XA-9323 audible alarm XCR-93234A, lighted XCR-93234B, lighted	TSH-22137	TT-22137	C

(2) Level A, TP4(+), TP10(-)
Level B, TP5(+), TP10(-)

(4) Toggle switches set on two-loop trouble
TLT-1A, 902, P1
TLT-1B, 702, P1

(9) Raise level A until TSH is lighted.
Verify DVM reading of 8.34±0.05V.
Lower level A until TSH goes off.
Verify DVM reading of 7.00±.05V.

(10) Raise level B until TSH is lighted.
Verify DVM reading of 8.34±.05V.
Lower level B until TSH goes off.
Verify DVM reading of 7.00±.05V.

FIGURE B.11(Continued)

TIME LINE FOR PRIMARY COOLANT PRESSURE SCRAM CALIBRATION

SURVEILLANCE PROCEDURE #5.4.1.1.9.C-R

References: Drawing EL-169-3109

Instruments: See Writeup

GO Chart Reference No.: FSV-2

Frequency: Refueling (once/yr)

Surveillance Events

1. Remove cover plate (Sig. #326)
2. Close valves A, B (Sig. #326)
3. Connect nitrogen bottle (Sig. #326)
4. Open Valve C (Sig. #326)
5. Adjust pressure and record (10 steps) volt (Sig. #326)
6. Close valve C, disconnect test guage and nitrogen bottle (Sig. #326)
7. Open valves A, B (Sig. #326)
8. On MTU-1 rotate MODE to PRESS TEST (Sig. #1226)
9. Connect DVM to PT
10. On MTU-1 adjust level A (Ø V.) Verify LO TRIP readings on PI, PSH and PSL
11. On PT, rotate and hold switch to TEST (Sig. #38)
12. On MTU-1, adjust level A (9.V) Verify HI TRIP readings on PI, PSH and PSL
13. On PT, rotate and hold switch to TEST (Sig. #38)
14. On MTU-1 set level A (7.V) to 7.00 volts
15. Visually verify NO TRIP readings on PI, PR, PSH and PSL
16. Calibrate PI and PR if necessary
17. Disconnect all test equipment and set MTU-1 MODE to VOLT GEN

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NOTE: This procedure contains 52 steps. The above time line is valid for steps 1-17, steps 18-35 and steps 36-52. Following table shows instrumentation differences.

	Event 1 Cover Plate	Event 2 Valves (A,B)	Event 3 Nitrogen Bottle Connected to	Event 4 Valve (C)	Event 5 Adjust Pressure to PE	Event 6 Valve (C)	Event 7 Valves (A&B)	Events 8,10, 12,14,17 MTU Location	Events 9,11,13 PT Location	Events Containing PI,PR,PSH,PSL
Steps 1 -17	B1	11849 11850	PE-1108	11962	PE-1108	11962	11849 11850	MTU-1,305,P6	PT-1108,305,P5	PI-1108 PR-1108 PSH-1108-1 PSL-1108-1
Steps 18-35	B3	11974 11866	PE-1109	11996	PE-1109	11996	11974 11866	MTU-1,105,P6	PT-1109,105,P5	PI-1109 PSH-1109-1 PSL-1109-1
Steps 36-52	B2	11856 11969	PE-1110	11966	PE-1110	11966	11856 11969	MTU-1,205,P6	PT-1110,205,P5	PI-1110 PSH-1110-1 PSL-1110-1

(10) On MTU-1 adjust LEVEL A until DVM shows 0.0v ± 0.10v. Verify PSH and PSL read zero. Same for steps 28 and 45.

(12) For step 12 (HI TRIP) DVM shows 9.00v ± 0.05v, PI, PSH and PSL read 900 psia.

For step 30 (HI TRIP) DVM shows 10.00v ± 0.50v, PI, PSH, PSL read 1000 psia.

For step 47 (HI TRIP) DVM shows 9.50v ± 0.50v, PI, PSH, PSL read 950 psia.

(15) For step 15, verify PI and PR read 700 psig. For steps 33 and 50 verify PI shows 700 psia. PSH and PSL read 700 psia.

FIGURE B.12

TIME LINE FOR PRIMARY COOLANT PRESSURE SCRAM TEST
SURVEILLANCE PROCEDURE #5.4.1.1.9.b-M/5.4.1.2.9.a-M

References: ELJ-169-3109
ELJ-169-3107
ELJ-169-3108
Instruments: See Description Writeup
GO Chart Ref: FSV-2
Frequency: Monthly

Surveillance Events	
1	On MTU-1, set RANGE B to 100 MV, set MODE switch to PRESS TEST set LEVEL A to 7.00.
2	On TT, connect DVM. On CIRCULATOR INLET TEMPERATURE on TT, rotate and hold mode switch to TEST through 1st part of Event 13. (Sig. #27)
3	On MTU-1, adjust level B on REACTOR PRESSURE PT-1108, rotate and hold switch to TEST through Event 25. On MTU-1, increase level A. (Sig. #38)
4	Visual verification.
5	Set HS 1187 to position 1 (Temp. Induc.).
6	Visual verification.
7	On MTU-1, adjust LEVEL A and LEVEL B.
8	Visual verification.
9	On MTU-1, set LEVEL B.
10	Visual verification.
11	On MTU-1 raise LEVEL B and lower LEVEL A.
12	Visual verification, including raising and decreasing LEVEL A and returning LEVEL B to proper setting on TT.
13	On TT return mode switch to OPER. Reset TSH-1171 and TSL-1171. (Sig. #27)
14	On CIRCULATOR INLET TEMPERATURE, TT, rotate and hold mode switch to TEST. On TT, connect DVM. (Sig. #29)
15	On MTU-1, adjust LEVEL B and LEVEL A.
16	Visual verification.
17	Set HS-1187 to position 5 (Temp. Indic.).
18	Visual verification.
19	On MTU-1, adjust LEVEL A and LEVEL B.
20	Visual verification including adjusting Level B on MTU-1

Surveillance Events	
21	On MTU-1 raise LEVEL B and lower LEVEL A.
22	Visual verification.
23	On MTU-1 raise and then decrease LEVEL A.
24	Visual verification.
25	On TT 1175 return mode switch to OPER and remove DVM leads. On PT-1108 return mode switch to OPER and reset. (Sig. #29,38)
26	Place HS-22149, PRESELECT DUMP to LOOP 1.
27	Visual check.
28	Set rotary switches to position. Place toggle switches to position A.
29	On PSH-1108-1, rotate and hold mode switch to TEST. (Sig. #41)
30	Visual verification.
31	Place HS-22149 to LOOP 2.
32	Visual verification.
33	On PSH-1108-1 return mode switch to OPER and reset. Verify Events 30 and 32 indicate reset. (Sig. #41,102)
34	Check ISS in "Power". On CC-1A and CC-1B set toggle switches to center position. On TLT-1A, TLT-1B check toggle switches in center position.
35	On TLT-1A, TLT-1B set rotary switches to position and toggle switches to position A. On PSL 1108-1, rotate and hold mode switch to TEST. (Sig. #40)
36	Visual verification.
37	On PSL 1108-1 return mode switch to OPER and reset. On TLT-1A, TLT-1B place toggle switches to off. (Sig. #40)
38	Verify indications of Event 36 are all reset.
39	Reset channel scram. (Sig. #163)
40	Verify all trips and alarms actuated during this section of test are reset.

NOTE: The above time line is valid for all 3 channels A, B and C except for specific instrumentation. Since this instrumentation is extensive, tables are not made until later - see surveillance procedure writeup. In the following discussion of events specific instrumentation numbers are omitted.

FIGURE B.13

(4) Verify:
TSH shows 740±10°F
TM shows 740±10°F
PSH shows 750±10 psia
XCR's red trip light lit
XI's lit
PI's show proper reading
PR shows 750±10 psia
Solenoids show proper indications

(6) Verify:
TI shows 742±10°F
ZI lit
PAH, PAL, audible alarms
ISS switch in power position

(8) Verify:
TIA lit
TAHL; audible alarm
TSH shows 800±10°F

10) Verify:
TSL tripped
TSHL shows 400±10°F
TAHL, audible alarm
Two PSH's, red trip light lit

(12) Verify:
PSH, PSL, red light off
MTU-1, LEVEL A is adjusted
PSL shows 540±10 psia
TSHL shows 570±10°F
PI's show proper reading
Return MTU-1, LEVEL A and LEVEL B, to proper setting

(16) Verify:
TSHL, TM, PSH, three PI's show proper readings.

(18) Verify:
TI shows 742±10°F
ZI is on

(20) Verify:
TIA light on
TAHL, alarm
TSNL shows 800±10°F
Set MTU-1 LEVEL B properly
TI has proper reading
TSL tripped
TAHL, alarms
TIA light on
PSH's, red trip light on

(22) Verify on two PSH's, trip lights off.

(24) Verify:
PSL reads properly
TSHL has proper reading
PI's have proper setting

(27) On CC-1A, CC-1B, check toggle switches are in center position.

(30) Verify:
On 8 XCR's proper lights lit
TLT test lights lit
XCR red trip light lit
TLT test lights lit

(32) Verify:
On 3 XCR's proper lights lit
TLT test lights lit
XCR, red trip light lit
TLT test lights lit
On 4 XCR's, test lights lit

(36) Verify:
3 XCR's, proper lights lit

FIGURE B.13(Continued)

References: EL-169-3290
EL-169-3109
Instruments: See Writeup.
GO Chart Ref: FSV-2
Frequency: Refueling (once/year)

TIME LINE FOR CIRCULATOR INLET TEMPERATURE SCRAM CALIBRATION

SURVEILLANCE PROCEDURE #5.4.1.1.10.c-R

Surveillance Events	
1	Remove TW cover and remove thermocouple from well (decon-taminate, if required). (Sig. #331, 334)
2	Calibrate and stabilize thermocouple, then replace. (Sig. #331, 334)
3	Rotate TT switch to TEST if indication or action on TT, TSH, TSL is required. (Sig #27, 29)
4	Connect DVM to MTU-1. DVM must be ungrounded. On MTU-1, switch RANGE A to 100 MV.
5	Connect VM to TT.
6	Adjust LEVEL Lo, Hi, and medium on MTU-1 and verify voltages. (Lo Trip, Hi Trip)
7	Reset TSH and TSL.
8	On MTU-1 increase LEVEL A until TSH trips. Verify TSH trips at TT output equal to 8.22v ± 0.05v. (HI TRIP)
9	Adjust LEVEL A on MTU-1 for Lo trip, making proper verifications.
10	Reset and disconnect test equipment.
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

NOTE: The above time line is valid for the 8 different procedures in the writeup except for instrumentation. The i th procedure, $1 \le i \le 8$, uses TW-117i, thermocouple 117i, TT-117i, TSH-117i, TSL-117i.

(2) See writeup for calibration procedures

(6) Adjust LEVEL A until DVM shows VT_1 - see event (2). Verify VM reads $4.67 \pm 0.01V$. If reading is not correct adjust MV/I converter ZERO potentiometer to obtain correct reading. Adjust LEVEL A equal to VT_2. Verify TT reads $8.22 \pm 0.01V$. If voltage is not 8.22 adjust SPAN potentiometer. Adjust LEVEL A output to $\simeq 6V$.

(9) Reduce LEVEL A until TSH shows 780^oF. Reset TSH. Verify yellow light not on. On MTU-1 decrease LEVEL A until TSL trips. Verify TSL trips at TT output equal to $4.67V \pm 0.05V$. Adjust LEVEL A until TSL meter indicates 450^oF. Verify TSL red light not on. Reset TSL. Verify yellow light not on. On TM verify meter indication increases as LEVEL A is increased.

CITs effected (In SP. para #5.1-5.8)

1171
1172
1173
1174
1175
1176
1177
1178

FIGURE B.14

TIME LINE FOR CIRCULATOR INLET TEMPERATURE SCRAM CALIBRATION

SURVEILLANCE PROCEDURE #5.4.1.1.10.c-R

The following time line pertains to sections 5.9-5.12 of this procedure.

Surveillance Events	
1	On MTU-1 switch RANGE A and RANGE B to 10V. Adjust LEVEL A and LEVEL B to 4.67±0.01
2	On TM rotate switch to 1. Connect DVM to TM. Verify DVM shows 0.0V+100MV. Adjust R8 if necessary (Sig. #32, 33)
3	On TM, rotate to switch 2. Verify TM shows 400°F. (Sig. #32, 33)
4	On MTU-1, vary LEVEL A from 4.67 to 8.22. Verify meter goes from 400°F to 800°F and TM output is 8.22±.05V
5	On MTU-1 reduce LEVEL A to zero. Verify TM output to be 4.67±.01 and meter goes from 800°F to 400°F
6	On MTU-1 return LEVEL A to 4.67V±.01
7	Repeat events 3-5 using MTU-1, LEVEL B
8	On TM return switch to OPERATE. Disconnect all test equipment (Sig. # 32, 33)

Note: The above time line is valid per sections 5.9-5.12 of this procedure except for instrumentation. The following table indicates the instrumentation.

(7) Precisely based on Steps 7-10 in procedure writeups. See writeups.

	Events pertaining to MTU-1 location	Events pertaining to TM
Sect. 5.9 CIT 1172-1176	MTU-1, 105, P6	TM-1151-1, 306, P4
Sect. 5.10 CIT 1171-1175	MTU-1, 305, P6	TM-1151-1, 306, P4
Sect. 5.11 CIT 1173-1177	MTU-1, 205, P6	TM-1153-1, 206, P4
Sect. 5.12 CIT 1174-1178	MTU-1, I-27	TM-1190, I27

FIGURE B.14(Continued)

References: Drawing EL-169-3109
Frequency: Monthly
GO Chart Reference No.: FSV- 2
Instruments - See writeup

TIME LINE FOR CIRCULATOR INLET TEMPERATURE SCRAM TEST

SURVEILLANCE PROCEDURE 5.4.1.1.10.b-M

Surveillance Event	
1	On MTU-1, set range B to 100 MV
2	On TT rotate and hold switch to TEST. Connect DVM (Sig. #27)
3	On MTU-1 set LEVEL B to obtain output of 8.22V on TT
4	On TSH verify upper red and yellow lights on. Verify TSH indicates 800±10°F (Hi Trip)
5	On MTU-1, set LEVEL B to obtain an output of 4.67V on TT
6	On TSL verify lower red and yellow lights on. Verify TSL meter shows 400±10°F (Lo Trip)
7	On TT rotate switch to OPER (Sig. #27)
8	On TSH, TSL reset upper and lower trips. Verify no lights on TSH and TSL
9	On TT, rotate and hold switch to TEST. Connect DVM (Sig. #29)
10	On MTU-1 set level B to obtain output of 8.22V on TT. (Hi Trip)
11	On TSH, TSL verify upper red and yellow lights on. On TSH verify meter reads 800±10°F
12	On MTU-1, set LEVEL to obtain output of 4.67V on TT (Lo Trip)
13	On TSL verify meter reads 400±10°F
14	On TT rotate switch to OPER (Sig. #29)
15	On TSH, TSL reset upper and lower trips. Verify no lights on TSH, TSL
43	

Note: The above time line is valid for steps 1-15, steps 16-29, 30-43, except for instrumentation differences. Note similarity between events 2-8 and events 9-15. The following table shows instrumentation differences.

	Events referring to MTU-1 location	Events 2, 3, 5, 7 TT Designation	Events 4, 6, 8 TSH, TSL Designations	Events 9, 10, 12, 14 TT Designation	Events 11, 13, 15 TSH, TSL Designations
Steps 1-15	MTU-1, 305, P6	TT-1171	TSH-1171 TSL-1171	TT-1175	TSH-1175 TSL-1175
Steps 16-29	MTU-1, 105, P6	TT-1172	TSH-1172 TSL-1172	TT-1176	TSH-1176 TSL-1176
Steps 30-43	MTU-1, 205, P6	TT-1173	TSH-1173 TSL-1173	TT-1177	TSH-1177 TSL-1177

FIGURE B.15

Reference: Drawing ELJ-169-3109
Frequency: Refueling (once/year)
GO Chart Reference No.: FSV-3
Instruments: PSL 2269, XSL 2269,
PSL 2271, PSL 2273
XSL 2273, XSL 2271

TIME LINE FOR HOT REHEAT HEADER PRESSURE SCRAM CALIBRATION

SURVEILLANCE PROCEDURE # 5.4.1.1.11.6-R

Surveillance Events

1 Close Valve A (Sig. #324)

2 Connect Press Test Unit to PSL (A) (Sig. #324)

3 Stabilize PSL (a) at 80 psig. + 20 (Sig. #324)

4 Verify voltmeter reads "0" volts and disconnect

5 Reduce pressure until PSL (A) opens (volt will indicate 24V) (Adjust PSL (A) if necessary)

6 Open valve (A) (Sig. #324)

7 On XSL (A) rotate T/O switch to test (Sig. #43)

8 Visual verification of SCRAM

9 Rotate Switch to oper. (Sig. #43)

10 Visual verification and SCRAM chan. reset (Sig. #163)

30

Note: The above time line is valid for steps 1-10, steps 11-20, steps 21-30 except for instrumentation. The following table shows instrumentation differences.

	Events 1, 3 Valve (A) Designation	Event 2 PSL (A) Designation	Events with XSL (A) XCR (A) Designations	Event 8 Channel SCRAM Reference
Steps 1-10	2229	PSL 2269	XSL 2269 XCR 93125	A
Steps 11-20	2228	PSL 2271	XSL 2271 XCR 93126	B
Steps 21-30	2227	PSL 2273	XSL 2273 XCR 93127	C

(2) Connect dead weight tester to PSL

(3) Stabilize PSL input at 80 psig ± 20 psig
Connect DC voltmeter to PSL output.

(4) Verify meter shows "0" volts.

(5) Reduce pressure input until PSL opens. Voltmeter will indicate 24 V. (Record pressure) If pressure is not 35 psig ± 10 psig, adjust PSL to open at proper pressure.
On PSL verify band adjustment set a minimum. Disconnect dead weight tester and reduce all connections to normal.

(8) Verify both red and yellow lights are lighted. Verify SCRAM OUTPUT, XCR red TRIP is lit.

(10) Verify yellow light is not lit. Verify SCRAM OUTPUT red TRIP off. Verify reactor operator resets channel SCRAM.

FIGURE B.16

TIME LINE FOR HOT REHEAT HEADER PRESSURE SCRAM TEST (LO PRESS)

SURVEILLANCE PROCEDURE # 5.4.1.1.11.A-M

Reference: Drawing EL-169-3109
Frequency: Monthly
GO Chart Reference No.: FSV-3
Instruments: XSL-2269,
XSL-2271,
XSL-2273

Surveillance Events

1. Close both valves between PSL and main steam line (Sig. #324)
2. Remove pipe cap to PSL (Sig. #324)
3. Open valve to reduce PSL pressure to 0 psig (Sig. #324)
4. Visual verification of Lo Press SCRAM
5. Replace Pipe Cap (Sig. #324)
6. Close valve opened in Event 3 (Sig. #324)
7. Open valves closed in Event 1 (Sig. #324)
8. Verification Reset HS-9330 (Sig. #163)

Note: The above time line is valid for steps 1-12, steps 13-24, steps 25-36, except for instrumentation. The following table shows instrumentation differences. (Steps 1-12 are covered by events 1-8)

	Events with PSL Designation	Events with XSL Designation	Event 4
Steps 1-12	PSL 2269	XSL 2269	PAL 9339, XI 93181 XA 9319, XI 93235 XCR 93125 XSL 2269
Steps 13-24	PSL 2271	XSL 2271	PAL 9351, XI 93182 XA 9320, XI 93236 SCR 93126 XSL 2271
Steps 25-36	PSL 2273	XSL 2273	PAL 9363, XI 93183 XA 9321, XI 93237 SCR 93127

(4) Verify (for steps 1-12):
PAL 9339, I-03B, 1-7 audible alarm, XI93181, above bin, 301 lit XI 93235, above bin, 301 lit XA 9319, I-03 A, 5-1 audible alarm, XCR-93125, 301, P11 lit, STEAM PRESSURE HOT REHEAT, XSL 2269, 305P8, both red and yellow lights lit.

Verify (for steps 13-24):
PAL 9351, I-03B, 2-7, audible alarm, XI93182, above bin 101, lit. XI-93236, above bin 101, lit XA-9320, I-03 A, 5-2 audible alarm, SCR 93126, 101, P11, lit. On STEAM PRESSURE HOT REHEAT, XSL 2271, 105, P8, both red and yellow lights lit.

Verify (for steps 25-36):
PAL 9363, I-03B, 5-3 audible alarm, XI93183, above bin, 201 lit. XI-93237, above bin, 201 lit. XA-9321, I-03 A, 5-3 audible alarm, SCR-93127, 201, P11, lit.

(8) Verify:
Yellow light lit on XSL 2269, reactor operator resets HS9330, loss of all step conditions.

FIGURE B.17

TIME LINE FOR MAIN STEAM PRESSURE SCRAM TEST (LO PRESS)

SURVEILLANCE PROCEDURE # 5.4.1.1.12.a-M

References: Drawing EL169-3109
Frequency: Monthly
GO Chart Reference No. FSV-3
Instruments: XSL-2231, XSL-2233, XSL-2235

Surveillance Events

1. Close both valves between PSL(A) and main steam line (Sig. #321)
2. Remove Pipe cap to PSL (Sig. #321)
3. Open valve to reduce PSL(A) pressure to 0 psig (Sig. #321)
4. On Logic Common to both loops, CC-1B, move toggle switch to center position
5. On CC-1B set rotary switch to position and move tog-gle switch to A
6. On Logic common to both Loops, CC-1A, move tog-gle switch to center position
7. On CC-1A set rotary switch to position and move toggle switch to A
8. Visual Verification of Lo Trip
9. Replace Pipe Cap (Sig. #321)
10. Close Valve opened in event 3 (Sig. #321)
11. Open both valves closed in event 1 (Sig. #321)
12. Verify yellow light lighted on XSL(A)
13. Reset XSL(A) (Sig. #42)
14. Visual Verification and operator reset (Sig. #163)
15. On CC-1B move toggle switch to center position
16. On CC-1A move toggle

Note: The above time line is valid for steps 1-20, steps 21-40, steps 41-60 except for instrumentation. The instrumentation differences are shown in the following table. (Events 1-16 represent procedure steps 1-20.)

	Events 1, 2, 3 PSL(A) Designation	Events (A) With XSL and HS Designation	Event 8
Steps 1-20	PSL2231	XSL2231 HS93125	XSL2231, XCR93167A XCR93167B, XCR93168A XCR93168B, PAL9339 XI-93181, XI-93235 XA-9319, XCR93125
Steps 21-40	PSL2233	XSL2233 HS93126	XSL2233, XCR93167A XCR93167B, XCR93168A XCR93168B, PAL9350 XI-93182, XI-93236 XA9320, XCR93126
Steps 41-60	PSL2235	XSL2235 HS93127	XSL2235, SCR93167A XCR93167B, XCR93168A XCR93168B, PAL9362 XI93183, XI93237 XA9321, XCR93127

(8) Verify on STEAM PRESSURE MAIN:
XSL, red and yellow lights on
XCRs #2 TEST light on
PAL, audible alarm
XIs light on
XA, audible alarm
XCR, P11, on
See writeup for numbers omitted if necessary.

(14) On XSL no lights on. Verify reactor operator resets HS93125. Verify loss of event 8 indications.

FIGURE B.18

References: EL 169-3244
Prerequisites:
 2000 psi Pressure Source
 2000 psi Test Guage
 Simpson Voltmeter
Instruments:
 PSL-2231, XSL-2231
 PSL-2233, XSL-2233
 PSL-2235, XSL-2235
GO Chart Ref: FSV-3
Frequency: Refueling (once/year

TIME LINE FOR MAIN STEAM PRESSURE SCRAM CALIBRATION (LOW PRESS)

SURVEILLANCE PROCEDURE 5.4.1.1.12.b-R

Surveillance Events	
1	Close valve 22102. (Sig. #321)
2	On PSL-2231, connect dead weight tester to input. Adjust tester output to 2000 psig. (Sig. #321)
3	On PSL-2231, connect DC voltmeter. Set meter range for 24 volts. (Sig. #321)
4	Verify voltmeter shows "0" volts.
5	Reduce test input pressure. If pressure is not 1500 psig ± 75 psig, adjust PSL-2231 until it opens within limits. (Sig. #321)
6	Visual verification.
7	ON PSL-2231, return all input connections to normal. (Sig. #42)
8	Open HV-22102. (Sig. #321)
9	Verify voltmeter shows "0" volts.
10	Disconnect voltmeter.
11	Visual verification.
12	Reset XSL-2231, yellow light off. (Sig. #42)
13	Visual verification.
14	Reset Channel A scram. (Sig. #163)
15	*Close valve 22103.

Surveillance Events	
16	On PSL-2233 connect dead weight tester to input. Adjust tester output to 2000 psig.
17	PSL-2233, connect DC voltmeter. Set for 24v range.
18	Verify voltmeter shows "0" volts.
19	Reduce test input pressure. If pressure is not 1500 psig ± 75 psig, adjust PSL-2233 until it opens within limits.
20	Visual verification.
21	On PSL-2233, return all input connections to normal.
22	*Open HV-22103.
23	Verify Voltmeter shows "0" volts.
24	Disconnect voltmeter.
25	Visual verification.
26	Reset XSL-2233. Yellow light off.
27	Visual Verification.
28	Reset Channel B Scram.
29	*Close Valve 22104.
30	On PSL-2235 connect dead weight tester to input. Adjust tester output to 2000 psig.
31	On PSL-2235 connect DC voltmeter. Set meter range for 24 volts.
32	Verify voltmeter shows "0" volts.

FIGURE B.19

TIME LINE FOR MAIN STEAM PRESSURE SCRAM CALIBRATION (LOW PRESS)

SURVEILLANCE PROCEDURE 5.4.1.1.12.b-R

Surveillance Events

33 Reduce test input pressure. If pressure is not 1500 psig ± 75 psig adjust PSL-2235 until it opens within limits.

34 Visual verification.

35 On PSL-2235 return all input connections to normal.

36* Open HV-22104.

37 Verify voltmeter shows "0" volts.

38 Disconnect voltmeter.

39 Visual verification.

40 Reset XSL-2235. Yellow light off.

41 Visual verification.

42 Reset Channel C Scram.

(6) Verify STEAM PRESSURE MAIN, XSL-2231, red and yellow lights on.

(11) On XSL-2231, verify yellow light is on, red light is not on.

(13) Verify XCR-93125 red TRIP indicator off.

(20) Verify STEAM PRESSURE MAIN, XSL-2233, red and yellow lights on.

(25) On XSL-2233, verify yellow light is on, red light is not on.

(27) Verify XCR-93126 red TRIP indicator off.

(34) Verify STEAM PRESSURE MAIN XSL-2235, red and yellow lights on.

(39) On XSL-2235, verify yellow light is on, red light is not on.

(41) Verify XCR-93127 red TRIP indicator off.

*Human interface effects on Channels B&C incorporated by repeating Channel A for Channels B and C.

FIGURE B.19(Continued)

TIME LINE FOR TWO LOOP TROUBLE SCRAM TEST

SURVEILLANCE PROCEDURE #5.4.1.1.13.a-M

References: Vol #, Fig. 7.1.6
FSAR, EL-169-2661, 2681
Frequency: Monthly
GO Chart No.: FSV-12
Instruments: None Listed

Surveillance Events

1 On TLTT-1, set rotary switch to Position "X"

2 On TLTT-1, depress and hold TEST push button Sig. # (7206)

3 Visual Verification of Trip

4 On TLTT-1, release TEST push button Sig. # (7206)

5 Final Verification

6 Oper. resets reactor SCRAM Sig. # (6034, 6084, 6134)

Note: This procedure contains 72 steps, every six steps being identical except for instrumentation. Differences in instrumentation are shown in table at lower left.

Events:

(3) Verify XIs, SCR are lighted (see table at lower left). Also verify XAs give audible alarm. Verify that ALA, A2A, etc., are lighted (see table).

(5) Verify loss of all event 3 indications.

(6) Verify reactor operator resets HS.

	Event 1 Rotary Switch Position "X"	Event 3 Indications	Event 5 - HS Designation		Event 1 Rotary Switch Position "X"	Event 3 Indications	Event 5 - HS Designation
Steps 1-6	TLTT-1, 201, P5 Position 1	A1A, A2A XI-93181, XI-93235 XA-9319, XA-93369 XCR-93125	HS-93125	Steps 37-42	TLTT-1, 202, P5 Position 11	B1C, A2C XI-93183, XI-93237 XA-9321, XA-93371 XCR-93127	HS-93127
Steps 7-12	TLTT-1, 202, P5 Position 2	A1 , B2A XI-93181, XI-93235 XA-9319, XA-93369 XCR-93125	HS-93125	Steps 43-48	TLTT-1, 202, P5 Position 12	B1C, B2C XI-93183, XI-93237 XA-9321, XA-93371 XCR-93127	HS-93127
Steps 13-18	TLTT-1, 202, P5 Position 3	B1A, A2A XI-93181, XI-93235 XA-9319, XA-93369 XCR-93125	HS-93125	Steps 49-54	TLTT-1, 202, P5 Position 5	A1B, A2B XI-93182, XI-93236 XA-9320, XA-93370 XCR-93126	HS-93126
Steps 19-24	TLTT-1, 202, P5 Position 4	B1A, B2A XI-9318, XI-93235 XA-9319, XA-93369 XCR-93125	HS-93125	Steps 55-60	TLTT-1, 202, P5 Position 6	A1B, B2B XI-93182, XI-93236 XA-9320, XA-93370 XCR-93126	HS-93126
Steps 25-30	TLTT-1, 202, P5 Position 9	A1C, A2C XI-93183, XI-93237 XA-9321, XA-93371 XCR-93127	HS-93127	Steps 61-66	TLTT-1, 202, P5 Position 7	B1B, A2B XI-93182, XI-93236 XA-9320, XA-93370 XCR-93126	HS-93126
Steps 31-36	TLTT-1, 202, P5 Position 10	A1C, B2C XI-93183, XI-93237 XA-9321, XA-93371 XCR-93127	HS-93127	Steps 67-72	TLTT-1, 202, P5 Position 8	B1B, B2B XI-93182, XI-93236 XA-9320, XA-93370 XCR-93126	HS-93126

FIGURE B.20

References: Drawing EL-169-3104
Instruments: None Listed.
GO Chart Reference: FSV-12
Frequency: Refueling (once/year)

TIME LINE FOR TWO LOOP TROUBLE SCRAM TEST

SURVEILLANCE PROCEDURE #5.4.1.1.13.b-R

NOTE: This procedure contains 21 steps. Every 7 steps are identical except for instrumentation. Differences in instrumentation are shown in table at lower left.

Surveillance Events	
1	On TLTT-1 place rotary switch in start position "x".
2	Depress and hold TEST pushbutton. (Sig. #7206)
3	Visual verification. Later-move rotary switch from start position through next 3 positions.
4	Release TEST pushbutton. (Sig. #7206)
5	Verify indications/alarms reset.
6	Verify reactor operator resets channel scram. (Sig. #6034,6084,6184)
7	On TLTT-1, verify green RESET - indicator is on.
8	
9	
10	

(3) See table for specific instrument numbers. Verify XI's turned on, XCR red trip indicator on, XA's give audible alarm. Move rotary switch from 1-4, 5-8, or 9-12 and verify test lights are on as follows (third letter indicates channel A, B, C):

(5) Verify XCR, red trip off. XA reset. Test lights on TLTT-1 reset.

	Event 1 Rotary Switch Position		Event 3 Indications/Alarms	Event 5 Indications/Alarms	Events 6,7 Channel
	Start	Later			
Steps 1 - 7	1	(1-4)	XI-93181, XI-93235 XCR-93125, XA-9319 XA-93369 A1A, A2A, B1A, B2A	XCR-93125 XA-93369	A
Steps 8 -14	5	(5-8)	XI-93182, XI-93236 XCR-93126, XA-9321 XA-93370 A1B, A2B, B1B, B2B	XCR-93126 XA-93370	B
Steps 15-21	9	(9-12)	XI-93183, XI-93237 XCR-93127, XA-9323 XA-93371 A1C, A2C, B1C, B2C	XCR-93127 XA-93371	C

Rotary Switch Position	Test Lights On	
1	A1A	A2A
2	A1A	B2A
3	B1A	A2A
4	B1A	B2A
5	A1B	A2B
6	A1B	B2B
7	B1B	A2B
8	B1B	B2B
9	A1C	A2C
10	A1C	B2C
11	B1C	A2C
12	B1C	B2C

FIGURE B.21

TIME LINE FOR PLANT 480 V POWER LOSS SCRAM TEST
SURVEILLANCE PROCEDURE # 5.4.1.1.14.-A-M

References: Drawing EL-169-3109
Frequency: Monthly
GO Chart Reference No.: FSV-1
Instruments: XSL-93362, XSL-93363
XSL-93364

Surveillance

Events

1. On N-9211 depress push-button 1 and 3. On N-9213, 480V SWGR room (Sig. #317, 318)
2. Verify PLANT POWER LOSS, XSL, trips, red and yellow lights both on.
3. Release push-button (Sig. #317, 318)
4. Verify XSL red light not on and yellow light is on
5. Reset XSL
6. Verify no XSL lights are on
7. Rotate switch to TEST on XSL. Record time to get single channel SCRAM (Sig. #44)
8. Visual Verification
9. Rotate switch to OPER on XSL (Sig. #44)
10. Reset XSL
11. Final Verification (SCRAM Reset Button) (Sig. #163)

Note: This procedure contains 33 events. Every 11 events are repetitive except for instrumentation. Differences in instrumentation are shown in table at lower left.

(8) Verify event 7 time is 30 sec ± 3 sec
Verify $\overline{X}$I's, XCR, lit.
Verify XA, EAL give audible alarm. See lower left table for specific instrument numbers.

(11) Verify reactor operator resets HS: Verify loss of event 8 indications.

Events	Events, 1, 3 Pushbutton Desig.	Events pertaining to XSL	Event 8 Indications	Event 11 HS Designation
1-11	1A, 3A	XSL-93362, 305, P2	XI-93181 XI-93235 XCR-93125 XA-9319 EAL-93309	HS-93125
12-22	1B, 3B	XSL-93363, 105, P2	XI-93182 XI-93236 XCR-93126 XA-9320 EAL-93310	HS-93126
23-33	1C, 3C	XSL-93364, 205, P2	XI-93183 XI-93237 XCR-93127 XA-9321 EAL-93311	HS-93127

FIGURE B.22

TIME LINE HIGH AMBIENT TEMPERATURE
SCRAM CALIBRATION (REACTOR BUILDING TEMP)
SURVEILLANCE PROCEDURE #5.4.1.1.15.c-R

Reference: Drawing EL-169-3109
Frequency: Refueling (once/yr)
GO Chart Reference No.: FSV-1
Instruments: See Writeup

Surveillance Events	
1	Place thermometer within 2" of TE. On TE connect a L&N millivolt potentiometer to the thermocouple leads (Sig. #328)
2	Allow 10 minutes for thermometer temperature to reach ambient. Complete table. Verify TE is $\pm 3^{o}$F of thermometer ^{o}F. If not, replace TE (Sig. #328)
3	Disconnect L&N box on TE
4	Measure and record temperature at cold junction input of REACTOR BUILDING TEMPERATURE, TT. Convert ^{o}F to MV. (Sig. #328)
5	Measure temperature where TT and its reference junction compensator are mounted. Record temperature. Complete chart
6	On MTU-1, set RANGE B to 100MV, set LEVEL B to 0.1. Connect millivolt indicator. Connect jumper from MTU-1 to TT (Sig. #328)
7	On REACTOR BUILDING HIGH TEMPERATURE, TT, connect DVM. Rotate and hold mode switch to TEST. (Sig. #35)
8	Visual Verification of B/S level trips
9	On MTU-1, increase LEVEL B until red trip light TSH is on. On TT, verify DVM reading of 8.40V±.05V. On MTU-1, decrease LEVEL B until red trip light TSH goes off. Verify (Sig. #1153)
10	On TT, release mode switch to OPERATE (Sig. #35)
11	On TSH, reset yellow trip light (Sig. #36)
12	Visual Verification including oper reset channel SCRAM (Sig. #163)
13	Remove all test leads and equipment

First 24 steps of procedure are covered by the first 4 steps above. Every 8 steps are identical except for instrumentation. See Table below for TE, TT designations.

Steps 25-66 of procedure are covered by steps 5-13 above. Every 14 steps are identical except for instrumentation. See table below for instrumentation differences.

Surveillance Event	
14	On MTU-1 set RANGE to 1.0V and set LEVEL -- to 10.0V
15	On REACTOR BUILDING TEMPERATURE HIGH, TSH, rotate and hold switch to TEST (Sig. #36)
16	Visual Verification of SCRAM
17	On TSH rotate switch to OPER (Sig. #36)
18	Reset TSH
19	Verification including Oper Reset of SCRAM (Sig. #163)

Steps 67-90 of procedure are covered by steps 14-20. Every 8 steps are identical except for instrumentation. See Table on following page.

FIGURE B.23

TIME LINE FOR HIGH AMBIENT TEMPERATURE
SCRAM CALIBRATION (REACTOR BUILDING TEMP)
SURVEILLANCE PROCEDURE #5.4.1.1.15.c-R

	TE and TT Designations
Steps 1-8	TE93472 TT93472
Steps 9-16	TE93473 TT93473
Steps 17-24	TE93474 TT93474

	Events with MTU-1 TT, TSH Designations	Event 8 Indications	Event 12 XCR Designation
Steps 25-38	MTU-1, 305, P6 TT 93472 TSH 93472	XI93235 XI93181 XCR93125 XA9319 TAH93472 TSH93472	XCR93125
Steps 39-52	MTU-1, 105, P6 TT93473 TSH93473	XI93236 XI93182 XCR93126 XA9321 TAH93473 TSH93473	XCR93126
Steps 53-66	MTU-1, 205, P6 TT93474 TSH93474	XI93237 XI93183 XCR93127 XA9323 TAH93474 TSH93474	XCR93127

	Event 14	Event with TSH and HS Designation	Event 16 Indications
Steps 67-74	MTU-1, 305, P6 RANGE A LEVEL A	TSH93472 HS93125	XI93235 XI93181 XCR93125 XA9319 TAH93472 TSH93472
Steps 75-82	MTU-1, 105, P6 RANGE B LEVEL B	TSH93473 HS93126	XI93182 XI93236 XCR93126 XA9320 TAH93473 TSH93473
Steps 83-90	MTU-1, 205, P6 RANGE B LEVEL B	TSH93474 HS93127	XI93183 XI93237 XCR93127 XA9321 TAH93474 TSH93474

(8) Verify XIs lit, XCR red TRIP light on, XA and TAH audible alarms, on TSH yellow light on.

(12) Verify reactor operator resets XCR channel A SCRAM. Verify loss of all event 8 indications.

(16) Verify XIs lit, XCR lit. Verify XA, TAH, audible alarm. Verify TSH, red and yellow lights on.

(19) Verify reactor operator resets HS. Verify loss of all event 16 indications.

FIGURE B.23(Continued)

References: EL-169-3109
Frequency: Monthly
GO Chart Reference No.: FSV-
Instruments: TSH-93472, TSH-93473, TSH-93474

TIME LINE FOR HIGH AMBIENT TEMPERATURE SCRAM TEST (REACTOR BUILDING TEMP)

SURVEILLANCE PROCEDURE # 5.4.1.1.15.b-M

Surveillance Events	
1	On MTU-1 set RANGE - to 1.0V. Also set LEVEL - to 10.0
2	On REACTOR BUILDING TEMPERATURE HIGH, TSH, rotate and hold switch to TEST (Sig. #36)
3	Visual Verification of SCRAM
4	Rotate switch to OPER on TSH (Sig. #36)
5	Reset TSH
6	Final Verification and Reset of SCRAM channel (Sig. #163)

Note: This procedure has 24 steps. Every 8 steps are identical except for instrumentation. Differences in instrumentation are shown at lower left.

(3) Verify XIs lighted
Verify XCR lighted
Verify XA, TAH, audible alarms
Verify TSH yellow light is on.

(6) Verify reactor operator resets HS-93127, 126, or 125. Verify loss of all event 3 indications.

Note: Events 1-6 represent 8 steps in procedure

	Event 1 Designations	Events with TSH	Event 3 Indications	Event 6 HS Designation
Steps 1-8	MTU-1, 205, P6 RANGE B LEVEL B	TSH-93474,206,P6	XI-93183 XI-93237 XCR-93127 XA-9321 TAH-93474 TSH-93474	HS-93127
Steps 9-16	MTU-1, 105, P6 RANGE B LEVEL B	TSH-93473,106,P8	XI-93182 XI-93236 XCR-93126 XA-9320 TAH-93473 TSH-93473	HS-93126
Steps 17-24	MTU-1, 305, P6 RANGE A LEVEL A	TSH-93472,306,P8	XI-93235 XI-93181 XCR-93125 XA-9319 TAH-93472 TSH-93472	HS-93125

FIGURE B.24

SYSTEM OPERATING PROCEDURE 12-01, 12-02, 12-03 Reactivity Control System Control Rods

EVENTS	SYSTEM OPERATION
1	Check prerequisites to operation
* 2	Check 2.1.1, SOP 93-01 pertaining to nuclear instrumentation. Check scrams, rod withdrawal prohibit, and other functions of PPS system completed
3	Check that at least 36 control pairs are operable
4	Check 6 of the 7 sub group of Reserve Shutdown units, and 29 of the 30 subgroups of reserve shutdown units are operable
5	Key for RMS (HS 1216) inserted
* 6	See Table 2.2.2.1 for rod withdrawal sequence for the initial core except for scram or low Power physics testing or:
7	Runback groups may be partially inserted during a runback and re-withdraw during recovery from runback
8	Check reactivity status If too large per LCO 4.1.8 shutdown reactor and examine
9	Make prediction of critical rod configuration
* 10	Make initial checks per 2.2.4.1-2.2.4.7 of SOP 12-01
11	Select Channel I or II for recording the startup count rate
12	Select CH III, IV or V for recording wide range log flux level
13	Turn rod group bypass switch to "Normal"
14	Turn Interlock Sequence switch to "Start"
15	Turn reactor mode switch to "RUN" and obtain fully rodded count rate
16	Select Sequence #1 rod group on "Odd Group Select" switch or on "Even Group Select" switch

EVENTS	SYSTEM OPERATION
17	Turn "Odd-Even Group Select" to proper position
18	Announce reactor will start and make final check
*19	Commence rod pair withdrawal by turning "Rod A actuate" switch to "Out" position
20	Follow indicated rod movement. Release the "Rod A Actuate" switch if rate of change 1-1/2 DPM
*21	Reinsert rod pair "A" as required to stay within 1-1/2 DPM
22	Silence alarm when rod pair is withdrawn 12"
23	Proceed as in events 19-22 to withdraw rod pair B to position of 24" using "Rod B Actuate", etc.
24	Proceed as in events 19-22 to withdraw rod Pair C to position of 24" using "Rod C Actuate", etc.
25	Repeat withdrawal procedures for rod pairs of the selected group in 24" increments until rod group is fully withdrawn
26	Record count rate, etc.
27	Select sequence #2 rod group on "Odd Group Select" switch or "Even Group Select" switch
28	Turn "Odd-Even Select" switch to the "Odd" or "Even" position
29	Repeat events 19-26 for withdrawal of rods of sequence #2
30	Preselect next rod group for withdrawal in accordance with rod group withdrawal sequence table. Continue group withdrawal in accordance with events 19-26 to bring reactor critical
31	Reactor Power will be increased by manual withdrawal of rods to 5%. Then turn ISS to "Low Power"
*32	After 6% power is reached, turn "Mode" switch HS-1246 to "Man."
33	Turn "setpoint" switch to "Local"
34	Turn "Regulating Rod" selector to the Number 1 position

EVENTS	SYSTEM OPERATION
35	When #1 rod pair is withdrawn to a central position transfer flux control to automatic
36	Maintain flux level desired by manual withdrawal of rod groups selected in proper sequence
37	If flux controller is to operate in cascade with hot reheat steam temp. controller refer to SOP 93-02
38	When reactor reaches 30% power turn ISS to "Power Operation" position
39	Begin withdrawal of rods of next group in sequence at proper time
*40	Make visual checks and records
41	Reduce reactor power and flux by selecting rod groups in required sequence at "Odd" and "Even" group selectors
42	Insert rods manually as the flux demand is reduced with lowering of the hot reheat steam temperature setpoint, maintaining regulating rod in central position
43	At proper time transfer auto-rod position control to manual by rotating "MODE" switch to "MAN." Regulating rod position is now controlled manually
44	Continue reduction of reactor power level by manual insertion of control rods in proper sequence
45	Change ISS position to "LO POWER" at 10% power wait for RWP
46	Continue reducing power, changing ISS position to "Start" at 4% power wait for RWP
47	When power level < 2% operate manual scram switch to shut down reactor. Record appropriate data.
48	When control rods are fully inserted turn reactor Mode Switch to "OFF"
49	Determine shutdown margin using appropriate data sheets
*50	Depress any 2 of the 3 pushbutton switches to initiate scram signal to PPS
51	Monitor neutronic indicators for a decreasing flux indication to subcritical level

FIGURE B.25

SYSTEM OPERATION

EVENTS

52 Continue shutdown in accordance with Emergency Procedure #B-1

*53 Verify automatic stopping of rod motion-log rod position, notify supervisor

54 Depress slack cable by-pass switch

55 Actuate rod pair control in the"OUT" direction

56 If rods stuck, attempt manual withdrawal. This should free rod or trip overload relay

57 Check limiting conditions for operation with inoperable rod

*58 Manually insert the three normal shim rods in normal sequence followed by withdrawal as required

59 Perform proper steps if automatic flux controller drops out of automatic operation

60 Following setback follow proper steps to return to Power operation

61 Follow proper steps for powered insertion of rod pair following scram

62 Check list of alarms, causes and immediate action concerning control rods

NOTE:

1) See Sect. 2.1, SOP 12-01

35) See Steps in 2.3.1.5, SOP 12-01

36) See Steps in 2.3.1.6, SOP 12-01

40) See steps 2.4.2.1-3, SOP 12-01

59) Adjust position of 3 shim rods in normal sequence until difference between temperature controller set point and reactor flux $< \approx$ 5%
Depress "confirm auto" push button to regain automatic flux control
Continue to manually adjust position of 3 shim rods to maintain the automatic control rod at central position

60) See Steps in 2.6.2.3, SOP 12-01

61) See Steps in 2.6.3, SOP 12-01

62) See List in 2.6.4, SOP 12-01

*Events 2-5--Pre-Start Conditions
*Events 6-8--Rod Withdrawal Sequence
*Events 10-19--Startup Procedure
*Events 19-20--Begin Rod Withdrawal
*Events 21-31--Startup Rod Withdrawal
*Events 32-39--Routine Operation
*Events 40-49--Shutdown
*Events 50-52--Rod Scrams-Manual Scram
*Events 52-57--Abnormal Operation-Slack Cable Procedure
*Events 58-60--Abnormal Procedure-Run Back

FIGURE B.25(Continued)

STARTUP INITIAL CONDITIONS

EVENTS	
1	Verify control systems are operable and operate in proper modes
2	Electrical systems operating and/or operable
3	Instrument air system operating
4	Service water sytem operating
5	Auxiliary Boiler operating and supplying steam to the the 150# headers
6	Reactor plant and control room ventilation systems operating
7	ALL Plant protective systems operating or operable
8	Hydraulic Power units in service
9	Purification cooling water system is operating
10	Helium purification train is operating
11	PCRV cooling water system operating
12	Condenser in service
13	Circulating water system operating
14	Feedwater heaters #1, 2, 3, 5 and 6 are in service
15	One 60% condensate pump operating, discharging through normal route to deaerator. Deaerator level control on "auto".
16	Bypass flash tank level control valve in "auto" maintaining proper level in flash tank. HS 3220 in position #3
17	One steam generator loop is operating on emergency condensate line supply
18	Startup bypass valve in the operating steam generator, Loop is controlling back pressure at 225 psig
19	Fire water protection system operable
20	Chemical treatment system operable

STARTUP INITIAL CONDITIONS

EVENTS	
21	Main steam piping after isolation valves and hot reheat piping are drained
22	Pre-boiler cycle-cleanup line in the feedwater heater #6 bypass is lined up for returning flow to bypass flash tank drain line
23	Helium circulator auxillaries are operating as required in each loop
24	Motor driven boiler feedwater pump is operating to supply water to two pelton wheels, via emergency feedwater line
25	Helium circulator Nitrogen pressurization system in service
26	Two helium circulators in the operating loop are running on pelton wheels
27	Main turbine generator unit is on turning gear. Stator cooling, bus cooling, lube oil system, EHC fluid system, H_2 seal oil system are operating
28	Steam seals established on main turbine and boiler feed pump turbines
29	Rod control system operating
30	Orifice valves are set
31	Vacuum on main condenser
32	Steam and water sample system operating
33	Verify initial conditions on OPOP III Check List #2

NOTE:

2) SOP 92
3) SOP 82
4) SOP 42
5) SOP 84
6) SOP 73, SOP 75
7) SOP 93-01
8) SOP 91
9) SOP 47
10) SOP 23
11) SOP 46
12) SOP 31
13) SOP 41
14) SOP 32
15) SOP 31
Deaerator is pegged with 5 psig steam from bypass flash tank or from 150# header at 3 psig per SOP 32
16) SOP32
17) Other loop is shutdown, filled with water, and pressurized with nitrogen. Both reheaters are shutdown, isolated and drained, and blanketed with nitrogen per SOP 22-01
18) SOP 22-01
19) SOP 45
20) SOP 33
21) Cold reheat piping is floating with bypass flash tank and drains cracker, per SOP 22-02
22) SOP 31
23) SOP 21-02
26) The remaining two circulators are rotating on bearing water system per SOP 21-02
27) SOP 51
28) SOP 51
29) SOP 12-01
SOP 93-01
30) SOP 12-04
31) SOP 31
32) SOP 33

FIGURE B.26

OPOP III STARTUP TO 25% LOAD C. Startup Procedure

STARTUP PROCEDURE

EVENTS	
1	Verify permission to startup. Verify technical specifications requirements
2	Start to repressurize PCRV if required and upon equalization pump up
3	Start turbine driven boiler feedwater pump
4	When feedwater iron concentration stabilizes route all bypass flash tank drains properly
5	Increase cycle cleanup flow as required
6	Make precritical instrument checks
7	Determine critical rod height. Record
8	Set Rod Group Sequence bypass switch to "Normal" set interlock sequence switch to "Start"
9	Announce reactor start. Make final check of conditions and instrumentation affecting reaction operation
10	*Withdraw control rod groups up to group required for criticality
11	Clean up feedwater and condensate systems as required
12	*Commence loop feedwater flow to the operating steam generator loop via normal feedwater flow path
13	*Remove N_2 blanket and commence loop feedwater flow to the second loop, maintaining 225 psig backpressure
14	Perform proper steps to prepare circulator steam turbine operation
15	*Using emergency feedwater line, start one circulator on pelton in loop that was shutdown and shutdown one circulator in the loop that was in operation during decay test removal and balance loop helium flow
16	*Increase feedwater flow Also increase backpressure to each steam generator

STARTUP PROCEDURE

EVENTS	
17	Verify technical specifications are met
18	*Begin moving rods to critical position--make required visual verifications
19	Complete any low power physics testing
20	Raise reactor power to 1% rated. check compliance and record
21	*Increase reactor power to 2% at 1.5 DPM
22	Start shutdown circulator in loop #1 on flash tank steam balance Loop #1 to Loop #2 helium flow
23	Shutdown pelton wheel of Loop #1. Maintain 5 psig backpressure by adjusting hot reheat bypass valves. Balance Loop #1 to Loop #2 helium flow
24	Start shutdown circulator in loop #2 on flash tank steam balance Loop #2 to Loop #1 helium flow
25	Shutdown pelton wheel of Loop #2. Maintain 5 psig backpressure by adjusting hot reheat bypass valves. Balance Loop #2 to Loop #1 helium flow. Shutdown Helium Circ. Nitrogen Pressurization System
26	Shutdown motor driven boiler feed pump
27	Start the second circulator in Loop #1 on flash tank steam. Balance Loop #1 and Loop #2 helium flows
28	Start second circulator in Loop #2 on flash tank steam. Balance Loop #2 and Loop #1 helium flows
29	*Adjust reactor power at .2%/min to about 5% by manually withdrawing rods. Adjust reactor as required to stabilize
30	*Go to "Local Auto" on flux controller when above 5% power
31	When reactor power is adjusted as required verify compliance and record results
32	See steam generator clean up, Diagram OPOP III C-2 and Table III C-2

STARTUP PROCEDURE

EVENTS	
33	Conclude regenerative heating in feedwater heaters #3 and #2. Line up heaters for normal operation-drain extraction lines. Place H5 in "OFF" position. Drain bypass flash tank as required.
34	When superheater outlet temperature stabilizes at 400°F, start rotor and H.P. casing prewarming
35	When below water chemistry limits are met, increase startup bypass valve pressure setting in each steam generator loop to 2400 psig
36	*Raise superheater and reheater outlet temperature at maximum rate by increasing reactor power. Increase helium flow
37	*Begin warming main steam line via each loop main steam stopcheck bypass valve. Charge main steam line and open main steam isolation valves
38	Adjust core orifices and steam generator subheader trim valves as required
39	Raise startup bypass valve pressure controller setting thus transferring flow to main steam bypass valve
40	Warm the control valve chest and steam lines to the H.P. turbine
41	Roll main turbine generator, bring to speed, synchronize, and apply initial load
42	Open the circulator bypass pressure control valves manually to achieve a 1.3 pressure ratio. Transfer to closed loop control
43	Adjust main steam temperature controller settings to match superheater outlet temperatures. Place main steam temperature control in automatic
44	With hot reheat steam temperature controller in manual, transfer neutron flux control to "remote setpoint"
45	Increase turbine load to 25% of rated
46	Transfer feedwater from local low flow range control to remote normal range control. Transfer throttle pressure controller from manual to automatic control and adjust throttle pressure to 2400 psig
47	With main steam bypass valves closed adjust the setpoint of main steam bypass controller to 2550 psig

FIGURE B.27

STARTUP PROCEDURE

EVENTS

48 Transfer reheat steam attemperator flow controllers from manual to local automatic to remote automatic control

49 Place steam generator module feedwater trim valve controllers for all modules in automatic. Place temperature differential indicator controllers in remote setpoint

50 *Raise plant load until 30% reactor power is reached and an RWP is received. Check and record. Change ISS position from LOW POWER to POWER transfer house power to unit aux transformer

51 See diagram for 25% load, 31 OPOP III.C-3 and Table III.C-3

52 Check indicated reactor power versus control rod position

53 Perform technical specification tests

NOTE: The events defined above frequently contain much more information. Each event usually corresponds to a step with the same number in the OPOP Manual. Frequently SOP's are referenced.

1) Verify technical specification requirements met as in OPOP IA 4 & 5 Record on OPOP III Check List #3 RMS—→Run - C.1 in progress, record time, etc.

2) Per SOP 23 and 24

3) The increase flow through pre-boiler cycle cleanup line to about 15% flow, regulating flow on the cycle cleanup line glove valves. Maintain turbine speed desired manually. 1B boiler feed pump normal; feedwater header discharge valve closed. See SOP 31

4) See SOP 33, SOP 32, and OPOP III C4 for proper routing

5) When condensate to the deaerator reaches a temperature of about 180°F, cycle cleanup flow should be increased to about 25% total flow

6) OPOPI, C.1 and C.2, Pre-critical Instrument checks complete. Record on OPOP III check list #6

7) Prepare 1/M data sheets per SOP <u>12-01</u> and record on OPOP III check list #7 & 8. Record time 1st control rod withdrawn on OPOP Check List #10

10) Per <u>SOP 12-01</u>

11) See OPOP III C 10 and <u>SOP 22-01</u> Also see "Feed water system cleanup, Diagram III C-1"

12) Maintain about 225 psig backpressure on the steam generator, using the startup bypass valve pressure controller. Per <u>SOP 22-01</u> and <u>SOP 93-02</u>. Also see OPOP C-12.

13) Per <u>SOP 22-01</u>

14) See SOP 22-01 and steps listed in OPOP III C-14

15) Per SOP 21-01

16) See OPOP III-C-16 and <u>SOP 93-02</u>

17) Verify as in OPOP I, A, 6. Record OPOP III Check List #12

18) See SOP 12-01. Record and verify as in OPOP III C-18

20) Check compliance with LCO 4.1.9 and record results on OPOP III check list, No. 16

21) See cautions and note in OPOP III-21

22) SOP 21-01, 21-02, <u>93-02</u> Assume "Local" control of circulator speed

23) SOP 21-01, 21-01, <u>93-02</u>

24) SOP 21-01, 21-02, <u>93-02</u> Assume "Local" control of circulator speed

25) SOP 21-01, 21-03, <u>93-02</u>

26) See OPOP III C-26. Leave pump in stand-by per SOP 21-02 and SOP 31

27) SOP 21-01, 21-02, <u>93-02</u> Assume "Local" control of circulator speed

28) SOP 21-01, 21-02, <u>93-02</u> Assume "Local" control of circulator speed

29) See OPOP IIIC-29. Also SOP 22-02

30) Per SOP <u>93-09</u>

31) Verify compliance with LCO4.1.9 after reactor power adjustment maintains 400°F steam generator outlet temperature. Record results on OPOP Check List #19

33) See OPOP III C-33. Also SOP 32

34) Per SOP51 Procedures for starting main T/B unit.

FIGURE B.27(Continued)

NOTE: (CONTINUED)

35) Per SOP 93-03. See also OPOP III C-35

36) See SOP 12-01, SOP 21-01 SOP 22-01. Also see cautions in OPOP III C-36

37) SOP 51

38) SOP 12-04, 22-01

39) See OPOP III C-39 for proper settings. Also see SOP 93-02

40) Per SOP 51

41) Per SOP 51 and G-E instruction book. Make appropriate recording, see OPOP III C-41

42) Per SOP 21-01

43) See SOP 93-02

44) Also transfer hot reheat steam temperature controller to "Local setpoint" automatic. See SOP 93-02, 93-09

45) See SOP 51 and OPOP III C-45 SOP 93-02 and SOP 22-01

46) SOP 93-02

47) See SOP 93-02

48) See SOP 93-02, 22-01

49) See SOP 93-02, 22-01

50) See OPOP III C-50 for recording procedure and cautions

51) See OPOP III C-51 for settings, etc.

52) Per SOP 12-01. See OPOP IIIC-52 for recording procedure and note

53) Tests are
5.4.1.1.4.C-D
5.4.1.1.5.C-M
They are performed at 30% power. Record on OPOP III check list #25

FIGURE B.27(Continued)

LOAD INCREASE
25-100% LOAD OPERATION

EVENTS

1 Make visual checks, records and requests as required
2 Shutdown auxiliary boiler if not already done
3 Transfer house load from auxiliary transformer to unit auxiliary transformer if not already done
4 Notify system dispatcher that unit is ready to accept system load at his verbal request
5 Trim position the reactor core orifices to balance helium temperatures if needed
6 Increase load to about 135 MW(e) @ 1%/min
7 Stabilize plant load @ 135 MW(e)
8 Check indicated reactor power vs control rod position
9 Start second boiler feed pump turbine on manual control and switch to "auto" when total feedwater is 40%
10 Increase load to about 200 MW(e) @ 1%/min
11 Trim position the reactor core orifices to balance helium temperatures as needed
12 Stabilize plant load at 200 MW(e)
13 Check indicated reactor power vs. control rod position. Conduct rod worth and reactivity coefficient measurements
14 Transfer boiler feed pump turbines from cold reheat steam to low pressure turbine crossover steam
15 Start second large (60%) condensate pump

LOAD INCREASE
25-100% LOAD OPERATION

EVENTS

16 Increase load at 1%/min
17 At approximately 70% plant load shutdown high pressure heater drain pump
18 Increase load to about 270 MW(e) @ 1% min
19 Stabilize plant load @ 270 MW(e)
20 Check indicated reactor power vs. control rod position
21 Start electric motor driven feed pump
22 Stabilize plant feedwater flow
23 Increase load to 342 MW(e) @ 1%/min
24 Trim position the reactor core orifices to balance the helium temperatures
25 Stabilize plant load at 342 MW(e)
26 Check indicated reactor power vs. control rod position

NOTE: The time line above-left is valid when LOAD INCREASES.

1) See OPOP IV-C-1 for approximate settings and recording procedure. Request results department proceed with OPOP I C.3 if required

2) See SOP 84-01

3) See SOP 92-01

5) See SOP 12-04

7) See OPOP IV-C-7 for approximate settings and recording procedure

8) Per SOP 12-01. See OPOP IV-C-8 for recording procedure and note.

9) SOP 31 and SOP 93-02

11) SOP 12-04

12) See OPOPIV-C-12 for approximate operating conditions and recording procedure

13) Per SOP 12-01. See OPOP IV-C-13 for recording procedure and note. Also see SUT B-8, B-9, and A-6 for making measurements.

14) SOP 31

15) SOP 31

NOTE: (CONTINUED)

17) SOP 32

19) See OPOP IV-C-19 for approximate settings and recording procedure

20) SOP 12-01. See OPOP IV-C20 for recording procedure and note

22) SOP 31

24) SOP 12-04

25) See OPOP C-IV-25 for approximate settings and recording procedure

26) SOP 12-01. See OPOP IV-C-26 for recording procedure

FIGURE B.28

NOTE: See OPOPIV-E for loss of helium circulator. See OPOP IV-F for loss of steam generator loop.

LOSS OF BOILER FEED PUMP

EVENTS	
1	Reduce plant load to 60% of rated plant load. Start auxiliary boiler if necessary. Close boiler feed pump main and emergency feedwater header discharge valves
2	Make visual checks. Set main turbine generator load limit to 65%

LOAD DECREASES 25-100% LOAD OPERATION

EVENTS	
1	Load reduction will be in automatic under control of system dispatcher or local control
2	At about 270 MW(e) motor driven boiler feed pump may be shutdown by closing both outlet valves slowly
3	At about 200 MW(e) one large condensate pump may be shutdown
4	At about 135 MW(e) one turbine driven boiler feed pump may be shutdown
5	At 85 MW(e), transfer housepower from unit transformer to auxiliary transformer

See OPOP IV-D for other details and approximate operating conditions.

FIGURE B.28(Continued)

APPENDIX C

ELECTRICAL/GO LOGIC DRAWINGS

APPENDIX C
ELECTRICAL/GO LOGIC DRAWINGS

MAIN SCRAM

FSV-1G	Plant Electrical Service
FSV-1E	Reactor Building Temperature (High) 480V Surge Undervoltage
FSV-2G	Reactor Pressure
FSV-2E	Core Inlet Temperature
FSV-3G	Hot Reheat Steam Pressure (Low)
FSV-3E	Superheat Steam Pressure (Low) Reheat Steam Temperature (High)
FSV-4G	Startup Channels I, II
FSV-4E	Startup/Wide Range/Linear Range
FSV-5G	Wide Range Channel III
FSV-6G	Linear Power Channel VI

TWO LOOP TROUBLE

FSV-7G/E	Circulator Seal Malfunction
FSV-8G	Steam Pipe Rupture
FSV-8E	
FSV-9G	Reheat Header Activity
FSV-9E	Steam Generator Penetration Overpressure
FSV-10G	Low Superheat Header Temperature
FSV-10E	
FSV-11G	Moisture Monitors
FSV-11E	Reactor Pressure

ELECTRICAL/GO LOGIC DRAWINGS

FSV-12G Two Loop Trouble Output

FSV-12E

CIRCULATOR TRIP

FSV-13G Loss of Bearing Water, Circulator
Seal Malfunction (C/T)
Reheat Header Activity (C/T)

FSV-13E Loss of Bearing Water, Circulator
Seal Malfunction (C/T)
Reheat Header Activity (C/T)
Circulator Drain Malfunction
Circulator Trip Output Logic

FSV-14G Circulator Drain Malfunction
Circulator Trip Output Logic

FSV-15G/E Fixed Low Flow Trip

FSV-16G/E Circulator Penetration Pressure (High)
Manual Trip

FSV-17G Speed Trip Sensors

FSV-17E

FSV-18G Main SCRAM Gate

FSV-18E SCRAM Brake Control

FSV-19G Rod Control System

FSV-19E-1
FSV-19E-2

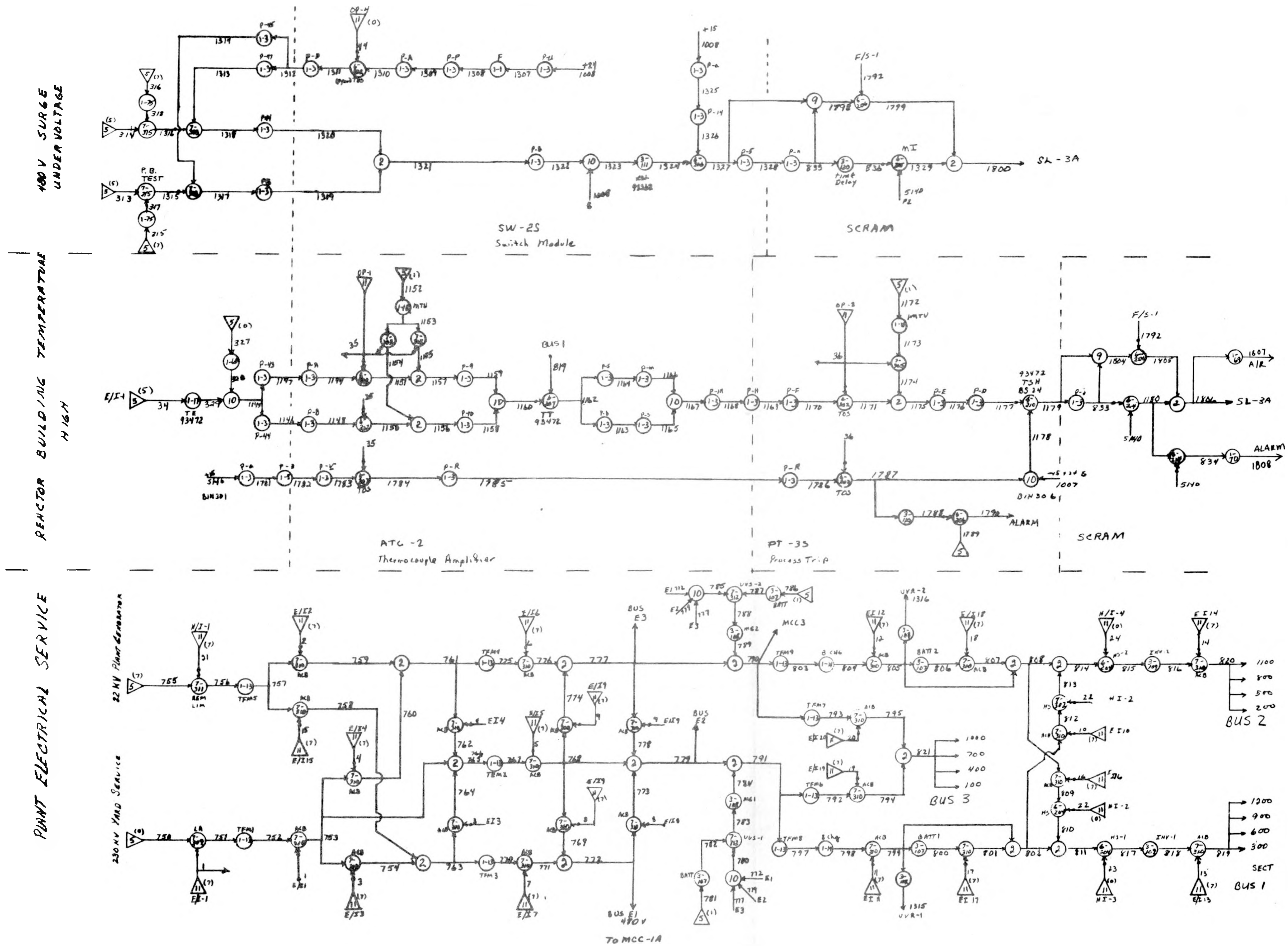
FSV-20G Rod Gear Drive

FSV-20E Final Output

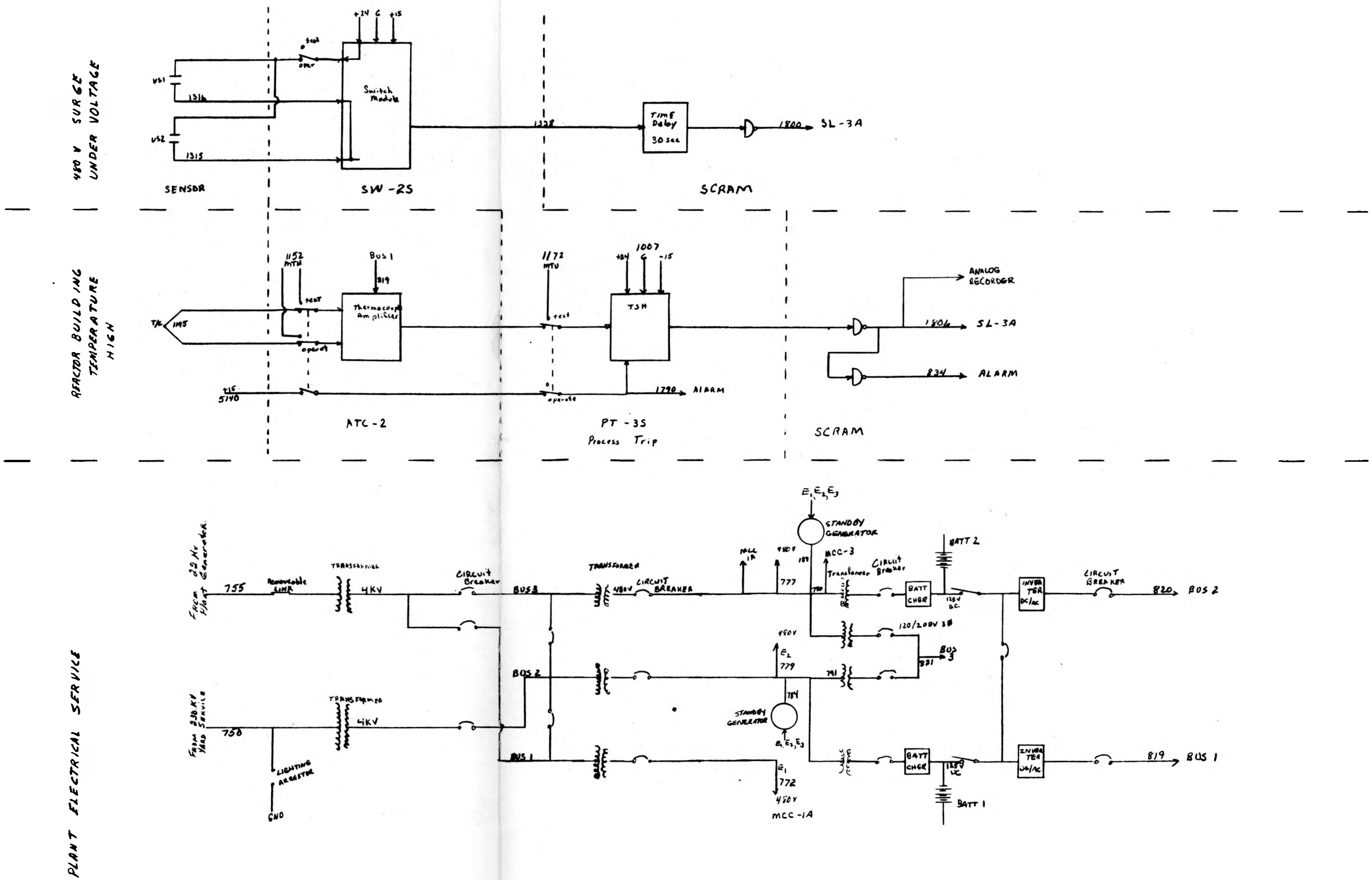
FSV-21 SCRAM Input Model for Startup

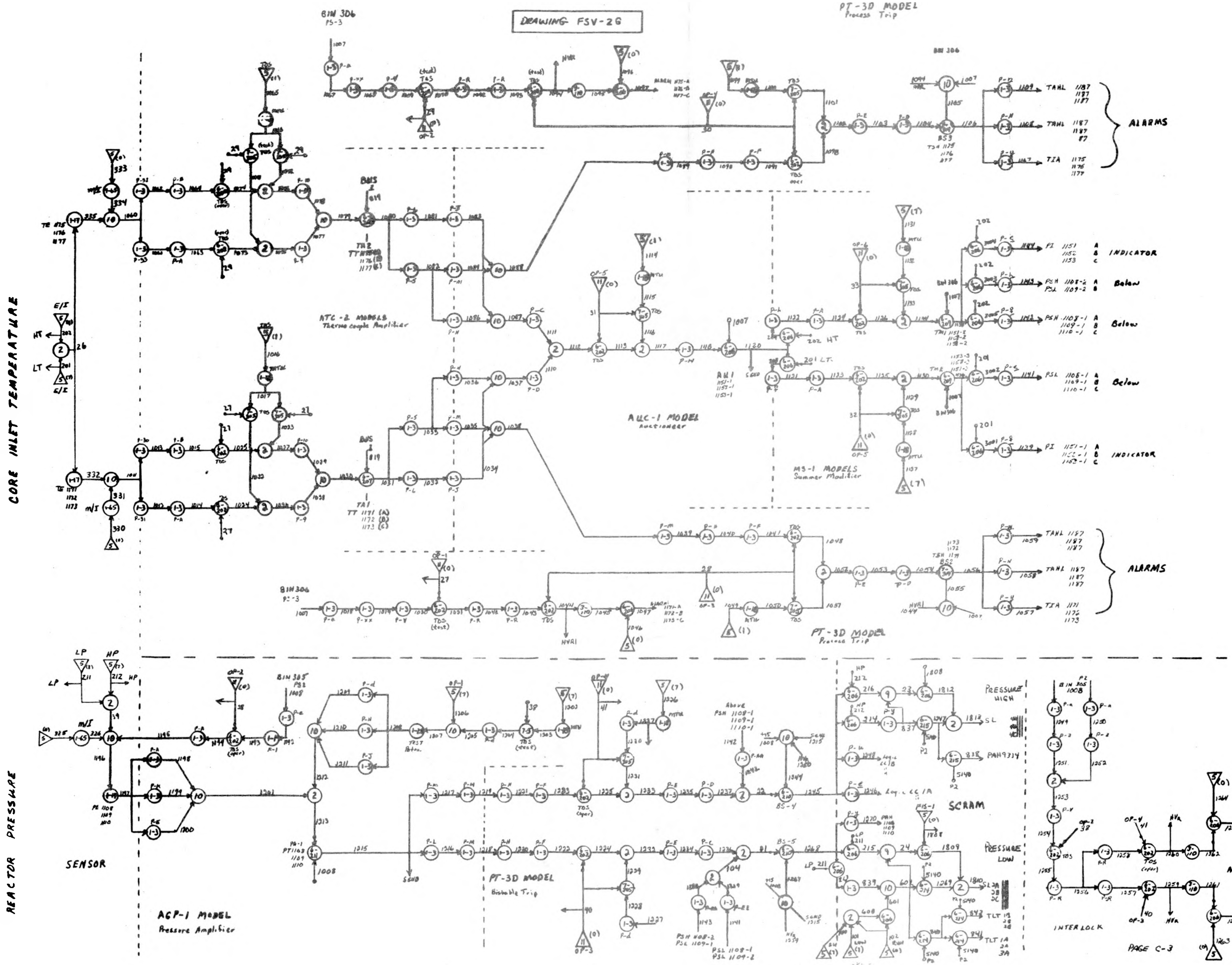
NOTES: G - indicates GO type Logic Drawing.
E - indicates Electrical Logic Drawing.

DRAWING FSV-1G

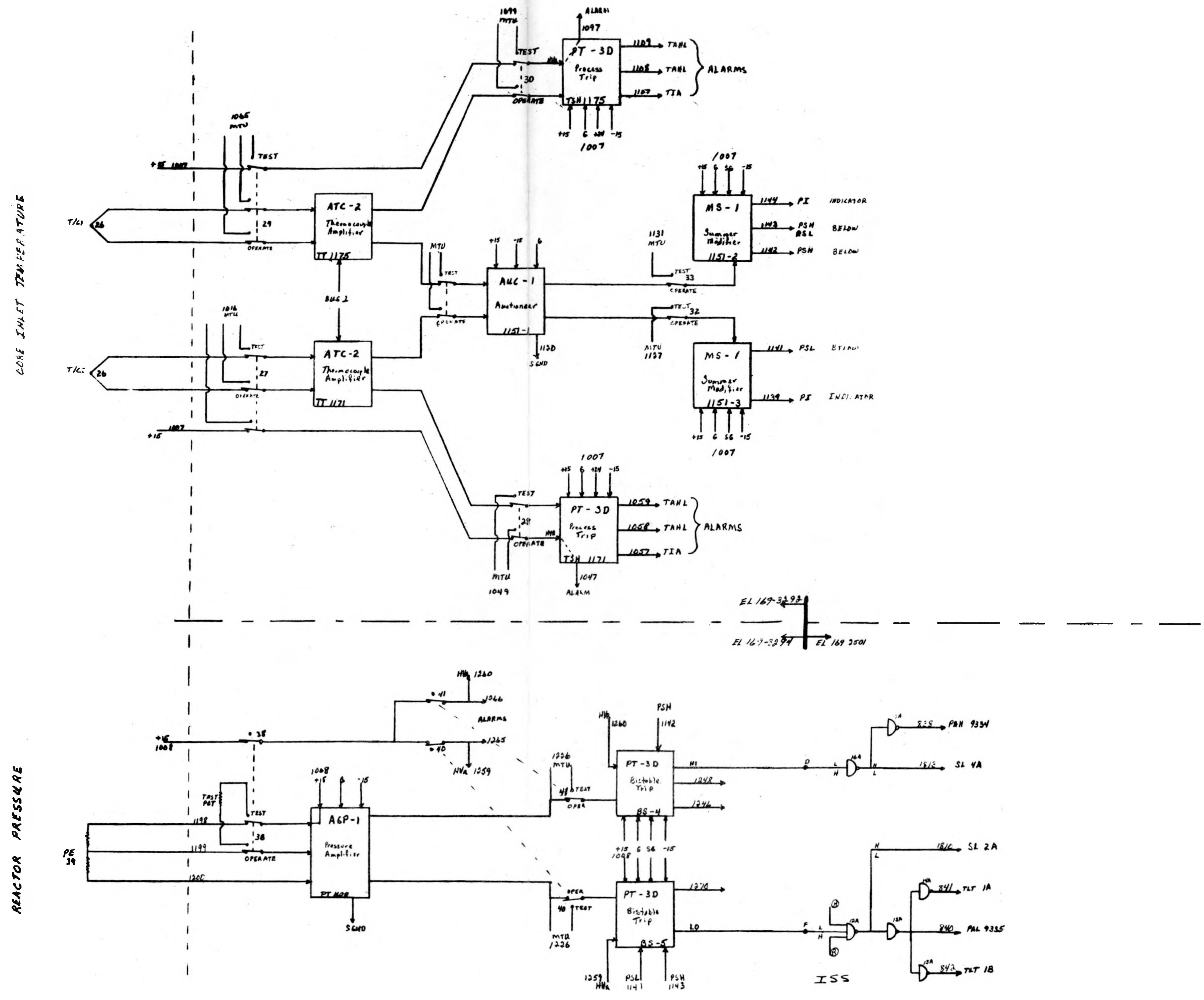


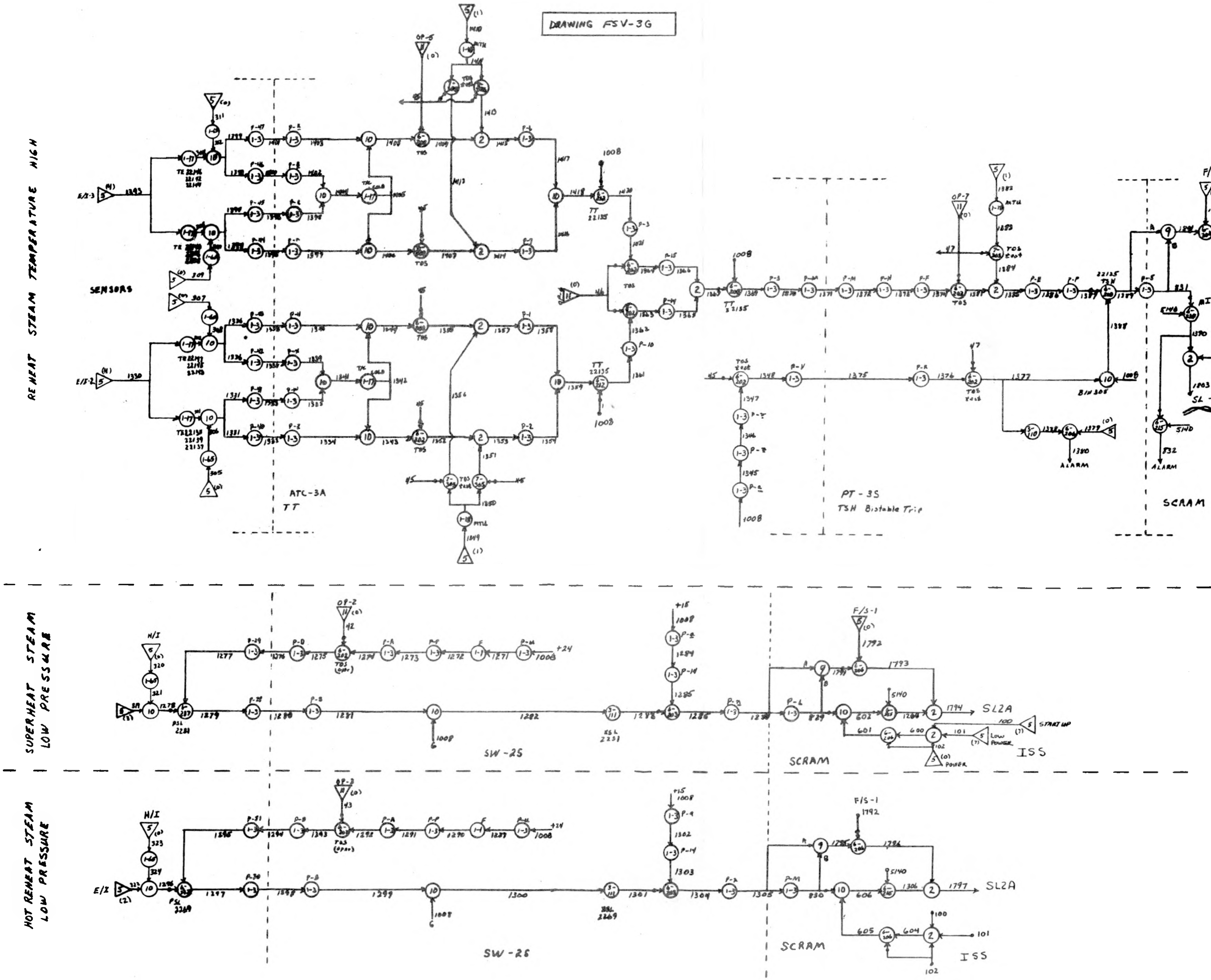
DRAWING FSV-1E



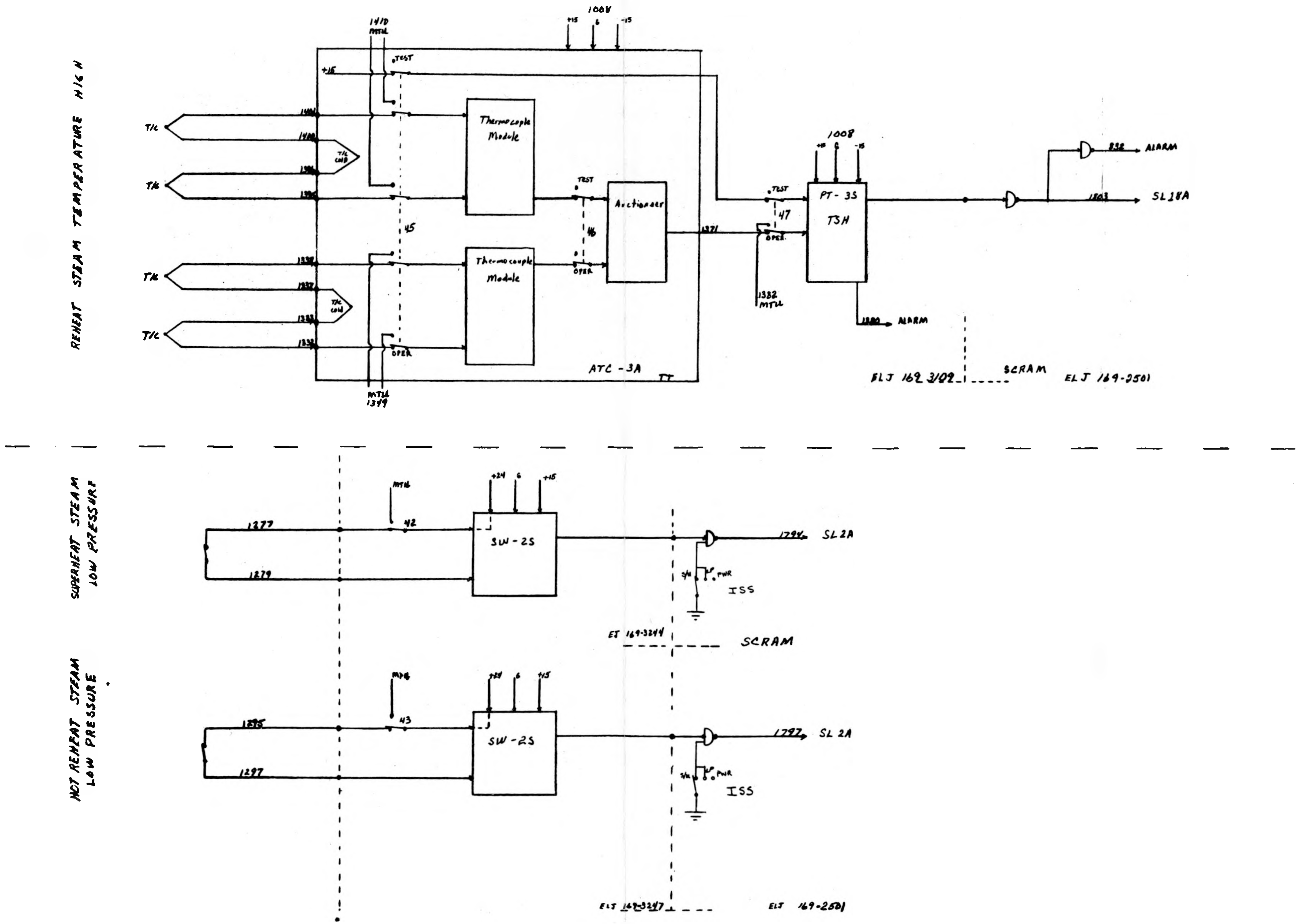

DRAWING FSV-26
PT-3D MODEL
Process Trip
ALARMS
INDICATOR
Below
ATC-2 MODELS
Thermocouple Amplifier
AUC-1 MODEL
Auctioneer
MS-1 MODELS
Summer Modifier
CORE INLET TEMPERATURE
REACTOR PRESSURE
SENSOR
ACP-1 MODEL
Pressure Amplifier
PT-3D MODEL
Bistable Trip
PRESSURE HIGH
SCRAM
PRESSURE LOW
INTERLOCK
ALARMS
PAGE C-3

DRAWING FSV-2E

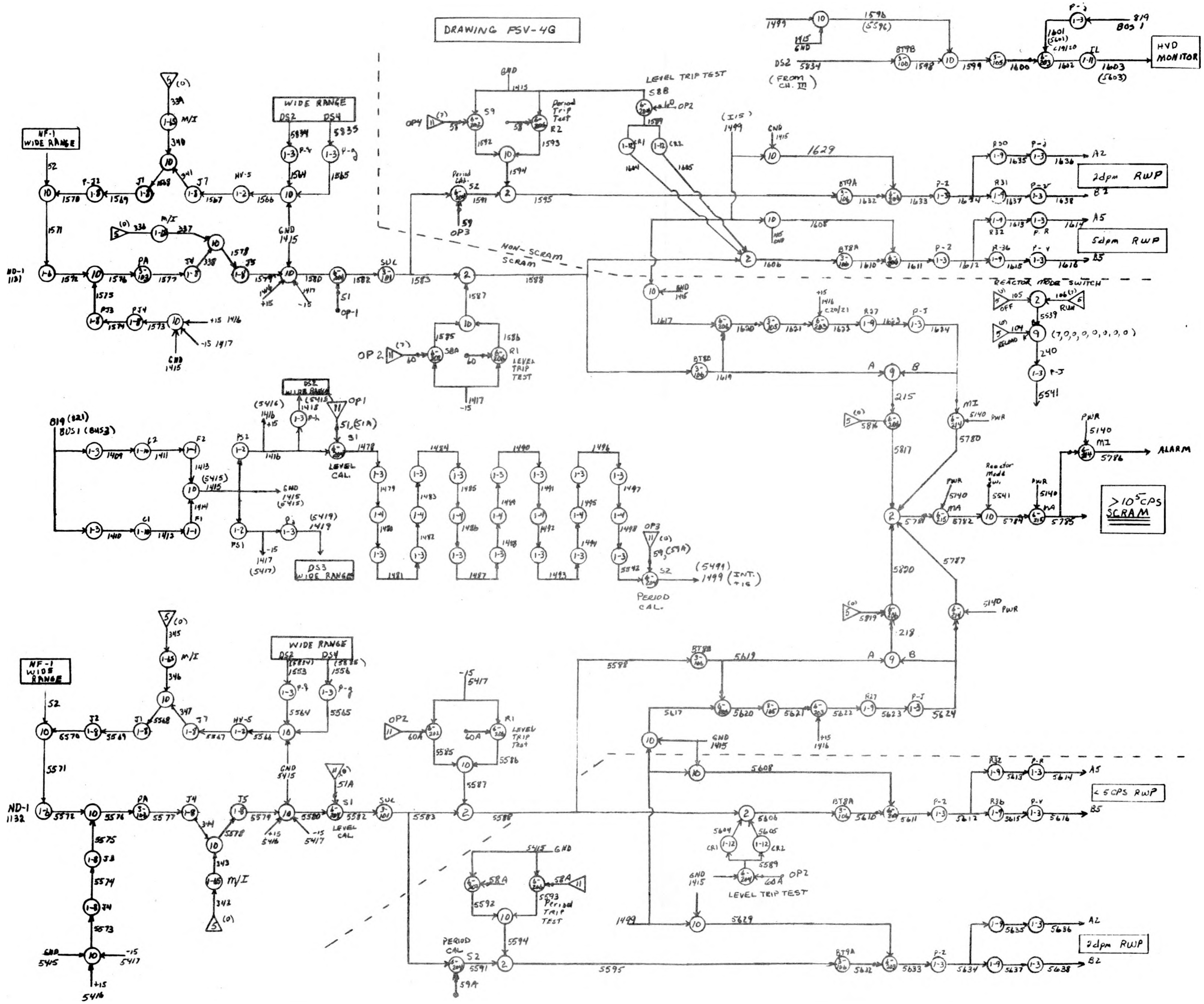



DRAWING FSV-3G
REHEAT STEAM TEMPERATURE HIGH
SENSORS
ATC-3A
TT
PT-3S
TSH Bistable Trip
SCRAM
ALARM
SL-18A
SUPERHEAT STEAM LOW PRESSURE
SW-2S
SCRAM
SL2A
ISS
START UP
HOT REHEAT STEAM LOW PRESSURE
SW-2S
SCRAM
SL2A
ISS

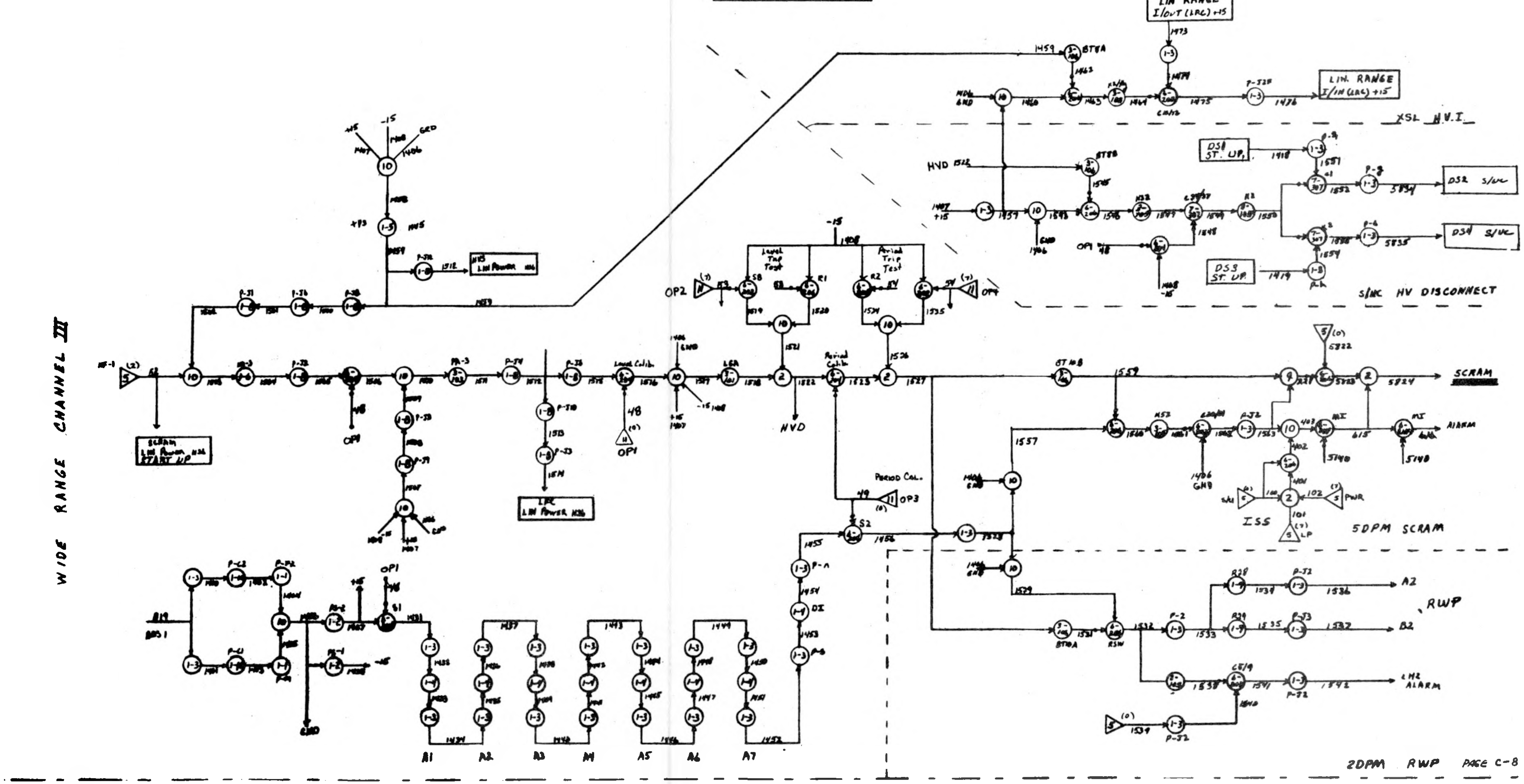
DRAWING FSV-3E



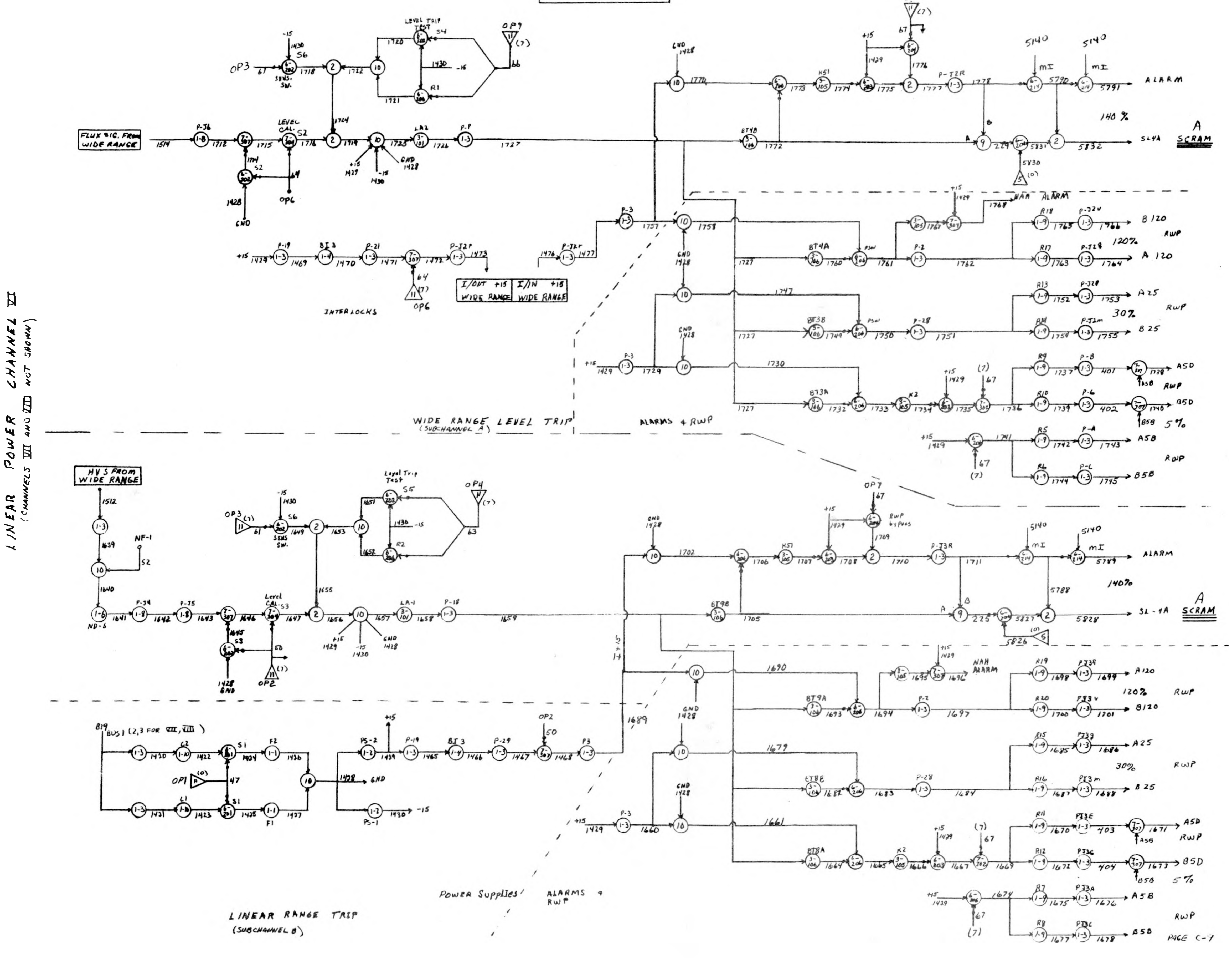
START UP CHANNELS



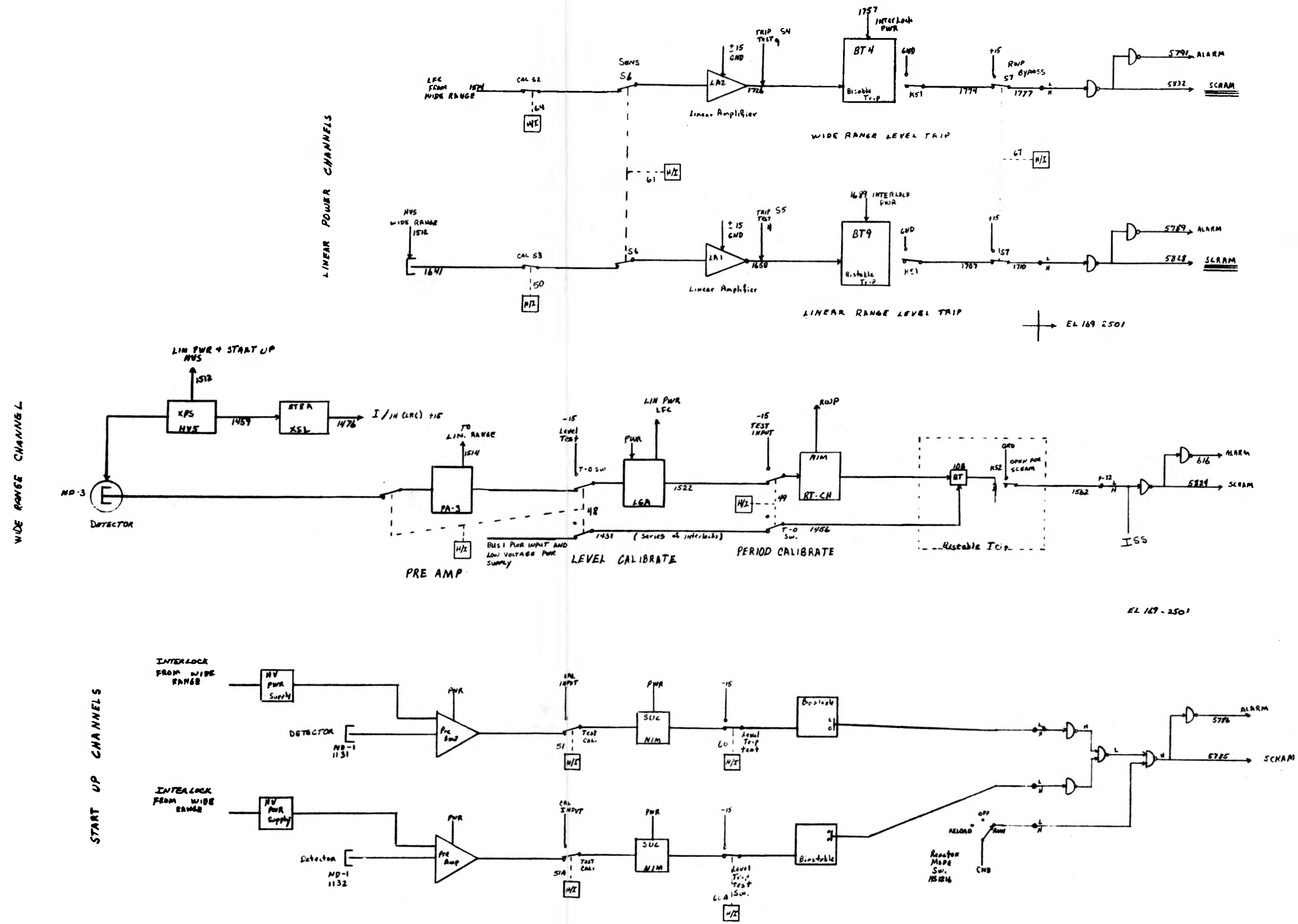
DRAWING FSV-5B



DRAWING FSV-6G



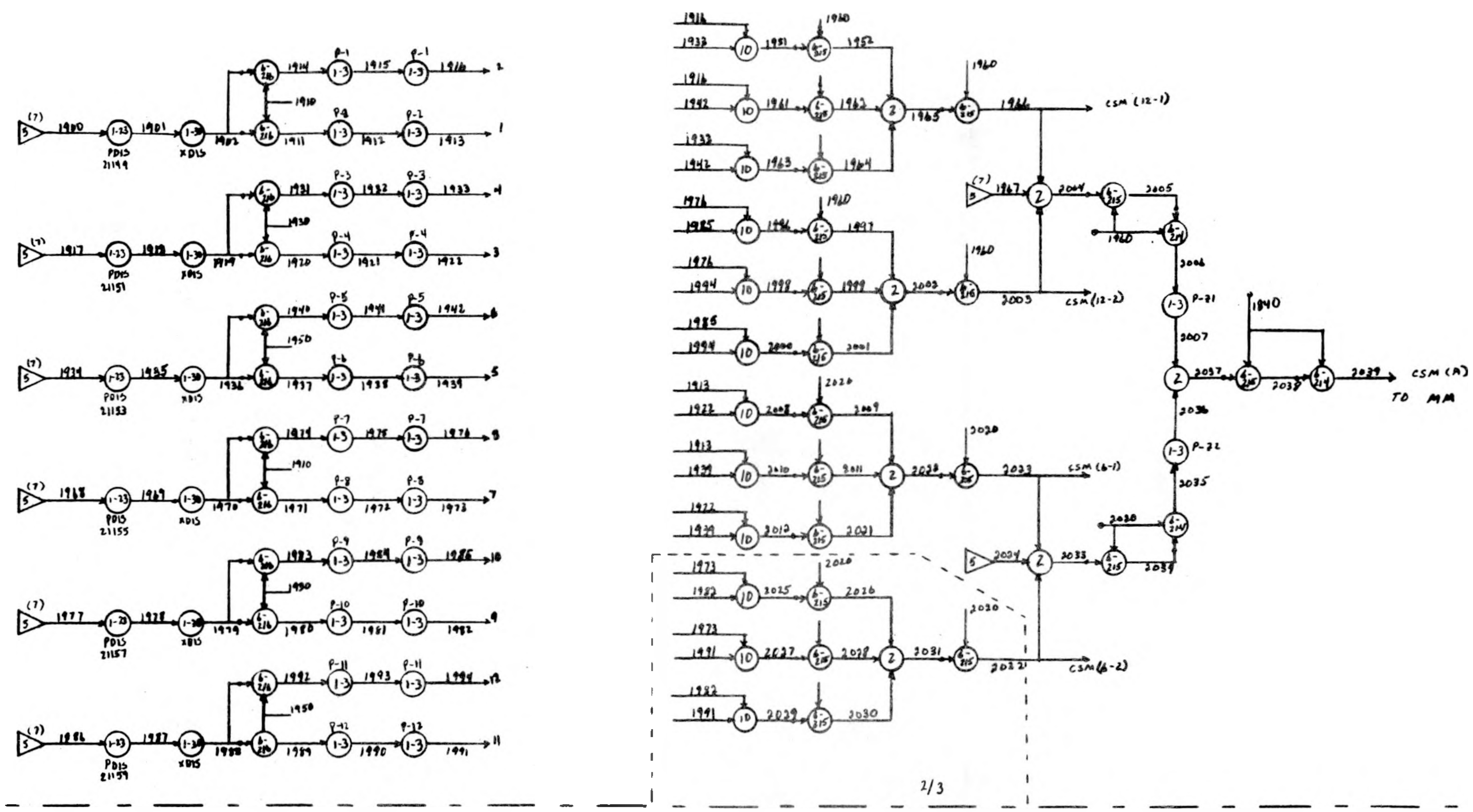
DRAWING FSV-4E



DRAWING FSV-7G/E

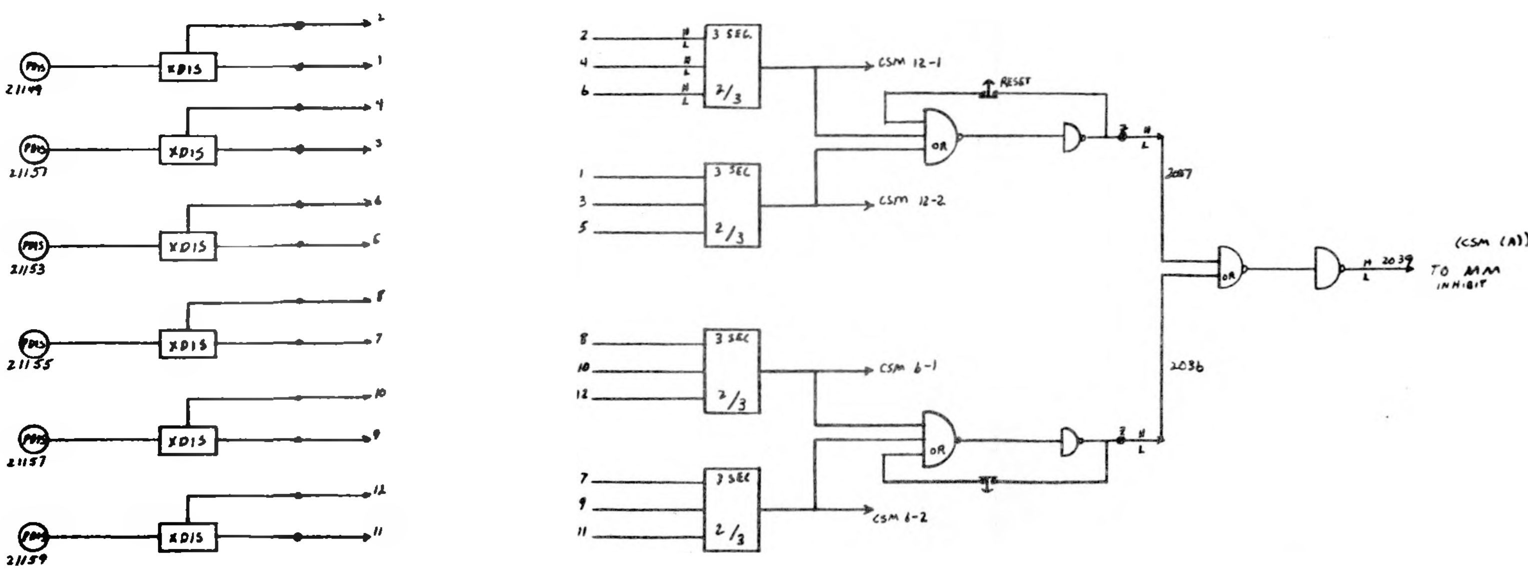
CIRCULATOR SEAL MALFUNCTIONS LOOP 1

(IDENTICAL CIRCUIT USED FOR LOOP 2 3191 - 3330 (FROM ALL SENSORS 21150 THRU 21160))



CIRCULATOR SEAL MALFUNCTION LOOP 1

(CIRCUIT IS IDENTICAL AS THIS FOR LOOP 2)

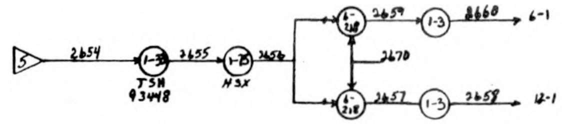


EL 169 2641

DRAWING FSV-8G

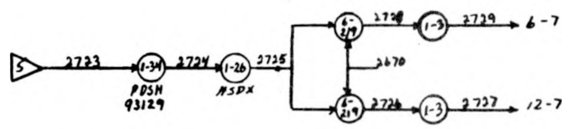
STEAM PIPE RUPTURE UNDER (SPRU)
STEAM PIPE RUPTURE OUTSIDE (SPRO)

6 SENSORS



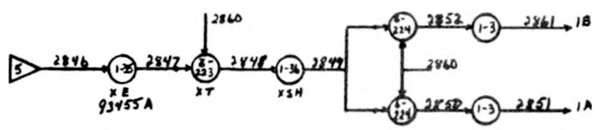
SENSOR	TYPE	INPUT SIG.	OUTPUT	No.
93448	SPRU	2654	2658 2660	12-1 6-1
93449	SPRU	2661	2681 2691	12-2 6-2
93450	SPRU	2692	2696 2698	12-3 6-3
93451	SPRO	2764	2768 2770	12-4 6-4
93452	SPRO	2771	2775 2777	12-5 6-5
93453	SPRO	2778	2782 2784	12-6 6-6

6 SENSORS

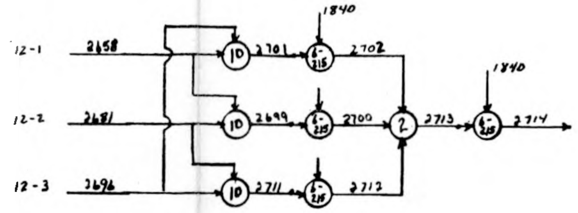


SENSOR	TYPE	INPUT SIG.	OUTPUT	NO
93129	SPRU	2723	2727 2729	12-7 6-7
93130	SPRU	2730	2734 2736	12-8 6-8
93131	SPRU	2737	2741 2743	12-9 6-9
93132	SPRO	2801	2805 2807	12-10 6-10
93133	SPRO	2808	2812 2814	12-11 6-11
93134	SPRO	2815	2819 2821	12-12 6-12

18 SENSORS

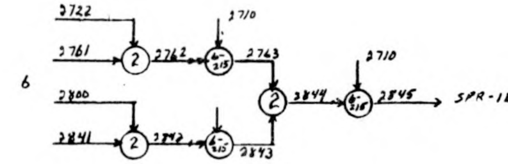


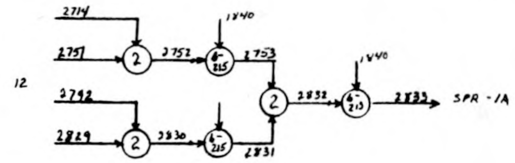
SENSOR	TYPE	INPUT SIG.	OUTPUT	NO
93455A	SPRO	2846	2851 2861	1A 1B
B		2862	2875 2877	2A 2B
C		2878	2891 2893	3A 3B
93457A	SPRO	2910	2915 2917	4A 4B
B		2918	2923 2925	5A 5B
C		2926	2931 2933	6A 6B
93971 A	SPRU	2950	2955 2957	7A 7B
B		2958	2963 2965	8A 8B
C		2966	2971 2973	9A 9B
93454 A	SPRO	2994	2999 3001	10A 10B
B		3002	3015 3017	11A 11B
C		3018	3023 3025	12A 12B
93456A	SPRO	3042	3047 3049	13A 13B
B		3050	3055 3057	14A 14B
C		3058	3063 3065	15A 15B
93470A	SPRU	3082	3087 3089	16A 16B
B		3090	3095 3097	17A 17B
C		3098	3103 3105	18A 18B

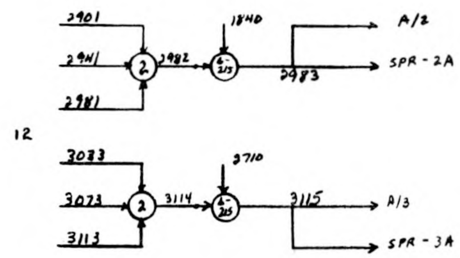


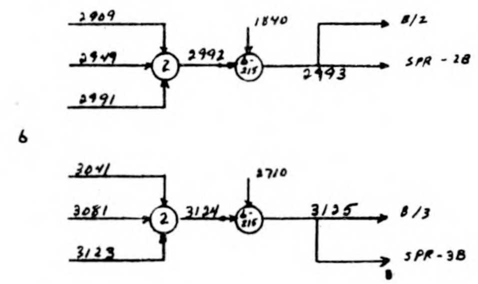
TYPICAL 2/3

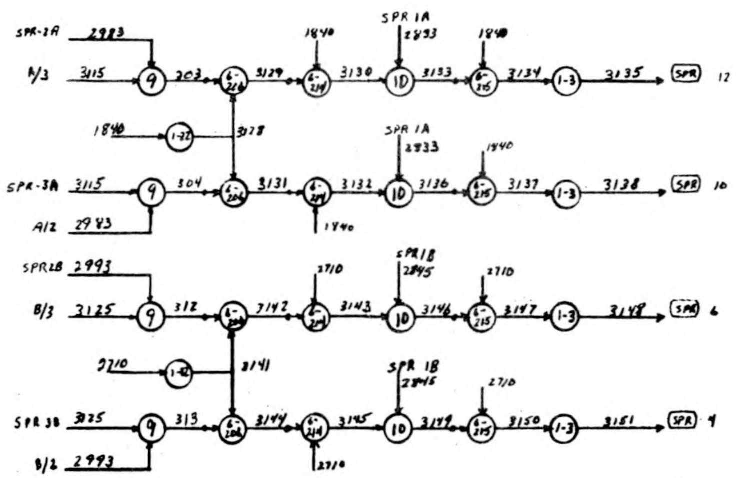
NO.	INPUT SIG.	OUTPUT SIG.	
12-1 2 3	2658 2681 2696	2714	12
12-7 8 9	2727 2734 2741	2751	
12-4 5 6	2768 2775 2782	2792	
12-10 11 12	2805 2812 2819	2829	
6-1 2 3	2660 2691 2698	2722	6
6-7 8 9	2729 2736 2743	2761	
6-4 5 6	2770 2776 2783	2800	
6-10 11 12	2807 2814 2821	2841	
1A 2A 3A	2851 2875 2891	2901	12
4A 5A 6A	2915 2923 2931	2941	
7A 8A 9A	2955 2963 2971	2981	
10A 11A 12A	2999 3015 3023	3033	12
13A 14A 15A	3047 3055 3063	3073	
16A 17A 18A	3087 3095 3103	3113	
1B 2B 3B	2861 2877 2893	2909	6
4B 5B 6B	2917 2925 2933	2949	
7B 8B 9B	2957 2965 2973	2991	
10B 11B 12B	3001 3017 3025	3041	6
13B 14B 15B	3049 3057 3065	3081	
16B 17B 18B	3089 3097 3105	3123	







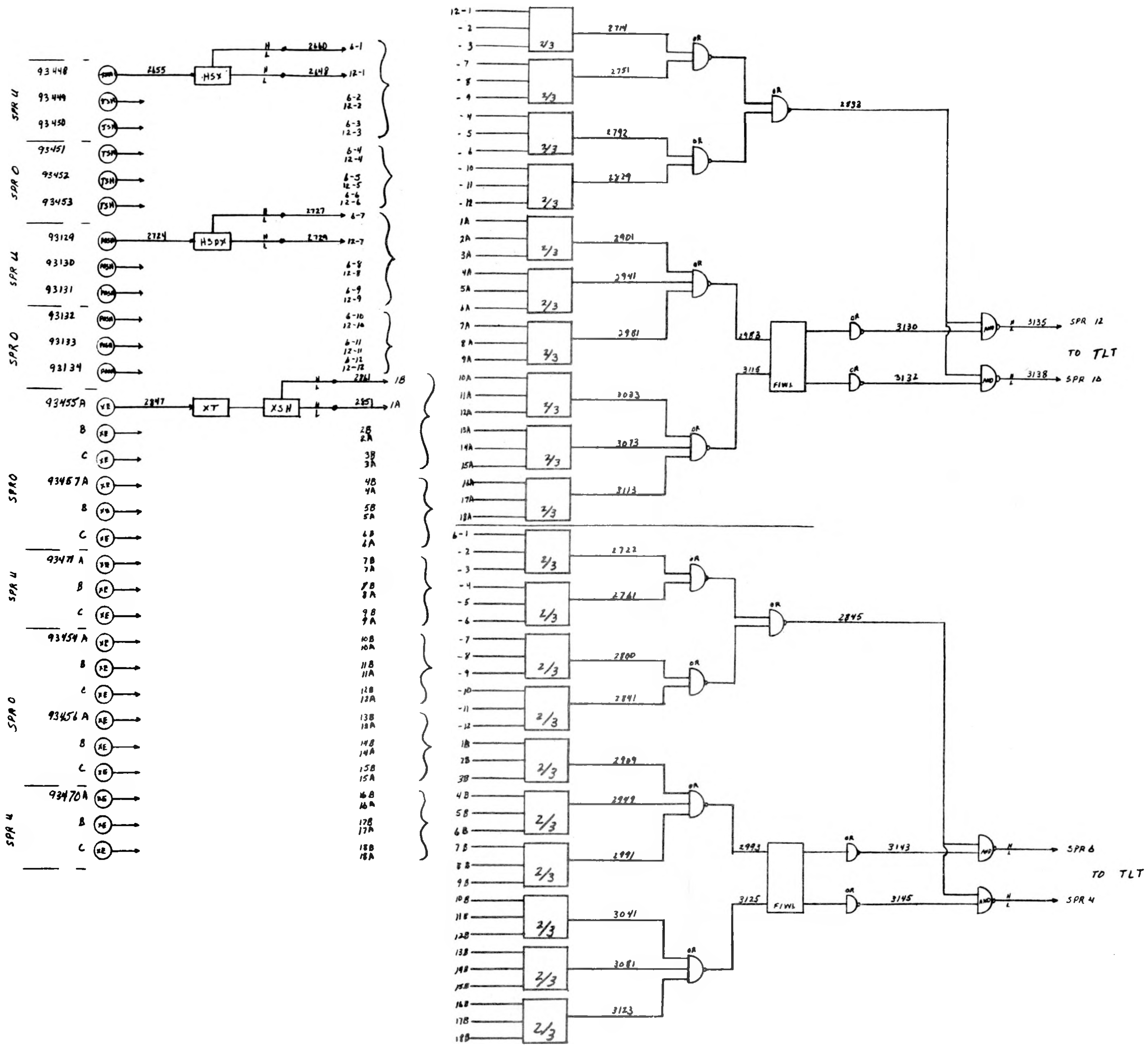




DRAWING FSV-8E

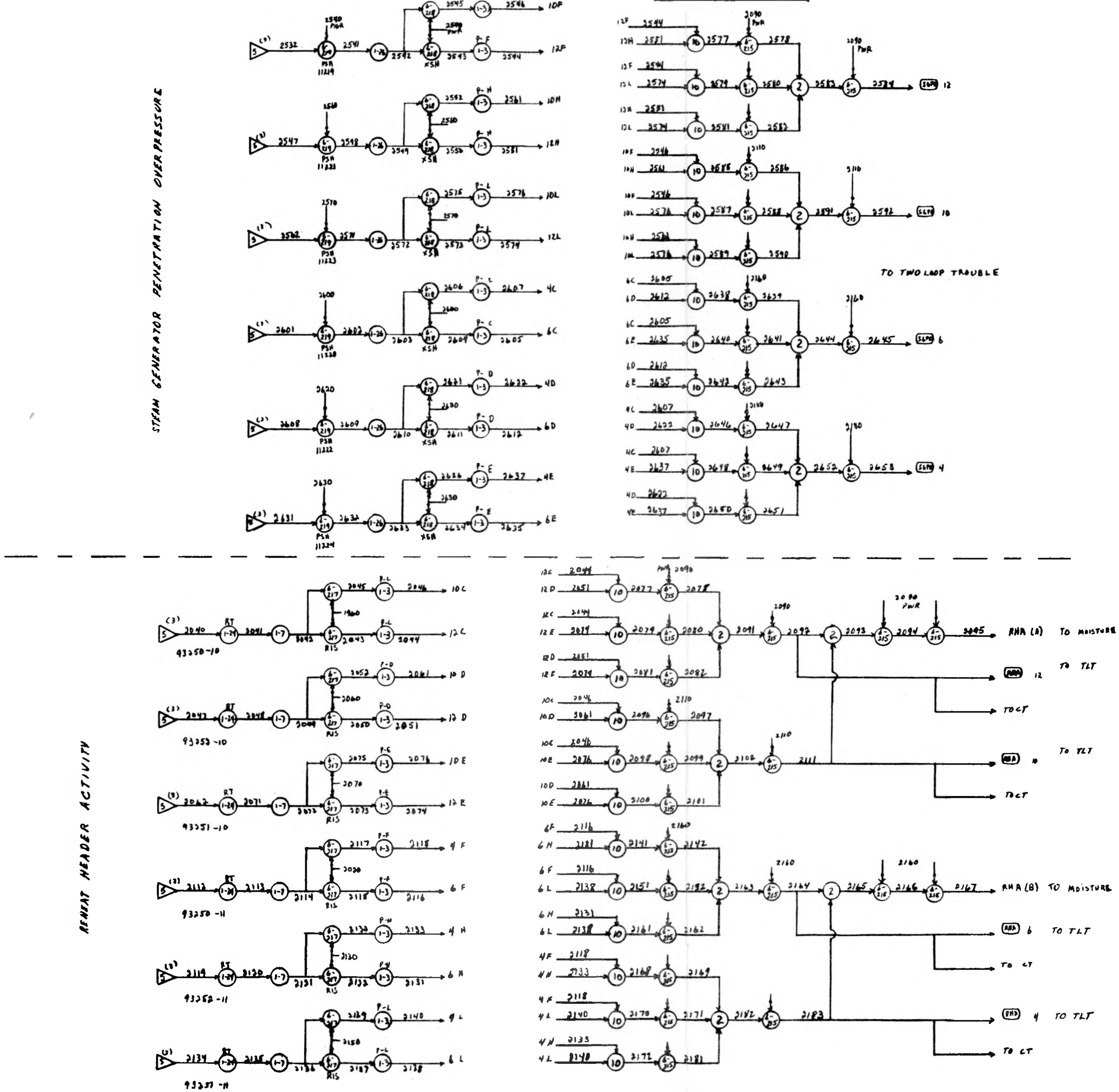
STEAM PIPE RUPTURE UNDER (SPRU)

STEAM PIPE RUPTURE OUTSIDE (SPRO)

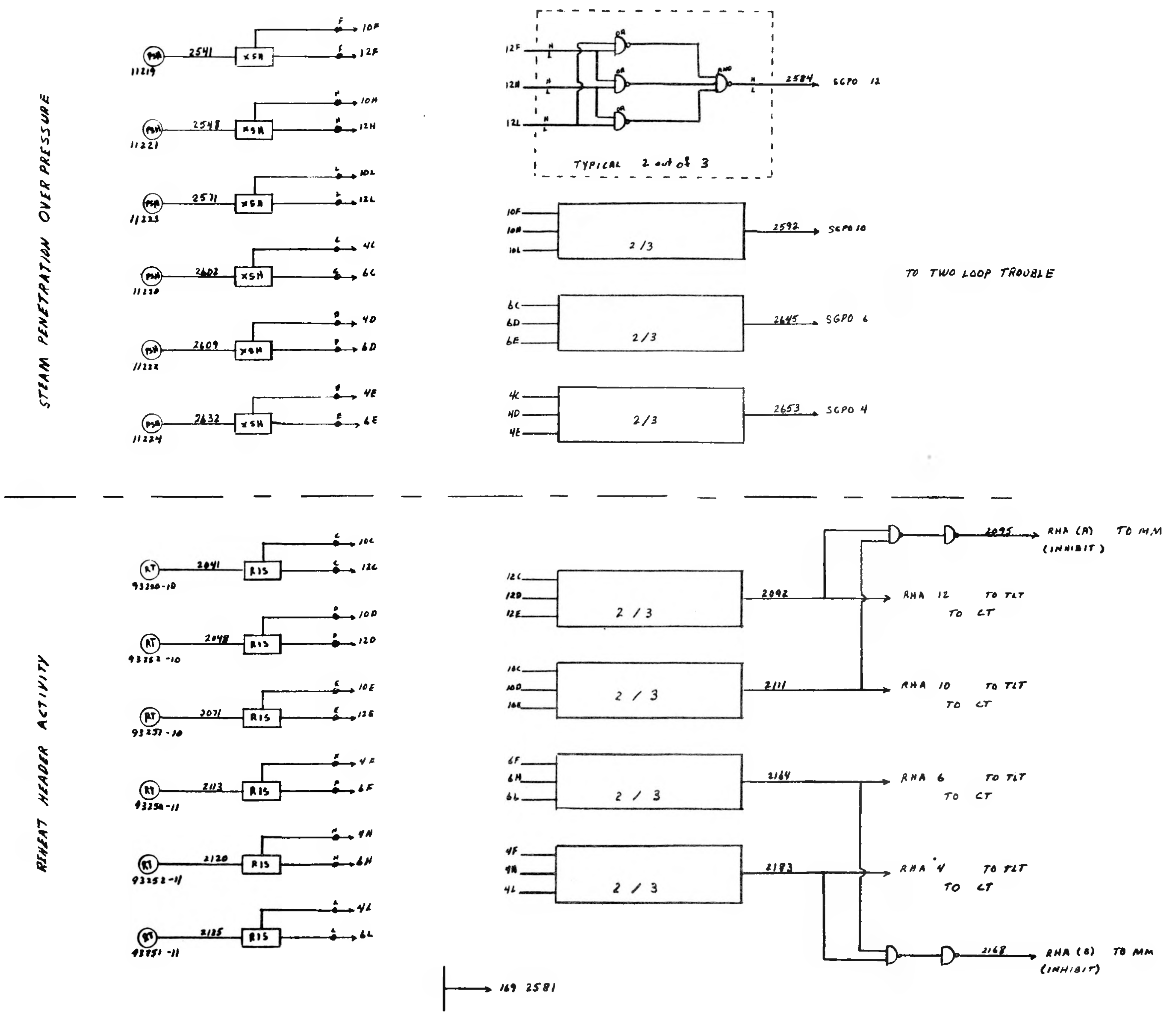


EL 169 - 2601

DRAWING FSV-9G

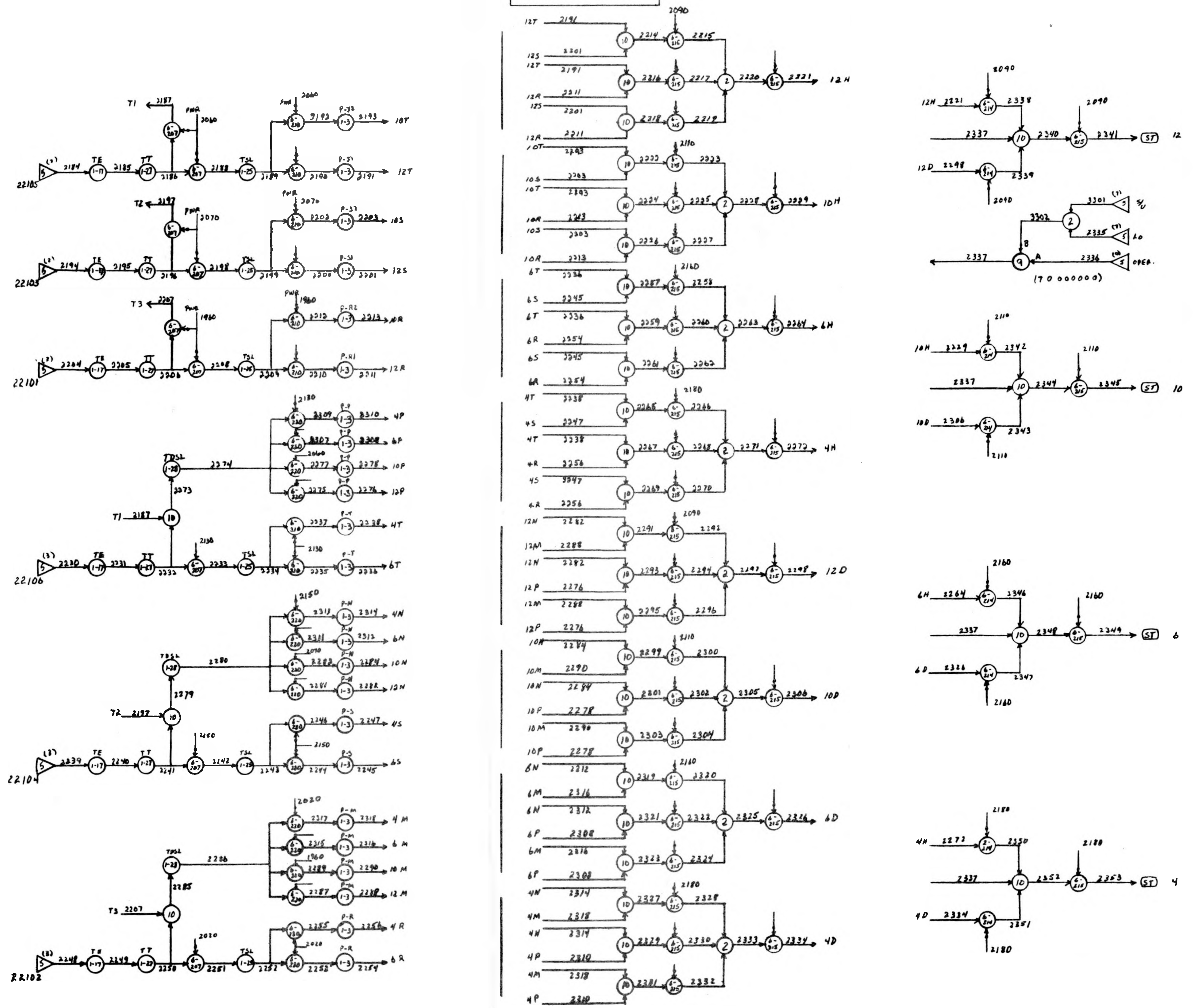


DRAWING FSV-9E

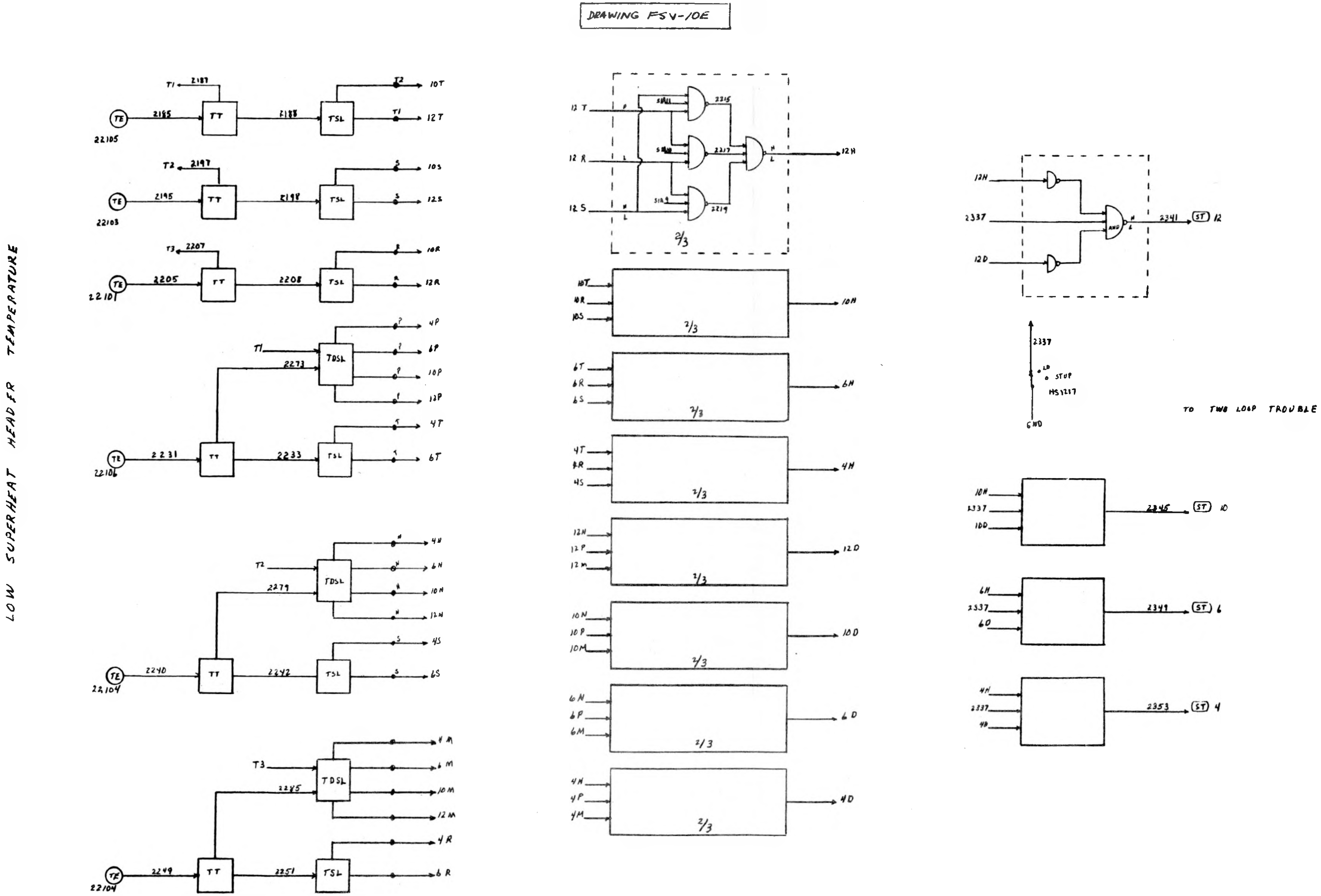


LOW SUPER HEAT HEADER TEMPERATURE

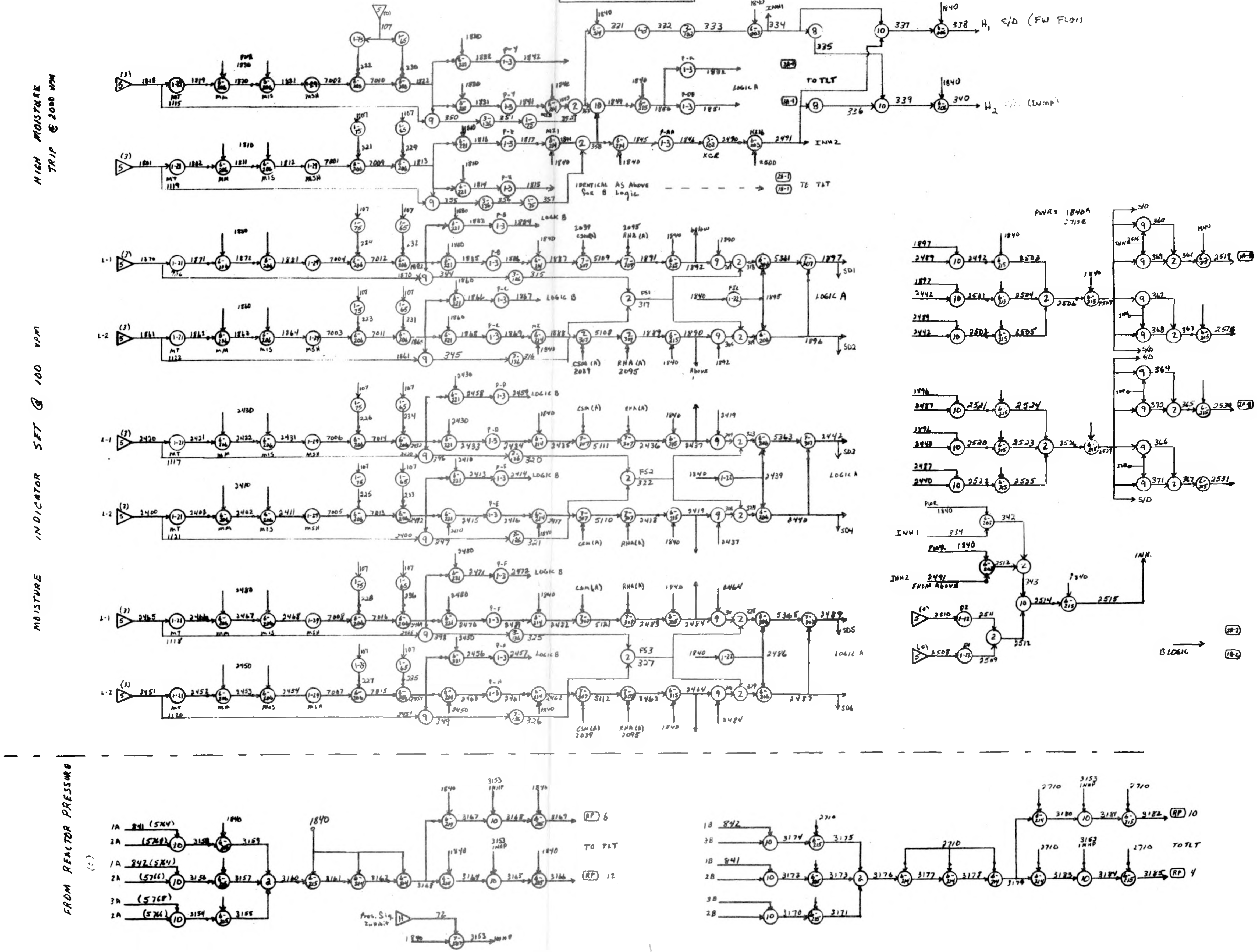
DRAWING FSV-10G

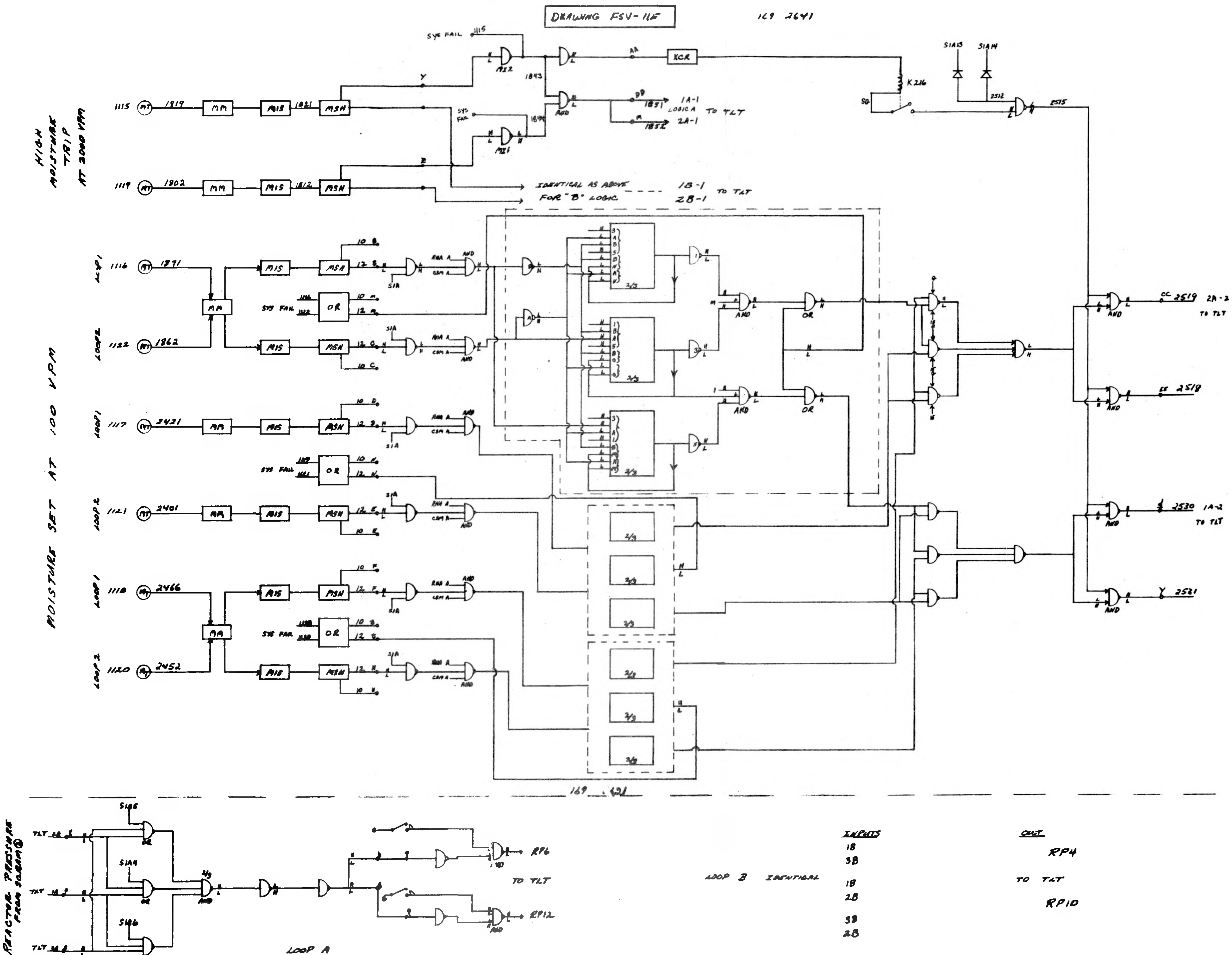


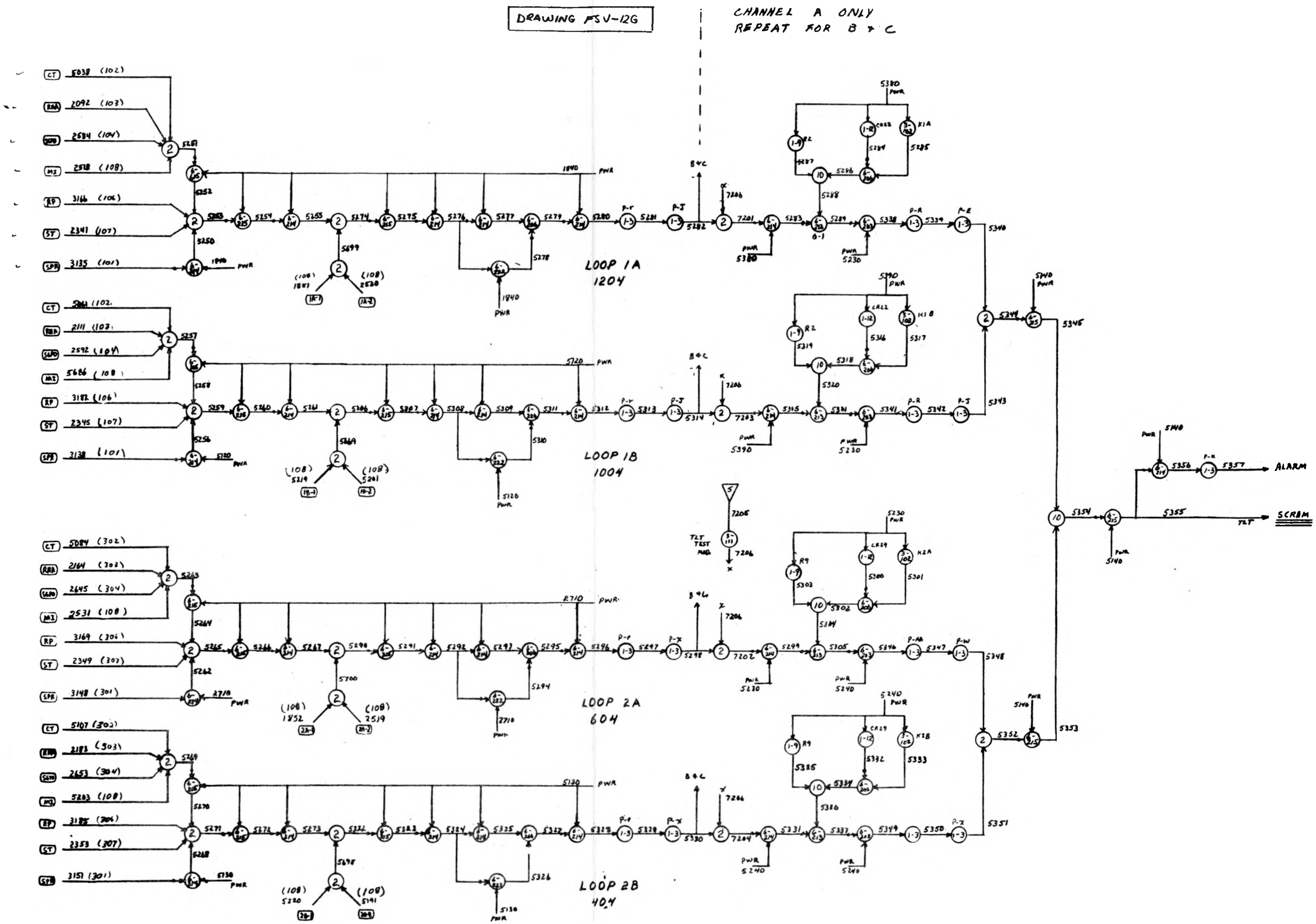
2/3


DRAWING FSV-10E
LOW SUPERHEAT HEADER TEMPERATURE
TE
TT
TSL
TDSL
2/3
TO TWO LOOP TROUBLE
STOP
HS 2217
GND
2337
2341
2345
2349
2353
ST

DRAWING FSV-11G

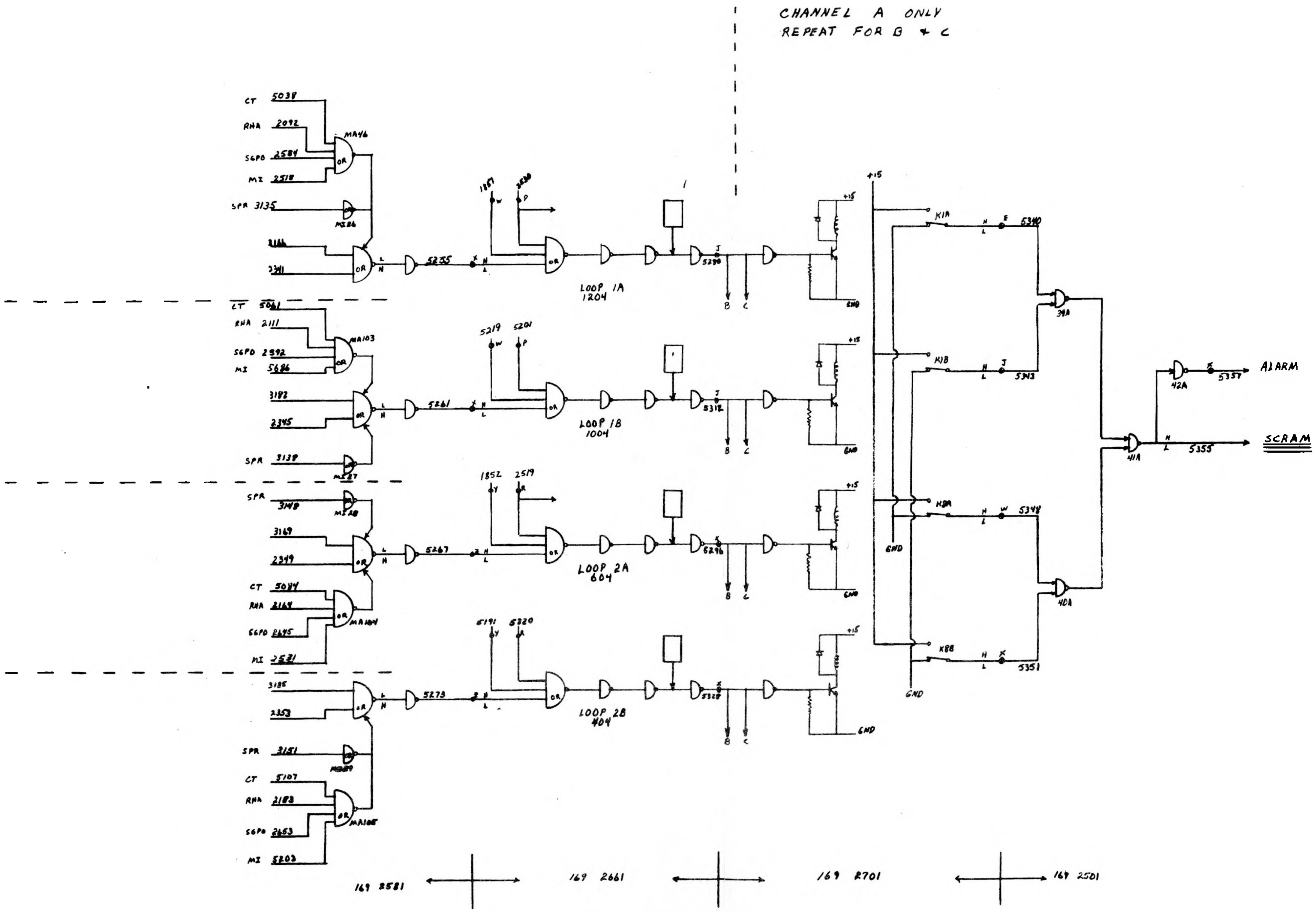



DRAWING FSV-11E
169 2641
HIGH MOISTURE TRIP AT 2000 VPM
MOISTURE SET AT 100 VPM
SYS FAIL
XCR
K216
IDENTICAL AS ABOVE FOR "B" LOGIC
1B-1
2B-1
TO TLT
1A-1
2A-1
LOGIC A
REACTOR PRESSURE FROM SORBIA
LOOP A
LOOP B IDENTICAL
INPUTS
1B
3B
1B
2B
3B
2B
OUT
RP4
RP10
RP6
RP12
TO TLT



TWO LOOP TROUBLE OUTPUT

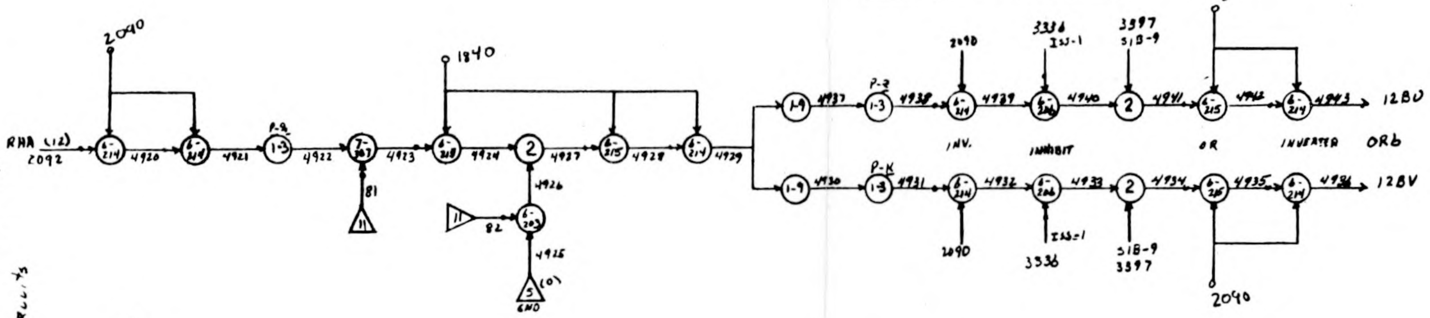
DRAWING FSV-12E



TWO LOOP TROUBLE OUTPUT

DRAWING FSV-13G

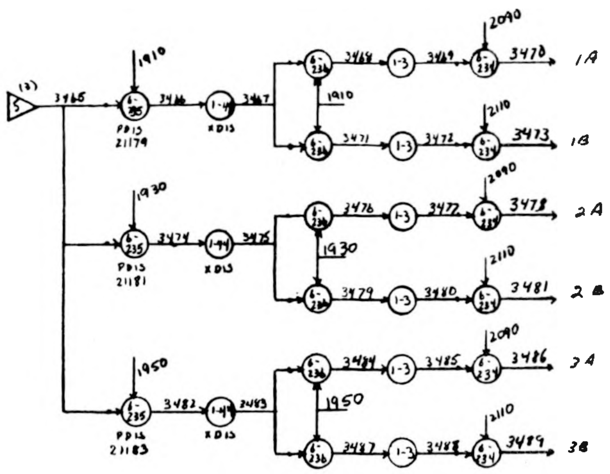
REHEAT HEADER (C/T) ACTIVITY



Four identical circuits

INPUT		OUTPUT		
RHA (10)	2111	OR-6	10BV	4984
			10BU	4991
RHA (6)	2164		6BV	4960
			6BU	4967
RHA (4)	2183		4BV	5008
			4BU	5015
RHA (12)	2092		12BV	4936
			12BU	4943

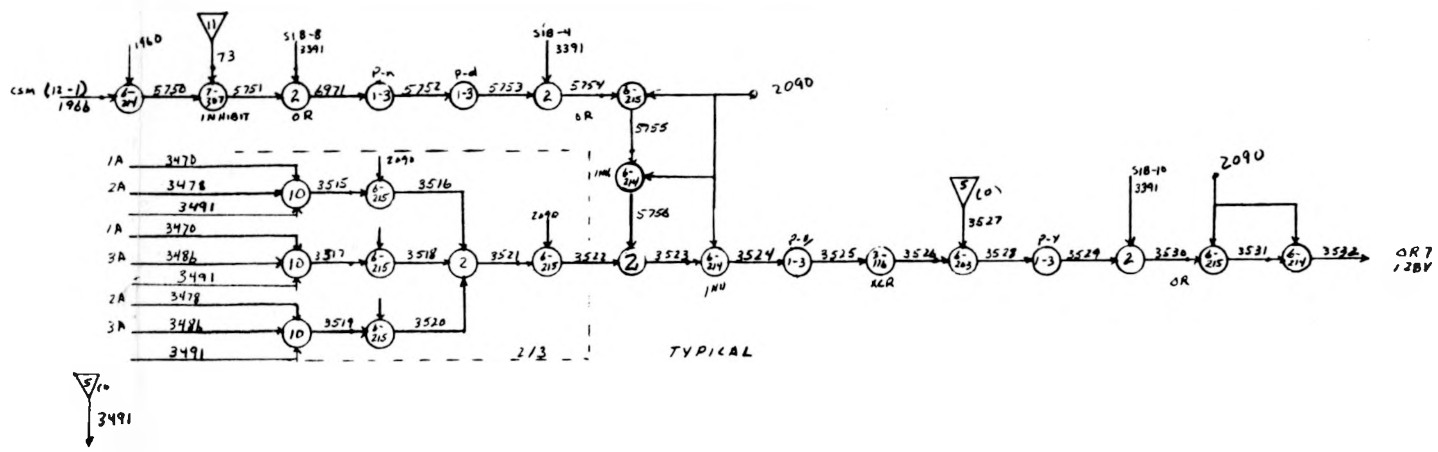
LOSS OF BEARING WATER + CIRCULATOR SEAL HALF (C/T)



TYPICAL

FOUR SETS OF SENSORS WITH IDENTICAL CIRCUIT

INPUT SENSOR	SIGNAL	OUTPUT NO	OUTPUT SIGNAL
21179	3465	1A	3470
		1B	3473
21181		2A	3478
		2B	3481
21183		3A	3486
		3B	3489
21173	3533	4A	3538
		4B	3541
21175		5A	3546
		5B	3549
21177		6A	3554
		6B	3557
21180	5722	7A	5728
		7B	5731
21182		8A	3652
		8B	3663
21184		9A	3668
		9B	3671
21174	3722	10A	3727
		10B	3730
21176		11A	3735
		11B	3738
21178		12A	3743
		12B	3746



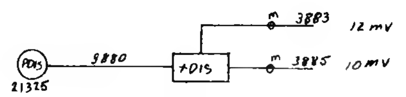
TYPICAL

INPUT NO	INPUT SIGNAL		OUTPUT SIGNAL	OUTPUT NO
1 A	3470		3532	OR7 - 12BV
2 A	3478			
3 A	3486			
LBW + CSM (11-1)		1966		
4 A	3538		3582	OR7 - 12BU
5 A	3546			
6 A	3554			
LBW + CSM (11-2)		2003		
7 A	5728		3696	OR7 - 6BV
8 A	3652			
9 A	3668			
LBW + CSM (6-1)		3225		
10 A	3727		3771	OR7 - 6BU
11 A	3735			
12 A	3743			
LBW + CSM (6-2)		3771		
1 B	3473		3607	OR7 - 10BV
2 B	3481			
3 B	3489			
LBW + CSM (10-1)		2023		
4 B	3541		3632	OR7 - 10BU
5 B	3549			
6 B	3557			
LBW + CSM (10-2)		2032		
7 B	5731		3721	OR7 - 4BV
8 B	3663			
9 B	3671			
LBW + CSM (4-1)		3215	3796	OR7 - 4BU
10 B	3730			
11 B	3738			
12 B	3746			
LBW + CSM (4-2)		3243		

DRAWING FSV-13E

169 - 2541 | 169 2561

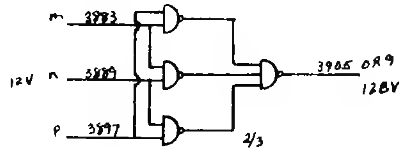
CIRCULATOR DRAIN MALFUNCTION



12 SENSORS

TYPICAL

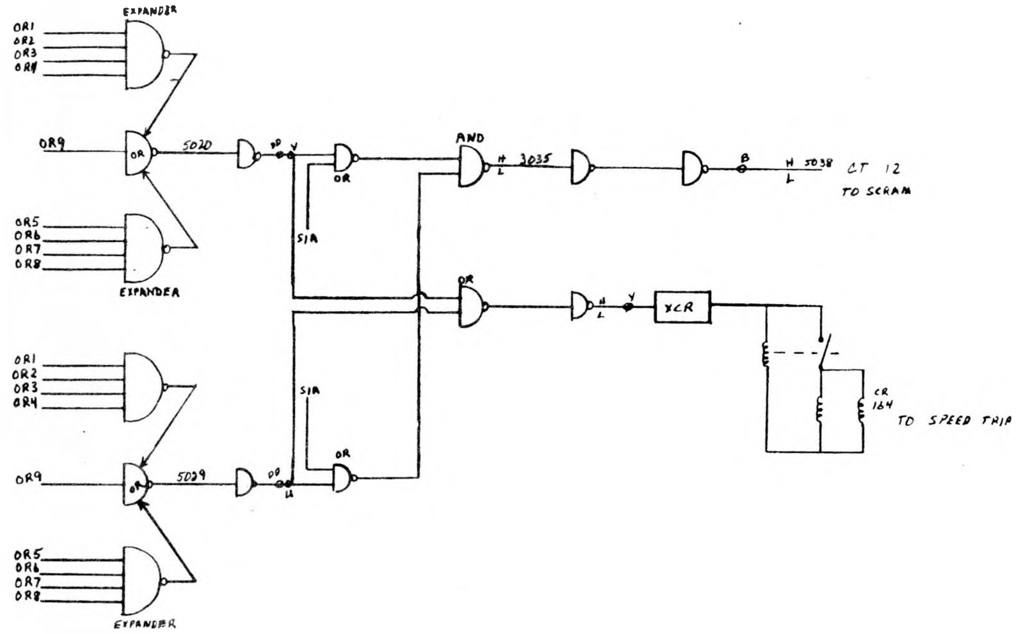
SENSOR	OUTPUT	
21325	3883	12 mV
	3885	10 mV
21327	3889	12 nV
	3891	10 nV
21329	3895	12 PV
	3897	10 PV
21319	3918	12 mu
	3920	10 mu
21321	3924	12 nu
	3926	10 nu
21323	3930	12 pu
	3932	10 pu
21326	3953	6 mV
	3955	4 mV
21328	3959	6 nV
	3961	4 nV
21330	3965	6 PV
	3967	4 PV
21322	3988	6 mu
	3990	4 mu
21324	3994	6 nu
	3996	4 nu
21326	4000	6 pu
	4002	4 pu



INPUT		OUTPUT OR9	
12 V	m, n, p	12 BV	3905
12 U	m, n, p	12 BU	3940
10 V	m, n, p	10 BV	3913
10 U	m, n, p	10 BU	3948
6 V	m, n, p	6 BV	3975
6 U	m, n, p	6 BU	4010
4 V	m, n, p	4 BV	3983
4 U	m, n, p	4 BU	4018

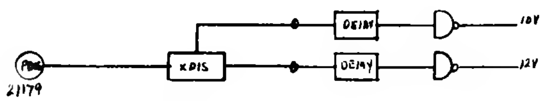
CIRCULATOR TRIP OUTPUT LOGIC

12 BV | 12 BU



LOGIC FOR CIRCUIT 10, 6, AND 4 ARE IDENTICAL TO CIRCUIT 12 ABOVE

LOSS OF BEARING WATER



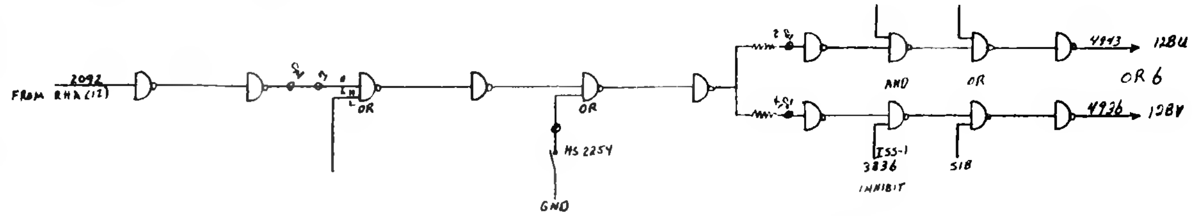
12 SENSORS

	OUTPUT	
21179	12 AV	10 AV
21181	12 BV	10 BV
21183	12 CV	10 CV
21173	12 AU	10 AU
21175	12 BU	10 BU
21177	12 CU	10 CU
21180	6 AV	4 AV
21182	6 BV	4 BV
21184	6 CV	4 CV
21174	6 AU	4 AU
21176	6 BU	4 BU
21178	6 CU	4 CU

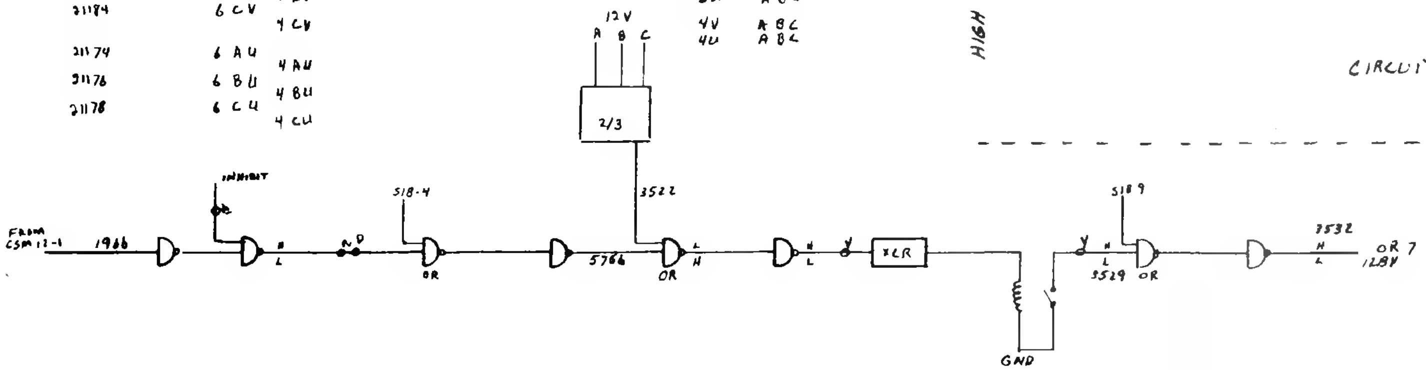
2/3 INPUTS

12V	ABC
12U	ABC
10V	ABC
10U	ABC
6V	ABC
6U	ABC
4V	ABC
4U	ABC

HIGH REHEAT HEADER



CIRCUITS FOR 10, 6, 4 ARE IDENTICAL TO 12 ABOVE

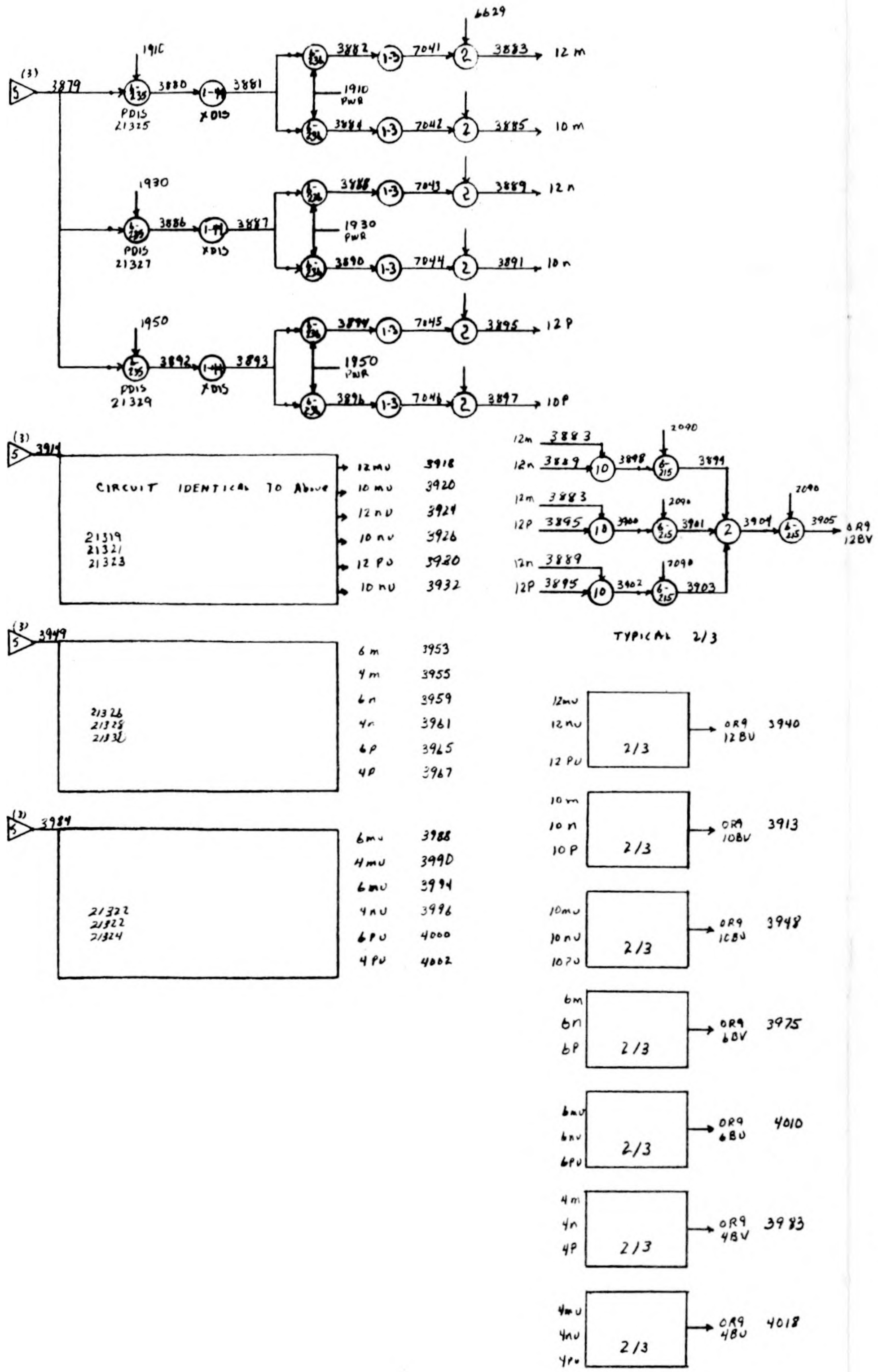


CIRCUITS IDENTICAL AS ABOVE

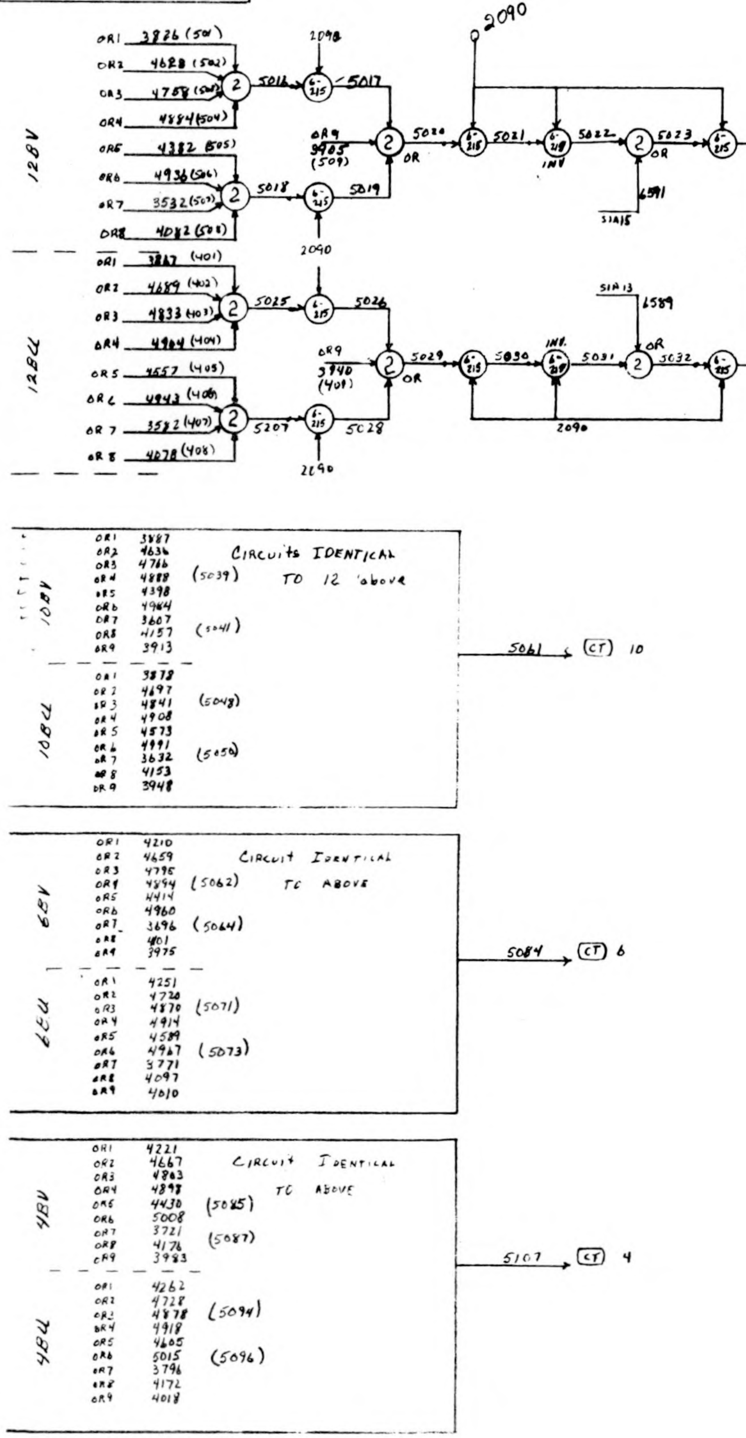
12 BU
10 BV
10 BU
6 BV
6 BU
4 BV
4 BU

169 2641 | 169 2541 | 169 3160 | 169 2541

CIRCULATOR DRAIN A/A1 FUNCTION

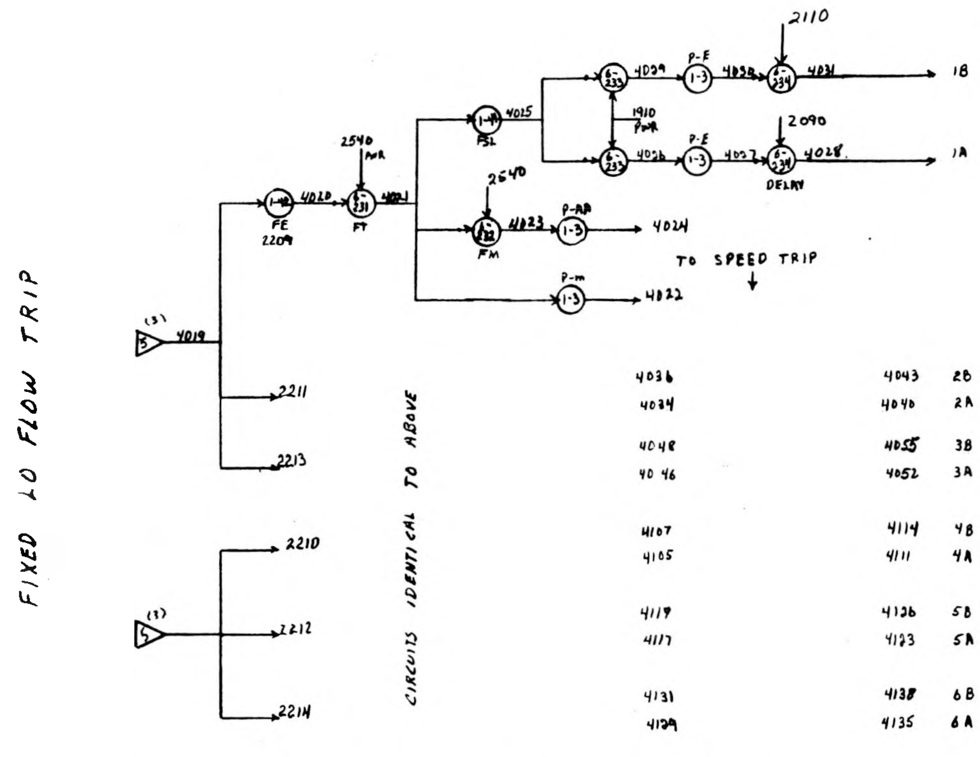


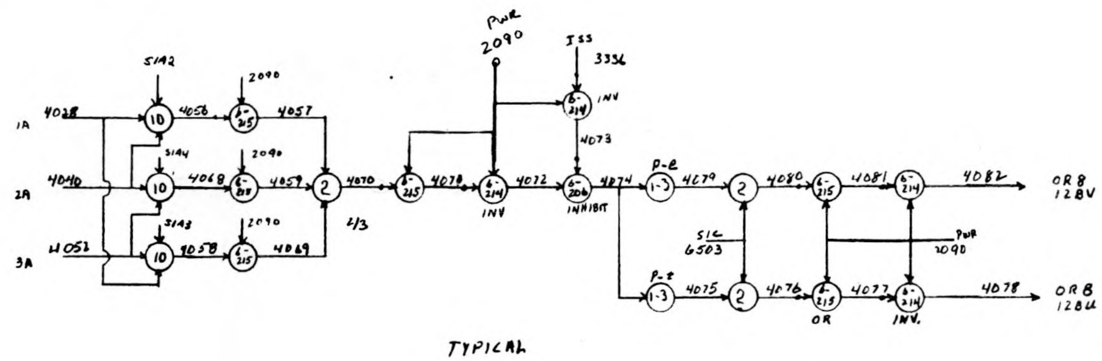
DRAWING FSV-14G



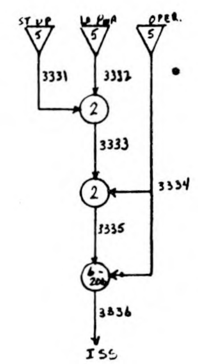
CIRCULATOR TRIP OUTPUT LOGIC

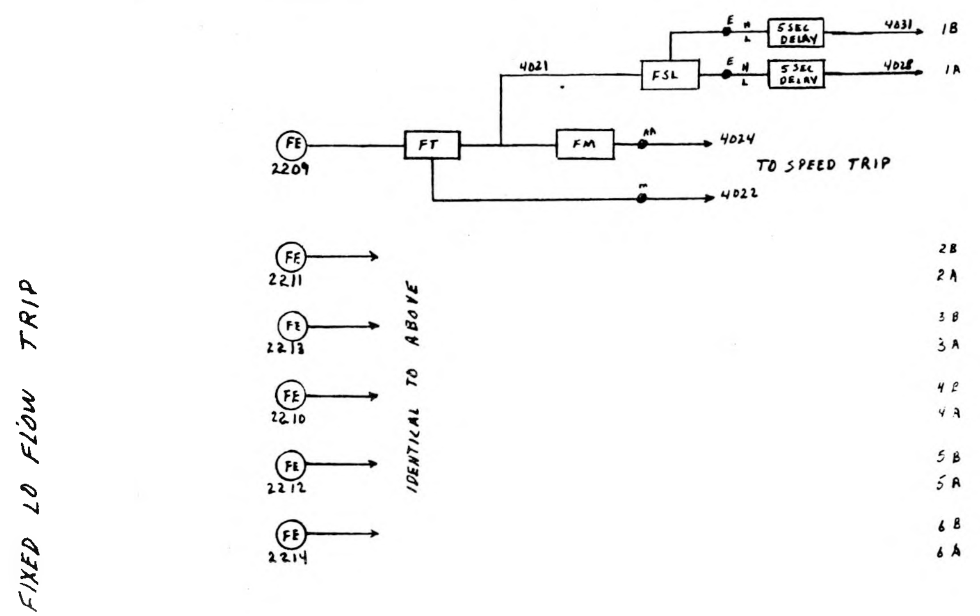
DRAWING FSV-15G/E

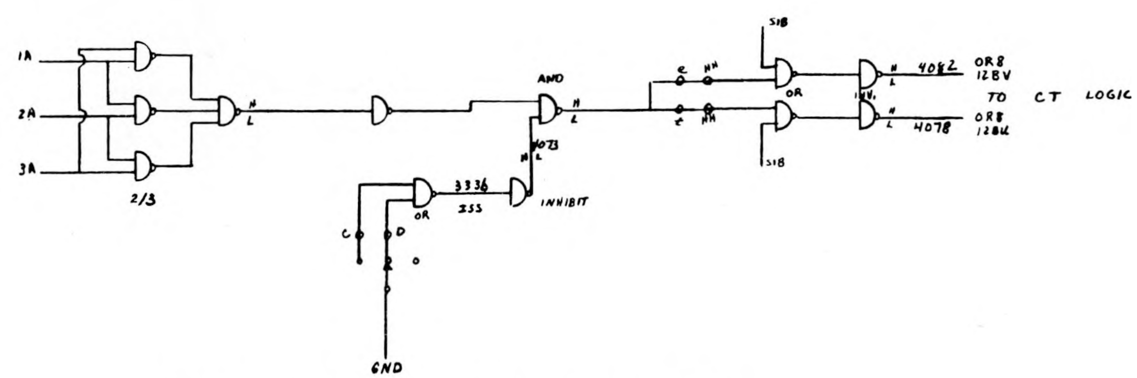




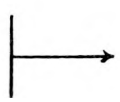
INPUT		OUTPUT	
1A	4028	4082	OR8 12BV
2A	4040	4078	OR8 12BU
3A	4052		
4A	4111	4157	OR8 10BV
5A	4123	4153	OR8 10BU
6A	4135		
1B	4031	4101	OR8 6BV
2B	4043	4097	OR8 6BU
3B	4055		
4B	4114	4176	OR8 4BV
5B	4126	4172	OR8 4BU
6B	4138		







TYPICAL LOGIC - IDENTICAL CIRCUITS FOR 10 LOGIC, 6 LOGIC, AND 4 LOGIC



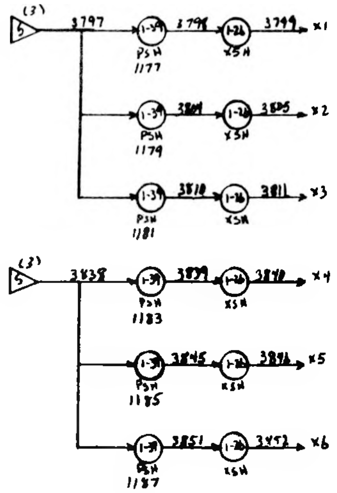
169 - 2561

169 - 2541

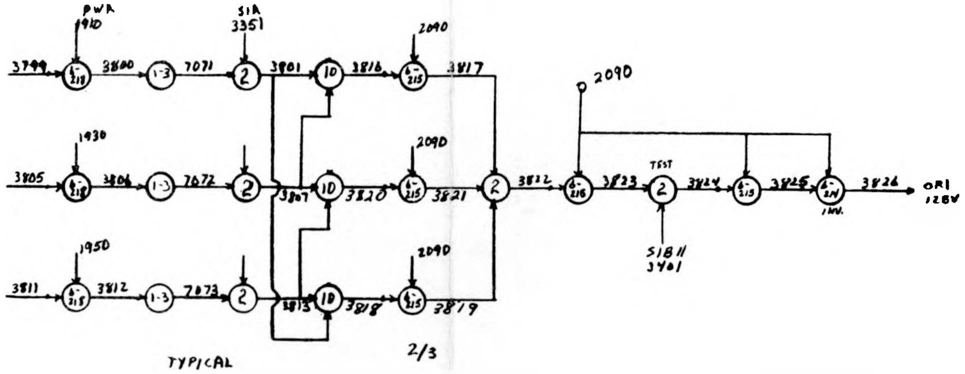
DRAWING FSV-16G/E

CIRCULATOR PENETRATION PRESSURE

12 SENSORS



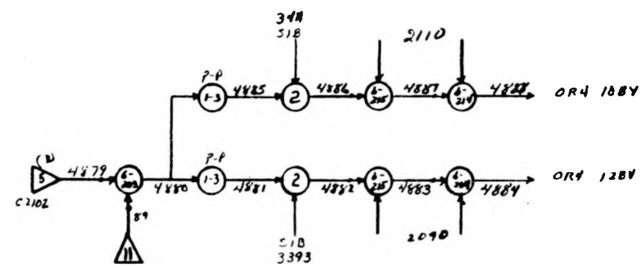
SENSORS	SIGNAL IN	OUT	
1177 1179 1181	3797	3799 3805 3811	X1 X2 X3
1183 1185 1187	3838	3840 3846 3852	X4 X5 X6
1178 1180 1182	4181	4183 4189 4195	X7 X8 X9
1184 1186 1188	4222	4224 4230 4236	X10 X11 X12



TYPICAL

INPUT		OUT	
X1 X2 X3	3799 3805 3811	3826	OR1 12BV
X1 X2 X3	3799 3805 3811	3837	OR1 10BV
X4 X5 X6	3840 3846 3862	3867	OR1 12BU
X4 X5 X6	3840 3846 3852	3878	OR1 10BU
X7 X8 X9	4183 4189 4195	4210	OR1 6BV
X7 X8 X9	4183 4189 4195	4221	OR1 4BV
X10 X11 X12	4224 4230 4236	4261	OR1 6BU
X10 X11 X12	4224 4230 4236	4262	OR1 4BU

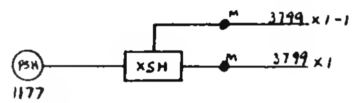
MANUAL TRIP



SENSOR	INPUT	OUTPUT	
93335	4879	4884 4888	OR4 12BV OR4 10BV
93333	4899	4904 4908	OR4 12BU OR4 10BU
93336	4889	4894 4898	OR4 6BV OR4 4BV
93334	4909	4914 4918	OR4 6BU OR4 4BU

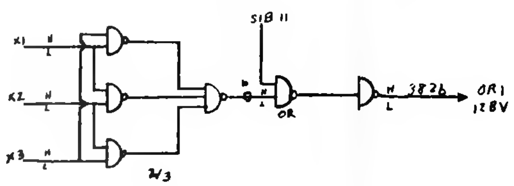
169 2511 — 169 2541

CIRCULATOR PENETRATION PRESSURE



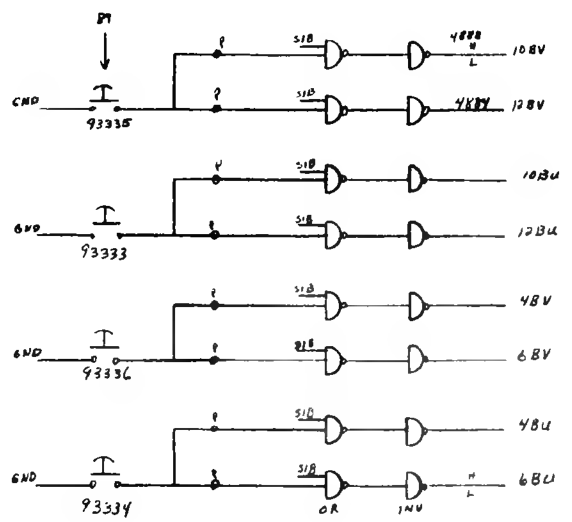
TYPICAL

SENSOR	OUTPUT	
1177 1179 1181	X1 X2 X3	X1-1 X2-1 X3-1
1183 1185 1187	X4 X5 X6	X4-1 X5-1 X6-1
1178 1180 1182	X7 X8 X9	X7-1 X8-1 X9-1
1184 1186 1187	X10 X11 X12	X10-1 X11-1 X12-1



INPUT	OUTPUT	
X1 X2 X3	OR1	12BV
X4 X5 X6		12BU
X7 X8 X9		6BV
X10 X11 X12		6BU
X1-1 X2-1 X3-1		10BV
X4-1 X5-1 X6-1		10BU
X7-1 X8-1 X9-1		4BV
X10-1 X11-1 X12-1		4BU

MANUAL TRIP

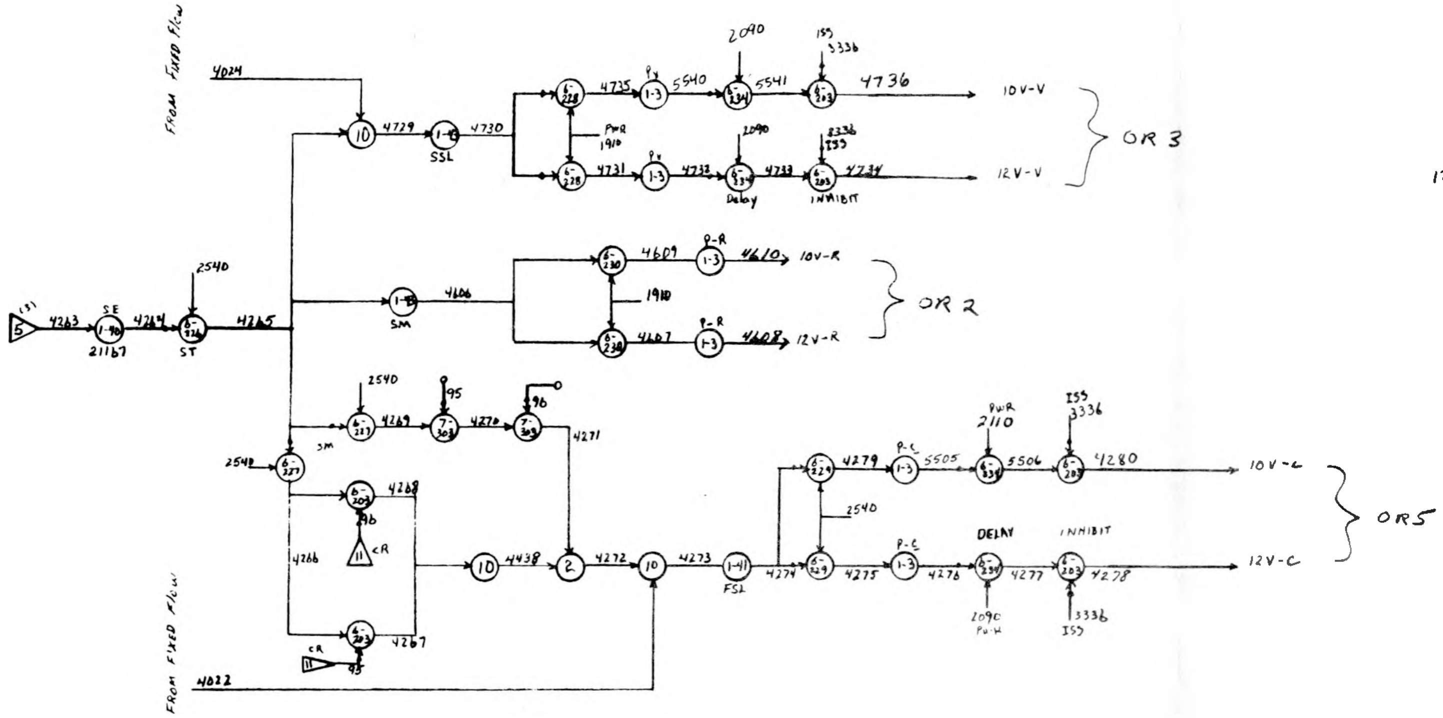


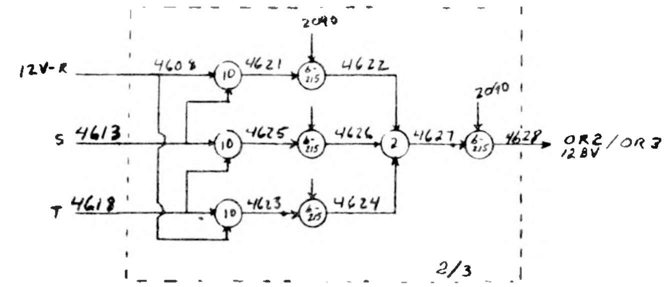
OR 4

169 2541

DRAWING FSV-17G

SPEED TRIP SENSORS





SENSOR	INPUT SIG	FIXED Flow	FIXED Flow	OUTPUT 12 1st	12 2nd	12 3rd	10 1st	10 2ND	10 3Rd
21167	4263	4024	4022	12V-V 4734	12V-R 4608	12V-c 4278	10V-V 4736	10V-R 4610	10V-c 4280
21169	4281	4036	4034	12V-W 4741	S 4613	d 4295	-W 4743	S 4615	d 4297
21171	4298	4048	4046	12V-X 4748	T 4618	e 4312	-X 4750	T 4620	e 4314
21168	4316	4107	4105	6V-V 4771	6V-R 4639	6V-c 4330	4V-V 4846	4V-R 4641	4V-c 4332
21170	4333	4119	4117	6V-W 4778	S 4644	d 4347	W 4853	S 4646	d 4349
21172	4350	4131	4129	6V-X 4785	T 4649	e 4364	X 4860	T 4651	e 4366
21161	4431	4024	4022	12U-V 4809	12U-R 4670	12U-c 4448	10U-V 4811	10U-R 4672	10U-c 4450
21163	4451	4036	4034	12U-W 4816	S 4675	d 4466	W 4818	S 4677	d 4468
21165	4469	4048	4046	12U-X 4823	T 4680	e 4484	X 4825	T 4681	e 4486
21162	4487	4107	4105	6U-V 4773	6U-R 4700	6U-c 4503	4U-V 4848	4U-R 4702	4U-c 4505
21164	4506	4119	4117	6U-W 4780	S 4705	d 4521	W 4855	S 4707	d 4523
21166	4524	4131	4129	6U-X 4787	T 4710	e 4539	X 4862	T 4712	e 4541

2/3

INPUT		OUTPUT		
12V-V	4734	OR2	12BV	4628
W	4741			
X	4748			
10V-V	4736	OR2	10BV	4636
W	4743			
X	4750			
6V-V	4771	OR2	6BV	4659
W	4778			
X	4785			
4V V	4846	OR2	4BV	4667
W	4853			
X	4860			
12U-V	4809	OR2	12BU	4689
W	4816			
X	4823			
10U-V	4811	OR2	10BU	4697
W	4818			
X	48[illegible]			
6U-V	4773	OR2	6BU	4720
W	4780			
X	4787			
4U-V	4848	OR2	4BU	4728
W	4855			
X	4862			
12V-R	4608	OR3	12BV	4758
S	4613			
T	4618			
10V-R	4610	OR3	10BV	4766
S	4615			
T	4620			
6V-R	4639	OR3	6BV	4795
S	4644			
T	4649			
4V-R	4641	OR3	4BV	4803
S	4646			
T	4651			
12U-R	4670	OR3	12BU	4833
S	4675			
T	4680			
10U-R	4672	OR3	10BU	4841
S	4677			
T	4681			
6U-R	4700	OR3	6BU	4870
S	4705			
T	4710			
4U-R	4702	OR3	4BU	4878
S	4707			
T	4712			

DEFINITIONS

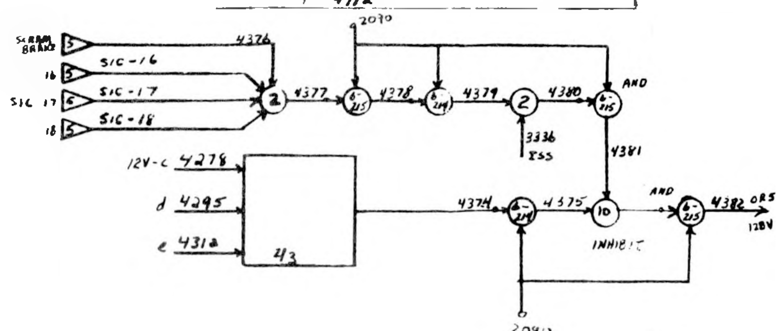
OR2 OVERSPEED TRIP

OR3 Low SPEED TRIP (PROG/Feedwater flow)

OR5 Low Feedwater Flow (PROG/circ. speed)

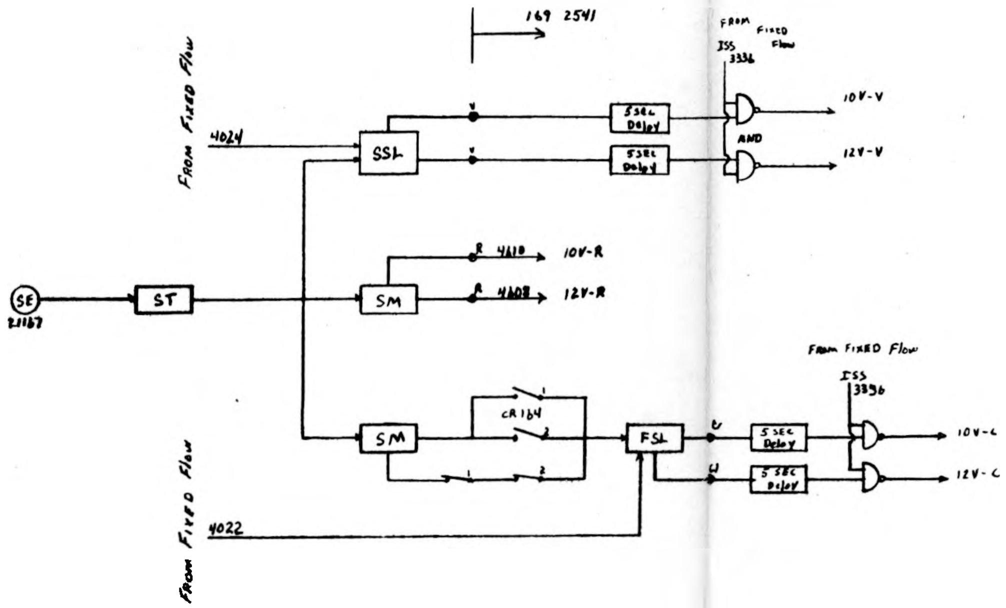
2/3 GATE LOGIC

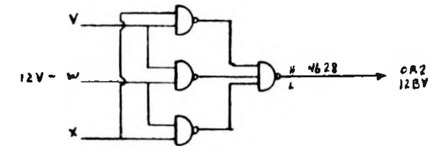
INPUT		OUTPUT		
12V c	4278	OR5	12BV	4382
d	4295			
e	4312			
10V c	4280	OR5	10BV	4398
d	4297			
e	4314			
6V c	4330	OR5	6BV	4414
d	4347			
e	4364			
4V c	4332	OR5	4BV	4430
d	4349			
e	4366			
12U c	4448	OR5	12BU	4557
d	4466			
e	4484			
10U c	4450	OR5	10BU	4573
d	4468			
e	4486			
6U c	4503	OR5	6BU	4589
d	4521			
e	4539			
4U-c	4505	OR5	4BU	4605
d	4523			
e	4541			



DRAWING FSV-17E

SPEED TRIP SENSORS





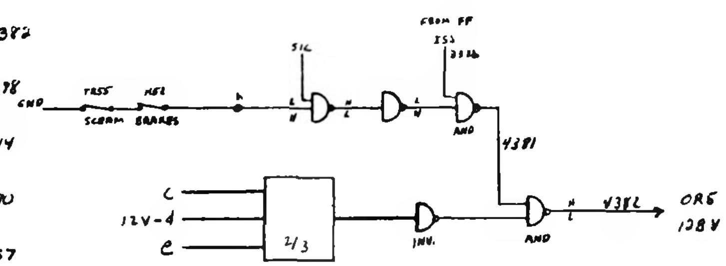
TYPICAL 2/3

12 SENSORS INPUT IDENTICAL TO ABOVE

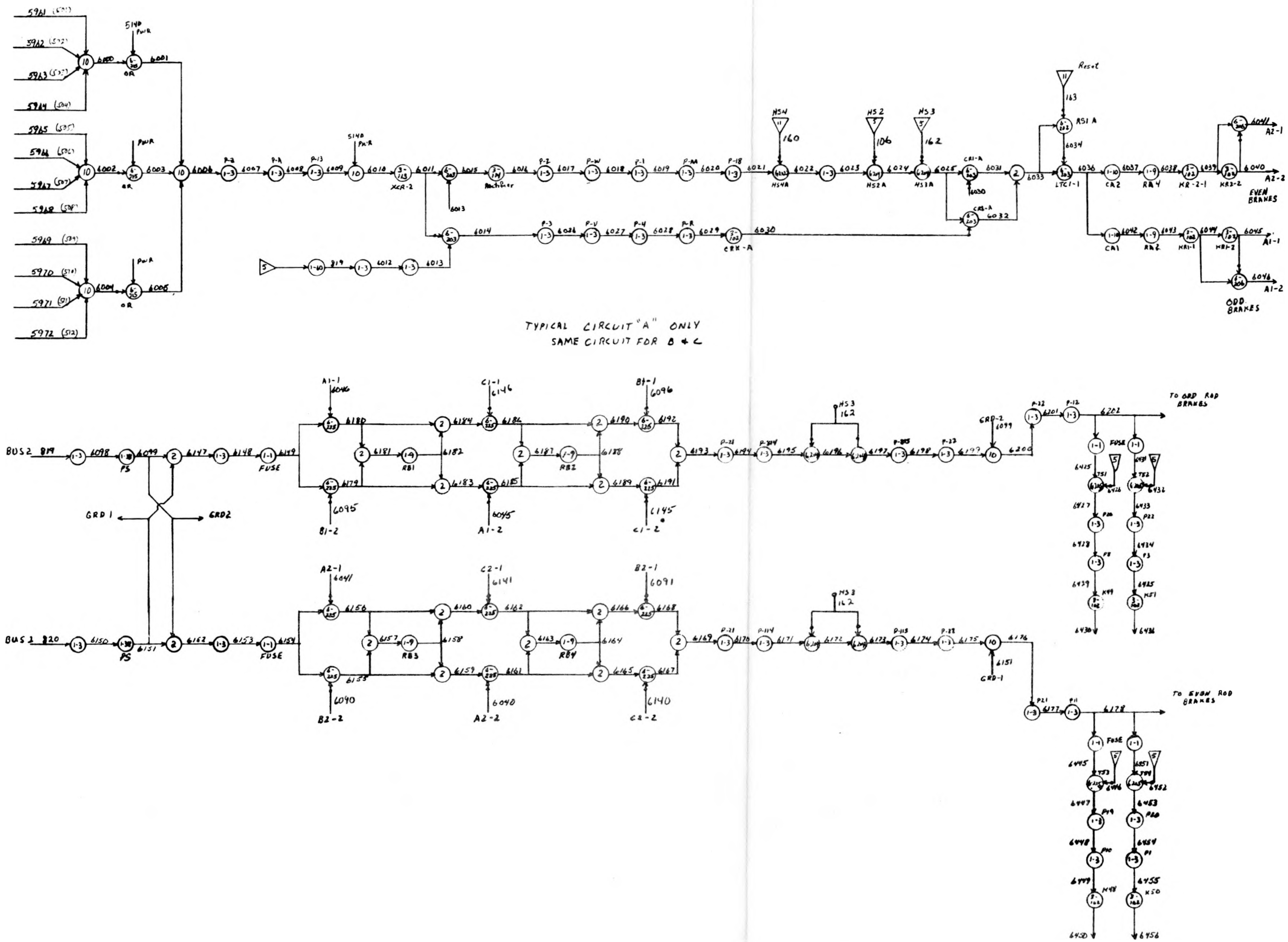
SENSOR	FIXED	FLOW INPUT	OUTPUT ←					→ OUTPUT
21167	4024	4022	12V-V	12V-R	12V-C	10V-V	10V-R	10V-C
21169	4036	4034	w	s	d	w	s	d
21171	4048	4046	x	T	e	x	T	e
21161	4024	4022	6V-V	6V-R	6V-C	4V-V	4V-R	4V-C
21163	4036	4034	w	s	d	w	s	d
21165	4048	4046	x	T	e	x	T	e
21168	4107	4105	12U-V	12U-R	12U-C	10U-V	10U-R	10U-C
21170	4119	4117	w	s	d	w	s	d
21172	4131	4129	x	T	e	x	T	e
21162	4107	4105	6U-V	6U-R	6U-C	4U-V	4U-R	4U-C
21164	4119	4117	w	s	d	w	s	d
21166	4131	4129	x	T	e	x	T	e

INPUT				OUTPUT	
12V-	V	4734	OR2	12BV	4628
	W	4741			
	X	4748			
10V-	V	4736		10BV	4636
	W	4743			
	X	4750			
6V-	V	4771		6BV	4659
	W	4778			
	X	4785			
4V-	V	4846		4BV	4667
	W	4853			
	X	4860			
12U-	V	4809		12BU	4689
	W	4816			
	X	4823			
10U-	V	4811		10BU	4697
	W	4818			
	X	4825			
6U-	V	4773		6BU	4720
	W	4780			
	X	4787			
4U-	V	4848		4BU	4728
	W	4855			
	X	4862			
12V-	R	4608	OR3	12BV	4758
	S	4613			
	T	4618			
10V-	R	4610		10BV	4766
	S	4615			
	T	4620			
6V-	R	4639		6BV	4795
	S	4644			
	T	4649			
4V-	R	4641		4BV	4803
	S	4646			
	T	4651			
12U	R	4670		12BU	4833
	S	4675			
	T	4680			
10U-	R	4672		10BU	4841
	S	4677			
	T	4681			
6U-	R	4700		6BU	4870
	S	4705			
	T	4710			
4U-	R	4702		4BU	4878
	S	4707			
	T	4712			

INPUT				OUTPUT	
12V	c	4278	OR 5	12BV	4382
	d	4295			
	e	4312			
10V	c	4280		10BV	4398
	d	4297			
	e	4314			
6V-	c	4330		6BV	4414
	d	4347			
	e	4364			
4V-	c	4332		4BV	4430
	d	4349			
	e	4366			
12U-	c	4448		12BU	4557
	d	4466			
	e	4484			
10U-	c	4450		10BU	4573
	d	4468			
	e	4486			
6U-	c	4503		6BU	4589
	d	4521			
	e	4539			
4U-	c	4505		4BU	4605
	d	4523			
	e	4541			



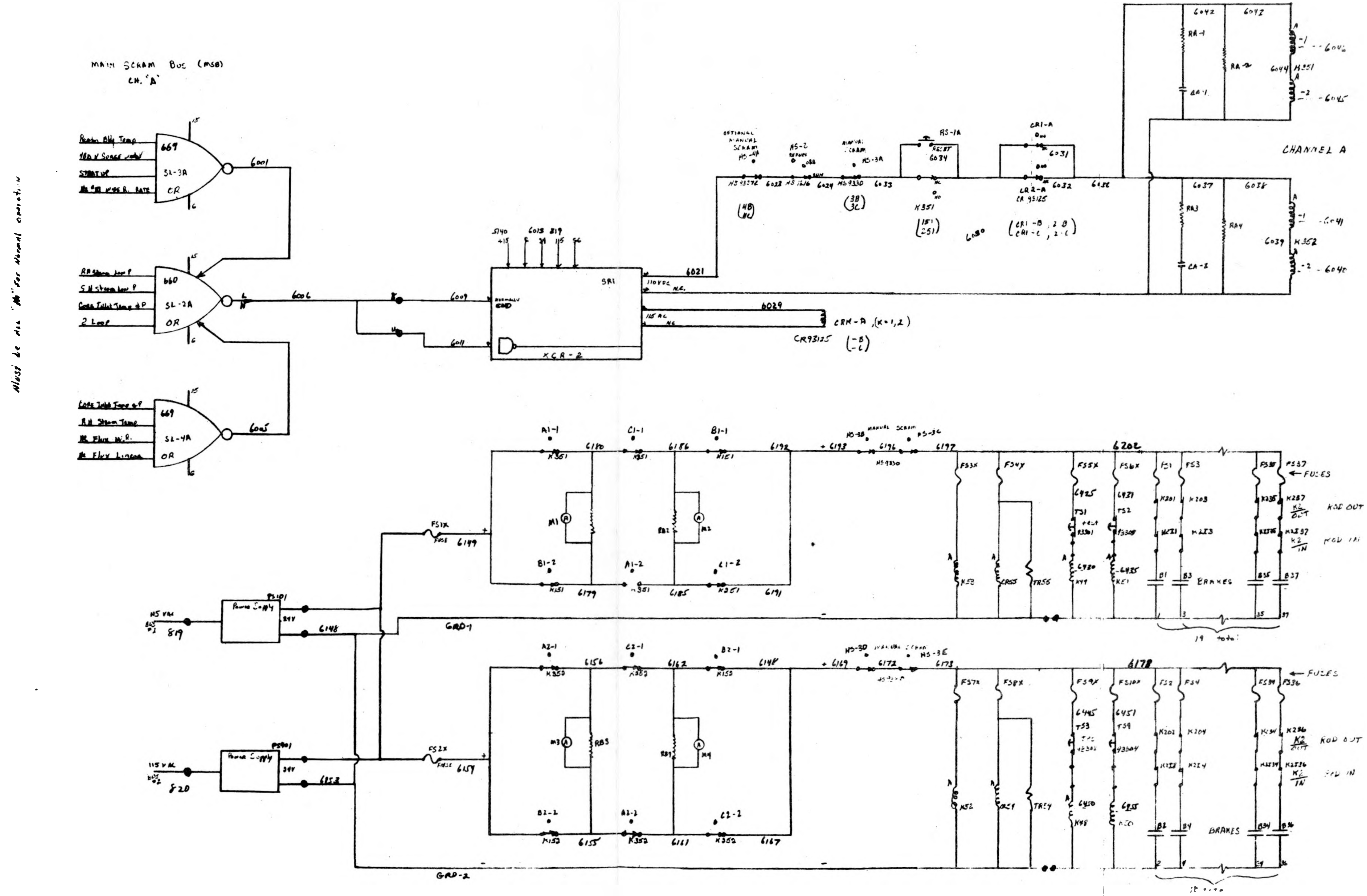
DRAWING FSV-18G



TYPICAL CIRCUIT "A" ONLY
SAME CIRCUIT FOR B & C

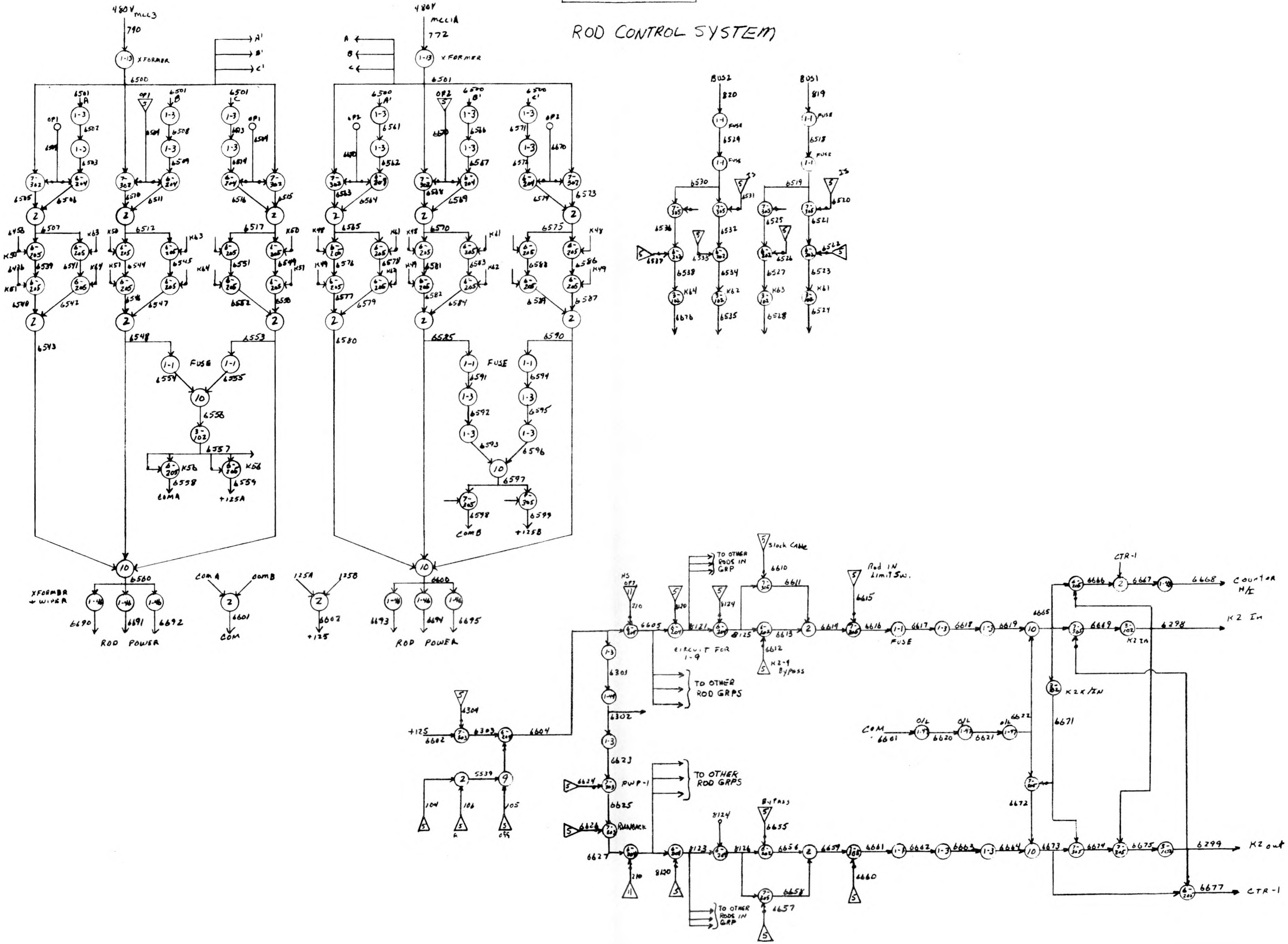
DRAWING FSV-18E

K151
CHANNEL B
K152
K251
CHANNEL A
K252



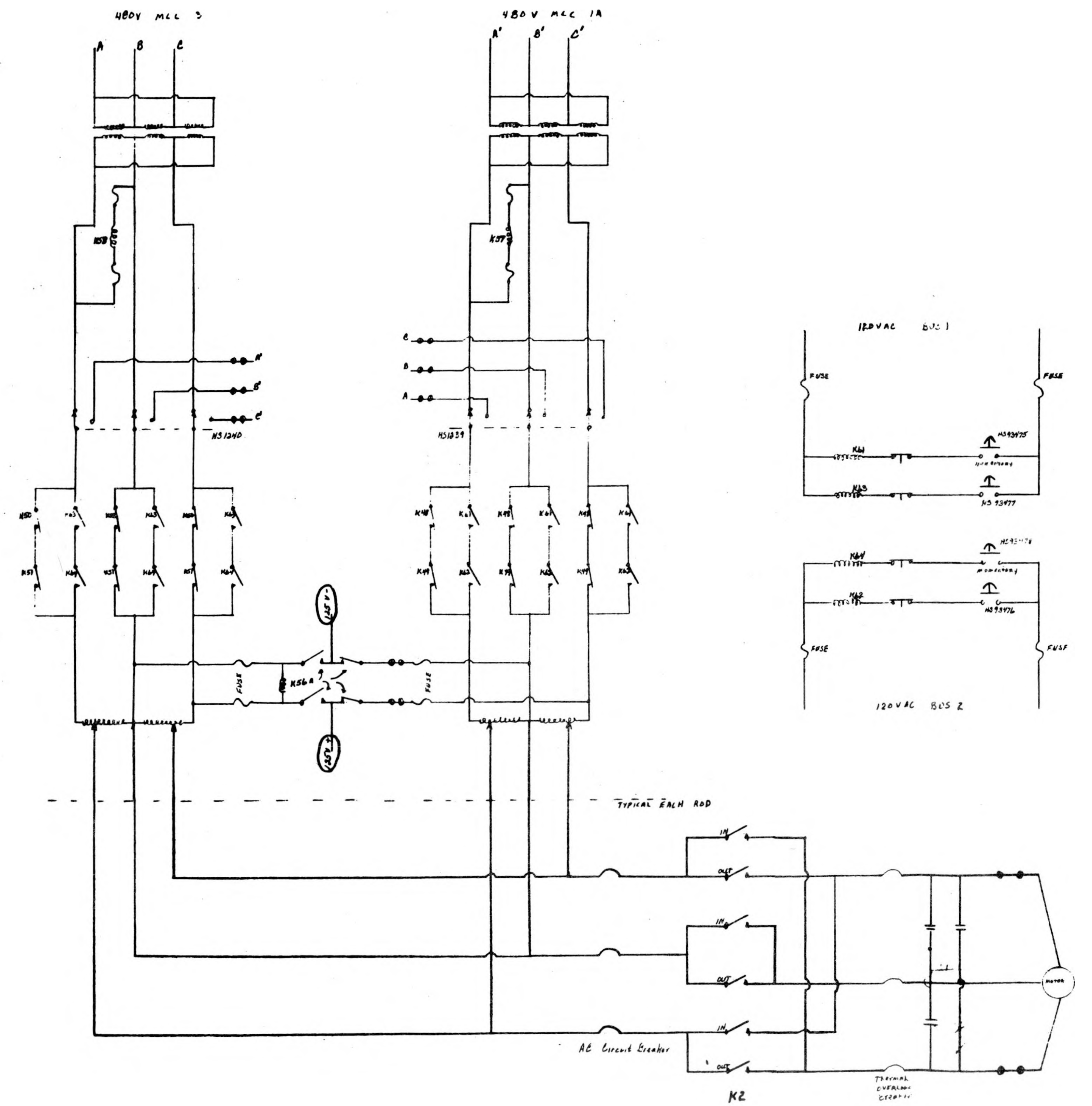
DRAWING FSV-19G

ROD CONTROL SYSTEM

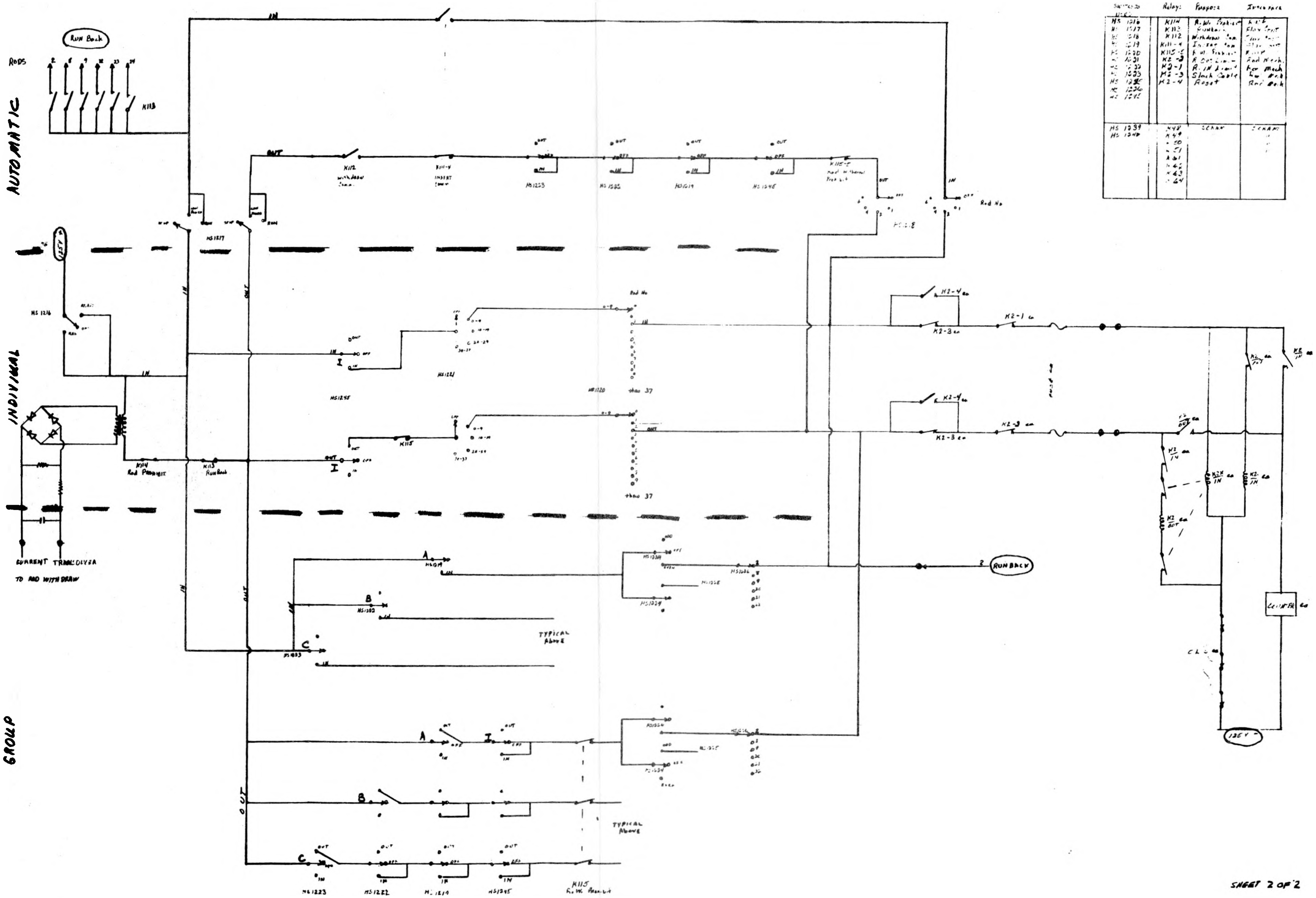


DRAWING FSV-19E-1

ROD CONTROL SYSTEM

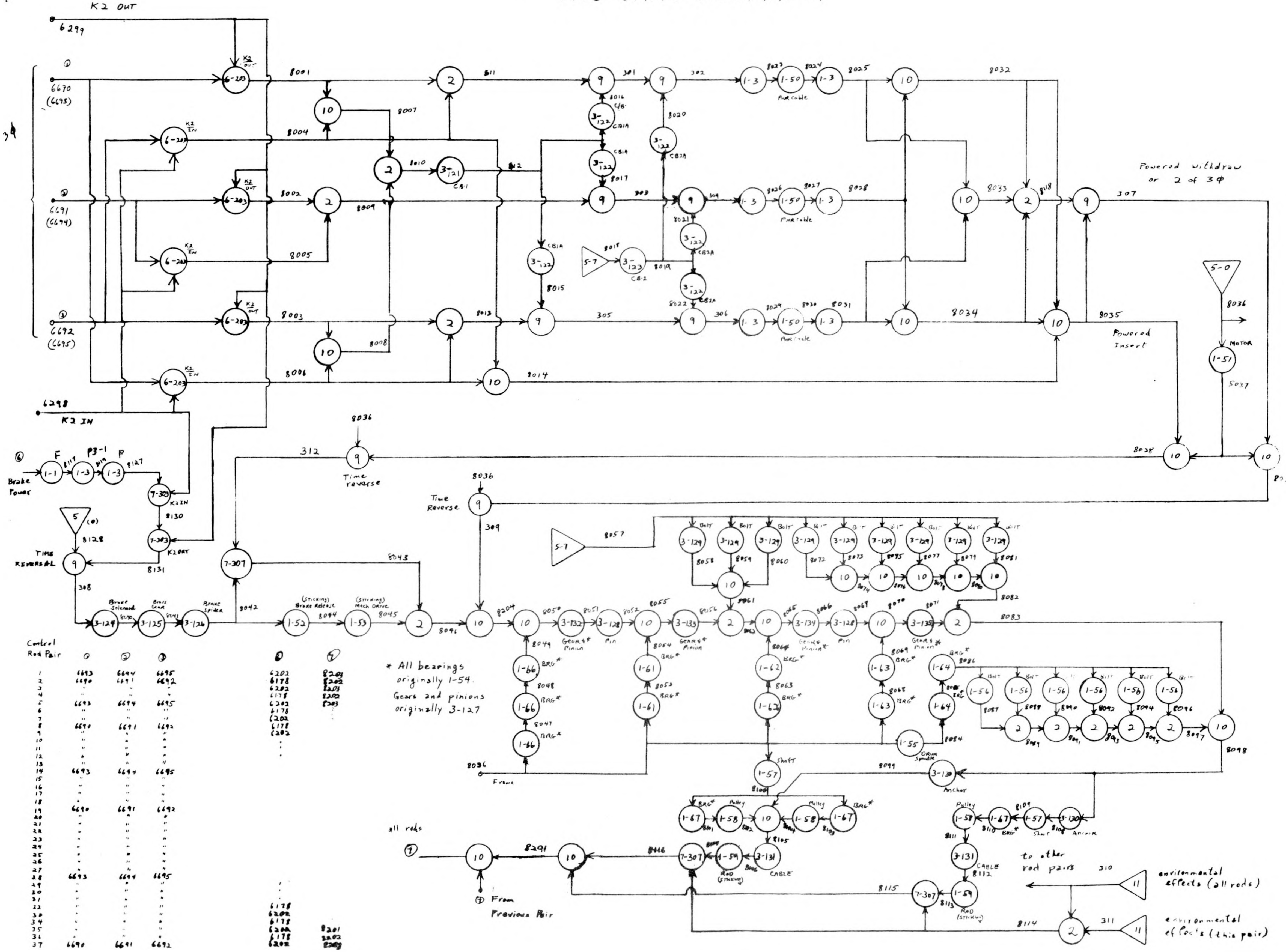


DRAWING FSV-19E-2



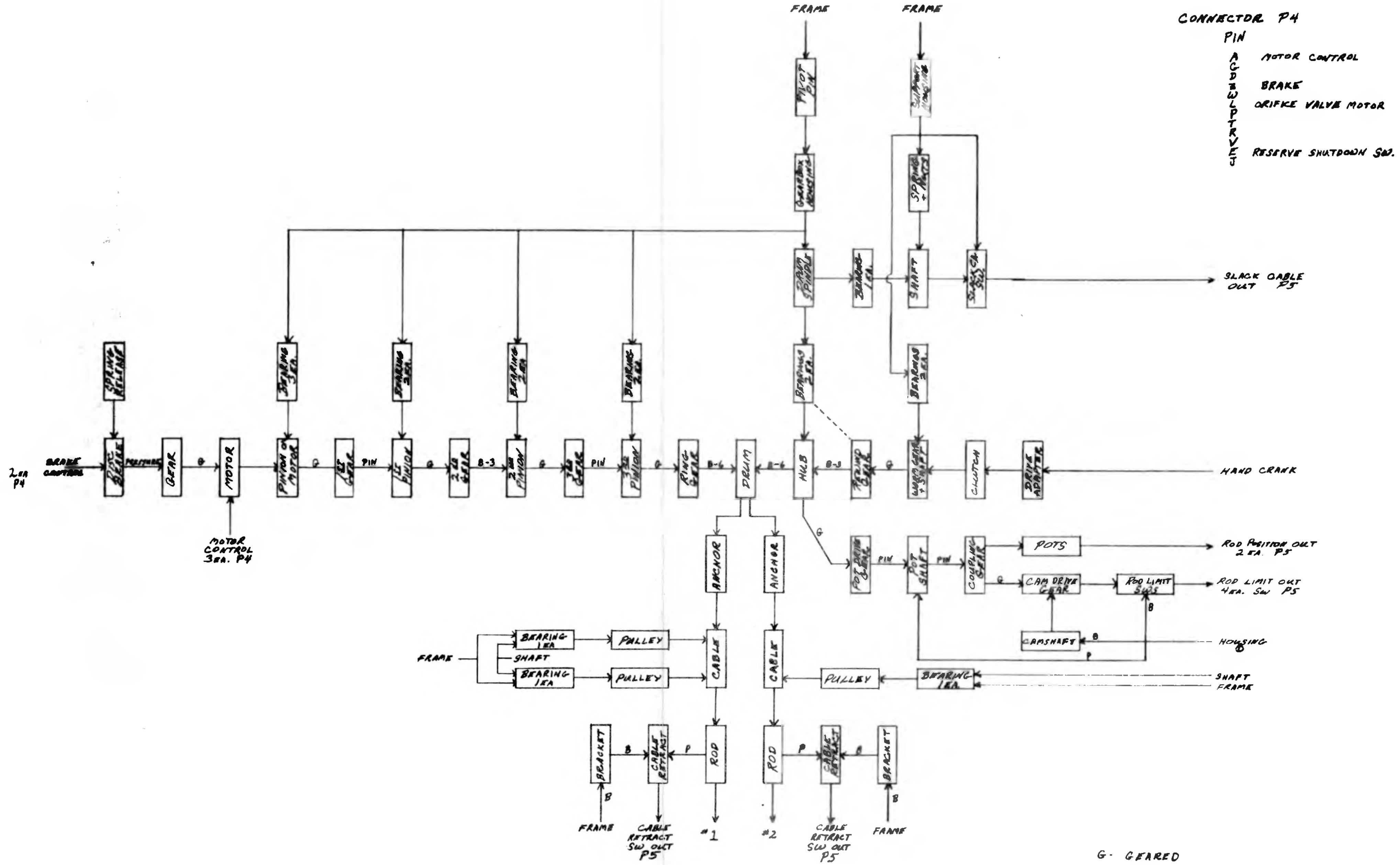
Switches Used	Relays	Purpose	Interface
HS 1216	K114	R.W. Prohibit	[illegible]
HS 1217	K113	Runback	Flux Cont
HS 1218	K112	Withdraw Com.	[illegible]
HS 1219	K111-4	Insert Com	[illegible]
HS 1220	K115-5	R.W. Prohibit	[illegible]
HS 1221	K2-2	R Out Limit	Rod Mech.
HS 1222	K2-1	R. IN Limit	Rod Mech
HS 1223	K2-3	Slack Cable	[illegible]
HS 1245	K2-4	Reset	Run Back
HS 1236			
HS 1242			
HS 1239	K48	SCRAM	SCRAM
HS 1240	K49		"
	K50		"
	K51		"
	K61		
	K62		
	K63		
	K64		

ROD DRIVE MECHANISM



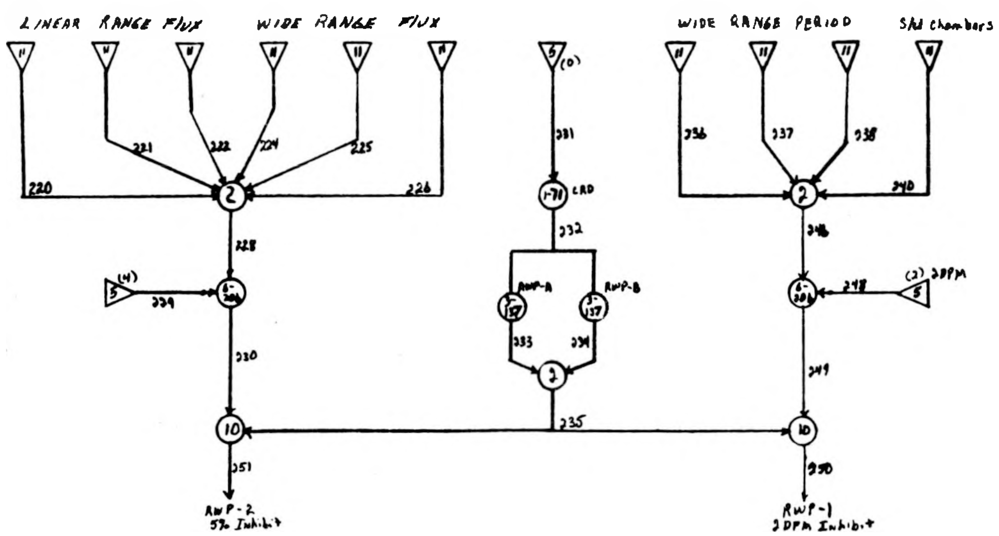
Control Rod Pair	(1)	(2)	(3)	(6)	(7)
1	6693	6694	6695	6202	8203
2	6690	6691	6692	6178	8202
3	"	"	"	6202	8203
4	"	"	"	6178	8202
5	6693	6694	6695	6202	8203
6	"	"	"	6178	
7	"	"	"	6202	
8	6690	6691	6692	6178	
9	"	"	"	6202	
10	"	"	"	.	
11	"	"	"	.	
12	"	"	"	.	
13	"	"	"		
14	6693	6694	6695		
15	"	"	"		
16	"	"	"		
17	"	"	"		
18	"	"	"		
19	6690	6691	6692		
20	"	"	"		
21	"	"	"		
22	"	"	"		
23	"	"	"		
24	"	"	"		
25	"	"	"		
26	"	"	"		
27	"	"	"		
28	6693	6694	6695		
29	"	"	"	.	
30	"	"	"	.	
31	"	"	"	.	
32	"	"	"	6178	
33	"	"	"	6202	
34	"	"	"	6178	
35	"	"	"	6202	8201
36	"	"	"	6178	8202
37	6690	6691	6692	6202	8203

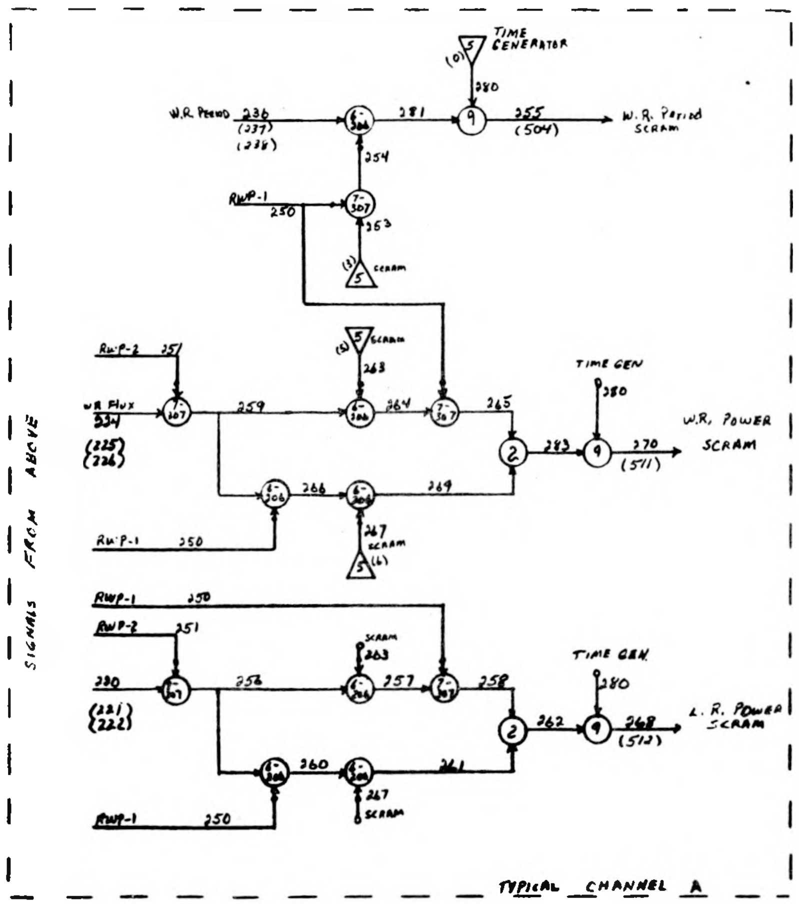
FSV-20E ROD GEAR DRIVE



DRAWING FSV-21G

SCRAM INPUT MODEL FOR START-UP FSV





Repeat Above Circuit For Channel B & C

APPENDIX D

TABLES OF
ELEMENT OR COMPONENT RELIABILITY VALUES
USED FOR ST. VRAIN HTGR SCRAM STUDY

TABLE 1 D-1

ELEMENT (KIND/TYPE) RANGE (1-99)	SYSTEM ELEMENT OR COMPONENT	FAILURE RATES PER (10^6 HRS) (λ)	720 HR. PROBABILITY OF FAILURE (F)	720 HR. PROBABILITY OF SUCCESS (S)
1-1	Fuze	0.1	.00007	.99993
1-2	15 V Power Supply (Nuclear Channel)		.0004	.9996
1-3	Connector/Pins	.06	.00004	.99996
1-4	Board Interlock	.05	.00004	.99996
1-5	Hi Volt Power Supply (Nuclear Channel)		.0006	.9994
1-6	Detector (Ion Chamber)	2.0	.001	.999
1-7	Input Amp-Reac Monitor (RIS)		.004	.996
1-8	Coaxial plug/jack	.04	.0004	.9996
1-9	Resistor	0.08	.00007	.99993
1-10	Capacitor	.2	.0001	.9999
1-11	Indicator Light	.2	.0001	.9999
1-12	Diodes	.8	.006	.994
1-13	Electric Transformer	.2	.0001	.9999
1-14	Battery Charger		.0007	.9993
1-15	24V, ± 15V Power Supply (Power Design)		.0003	.9997
1-16	120 V A.C. Plug	.05	.0004	.9996
1-17	Thermocouple		.0007	.9993
1-18	MTU		.004	.996
1-19	Pressure Transducer		.0004	.9996
1-20	Potentiometer (Test/Level)	1.3	.0007	.9993
1-21	Moisture Monitor (MM)	1F/12 mo.	.08	.92
1-22	First-In-With-Lockout (FILO)		.004	.996
1-23	Differential Pressure Monitor (Circ. Seal Malf) (PDIS)		.001	.999
1-24	Radioactivity Monitor (Reheat Header) (RRT)		.001	.999
1-25	Temp Switch Input Amp (TSL) (TSH)		.004	.996
1-26	Input Amp-Pres Switch (XSH) (XDSH)		.004	.996
1-27	Temp Trans Input (TT)		.001	.999

TABLE 1 (Continued)

ELEMENT (KIND-TYPE) RANGE (1-99)	SYSTEM ELEMENT OR COMPONENT	FAILURE RATES PER (10^6 HRS) (λ)	720 HR. PROBABILITY OF FAILURE (F)	720 HR. PROBABILITY OF SUCCESS (S)
1-28	Temp Differential Output (TDSL)		.0007	.9993
1-29	MM Input Amp (TSH)		.004	.996
1-30	Input Amp Circulator Seal (XDIS)		.004	.996
1-31	Induction Coil Choke (L1/2)		.0007	.99993
1-32	Input Circuit Split NAND SL-41		.0004	.9996
1-33	T/C Basement Temp (TSH)		.004	.996
1-34	Pressure Switch Basement (Diff)(PDSH)		.004	.996
1-35	Ultrasonic Microphone (XE)		.0007	.9993
1-36	Ultrasonic Trip Unit put (XSH)		.004	.996
1-37	Multiple Power Supply Conn.		.00004	.99996
1-38	SCRAM Brake Power Supply		.0006	.9994
1-39	Differential Pressure Sensors (Circ. Pen Trouble)		.001	.999
1-40	Speed Sensor (circ)		.002	.998
1-41	Lo Flow Bistable Amp (FSL)		.004	.996
1-42	Lo Flow Sensor		.002	.998
1-43	Speed Bistable Amp. SSH/SSL		.004	.996
1-44	Differential Pressure Switch Amp (XD1S)		.004	.996
1-45	Power Supply Filter		.0004	.9996
1-46	Auto Transformer		.0003	.9997
1-47	Overload Breaker		.0001	.9999
1-48	Counter (Rod Pointer)		.004	.996
1-49	Current Transformer (Rod Current Sensor)		.0001	.9999
1-50	Power Cable to control rod drive (Open)		.0004	.9996

TABLE 1 (Continued)

ELEMENT (KIND-TYPE) RANGE (1-99)	SYSTEM ELEMENT OR COMPONENT	FAILURE RATES PER (10 HRS) (λ)	720 HR. PROBABILITY OF FAILURE (F)	720 HR. PROBABILITY OF SUCCESS (S)
1-51	Control Rod Drive Motor		.001	.999
1-52	Disk Brake Release (Sticking)		.0002	.9998
1-53	Mechanical Drive (Sticking)		.0008	.9992
1-54	*Bearings, General		.00005	.99995
1-55	Drum Spindle		.00005	.99995
1-56	Bolt (Drum-to-Hub)		.001	.999
1-57	Cable Pulley Shaft		.00002	.99998
1-58	Cable Pulley		.00005	.99995
1-59	Control Rod (Sticking)		.00002	.99998
1-60	Bin Power Supply		.0063	.9937
1-61	*Bearings, 1st Gear		*	*
1-62	*Bearings, 2nd Gear		*	*
1-63	*Bearings, 3rd Gear		*	*
1-64	*Bearings, Hub		*	*
1-65	Mechanical/Human Interface (Calibration/Equip. Replace)		.001	.999
1-66	*Bearings, Motor		*	*
1-67	*Bearings, Cable Pulley		*	*
1-69	Analog/Digital Recorder		.04	.96
1-70	Alarms		.04	.96
1-71	Control Rod Drive Unit		.001	.999
1-75	Electrical/Human Interface (Reset/Test)		.001	.999

*See text for description of values used.

Part IV final system modeling Section 4D, Page 4-47

TABLE 2

(KIND-TYPE) RANGE (100-199)	SYSTEM ELEMENT OR COMPONENT	FAILURE RATES PER (10^6 HRS) (λ)	720 HR. PROBABILITY OF FAILURE (F)	720 HR. PROBABILITY OF PREMATURE (P)	720 HR. PROBABILITY OF SUCCESS (S)
3-101	Linear Amp		.002	.001	.997
3-102	Relay Coil		.001	.0007	.9983
3-103	Pre-Amp (Nuc)		.002	.001	.997
3-104	Switch Contact (Short)				
3-105	Relay Coil (Perfect)		0.	0.	1.0
3-106	Bi-Stable Amp. Trip Unit	5.76	.004	.004	.992
3-107	Battery		.006	.0007	.9933
3-108	Motor Generator		.03	.007	.9963
3-109	Invertor		.0007	.0007	.9986
3-110	Alarm Trigger Relay		.0004	.0004	.9992
3-111	Switch Input Module (XSL) & TLT Test Module)		.0002	.0001	.9997
3-112					
3-113	XCR2-SCRAM Relay Driver		.0001	.0002	.9997
3-114	XCR2-Rectifier (Perf)		0.	0.	1.0
3-115					
3-116	BRG Water Sensor Relay Driver (XCR)		.003	.0007	.9973
3-117					
3-118					
3-119					
3-120	30 Sec. (Under Volt) Timer Unit		.002	.001	.997
3-121	3Ø Circuit Breaker		.001	.003	.996
3-122	3Ø Circuit Breaker Contacts		.001	.0001	.9989
3-123	3Ø Thermal Overload Breaker		.0001	.0001	.9998
3-124	Disk Brake (Actuator) Solenoid		.0001	.0003	.9996
3-125	Disk Brake Gear		.00001	.00001	.99998

TABLE 2 (Continued)

ELEMENT (KIND/TYPE) RANGE (100-199)	SYSTEM ELEMENT OR COMPONENT	FAILURE RATES PER (10^6 HRS) (λ)	720 HR. PROBABILITY OF FAILURE (F)	720 HR. PROBABILITY OF PREMATURE (P)	720 HR. PROBABILITY OF SUCCESS (S)
3-126	Disk Brake Spider		.00001	.00001	.99998
3-127	Gear and Pinion		.0001	.00001	.99989
3-128	Pin		0.0	.0002	.9998
3-129	Bolt		0.0	.001	.999
3-130	Cable Anchor		0.0	.00001	.99999
3-131	Cable		0.0	.0001	.9999
3-132	*Motor Pinion (1st Gear)			*	*
3-133	*Motor Pinion (2nd Gear)			*	*
3-134	*Motor Pinion (3rd Gear)			*	*
3-135	*Motor Pinion (Ring Gear)			*	*
3-136	Moisture Monitor Failure Detector		.18	.02	.80
3-137	RWP Unit		.001	.004	.995

*See Text for description of values used.
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TABLE 3

ELEMENT (KIND-TYPE) RANGE (200-299)	SYSTEM ELEMENT OR COMPONENT	FAILURE RATES PER (10^6 HRS) (λ)	720 HR. PROBABILITY OF FAILURE (F)	720 HR. PROBABILITY OF PREMATURE (P)	720 HR. PROBABILITY OF SUCCESS (S)
6-201	Switch, Toggle (N/O)		.0003	.00007	.99963
6-202	Switch, Spring Loaded		.0003	.00004	.99966
6-203	Relay Contacts (N/O)		.00007	.0001	.99983
6-204	Switch Rotary (N/O)		.0003	.00007	.99963
6-205	Relay Contact (N/C)		.0001	.0007	.99983
6-206	Perfect (N/O) Switch (Or Contact)		0.	0.	1.0
6-207	T/C Amp (ATC-2)	17.75	.015	.004	.985
6-208	Auctioneer (AUC-1)	6.88	.006	.001	.993
6-209	Summer Amp (MS-1)	14.16	.006	.001	.993
6-210	Bistable Amp (PT-3D)	10.66	.004	.004	.992
6-211	Pressure Amp (AGP-1)	7.71	.006	.001	.993
6-212	ATC3 (1/2)	20.00	.011	.004	.985
6-213	Switching Transistor		.0002	.0001	.9997
6-214	Logic Inver (MI)		.0002	.0001	.9997
6-215	Logic NAND (MA)		.0002	.0001	.9997
6-216	XDIS Pressure Sw Amp (Output)		.006	.001	.993
6-217	Reactivity Amp (Output) (Sections RIS)		.006	.001	.993
6-218	Temperature Switch Amp (Bistable) (XSH) (Double)		.004	.004	.992
6-219	Pressure Switch Amp (PSH)		.004	.004	.992
6-220	Temp Differential Output (Relay Cont.)		.006	.001	.993
6-221	MM Output Amp Bistable (MSH-1/2)		.004	.004	.992
6-222	Multivibrator (MV)		.006	.001	.993
6-223	Noise Amp (XT)		.006	.001	.993

TABLE 3 (Continued)

ELEMENT (KIND-TYPE) RANGE (200-299)	SYSTEM ELEMENT OR COMPONENT	FAILURE RATES PER (10^6 HRS) (λ)	720 HR. PROBABILITY OF FAILURE (F)	720 HR. PROBABILITY OF PREMATURE (P)	720 HR. PROBABILITY OF SUCCESS (S)
6-224	Bistable Amp Single (PT-3S)	10.66	.004	.004	.992
6-225	SCRAM Contactor (Heavy duty Cont.)		.00007	.00007	.99986
6-226	Speed Sensor Trans (ST)		.003	.0007	.9963
6-227	Speed Signal Modifier (SM)		.006	.001	.993
6-228	Speed Low Lev. Amp (SSL)		.004	.004	.992
6-229	Prog. Flo/Speed Amp (FSL)		.006	.001	.993
6-230	Speed B/S Trip (SSH)		.004	.004	.992
6-231	Lo Flow Sensor Trans		.003	.0007	.9963
6-232	Low Flow Monitor		.006	.001	.993
6-233	Low Flow Bistable Trip		.004	.004	.992
6-234	5 Sec. (Time Delay) Unit		.002	.0007	.9973
6-235	Differential Pressure Switch Sensor (PDIS)		.001	.0007	.9983
6-236	Differential Pressure Switch (XDIS-1, -2) Amp		.006	.001	.993
6-237	Pressure Switch (N/C)		.002	.0007	.9973
6-238	Rod Braking Capacitor		.00007 (open)	.00007 (short)	.99986

TABLE 4

ELEMENT (KIND-TYPE) RANGE (300-399)	SYSTEM ELEMENT OR COMPONENT	FAILURE RATES PER (10^6 HRS) (λ)	720 HR. PROBABILITY OF FAILURE (F)	720 HR. PROBABILITY OF PREMATURE (P)	720 HR. PROBABILITY OF SUCCESS (S)
7-301	Switch, Toggle (N/C)		.0003	.00007	.99963
7-302	Switch, Rotary (N/C)		.0003	.00007	.99963
7-303	Relay Contact (N/C)		.0001	.00007	.99983
7-304	Alpha-Meter		.006	.001	.993
7-305	Switch, Spring Loaded (N/C)		.0003	.00004	.99966
7-307	Perfect (N/C) Switch (or contact)		0.	0.	1.0
7-308	Perfect Transistor		0.	0.	1.0
7-309	Lightning Arrestor		.0001	0.	.9999
7-310	Air/Circuit Breaker		.001	.003	.996
7-311	Remov. Link (Elect.)		.000007	0.	.999993
7-312	Under Volt Switch		.0007	.001	.9983
7-313	Pressure Switch		.002	.0007	.9973
7-314	Bistable (Rev Logic) PT/3D or PT/3S		.004	.004	.992
7-315	Push Button Test		.006	.001	.993

APPENDIX E

DRAWING REFERENCES

APPENDIX E

TABLE I

DRAWING NUMBER	TITLE
ELJ163-0003E	Schematic - Rod Control System, Rod Group Select and Control
ELJ163-0002G	Schematic - Rod Control System, Individual Rod Control
ELJ169-3105E	System Schematic - Current Sensing Monitor
ELJ163-0006	Schematic - Rod Control System, Rod Limit Indication, Typical Circuit
ELJ163-0009J	Schematic - Rod Control System, Rod Position Indication
ELJ169-2403E	Terminal Board Wiring - SCRAM Channel A, Vertical 300, I-9310
ELJ169-2521F	Schematic - Rod Withdrawal Prohibit (RWP)
ELD169-3292F	Helium Pressure Program-Circuit Diagram, PT-1108
ELD169-3290E	Core Inlet Temperature, Auctioneer Circuit Diagram
ELD169-3296E	Reheat System Average Temperature-Circuit Diagram
ELD169-3254A	Circuit Diagram-Reactor Building Temperature High
E-1203-396 thru 399	Schematic Diagram-Control Rod Drives, System 12

TABLE I (continued)

DRAWING NUMBER	TITLE
E-1203-399C	Schematic Diagram-Control and Orificing Assembly, Test and Control, System 12
ELD169-2951L	Schematic - SCRAM Circuit
E-1203-87E	Schematic Diagram - 480 Bus 1,2,3 Undervoltage Relays
ELJ169-3108J	System Schematic - Shut-down Loop Common B
ELJ169-3107J	System Schematic - Shut-down Loop Common A
ELJ169-3101	System Schematic - Circulator Trip Loop 1-B
ELJ169-3107J	System Schematic - Trip Shut-down, Steam Pipe Rupture
ELJ169-2501	Schematic - SCRAM Logic (SL)
90-IB-93-6K	Control Logic Diagram Plant Protective System
ELJ169-3109J	System Schematic - SCRAM Channel A
ELJ195-0010	Interconnection Schematic - Log Power Channel (Wide Range)
ELJ184-0010	Schematic - Dual Linear Channel
ELJ169-3111C	System Schematic - Nuclear Channels
ELJ194-0010E	Interconnection Schematic - Start Up Channel

TABLE I (continued)

DRAWING NUMBER	TITLE
ELJ169-3104J	Systems Schematic - Shutdown Group 1A, 1B, 2A, 2B
ELJ169-3100H-3103H	System Schematics Circulator Trip Group 1A through 2B
ELJ169-3110E	System Schematic Rod Withdrawal Prohibit PPS-PSC
ELC-154-500E	Schematic - SCRAM relay driver XCR-2
ELD132-0012G	Schematic Diagram - high voltage power supply, HP5A
ELC169-0031C	Schematic - XCR/Fast Power Shutdown Circuit
ELD132-0011G	Schematic Diagram - high voltage power supply, HP5A
ELJ169-3105	System schematic - current sensing monitor
ELJ169-3106	System schematic - reactor power to circulator mass flow ratio
ELJ169-3107	System schematic - shutdown loop common A
ELJ169-3108	System schematic - shutdown loop common B
ELJ169-3120	Cable installation-nuclear channels
ELJ169-3140	System schematic - moisture monitor logic and alarm connections

TABLE I (continued)

DRAWING NUMBER	TITLE
ELJ169-3198	Schematic loop 1, reheat header activity monitors
ELD169-3199	Schematic loop 2, reheat header activity monitors
ELC169-3200	Bearing water loss or seal malfunction circulator
ELC169-3212C	Penetration trouble and bearing drain differential pressure circulator
ELC169-3224D	Circuit diagram - 480V switch gear undervoltage
ELC169-3230C	Feedwater flow - high, circuit diagram
ELC169-3233C	Feedwater pressure low, circuit diagram
ELC169-3236C	Steam generator penetration over-pressure, circuit diagram
ELC169-3242	Superheat steam low pressure circuit diagram
ELC169-3254C	Hot reheat steam low pressure circuit diagram
ELC169-3248D	Building basement pressure increase circuit diagram
ELD169-3254A	Circuit diagram - reactor building temperature high
ELC169-3257A	Circuit diagram - building basement temperature increase

TABLE I (continued)

DRAWING NUMBER	TITLE
ELD169-3260D	Feedwater flow programming circuit diagram
ELD169-3266D	Circulator speed/flow circuit diagram
ELD169-3280C	Superheat header trip, loops 1 and 2, differential - circuit diagram
ELD169-3283F	Circuit diagram - ultrasonic noise under PCRV, loop 1
ELD169-3287A	Circuit diagram - ultrasonic noise outside PCRV, loop 1 north wall
ELC169-3289C	Control Rod drive, multi-rod withdrawal prohibit - circuit diagram
ELD169-3290D	Core inlet temperature and auctioneer - circuit diagram
ELD169-3293E	Helium pressure programmed - circuit diagram
ELD169-3296E	Reheat system average temperature - circuit diagram
E-1203-1621J	Schematic diagram - secondary cooling system
ELJ152-0001G	Schematic - pressure transmitter potentiometer
ELJ154-0001E	Schematic - XCR relay driver
ELC154-5001E	Schematic - SCRAM relay driver

TABLE I (continued)

DRAWING NUMBER	TITLE
ELC156-0001D	Schematic - Temperature transmitter module
ELD156-5001G	Schematic - Dual averaging and auctioneering temperature transmitter module
ELJ161-5001C	Schematic - Speed transmitter pulse
ELJ163-0001E	Schematic - Summer/modifier
ELJ171-0001D	Schematic - process input bistable trip
ELJ172-0001E	Schematic - signal deviation comparator
ELD180-0001C	Schematic - solonoid continuity monitor and indicator
ELD182-0001D	Schematic - switch input module (single switch)
ELD186-0001C	Schematic - auctioneer circuit
ELJ190-0001F	Schematic - ultrasonic noise amplifier
ELJ191-0001	Schematic - lamp/relay driver
ELJ169-2601H	Schematic - circulator common
ELJ169-2621J	Schematic - logic common (CC-1)
ELJ169-2661M	Schematic - two loop trouble (TLT-1)

APPENDIX F

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