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AGN-201 Safety Circuit Rebuild

By

Adam Mallicoat

A thesis

submitted in partial fulfillment

of the requirements for the degree of

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To the Graduate Faculty:

The members of the committee appointed to examine the thesis of Adam Mallicoat find it satisfactory and recommend that it be accepted.

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Curriculum Vitae

Adam L. Mallicoat was born on July 2nd, 1985 in Kansas City, MO. He graduated from high school in spring 2003. He attained the rank of Eagle Scout in 2002. He enrolled at Kansas State University, Manhattan KS, receiving a BS in Nuclear Engineering in spring 2008. While there he attained an emergency responder license from the Red Cross, a HAZWOPER license from OSHA, passed the Fundamentals of Engineering (FE) exam and a Reactor Operator's license, administered by the Nuclear Regulatory Commission, on the KSU 250 kW TRIGA Reactor. He spent the 2008 summer working as a research fellow at the Center for Space Nuclear Research at the Idaho National Laboratory, Idaho Falls. In fall 2008 he enrolled in the Master's Program for Nuclear Science and Engineering as a part-time student at Idaho State University. In May 2009 he obtained a Senior Reactor Operator's license from the Nuclear Regulatory commission and began working as the Reactor Supervisor for the AGN-201. He completed the Master's Program for Nuclear Science as and Engineering in May 2015 from Idaho State University.

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Definitions

Reactivity - A term expressing the departure of a reactor system from criticality. A positive (fraction) reactivity addition indicates a move toward supercriticality (power increase). A negative (fraction) reactivity addition indicates a move toward subcriticality (power decrease). [8]

Excess Reactivity - The amount of reactivity above critical (keff = 1). The excess reactivity is the amount of reactivity that would exist if all control rods were moved to their maximum reactive positions from the point where the reactor is exactly critical. [4]

Technical Specifications - Part of an NRC license authorizing the operation of a nuclear production or utilization facility. A Technical Specification establishes requirements for items such as safety limits, limiting safety system settings, limiting control settings, limiting conditions for operation, surveillance requirements, design features, and administrative controls. (See also Standard Technical Specifications.) [8]

Safety analysis report - The final safety analysis report shall include information that describes the facility, presents the design bases and the limits on its operation, and presents a safety analysis of the structures, systems, and components and of the facility as a whole. [8]

SCRAM - The sudden shutting down of a nuclear reactor, usually by rapid insertion of control rods, either automatically by safety (protection) circuits or manually by the reactor operator. Also known as a "reactor trip". [8]

Acronyms

SAR - Safety Analysis Report

LSS - Limiting Safety System Settings

LCO - Limiting Conditions of Operation

SL - Safety Limit

SSC - Structures, systems or components

CFR - Code of Federal Regulations

Abstract

The AGN-201 research reactor has been in operation since October 18th, 1967, during which time maintaining the 1950's technology control console and acquiring replacement components has become increasingly difficult over the years. In an effort to address this issue a new console was started in the late 1990s. While a great deal has been achieved, operations still rely on the original console. This project has been focused on rebuilding the safety circuit with solid state electronics for simpler operation and maintenance. This document outlines the necessary regulation justification documentation for switching to operations with the new console.

1.0 Introduction

The AGN-201 M at Idaho State University (ISU) is a Nuclear Regulatory Commission (NRC) licensed training reactor under license #R-110. The reactor is licensed to 6 watts but has a conservative operating limit of 5 watts thermal. The reactor itself was made by Aerojet General Nucleonics in the 1950s. Aerojet has long since stopped its nuclear reactor involvement. However five AGN reactors continue to operate today: Idaho State University, University of New Mexico, Texas A&M, Kyung Hee University (South Korea), and University Palermo (Italy). In order for these facilities to operate they must be upgraded as comparable replacement 1950's component, namely vacuum tubes, are difficult to obtain.

It is important to know that changing or modifying any nuclear reactor structures, systems or components (SSC) comes with its share of regulation. Any change or modification has to be put through a chapter 10 code of federal regulations (CFR) 50.59 regulation process, in which the modification is vetted against 8 questions as it relates to the reactors safe operation. Should the modification pass these 8 questions the change may proceed without prior approval from the Nuclear Regulatory Commission (NRC), otherwise a license amendment must be received from the NRC before the change may be made. Various modifications have been made to the reactor and it's control system since it's first criticality October 18, 1967 however more modification is necessary to the 1950's vintage control system to insure the reactor continues to operate in the decades to come.

Figure 1. ANG-201 Control Consoles: Original (top), New (bottom)

The AGN-201 console is currently largely made up of original components or components from Oregon State's disused console, with exceptions being: channel 1, Safety Rod 1 (SR1) chassis magnet, and chart recorders. The SCRAM circuit is controlled by the 6Y6 vacuum tube energizing the SCRAM bus and subsequently cutting off the magnets power and reverse powering the magnets with a charged capacitor. Without the magnet grasping the fuel rod bracket the fuel control rod is ejected from the core via gravity and compressed spring force, which can be seen in the Figure 2. It is important to note that the three magnets in the original (and current) control system are wired in series circuit. However, the new console is wired to control the magnets separately in a parallel circuit. The switch to a parallel magnet circuit was to be able to easily control the magnets individually without having to rely on special switches to short out and disengage them separately.

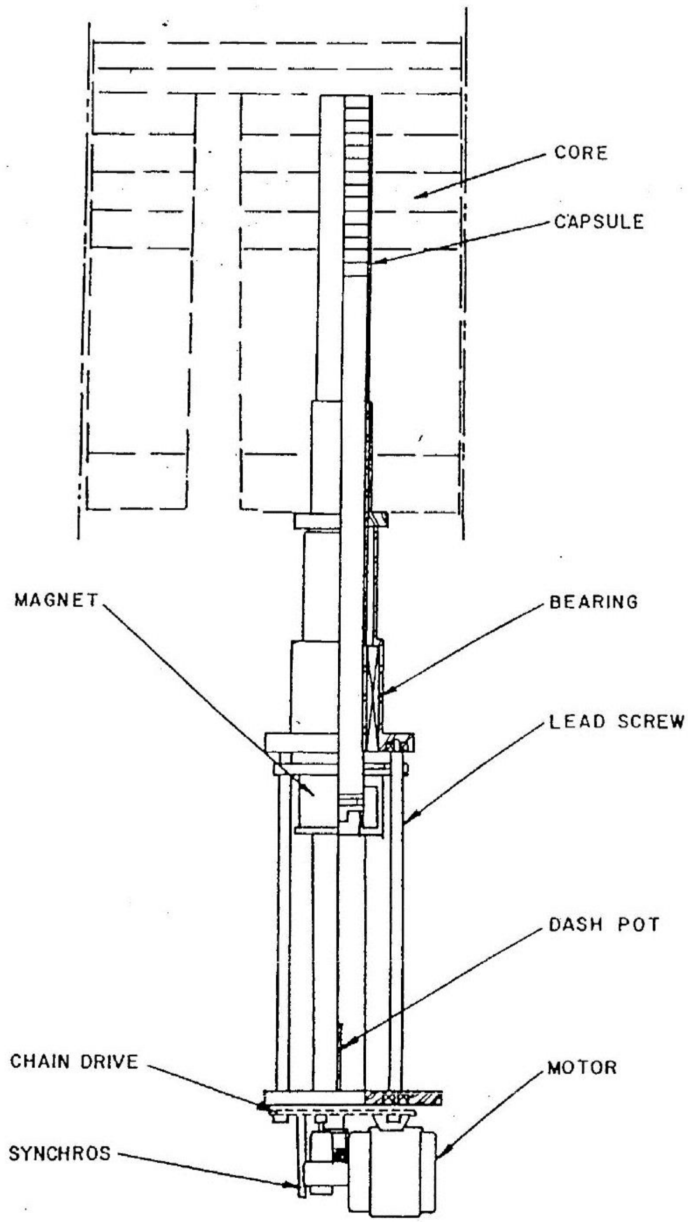


Figure 2. Control Rod Drive [3]

In the safety circuit there are 4 interlocks, 1 equipment protection circuit and 3 radiation detector channels (with a total of six SCRAMS), resulting in 11 total SCRAM mechanism. Should any of the interlocks or SCRAM safe operating conditions not be met the 6Y6 will engage, however there is a possible failure mode of the 6Y6 vacuum tube as described in the SAR, “The overcurrent meter relay provides protection from the possibility of a grid to cathode short in the 6L6 vacuum tube. p65". To address this over-current condition an over-current module is installed on the front of the console, the adjustable current limit allows for normal current fluctuations but will protect the magnets in the event of a current spike from a failed 6L6 vacuum tube or feedback from another failing electrical element. Once the 6Y6 vacuum tube mechanism is replaced by semiconductors, the over-current meter capabilities will not be necessary. However another more economical overcurrent protection device will be used. A failure mode of the 6L6 vacuum tube necessitates an overcurrent protection circuit as described in the SAR "The overcurrent meter relay is mounted on the front of the console rather than in the Safety Chassis. It provides protection from the possibility of a grid to cathode short in the 6L6 vacuum tube." p65. Each overcurrent meter is quite costly at $400 but this protects against the magnets from overcurrent damage, which results in the more costly $700 magnet rewiring (last performed in 2010).

Figure 3. Photo of Overcurrent Module

1.1 Prior Work

1.1.1 Rod Logic

The rod logic box is an analogue relay array that control what order the Safety and Control Rods may be Inserted, so long as the interlocks are okay and there are no SCRAMs. The current rod control logic requires that SR1 and then SR2 be inserted before the Course Control Rod (CCR) can be inserted. Once the Safety Rods are inserted they cannot be withdrawn. Therefore once the rods are inserted, the can only be removed by being dropped from the full height. In 1997 one of the dash pots at the bottom of the chassis failed. These dash pots are designed to absorb most of the shock incurred from scramming the rods. When the dash pot failed the full rod was subjected to the full force of ejection, causing stress failure in the rod's cladding. It was seen as desirable to allow the safety rods to be withdrawn, so that shutting down wouldn't have to always be an ejection from full height. This capability was developed in the "Control Rod Drive Logic Modification, Panel Design, and Proposed Check-Out and Change-Over Procedures for the ISU AGN-201" thesis by Scott William O'Connor and was verified through testing**.** The circuitry modifications were made on a spare rod logic drawer from the OSU reactor, this means that implementing the change is accomplished by simply switching the rod logic drawers.

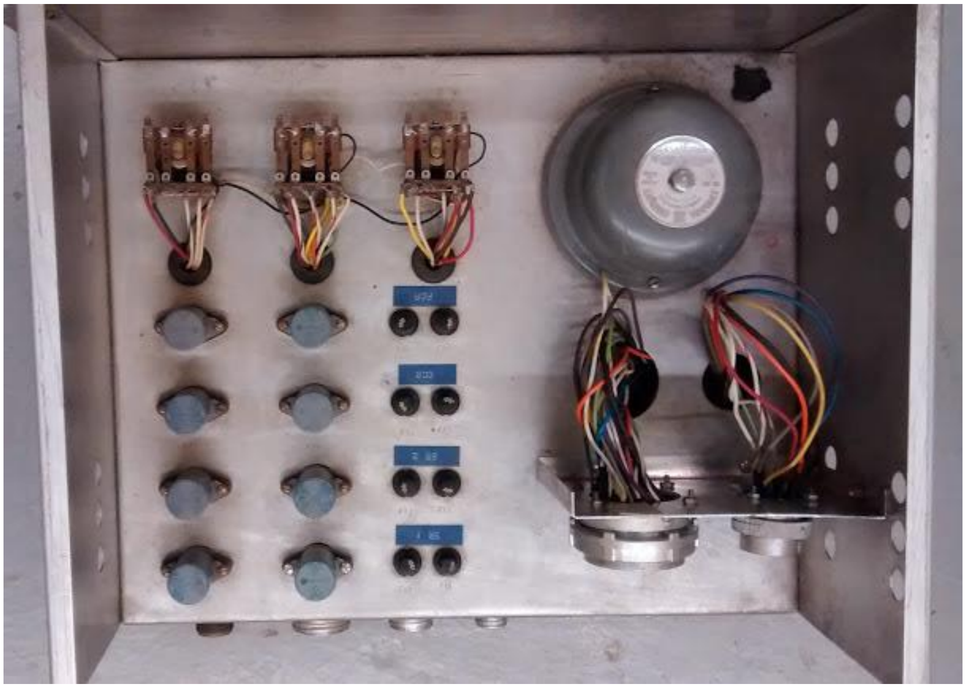


Figure 4. Rod Logic Drawer Photo

1.1.2 Additional Functionality

Over the years various features have been added to the console while many are not integral, they are still worth mentioning. A simple circuit was developed to detect the amperage of channel 3 and integrating the signal thus creating a Watt-hours counter. Two infrared beams/sensors coupled with reflectors on the shield doors on top of the reactor shield to serve as a binary indicator of the shield doors being opened or closed at the console. Area Radiation Monitors have been placed around the reactor bay running back to a bank of meters in the new console, some of these meters are not currently functional (suspected powering problem). The period meter that uses an analogue to digital converter to indicate discrete values such as (infinity, 20 sec, 10 sec, 5 sec) rather than a traditional needle and scale meter., which will be abandoned with the revised new console plan.

1.1.3 Printed Circuit Board Safety Circuit

The bulk of this conversion project in the last several years has been centered around the multilayered printed circuit board (PCB) safety circuit that was originally designed for the new console. The successful operation of that PCB circuit was demonstrated in 2009 through parallel connection with original console. However in attempting to verify the design and construction of the board for final 50.59 analysis, some of the wiring on the board was found to have been compromised. The PCB safety circuit was not working correctly and could not be fixed with the existing documentation, and concern of not having the ability to examine the center of the layered circuit board. The board itself consisted of 3 layers, 177 I/O connections, and various add-ons/deletions. After rigging the interlock and scram signals into the OK position and engaging the magnet circuit, the magnet voltage would enter the center PCB layer, and, it appeared to dead end somewhere within it. Various troubleshooting methods were attempted but ultimately a solution was not found. It was then decided to rebuild the safety circuit in a simpler manner that would be usable and maintainable. Simplicity calls for basic circuits in the original 3-layered PCB to be built into four separate prototype circuit boards, so each could be readily examined and tested.

1.1.4 Licensing & Regulations

Operations at a nuclear reactor the are outlined in the Technical Specifications documents, which specifies what is allowed and what isn’t, for everything from maximum reactor core power, to quantifications of reactor safety committee members, to what materials may be irradiated within the reactor. If an activity or situation is not expressly forbidden by the "tech specs" then it may be permissible so long that it also abides by facility procedures, general rules for operation, and ISU radiation safety documentation.

Any modification to a Structure, System, or Component (SSC) is often handled through the Section 10 Code of Federal Regulations (CFR) 50.59 process (see Appendix A for regulation), or, if regarding an aspect of the emergency plan, then 10 CFR 50.54 (q), or, if the quality assurance program, as referenced in the SAR, the activity would be covered in Regulatory Guide 2.5 (June, 2010) and 10 CFR 50.34**.** The changes regarding the new console will be covered through the 50.59 process but will also need the operating procedures to be reviewed and modified accordingly. The "brass tacks" of 50.59 is contained in 8 questions (see Appendix A) to better understand the risks or consequences associated with any change or modification. The flowchart below illustrates the 50.59 process for the ISU AGN-201. Every aspect of the new console change will have to be addressed with a 50.59 justification document and then approved by the RSC before it can be implemented.

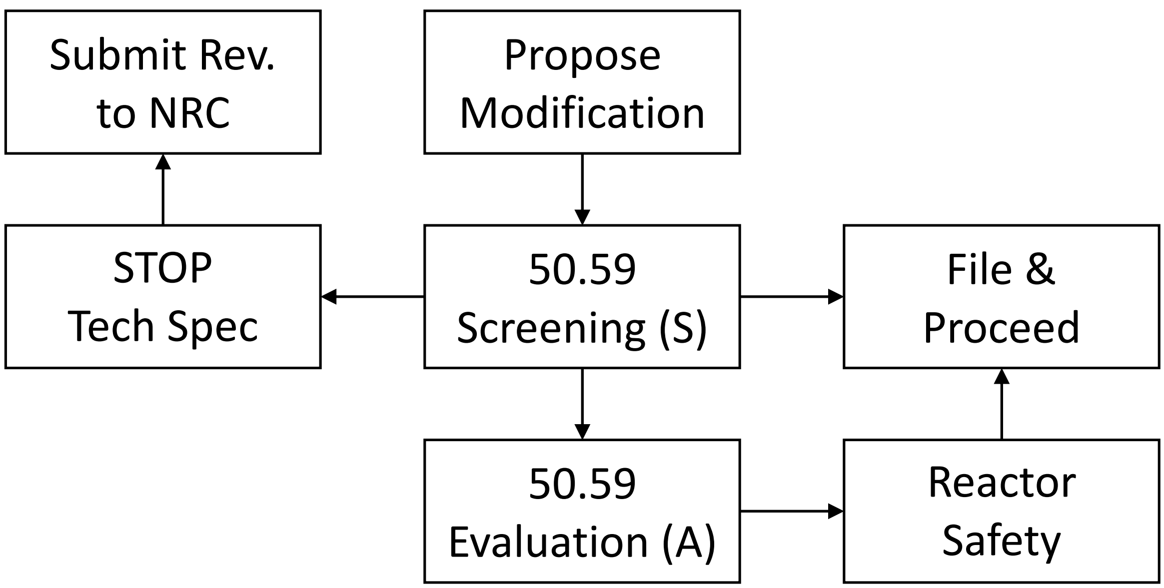


Figure 5. ISU AGN-201 50.59 Process Flowchart Draft

Once the new console is brought online there will be a significant number of differences between the current SAR and the facility. With the number of 50.59 changes being made it is advisable to update the SAR with a substantial revision to insure the completeness of the document, however this is not a requirement. However it is worth noting that, if the safety analysis philosophy is changed, that has to be addressed through 10 CFR 50.54.

2.0 Theory

2.1 NEW CONSOLE WORK

2.1.1 Digital Chart Recorder

As can be seen in Figure 1 the console has been upgraded replacing the paper chart recorders with a single multi-channel digital chart recorder. The digital chart recorder will be used in the new console as well. The digital chart recorder, installed atop the console, eliminates the need to maintain a mechanically geared paper feeding system and additionally removes consumption of paper and recorder tips. The 50.59 justification was approved by the Reactor Administrator (RA) 10/11/2012. The digital chart recorder also allows for channel 2 signal to be integrated over time, making the yearly calculation of operation watt-hours a far simpler process.

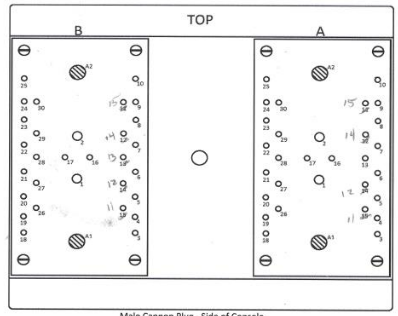
2.1.2 Breaker Box

It was found that part of the console's electronics would remain powered while the reactor's main power switch was in the off position. This power wiring posed a significant electrical hazard and proved to complicate troubleshooting efforts. It was deemed necessary for the progression of the new console that all the systems be powered through a central kill switch and individual breakers. Wiring all power through a central switch is primarily a safety mechanism and the breaker box protects individual components from overcurrent and allows individual circuits be disabled for maintenance. The breakers box uses standard 15 amp breaker switches, however it may be worthwhile to resize the breakers closer to their values at power load once the console is operational.

Figure 6. Breaker Box (right) and Kill Switch (left)

2.1.3 Signal Identification and Mapping

Efforts to troubleshoot the Printed Circuit Board (PCB) safety circuit were difficult due to a lack of present (as built) circuit diagrams and also wiring diagrams for the skirt door and reactor control cable pin-outs. Additionally it had to be determined what was the signal logic for each part of the safety circuit i.e. what voltage value represents a SCRAM condition for the period meter and is the operable condition of seismic scram an open or closed circuit. Figure 7 below (see appendix C for larger image) is an example of the diagrams that were produced to aid in troubleshooting and later circuit building.



Male Cannon Plug - Side of Console

B		
#	To	Description/Signal
1	TB3-37	SR2 Lower Limit Switch
2	TB3-36	SR2 Motor
3	TB3-44	SR2 CS
4	TB4-47	FR Upper Limit Switch
5	TB4-48	FR Motor
6	TB5-67	CR Upper Limit Switch
7	TB5-68	CR Motor
8	TB4-55	FR S3
9	TB4-56	FR S2
10	TB4-57	FR S1
11	TB4-52	FR Motor
12	TB4-53	FR Lower Limit Switch
13	TB5-71	CR Motor
14	TB5-72	CR Lower Limit Switch
15	TB5-75	Tank Ground
16	TB5-73	Interlock
17	TB5-77	CR CS
18	TB5-78	CR S3
19	TB5-79	CR S2
20	TB5-80	CR S1
21	TB2-30	SPARE
22	TB3-45	SPARE
23	TB2-27	Magnet
24	TB4-63	SPARE
25	TB4-64	SPARE
26	TB4-65	SPARE
27		
28		
29		
30		

A		
#	To	Description/Signal
1	TB1-12	Magnet
2	TB5-83	CR-R1, FR-R2
3	TB5-84	CR-R2, FR-R1
4	TB1-3	Interlock
5	TB1-1	SPARE
6	TB1-2	SPARE
7	TB2-17	SR1 Upper Limit Switch
8	TB2-18	SR1 Motor
9	TB2-19	SR1 Motor +
10	TB1-9	SPARE
11	TB2-21	SR1 Motor
12	TB2-22	SR1 Lower Limit Switch
13	TB2-29	SR1 CS
14	TB3-32	SR2 Upper Limit Switch
15	TB3-33	SR2 Motor
16	TB1-10	SPARE
17	TB1-11	SPARE
18	TB2-20	SR1 Motor -
19	TB3-34	SR2 Motor +
20	TB3-35	SR2 Motor -
21	TB5-69	CR Motor +
22	TB5-70	CR Motor -
23	TB4-49	FR Motor +
24	TB4-50	FR Motor -
25	TB1-13	SPARE
26	TB1-19	SPARE
27		
28		
29		
30		

Figure 7. Reactor Plug (left) & Cable Pinouts (right) (Full size in Appendix C)

2.2 Safety Circuit Rebuild

2.2.1 Safety Philosophy

It's worth taking a moment to explain safety circuit philosophy regarding priorities and potential trouble areas. In reactor console modification and design significant attention must be directed toward the possible failure modes of each circuit. All scram modes must be in the non-powered position. That way should a wire be disconnected or power lost, it will render the reactor inoperable. Truly every modification to a reactor must be made in a conservative but reasonable manner. All signal, test, logic, and control connections must be wired in such a way to insure reactor safety, in all things safe reactor operation must be the priority.

Currently there are no digital control consoles in NRC regulated research reactors. It is not that digital control consoles are themselves dangerous but rather that control consoles have traditionally been analogue and analogue has practically no risk from a cyber-security standpoint. It has been a tradition of the industry to stay with vetted analogue technology until newer technology can be exhaustively verified. A lower risk reactor such as the AGN-201 could potentially be a good candidate as the first completely digital NRC regulated research reactor control console, however this is not being attempted at this time.

The new console project has often been referred to as an analogue to digital conversion but this is not strictly accurate. It would be more accurate to refer to the project as a vacuum to solid state conversion, as essentially all components are strictly analogue. The primary reason for the console conversion is to remove the facility's dependence on vacuum tube technology, as parts can be difficult to acquire and the system challenging to maintain. The original console was constructed in the 1950s and has served it’s duties largely unchanged all this time. While the console went through the entire spring 2014 semester lab session without needing to be shutdown for maintenance, this is an achievement but this has not been the norm. Throughout 2014 the console has been very reliable and has less than half of the inadvertent SCRAMs of the previous year. This enhanced reliability is primarily the result of carefully examining virtually all of the connections in the system, and repairing those that had deteriorated.

2.3 Old Console Functionality

2.3.1 Interlock Circuit

The interlock circuit is to interrupt the power being applied to the rod drive magnets should any of the safety interlock criteria not be met. For the interlock master to be in the OK position to start up the reactor the following interlocks must be satisfied:

Seismic: The seismic interlock is a pedestal containing two electrical contacts on to which a brass ball is balanced, should an seismic event resulting in a 1/16 inch displacement (by tech spec) the electrical connection will be broken causing the interlock to open. The seismic interlock is to insure that if a substantial earthquake should occur during reactor operation, the reactor would be automatically shut down.

Water Level: The shield tank water level interlock is satisfied if the water level is within 10 inches of the manhole cover (by tech spec). This is accomplished by a micro switch being suspended off the platform by a rod and an air filled float that is on the water's surface. The water level interlock is necessary for insuring the presence of the water shield, so that the experimenters/operator are not exposed to unnecessary radiation.

Water Temperature: The water temperature interlock is satisfied by the reactor's bulk water shield tank being above 15 degrees Celsius and should the temperature drop to or below 15 degrees Celsius a thermo-switch will create an open circuit opening the interlock. The reactor has a negative temperature coefficient, which means that as the reactor heats up it will lose reactivity. Conversely as the reactor gets colder it gains reactivity and because of this there is a technical specification limit for operation below 15 degrees Celsius thereby limiting available excess reactivity during operation.

Rod Interlock: The rod interlock is satisfied when all the control & safety rod drives are connected in the appropriate manner, this is to prohibit operation if the chassis are installed incorrectly. The rod interlock is accomplished by a 12 volt signal being carried through the Amphenol™ cable in such a way that the relay will only be satisfied if the cables are connected to their correct corresponding control rod chassis.

If any of the interlock positions are not satisfied the interlock master will be in the "Interlock Open" position and the operator will not be able to energize the magnets, or the magnet's power will be cut if they are already energized. If all of above conditions are satisfied with the interlock bus the interlock master relay will be in the OK position and the 12 V signal will be passed on to the SCRAM circuit.

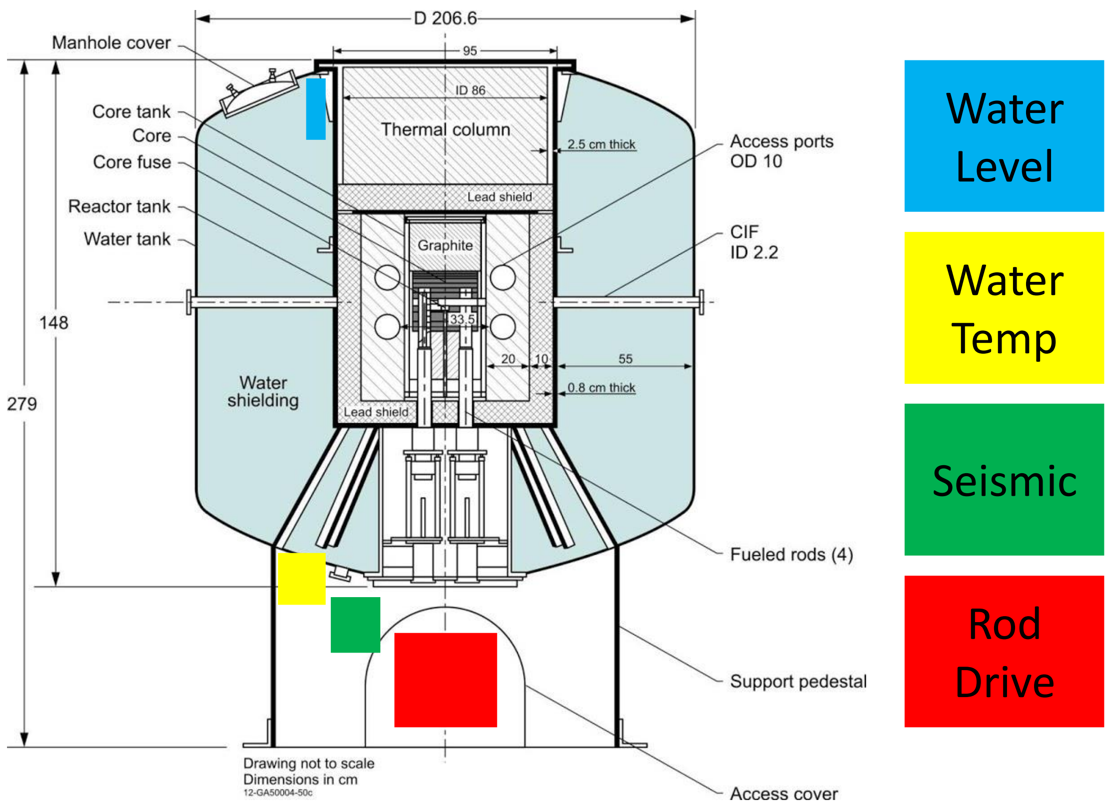


Figure 8. Reactor cross section (with Interlock locations added) [1]

2.3.2 SCRAM Circuit

There are 3 detector channels that must all be in the operation if the reactor multiplication factor is to be increased, by permitting the magnets to be engaged, and thereby operate the reactor. All the channel's detectors are uncompensated ion chambers. While all the channels serve different purposes, having multiple channels allows their measurements to be verified against each other, all channels have ranges covering many decades. Channel one is the start up channel, this insures that the reactor cannot be started when the reactor's neutron level is below a limit of 5 counts per second or 5% of full scale. Nuclear reactors have the ability to double in power very rapidly and are generally more susceptible to inadvertently reaching short doubling time at low power levels where neutron detection is subject to natural variations characterized as noise levels. Therefore it is common practice to have a start up channel with a relatively low minimum detection SCRAM set point, which thereby necessitates a minimum neutron population before the reactor may have its multiplication factor increased.

Channel two is the log channel and serves two main purposes: one, the channel displays the power logarithmically so that the entire power range of the reactor can be displayed; and two, the channel has a built in period meter that displays how fast the reactors power is increasing. Channel 3 is the reactor's linear channel, which serves as the main power indicating channel. Reactor power is determined from a calibration table correlating detector output (in amps) and reactor power (in watts). Additionally, Channels 2 and 3 provide a functionality check for one another as they are similar detector types, operated at the same voltage, in similar radiation fields and will therefore have similar outputs for a given power level.

2.3.3 New Console Overview

The new console construction was started in the late 1990s. Its current physical state can be seen in figure 9 below. Part of the wood paneling had to be removed to access wiring behind the distribution board. Once the console is operational exterior metal paneling will be fabricated and installed to cut down on electrical noise. On the left module is a rack containing rate meters that will be attached to various area radiation monitors around the reactor bay. The central panel contains a 3-channel paper chart recorder, channel outputs and the condition indicators for the interlocks and scrams. However, the paper chart recorder will be replaced by the digital chart recorder currently in use on the original console. The scram and interlock indication lights are simple 12V incandescent bulbs, and will light up on non-operable conditions (as applies to the reactor's operation).

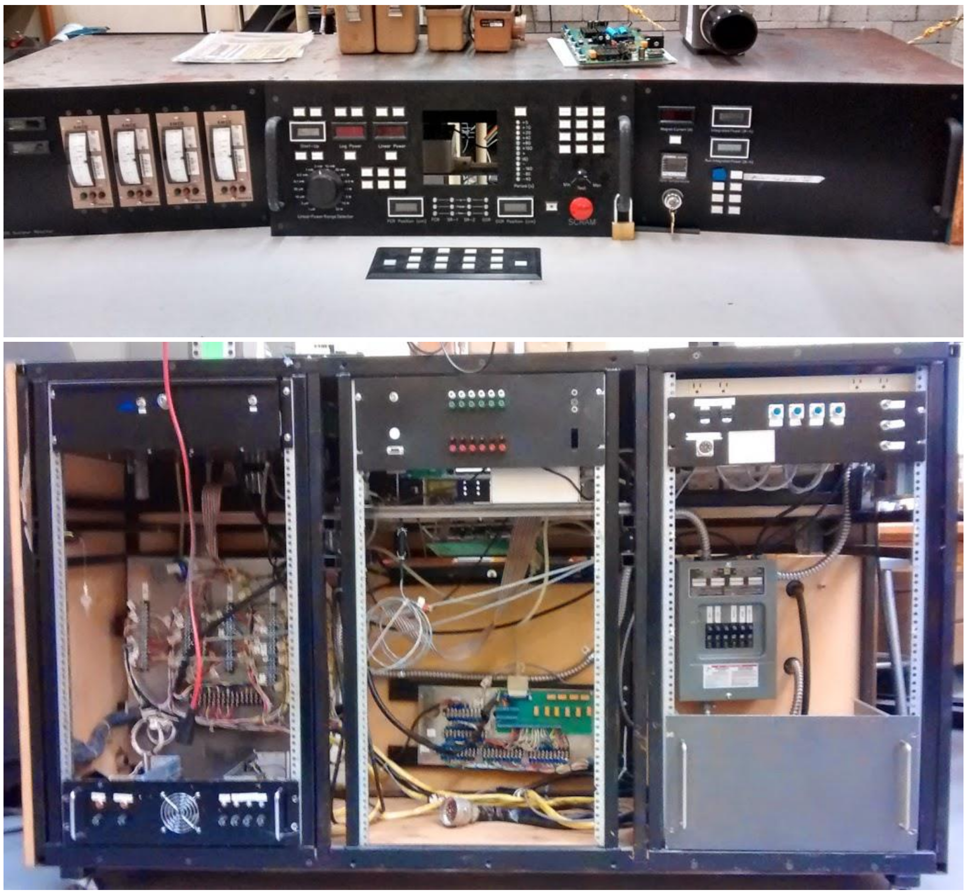


Figure 9. New Console Front (top) and Rear Photo (bottom)

The significant components that have been changed in the new console involve channels 1, 2 & 3, a modified rod logic box and parallel magnet operation. The new console's Channels 1, 2, & 3 are nearly identical in function & operation to the original console's Channels, however the change from vacuum tubes to solid state will be subjected to a new 50.59 evaluation. The modified rod logic box allows for the Safety Rods to be lowered after fully inserted. The new rod logic box has been tested but it will need to be approved by the reactor safety committee (RSC) via the new 50.59 evaluation before it may be implemented. Although a minor change, switching from using a series magnet circuit to a parallel magnet circuit must also go through the 50.59 process before being implemented.

The new console offers additional functionality in the form of a Watt-hour meter, multiple area radiation monitors, shield door position indication and individual interlock indication. These additional features will be documented through the 50.59 screening form but as these are new features and not modifications to existing components they most likely will not require full 50.59 evaluation and RSC approval.

2.4 TESTING

2.4.1 Reverse Bias Diode & Reverse Capacitor

In the process of the rebuild it was deemed advantageous to address the previous magnet failure with a more modern circuit to be evaluated under 10 CFR 50.59. To take advantage of the new consoles independent magnet control they reactors control rod chassis must be switched from a series magnet circuit to a parallel one. Additionally adding a reverse biased diode in parallel with each magnet will reduce the voltage spiking that occurs when a magnet is abruptly shut off, however for such a modification to occur it must be shown to not adversely affect the safety of the reactor.

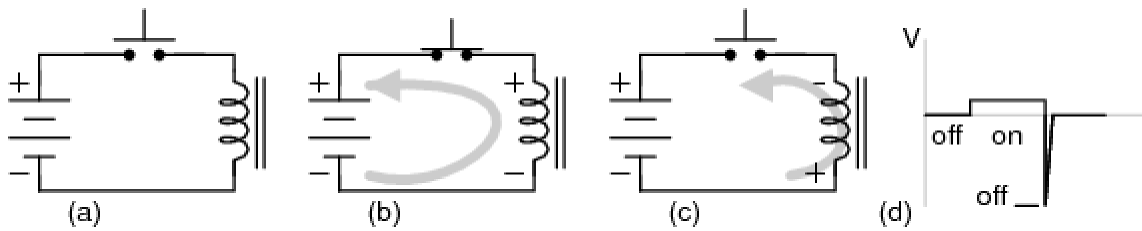


Figure 10. Power off magnetic current diagram [2]

When the power of an electro magnet is abruptly removed, it will behave like the inductor that it is and will try to maintain the flow of the current by acting like a voltage source, as the voltage is flipped across the magnet when the power is cut in section c, shown in figure 10 above. The magnetic field is collapsing and reverting back to an electrical field, the electrical potential created by this effect is theoretically infinite but is dampened by the magnet's internal resistance. In this condition arcing may occur across the magnet coils, potentially damaging the magnet. A common way to address this voltage spiking effect is to add a reverse biased diode giving an electrical path with less resistance than arcing across the coils, as shown in part c of figure 11.

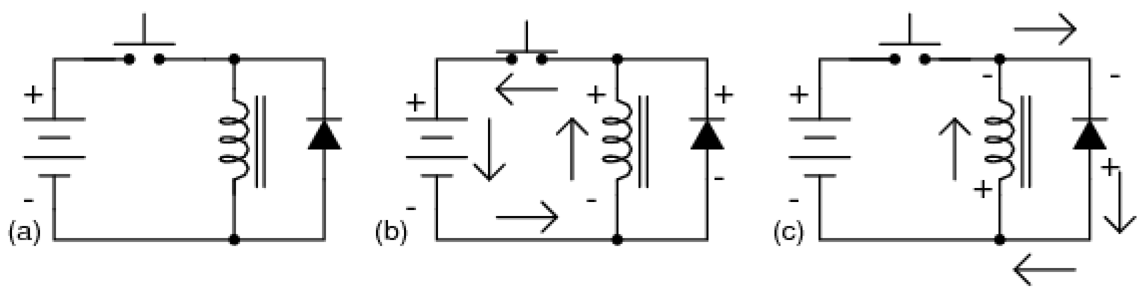


Figure 11. Reverse Biased Diode Circuit [2]

To demonstrate the magnetic field collapse voltage spiking, an oscilloscope was connected across the magnet to record the resulting waveform. Figure 12 below is the resulting waveform of a standard rod drive magnet with the standard +12V applied and then removed. Note that the scope meter had to be operated in a negative voltage mode to better show fast occurring effects, and therefore doesn't show the steady state operating voltage before time = 0 seconds when the magnet power is cut. It should be noted that the ringing effect in the figure 12 waveform is not solely caused by the voltage spiking itself but also a result from also an induced current of the voltage spiking effect on the meter's resistance.

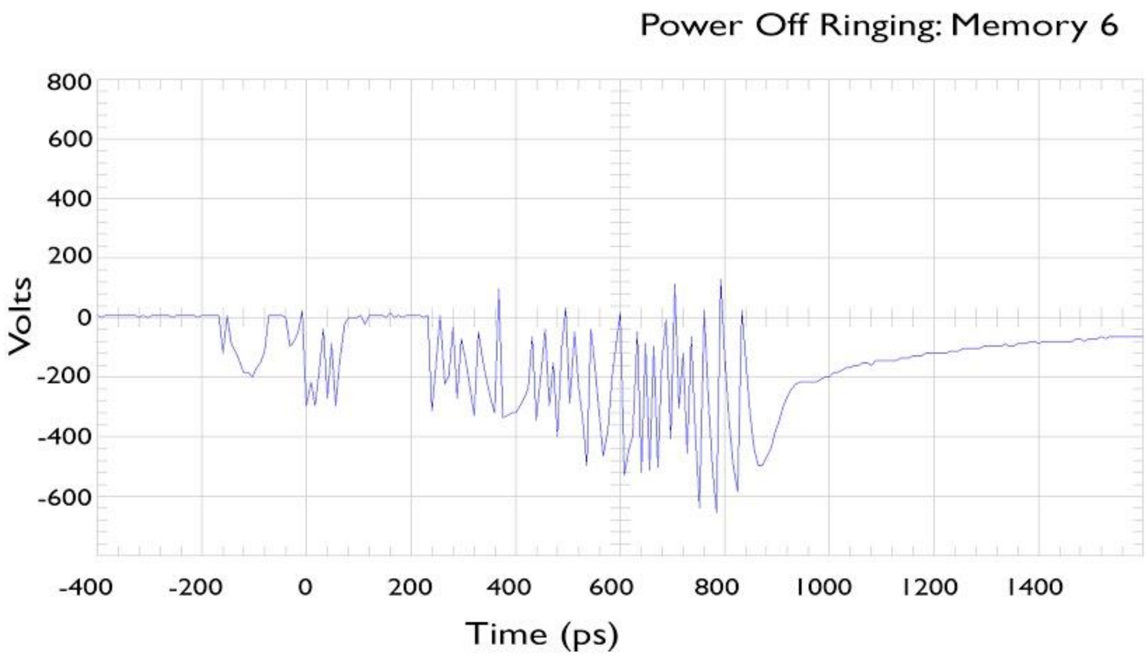


Figure 12. Magnetic field breakdown

Figure 12 above shows significant voltage spikes as much as -600V, this can potentially cause arcing between the magnet's coils, damaging the integrity of the magnet. The collapsing of the magnetic field was measured in the same way with a reversed biased diode placed in circuit. Figure 13 below shows a substantial reduction of the voltage peaking. This reduction of the voltage peaking will increase the longevity of the magnets. However the modified circuit must be tested for rod drop timing. A significant increase in the rod drop time could mean that the modified circuit would be unusable, as it could result in total rod drop times greater than the one second maximum allowed by the "Tech Specs".

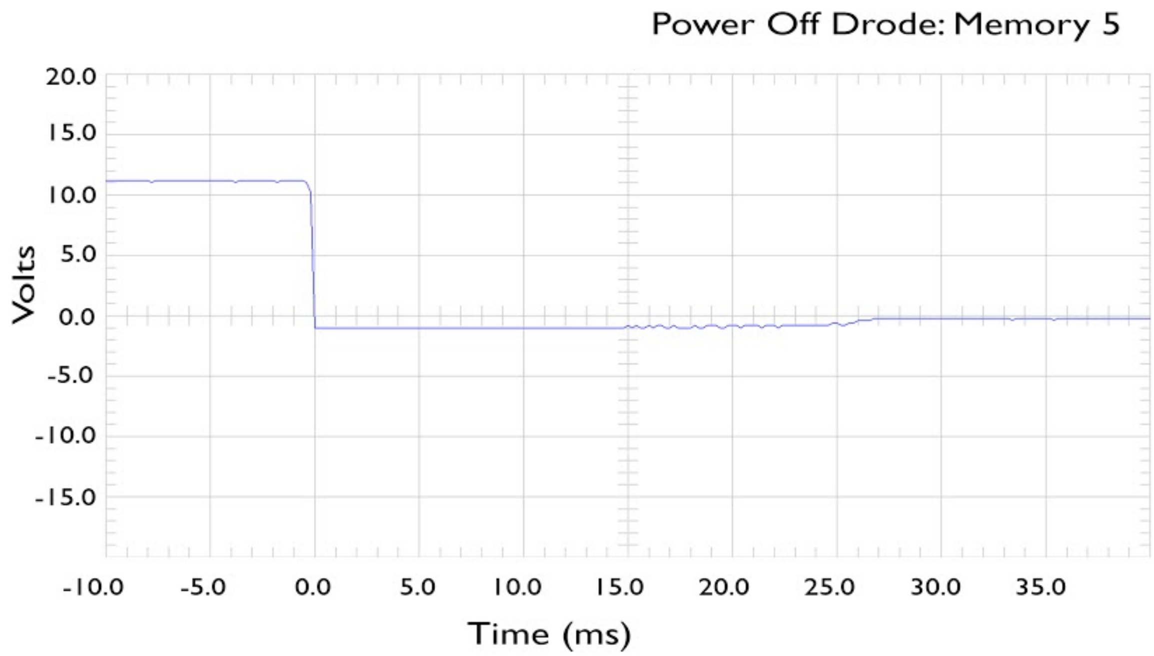


Figure 13. Magnetic field breakdown with reverse biased diode

There was potential that the current demands of the magnet to build up its magnetic field would trip the overcurrent fuse intended to protect the magnet from abnormal voltage spikes. The charge up time for the magnet can be seen in Figure 14 below. The scope meter trace is the top right of Figure 14 is the current draw while the electro magnet is generating its magnetic field. It was a concern that if the electrical load associated with the building of the magnetic field was significantly over the stead state load it could blow the magnet’s overcurrent protection fuses on start up. Figure 14 shows that the additional current drawn during the magnetic field buildup is not large enough or long enough to trip a over-current protection fuse.

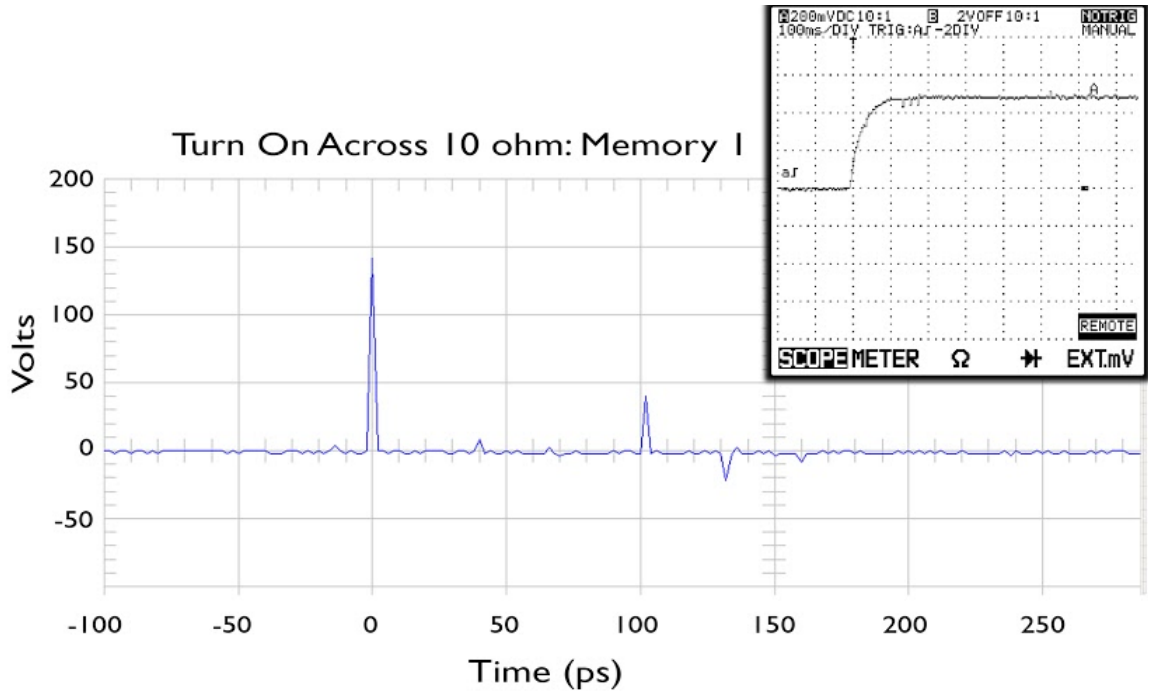


Figure 14. Oscilloscope trace across magnet during power up

Normally in testing the annual rod drop time a magnet is attached to the top of the rod and two Hall effect sensors are positioned along the rods full travel. The first Hall effect sensor is positioned to trigger as the rod leaves the full up position and the attached magnet will trigger the second Hall effect sensor as the rod reaches the rods full out position. Therefore, the time difference between the two sensors is the rod drop time for that rod drive. The Hall effect sensors have been temperamental to work with in the past due to inconsistent triggering as the magnet passed by them. Additional problems were found in the noise they induced on the scope meter and measuring the rod drop in this way does not account for potential delays in the circuitry. To get around these issues a new method was developed where the initial "start" signal would be provided by the connection of the manual SCRAM button and the "stop" signal would be provided by a photo diode and a light beam, obstructed at all times by the rod except when the rod is in the fully withdrawn position, see figure 15.The photo diode in the testing rig is "triggered" by a light beam reaching its surface from a high intensity LED mounted on the other side of the rod. These "start" and "stop" timing signals were measured on two separate channels on the scope meter. The voltage drop seen in Channel 1 indicated the "start' trigger and the .3 volts seen on the photo diode channel indicates the "stop" trigger. This new LED/photo diode method proved so successful it will later be incorporated into the reactor’s rod maintenance procedure and will replace the current Hall effect sensors, should it pass the 50.59 process.

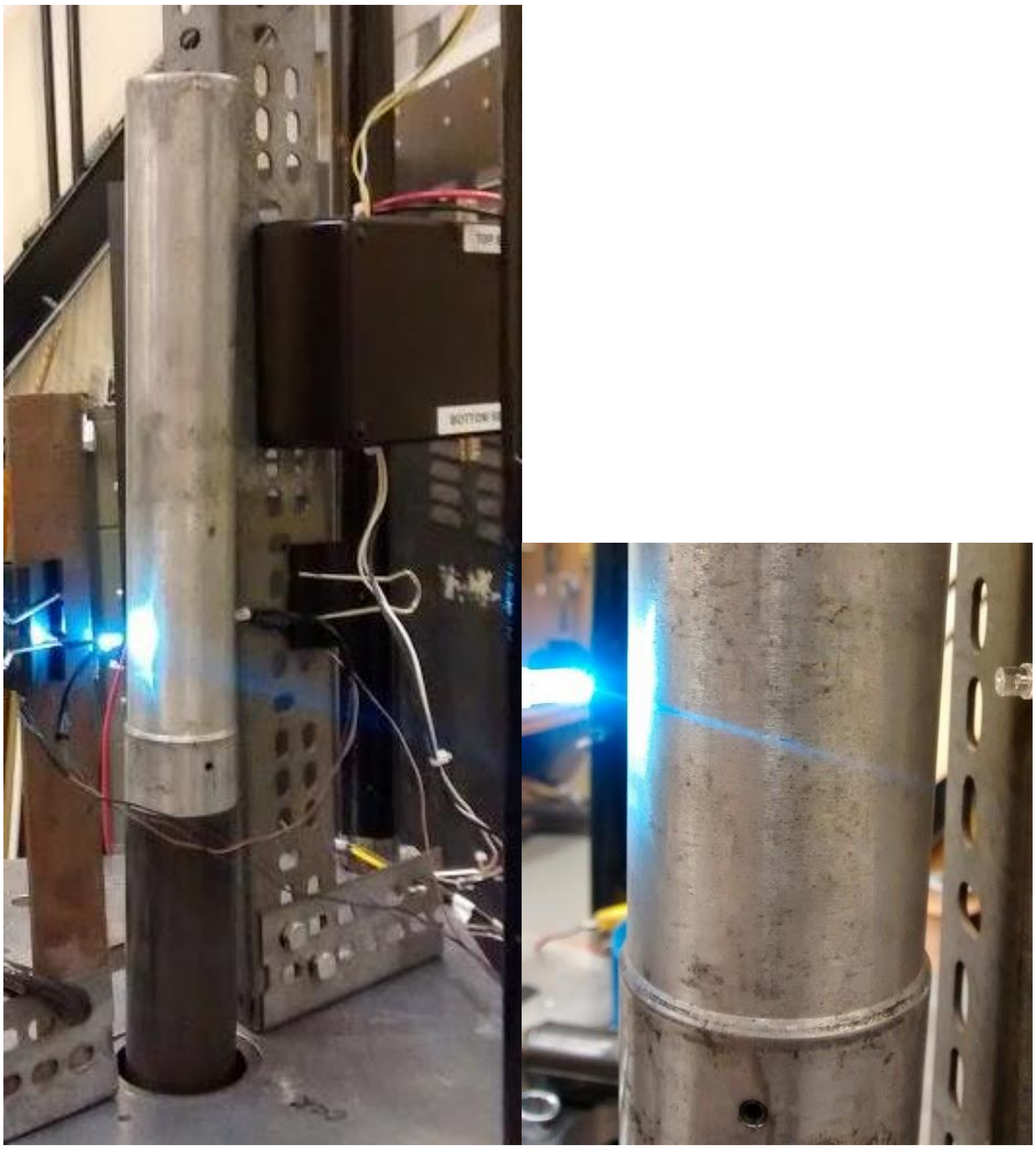


Figure 15. SR2 Rod Drop Testing Rig (left) & Lower Rod Position Close-Up (right)

For testing of the rod drop time with and without the reverse biased diode, the actual Safety Rod 2 chassis was pulled and installed into the test stand for these measurements. Figure 16 below show the trace of the oscilloscope's channel 1 on the manual SCRAM button. The only characteristic of note is the sharp drop at time zero, the effects seen afterwards are feedback of other mechanisms within the console. Figures 16 & 17 were measured with the original circuitry (no reverse biased diode) in place and use the same time stamp (magnet off at time = 0 seconds).

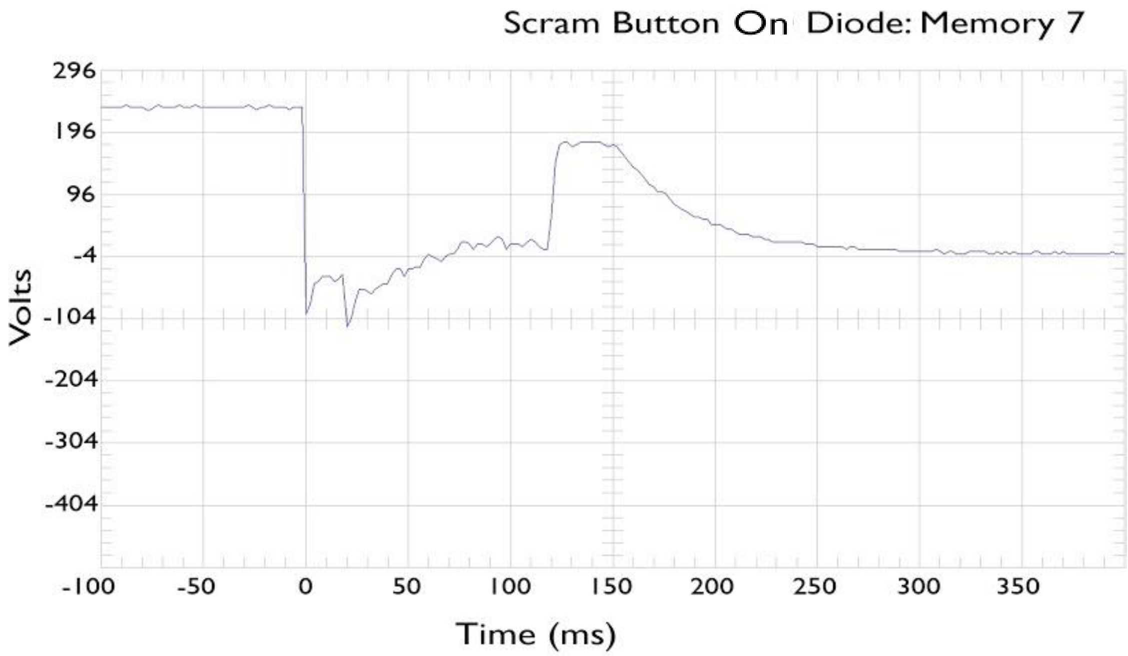


Figure 16. Ch 1 SCRAM Button Trigger (Original Circuitry with no reverse biased diode)

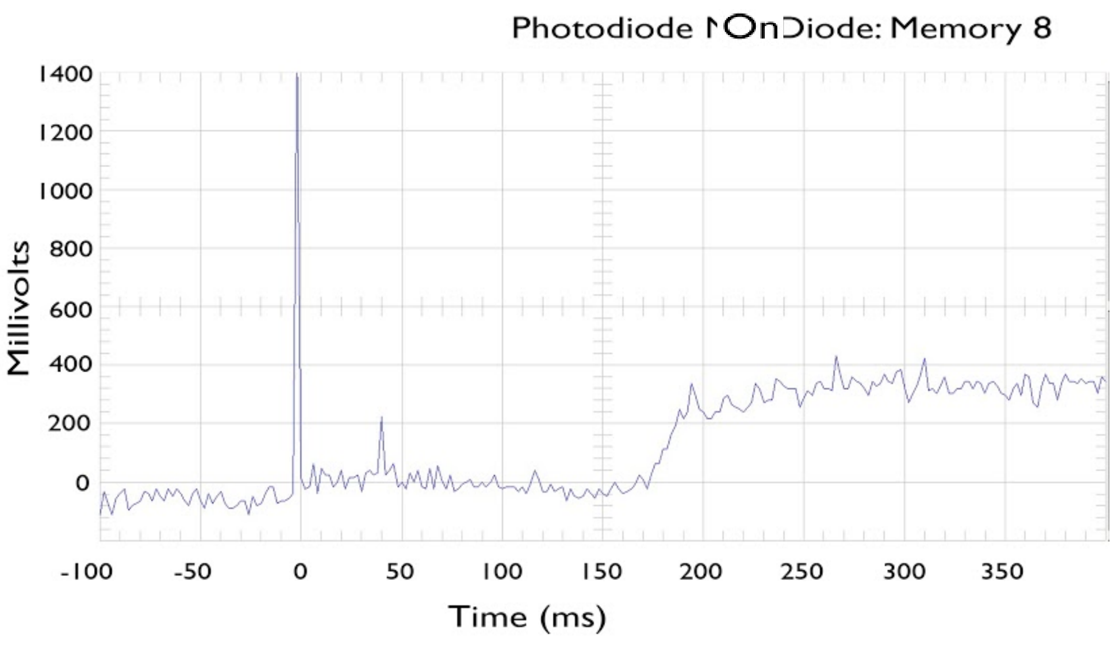


Figure 17. Ch. 2 Photo Diode Trigger (Original Circuitry with no reverse biased diode)

Figure 17 above is the trace captured on Channel 2 of the oscilloscope observing the photodiode, the peaks after the initial peak are not relevant, it is only when the voltage is above 200 mV and stable that the rod is in the fully removed position. Figures 16 & 17 were taken at the same time and share the same time scale. Therefore observing figures 16 & 17 together one can see the SCRAM button being pressed at time = 0 seconds and the rod reaching the lower position is approximately 3.5 divisions or 175 ms later. This shows that the total rod drop time including the circuitry delays to be approximately 175 ms.

2.4.2 Modified Circuitry Measurements

It's important to note that the only modification to the original circuit (Fig. 9) made was placing a reverse biased diode in parallel with the magnet (Fig. 10) and that the magnets are still in series. As in the previous measurement the initial large negative spike is the start of the timing as caused by depressing the manual SCRAM button, the Channel 1 trace is show below in Figure 18.

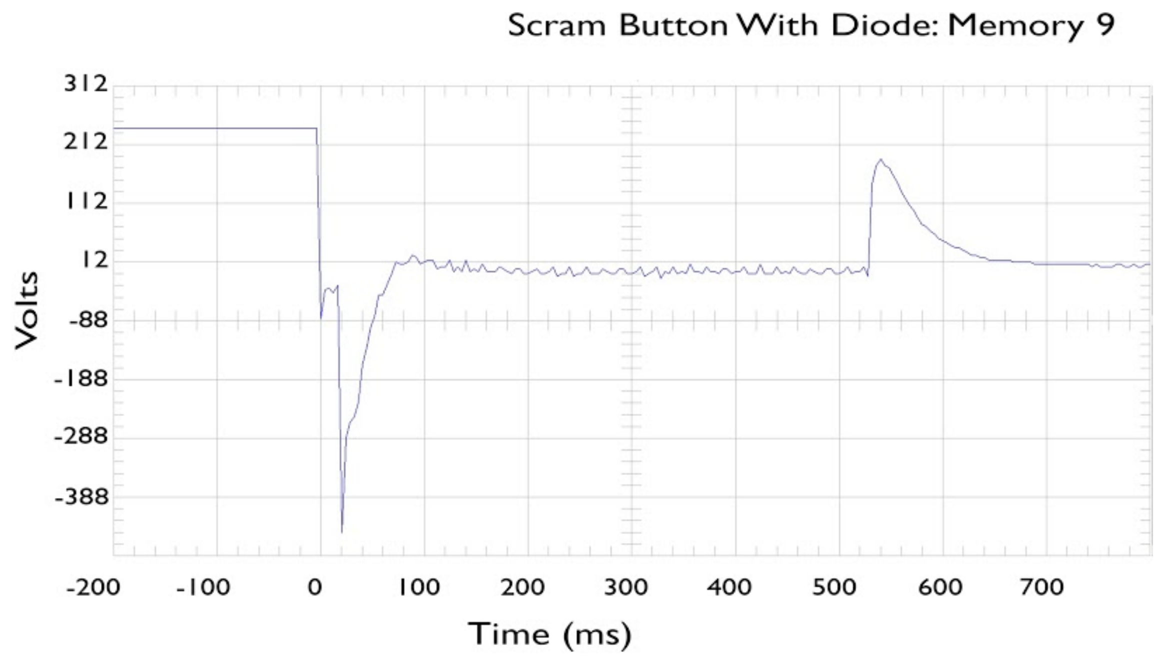


Figure 18. Ch. 1 (Oscilloscope) Manual SCRAM Button Trigger (with Reverse Biased Diode)

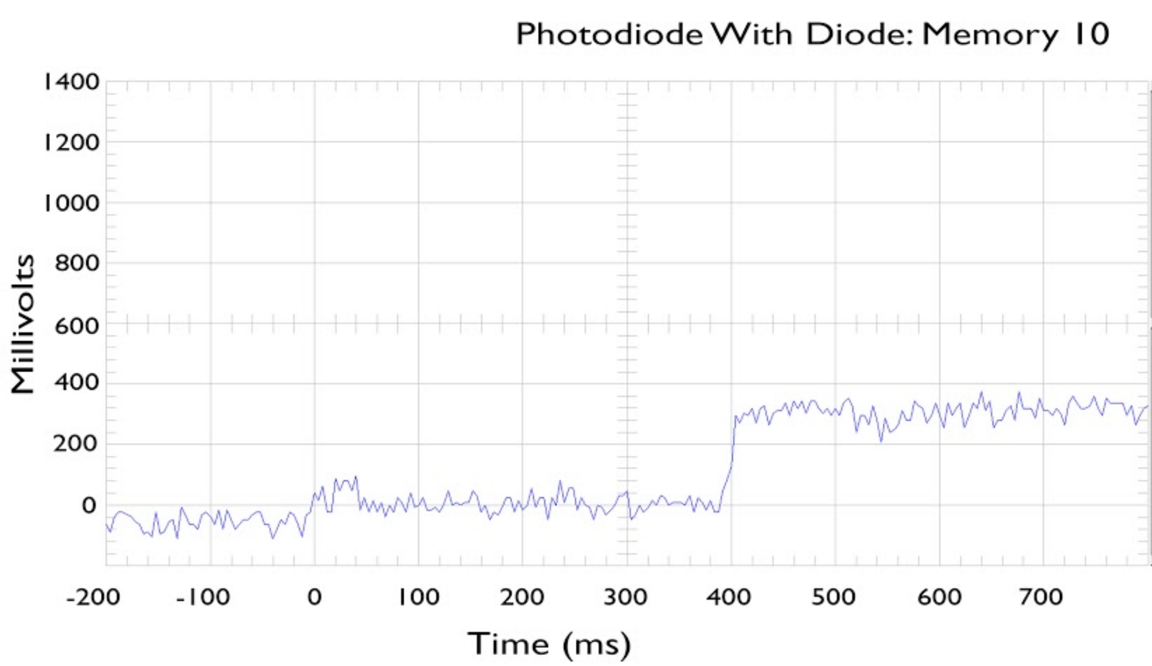


Figure 19. Ch. 2 (Oscilloscope) Photo Diode Trigger (with Reverse Biased Diode)

Figure 19 above is the Channel 2 trace of the photo transistor being triggered as the rod reaches its lowest position. The figures for Channel 1 & 2 share the same time stamp and show a rod drop time including circuitry delays to be approximately 4 divisions or 400 ms. It is worth reiterating that the intention of this reverse diode circuitry is to increase the longevity of the magnets, not reduce rod drop timing. While the modified circuit is marginally slower than original it is still well within the technical specification's 1 second rod withdrawal limit.

In the interest of being through, the magnet collapse effect was measured across the SR2 magnet, this will be slightly different as the reactor’s drive chassis magnets are wired in series, where the bench testing more closely represents the magnets in parallel. The negative voltage spiking can be seen in Figure 20 below, while still present the voltage spiking appears to be muted when the magnets are wired in series. Figure 21 shows how the voltage spiking is drastically reduced by a reverse biased diode being placed in parallel with the magnet.

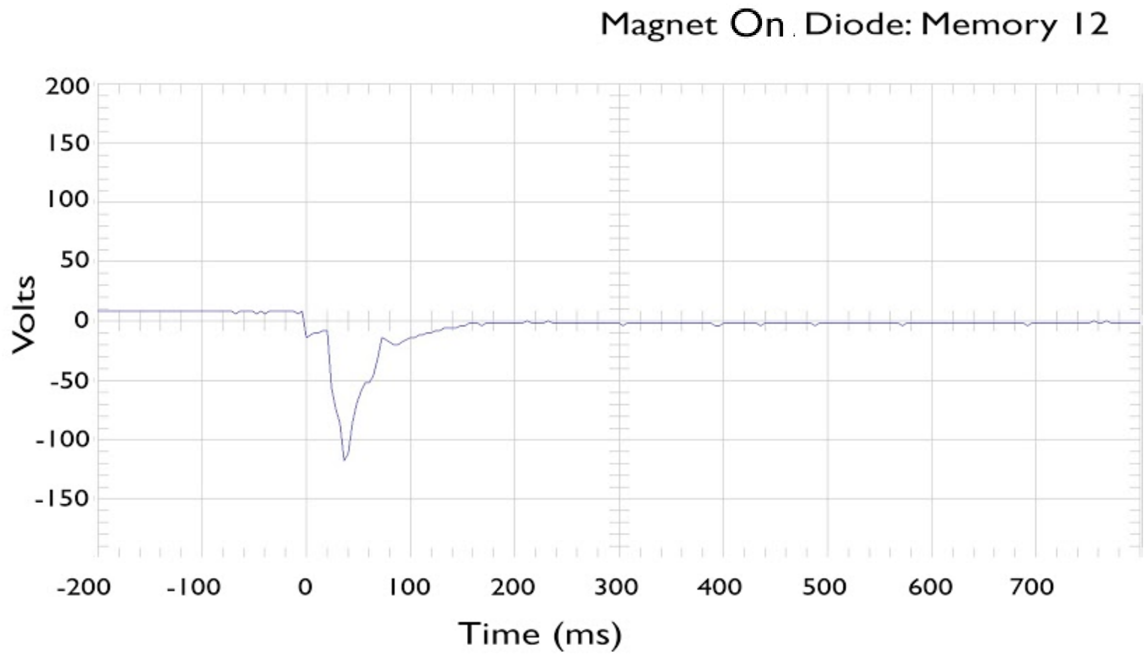


Figure 20. SR2 Voltage Spiking (Original Wiring)

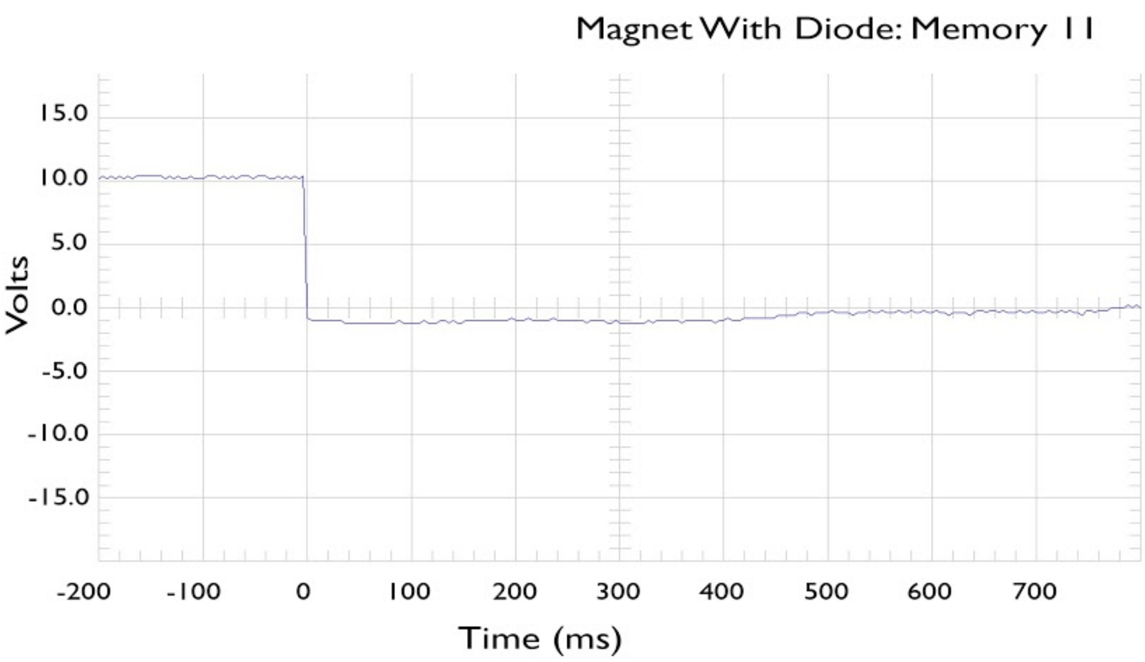


Figure 21. SR2 Voltage Spiking (Reverse Biased Diode in Parallel)

All of these measurements show that modifying the wiring of the rod drive magnets to include a reverse biased diode will reduce the electrical loads placed on the magnets.

This should increase the operational life of the magnets and reduce the frequency of rewinding the magnets, which is a costly and time consuming endeavor. The marginally increased rod drop time is still well within the 1 second safety limit found in the Tech Spec. However a 50.59 evaluation process and Reactor Safety Committee approval will be required before implementing a reverse biased diode circuit.

3.0 Results and Conclusions

3.1 The Final Build

The final build of the safety circuit encompasses three individual control circuits: SCRAM, Interlock, and Magnet circuits. They are constructed so that if any SCRAM mechanisms or Interlock mechanisms are in the trip condition the Magnet circuit will prevent the control rod magnets from energizing and de-energize the magnets should they be energized at the time. All of the components are strictly analogue and default to the off/SCRAM position. Using the components in this way prevents a failed wire connection indicating a false positive and assures that a loss of power to any circuit will cause the reactor to shut down.

3.1.1 SCRAM Circuit

For the 3 channels there are 6 SCRAMS as follows: Channel 1 (low), Channel 2 (period, high & low), and Channel 3 (high & low). In all of the high & low SCRAMS should a channels signal be below a low SCRAM set point or above a high SCRAM set point the associated relay will open cutting off magnet power and shutting down the reactor. The period SCRAM has to do with the reactor's period, the speed that the reactor is increasing in power by a factor of e. Therefore if the reactor is increasing in power too quickly (Currently set at 5 seconds for a factor of "e" increase) the accompanying relay will open and thereby cut power to the magnet control circuit and therefor the magnet themselves, shutting down the reactor. All the set points for these SCRAMs are defined by the "tech specs" table 3.1, see appendix. Should all the SCRAMs be in operable (non-SCRAM) condition a "master" SCRAM relay will be energized.

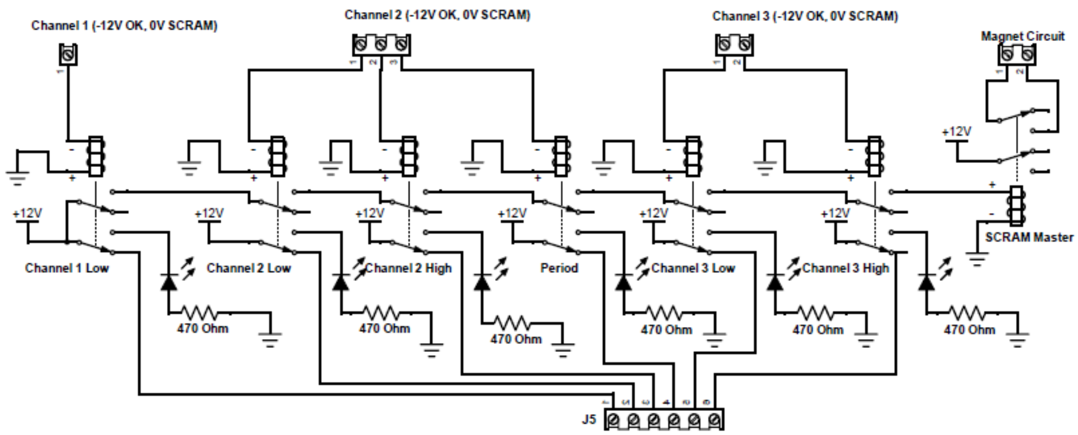


Figure 22. SCRAM Circuit (See Appendix A)

3.1.2 Interlock Circuit

The interlock circuit operates in much the same way as the SCRAM circuit but instead of being controlled by the reactor's channels it is instead controlled by the interlocks. There are four interlocks listed as follows: water level, water temperature, seismic, and rod interlock. Again all the interlock set points are defined by the "tech spec", and should all interlock conditions be satisfied a "master" interlock relay will be energized. If the "master" interlock relay is energized the magnets may be energized and should one of the interlock conditions change, such as in the event of an earthquake, power to the magnet circuit and rod drive magnets will be turned off automatically. The 470 Ohm resistors act as a current limiter for the LED it is connected to, insuring LED functionality and integrity.

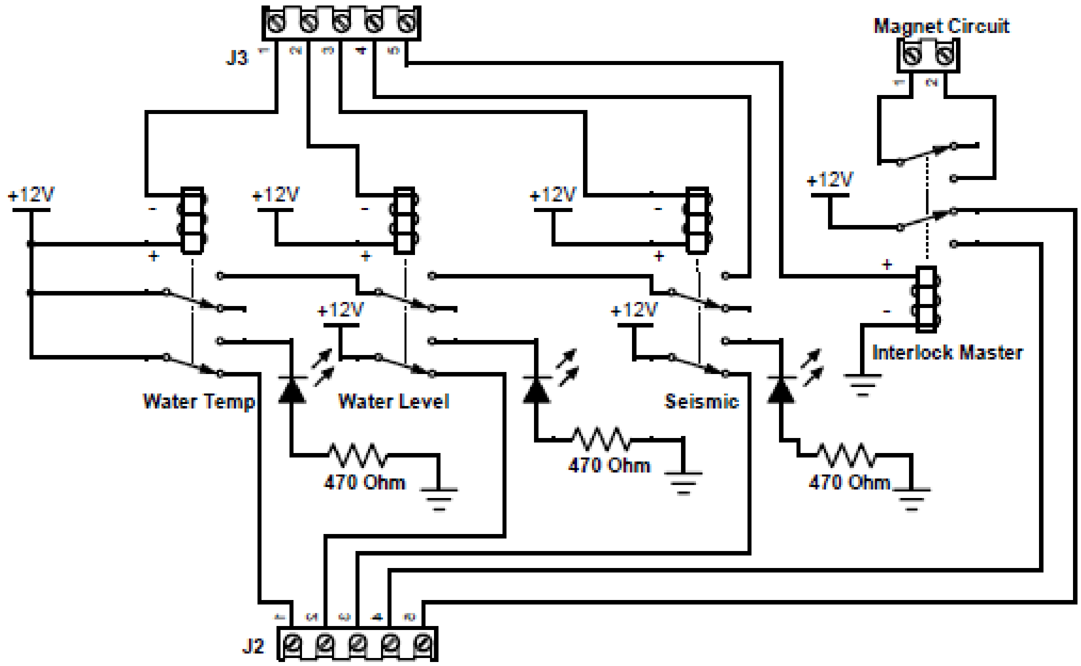


Figure 23. Interlock Circuit (See Appendix A)

3.1.3 Magnet Circuit

Both the interlock and SCRAM "master" relays must be engaged for power to be applied to the magnets via a push button controlled self-locking relay. The self-locking relay just allows the relay to remain closed without holding down the button, as can be seen in figure 24 below. The fuse is placed before the magnet in the circuit, as the only known failure mode is where a coil of the magnet shorts to ground. If the fuse were placed after the magnet in the circuit and the magnet failed it could still remain partially powered, making the potential problem more difficult to diagnose. It is important to point out that the new console will operate with the magnets to be wired in parallel (the old console is wired in series). Therefore the wiring will have to be vetted via 10 CFR 50.59, approved by the RSC, and then modified before the new console may be used.

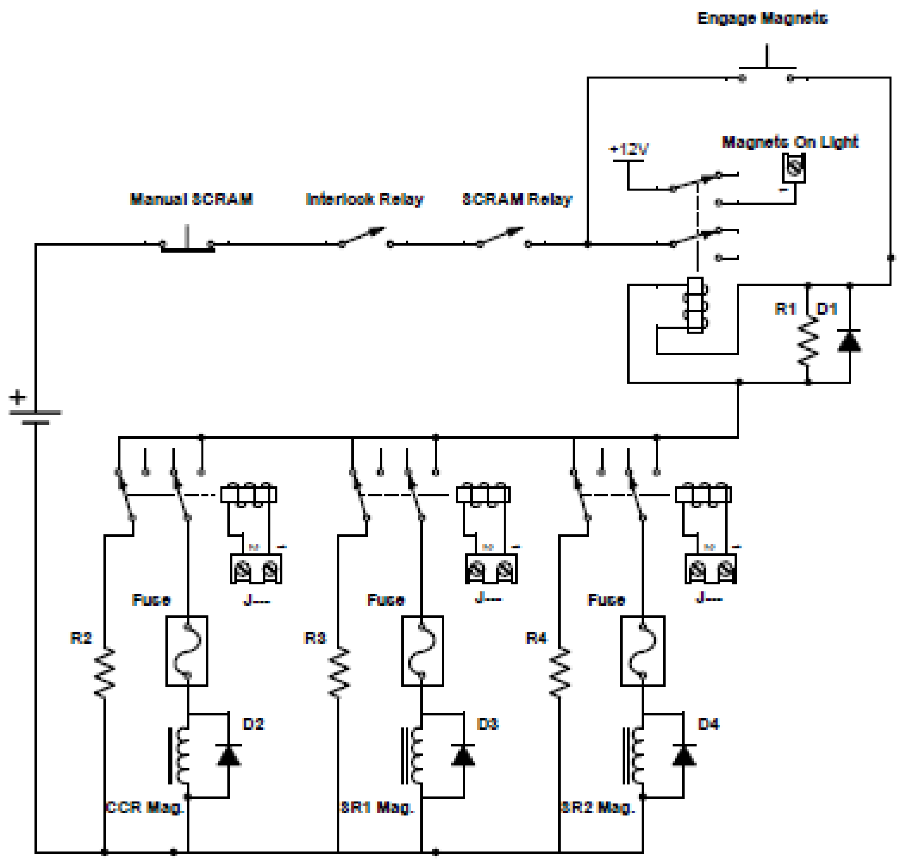


Figure 24. Magnet Circuit (See Appendix A)

3.1.4 Complete Modular Safety Circuit

The 3 circuit boards were bench tested to prove desired functionality and then soldered onto individual prototype boards with necessary signal cabling to be installed into the new console safety circuit drawer. Figure 25 below shows a comparison of the 3 layer PCB circuit and the 3 individual prototype boards that will replace it. The modular safety circuit will use the existing ribbon signal cable to interface with the rest of the console.

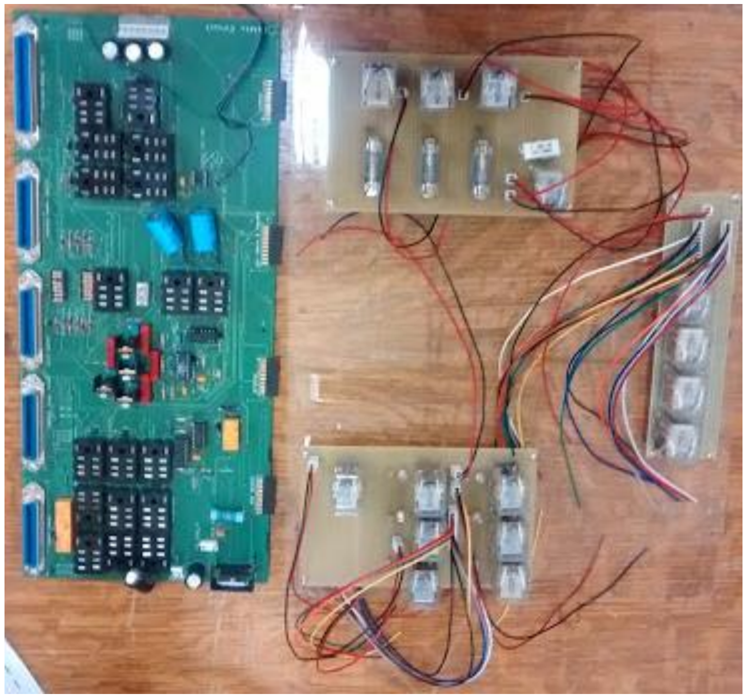


Figure 25. PCB Safety Circuit (left) Modular Safety Circuit (right)

3.2 Future Work

The SCRAM drawer of the new console has 8 multi-pin cables totaling 177 pins, many of which are unused “spares”. The connections at the top of figure 16 go to various parts of the new console and the lower section’s connections carry the signals for SCRAM conditions on the various channels. The cabling seen in the modular safety circuit of figure 25 will be spliced into distribution ribbon cable above and the SCRAM condition indicators below to complete the safety circuit.

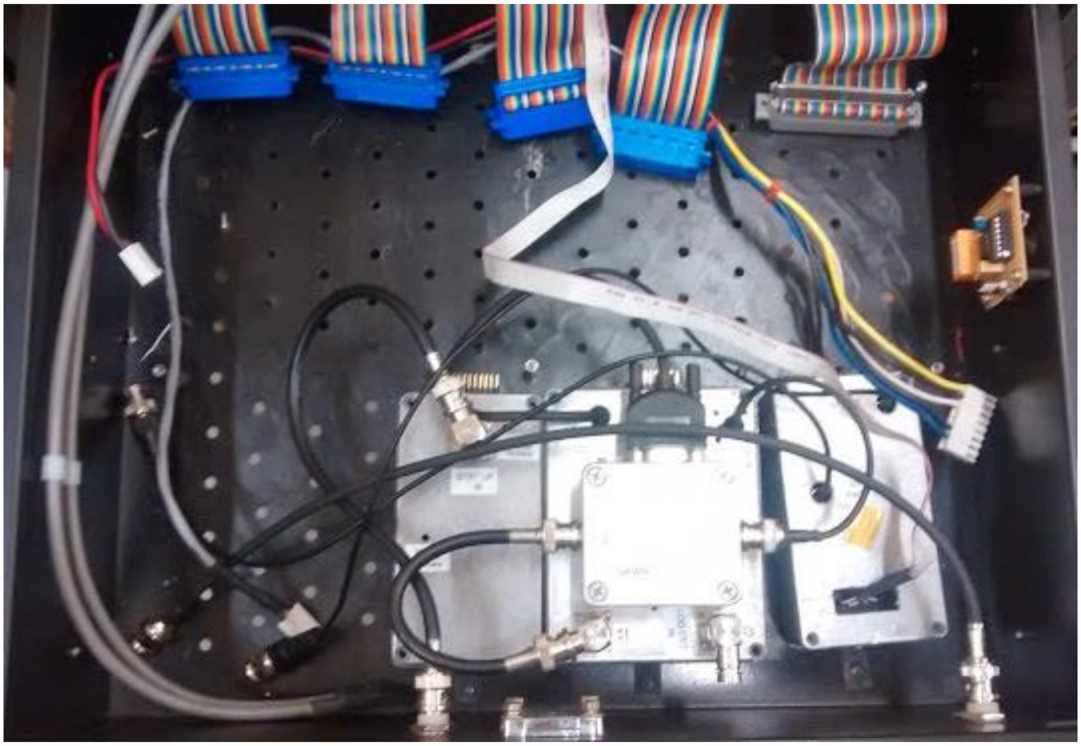


Figure 26. SCRAM drawer

Once all of the wiring is completed, every mechanism's functionality must be verified using the operational procedure 1 (OP-1) as a guideline. OP-1 is the startup procedure for the reactor where the functionality of every safety component is verified before starting up the reactor. The existing OP-1 will have to be rewritten for the new console and that new procedure the vetted through the 50.59 process. Numerous modifications will go through a 50.59 screening and many will require formal 50.59 evaluation. The additional wiring diagrams and figures developed in this safety circuit rebuild have been included in the appendices as supplemental information for the upcoming 50.59 screenings and evaluations. The redesign of the safety circuit itself and additional work surrounding it has made a clear path for the completion and use of the new console in operating the AGN-201.

References

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[2] All About Circuits,. 'Inductor Commutating Circuits : Diodes And Rectifiers - Electronics Textbook'. N.p., 2015. Web. 10 Feb. 2015.

[3] Safety Analysis Report of the Idaho State University AGN-201M Research Reactor. Pocatello : Idaho State University, 2003. Licesne No. R-110, Docket No. 20-284.

[4] Idaho State University. AGN-201 Technical Specifications. Facility Operating License, Number R-110. Docket No. 50-284 Amendment No.7. March 16, 2011.

[5] Montenegro, Daniel. 'Modern Control Console For The Idaho State University AGN-201 Nuclear Reactor'. Masters. Idaho State University, 2009. Print.

[6] Horowitz, Paul, and Winfield Hill. *The Art Of Electronics*. 2nd ed. New York: Cambridge University Press, 1989. Print.

[7] O-Connor, Scott "Control Rod Drive Logic Modification, Panel Design, and Proposed Check-Out and Change-Over Procedures for the ISU AGN-201" Masters. Idaho State University, 2002. Print.

[8] NRC Regulations Title 10, Code of Federal Regulations. (2015, April 14). Retrieved April 29, 2015, from http://www.nrc.gov/reading-rm/doc-collections/cfr/

Appendix A 50.59

10 CFR 50.59 Changes, Tests, and Experiments [8]

(a) Definitions for the purposes of this section:

(1) Change means a modification or addition to, or removal from, the facility or procedures that affects a design function, method of performing or controlling the function, or an evaluation that demonstrates that intended functions will be accomplished.

(2) Departure from a method of evaluation described in the FSAR (as updated) used in establishing the design bases or in the safety analyses means:

(i) Changing any of the elements of the method described in the FSAR (as updated) unless the results of the analysis are conservative or essentially the same; or

(ii) Changing from a method described in the FSAR to another method unless that method has been approved by NRC for the intended application.

(3) Facility as described in the final safety analysis report (as updated) means:

(i) The structures, systems, and components (SSC) that are described in the final safety analysis report (FSAR) (as updated),

(ii) The design and performance requirements for such SSCs described in the FSAR (as updated), and

(iii) The evaluations or methods of evaluation included in the FSAR (as updated) for such SSCs which demonstrate that their intended function(s) will be accomplished.

(4) Final Safety Analysis Report (as updated) means the Final Safety Analysis Report (or Final Hazards Summary Report) submitted in accordance with Sec. 50.34, as amended and supplemented, and as updated per the requirements of Sec. 50.71(e) or Sec. 50.71(f), as applicable.

(5) Procedures as described in the final safety analysis report (as updated) means those procedures that contain information described in the FSAR (as updated) such as how structures, systems, and components are operated and controlled (including assumed operator actions and response times).

(6) Tests or experiments not described in the final safety analysis report (as updated) means any activity where any structure, system, or component is utilized or controlled in a manner which is either:

(i) Outside the reference bounds of the design bases as described in the final safety analysis report (as updated) or

(ii) Inconsistent with the analyses or descriptions in the final safety analysis report (as updated).

(b) This section applies to each holder of an operating license issued under this part or a combined license issued under part 52 of this chapter, including the holder of a license authorizing operation of a nuclear power reactor that has submitted the certification of permanent cessation of operations required under § 50.82(a)(1) or § 50.110 or a reactor licensee whose license has been amended to allow possession of nuclear fuel but not operation of the facility.

(c)(1) A licensee may make changes in the facility as described in the final safety analysis report (as updated), make changes in the procedures as described in the final safety analysis report (as updated), and conduct tests or experiments not described in the final safety analysis report (as updated) without obtaining a license amendment pursuant to Sec. 50.90 only if:

(i) A change to the technical specifications incorporated in the license is not required, and

(ii) The change, test, or experiment does not meet any of the criteria in paragraph (c)(2) of this section.

(2) A licensee shall obtain a license amendment pursuant to Sec. 50.90 prior to implementing a proposed change, test, or experiment if the change, test, or experiment would:

(i) Result in more than a minimal increase in the frequency of occurrence of an accident previously evaluated in the final safety analysis report (as updated);

(ii) Result in more than a minimal increase in the likelihood of occurrence of a malfunction of a structure, system, or component (SSC) important to safety previously evaluated in the final safety analysis report (as updated);

(iii) Result in more than a minimal increase in the consequences of an accident previously evaluated in the final safety analysis report (as updated);
(iv) Result in more than a minimal increase in the consequences of a malfunction of an SSC important to safety previously evaluated in the final safety analysis report (as updated);
(v) Create a possibility for an accident of a different type than any previously evaluated in the final safety analysis report (as updated);
(vi) Create a possibility for a malfunction of an SSC important to safety with a different result than any previously evaluated in the final safety analysis report (as updated);
(vii) Result in a design basis limit for a fission product barrier as described in the FSAR (as updated) being exceeded or altered; or
(viii) Result in a departure from a method of evaluation described in the FSAR (as updated) used in establishing the design bases or in the safety analyses.
(3) In implementing this paragraph, the FSAR (as updated) is considered to include FSAR changes resulting from evaluations performed pursuant to this section and analyses performed pursuant to Sec. 50.90 since submittal of the last update of the final safety analysis report pursuant to Sec. 50.71 of this part.
(4) The provisions in this section do not apply to changes to the facility or procedures when the applicable regulations establish more specific criteria for accomplishing such changes.
(d)(1) The licensee shall maintain records of changes in the facility, of changes in procedures, and of tests and experiments made pursuant to paragraph (c) of this section.
These records must include a written evaluation which provides the bases for the determination that the change, test, or experiment does not require a license amendment pursuant to paragraph (c)(2) of this section.
(2) The licensee shall submit, as specified in § 50.4 or § 52.3 of this chapter, as applicable, a report containing a brief description of any changes, tests, and experiments, including a summary of the evaluation of each. A report must be

submitted at intervals not to exceed 24 months. For combined licenses, the report must be submitted at intervals not to exceed 6 months during the period from the date of application for a combined license to the date the Commission makes its findings under 10 CFR 52.103(g).

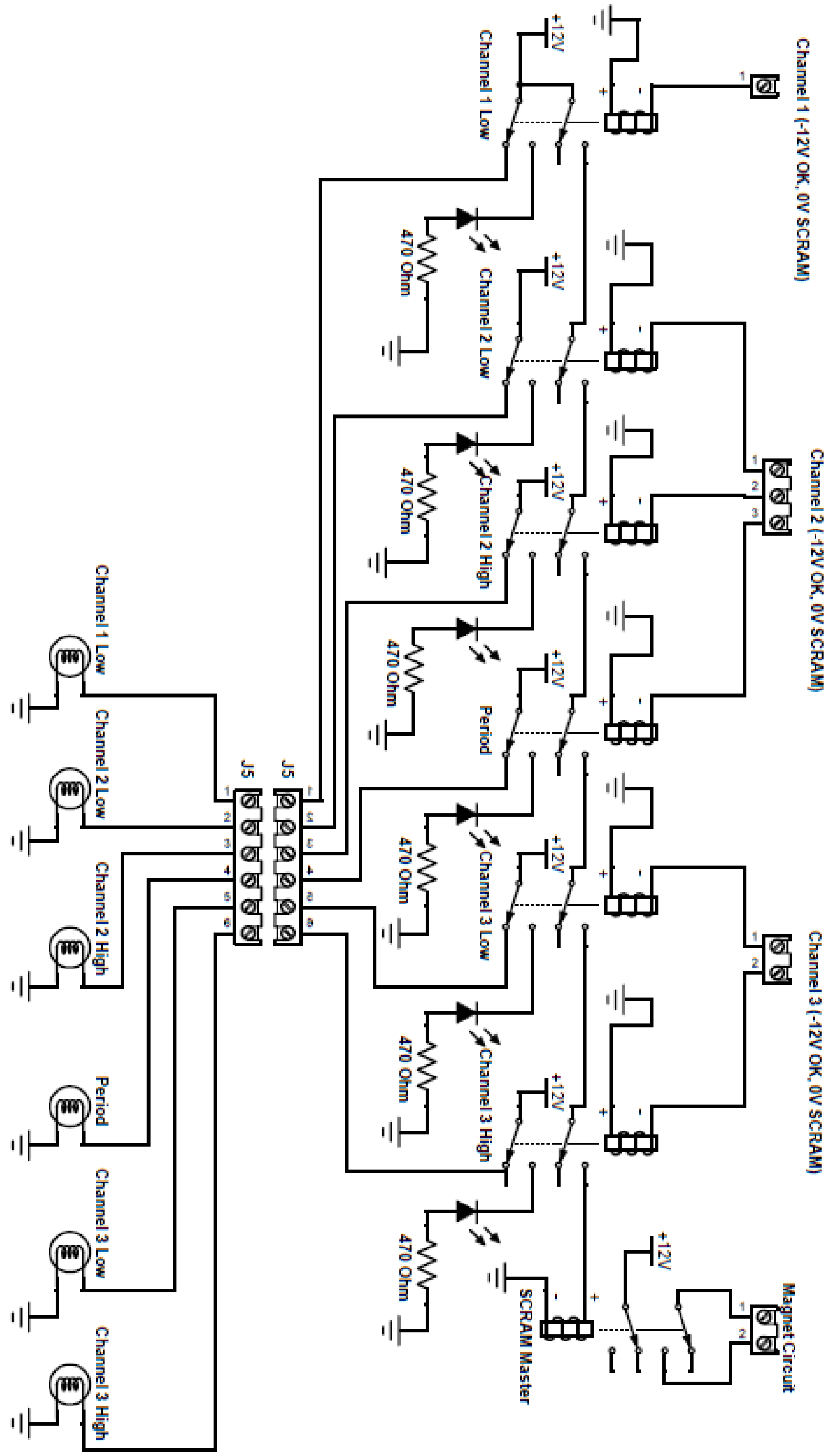
(3) The records of changes in the facility must be maintained until the termination of an operating license issued under this part, a combined license issued under part 52 of this chapter, or the termination of a license issued under 10 CFR part 54, whichever is later. Records of changes in procedures and records of tests and experiments must be maintained for a period of 5 years.

[64 FR 53613, Oct. 4, 1999, as amended at 66 FR 64738, Dec. 14, 2001; 72 FR 49500, Aug. 28, 2007]

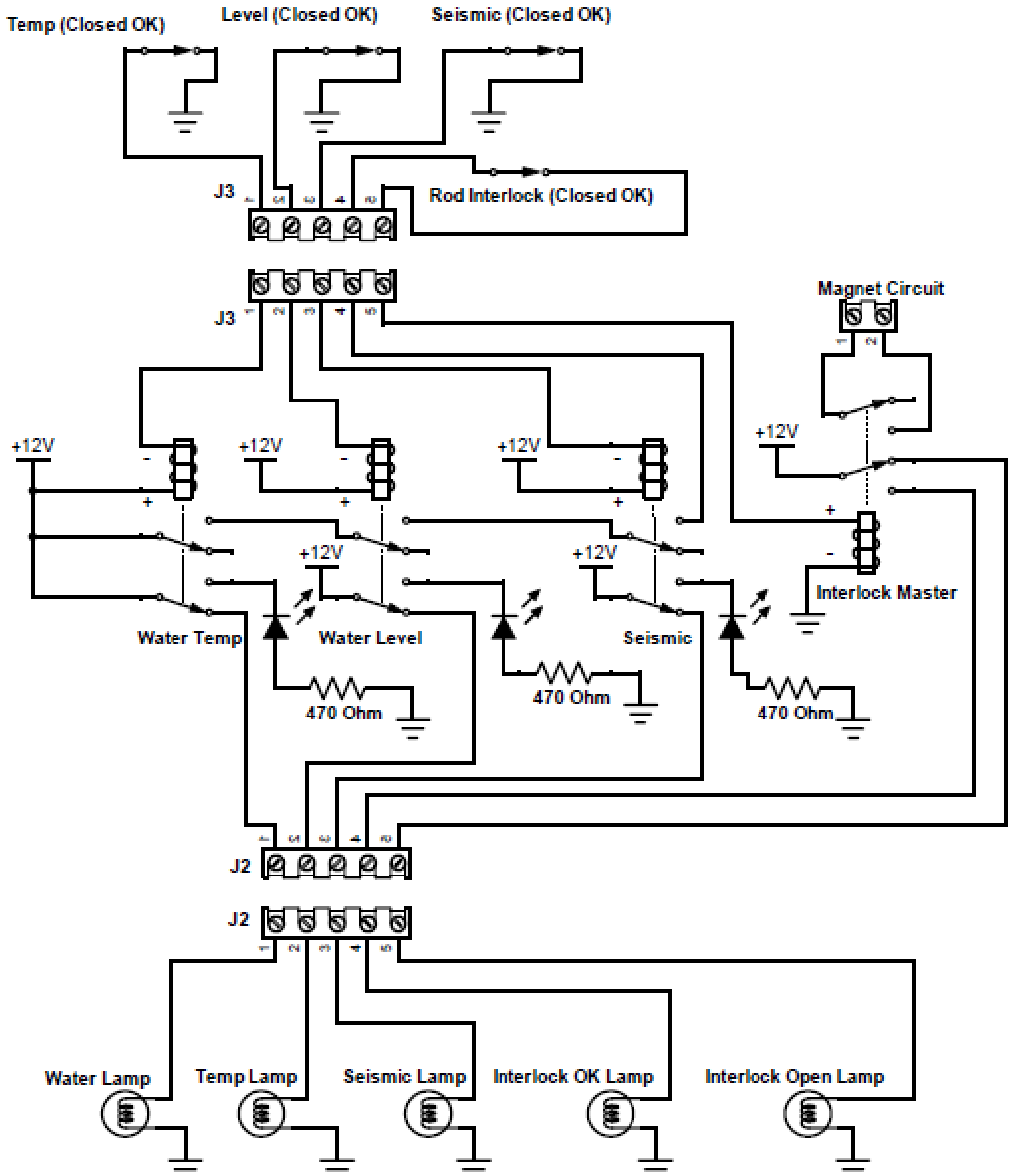
Page Last Reviewed/Updated Thursday, July 25, 2013

Appendix B Circuit Diagrams

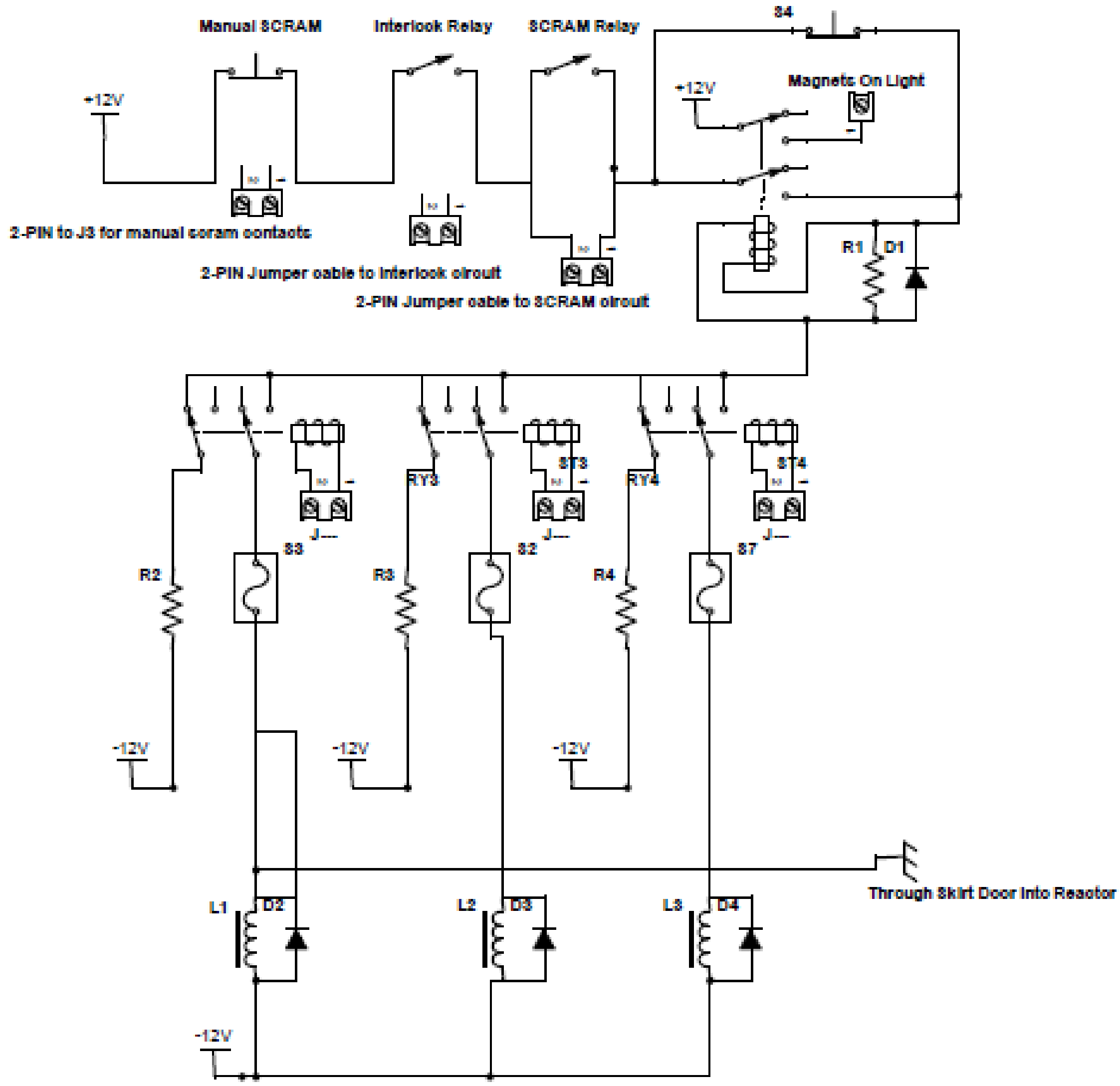
SCRAM Circuit



Interlock Circuit

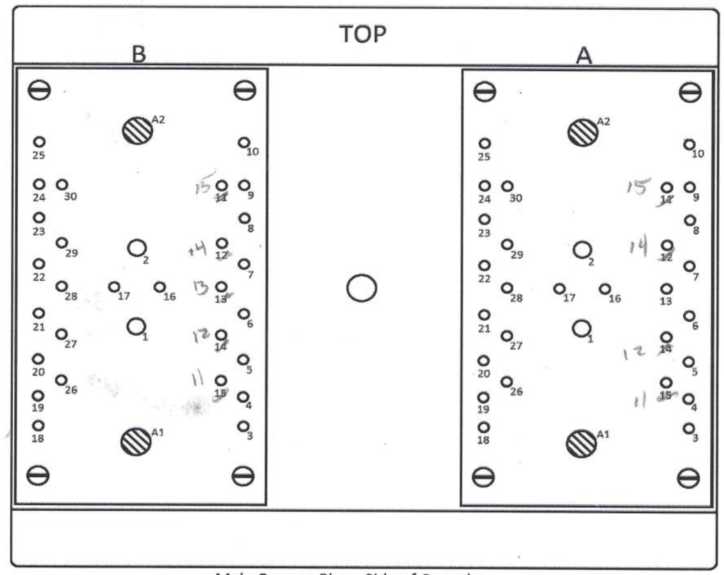


Magnet Circuit



Appendix C Wiring Diagrams

Reactor Cable Pin Outs



Male Cannon Plug - Side of Console

B

#	To	Description/Signal
1	TB3-37	SR2 Lower Limit Switch
2	TB3-36	SR2 Motor
3	TB3-44	SR2 CS
4	TB4-47	FR Upper Limit Switch
5	TB4-48	FR Motor
6	TB5-67	CR Upper Limit Switch
7	TB5-68	CR Motor
8	TB4-55	FR S3
9	TB4-56	FR S2
10	TB4-57	FR S1
11	TB4-52	FR Motor
12	TB4-53	FR Lower Limit Switch
13	TB5-71	CR Motor
14	TB5-72	CR Lower Limit Switch
15	TB5-75	Tank Ground
16	TB5-73	Interlock
17	TB5-77	CR CS
18	TB5-78	CR S3
19	TB5-79	CR S2
20	TB5-80	CR S1
21	TB2-30	SPARE
22	TB3-45	SPARE
23	TB2-27	Magnet
24	TB4-63	SPARE
25	TB4-64	SPARE
26	TB4-65	SPARE
27		
28		
29		
30		

A

#	To	Description/Signal
1	TB1-12	Magnet
2	TB5-83	CR-R1, FR-R2
3	TB5-84	CR-R2, FR-R1
4	TB1-3	Interlock
5	TB1-1	SPARE
6	TB1-2	SPARE
7	TB2-17	SR1 Upper Limit Switch
8	TB2-18	SR1 Motor
9	TB2-19	SR1 Motor +
10	TB1-9	SPARE
11	TB2-21	SR1 Motor
12	TB2-22	SR1 Lower Limit Switch
13	TB2-29	SR1 CS
14	TB3-32	SR2 Upper Limit Switch
15	TB3-33	SR2 Motor
16	TB1-10	SPARE
17	TB1-11	SPARE
18	TB2-20	SR1 Motor -
19	TB3-34	SR2 Motor +
20	TB3-35	SR2 Motor -
21	TB5-69	CR Motor +
22	TB5-70	CR Motor -
23	TB4-49	FR Motor +
24	TB4-50	FR Motor -
25	TB1-13	SPARE
26	TB1-19	SPARE
27		
28		
29		
30		

Skirt Door Distribution Board