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Guidance on Relay Chatter Effects

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Prepared for
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Lawrence
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ABSTRACT

A number of studies have recently been completed to examine the contribution of relay chatter to plant risk during a seismic event. Guidance has been given in the USI A-46 resolution program, the EPRI seismic margin methodology and its application to two trial reviews, and the Diablo Canyon PRA study. A number of test programs are currently underway to develop relay fragilities. These programs will identify which relays and breakers are particularly susceptible to seismic events. The present report summarizes the relay chatter issues, the state-of-the-art in the treatment of relay chatter effects in seismic PRAs and margin studies and provides guidelines on the seismic capacities of relays for the Severe Accident Policy Implementation. Relays needing particular attention are identified based on ongoing efforts at EPRI, BNL and LLNL. The minimum scope of systems for which relay chatter may be important will be identified by system analysts in the conduct of IPEEE.

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PREFACE

The U.S. Nuclear Regulatory Commission is conducting research to support their Generic letter for the Individual Plant Examinations for External Events (IPEEE) as part of the Severe Accident Program. This work was conducted by Lawrence Livermore National Laboratory under contract to the Nuclear Regulatory Commission. John T. Chen of the NRC Office of Nuclear Regulatory Research was the Project Manager for this effort. Robert C. Murray of Lawrence Livermore National Laboratory was the contractor Project Manager.

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EXECUTIVE SUMMARY

Lawrence Livermore National Laboratory (LLNL), under a Nuclear Regulatory Commission (NRC) funded project, is developing procedures for external event analysis as part of the Individual Plant Examination (IPE) of nuclear power plants in the United States. The aim of this examination is (1) to develop an appreciation of severe accident behavior, (2) to understand the most likely severe accident sequences that could occur, (3) to gain a more quantitative understanding of the overall probabilities of core damage and fission product releases, and (4) if necessary, to reduce the overall probabilities of core damage and fission product release by modifying, where appropriate, hardware and procedures that could help prevent or mitigate severe accidents [NRC Generic Letter No. 88-20, November 23, 1988].

Seismic event constitutes one of the main external events under consideration. The draft Generic Letter on IPE for External Events has stated that both seismic Probabilistic Risk Assessment (PRA) and Seismic Margin procedures are acceptable for identifying severe accident vulnerabilities. Relay chatter effects need to be considered in either of these options.

During an earthquake, relay chatter can affect the functionality of components required to bring the reactor to a safe shutdown condition. In a nuclear plant subjected to earthquakes, relays may chatter and send spurious signals to other electrical and control devices such as circuit breakers, motor starters or other relays. These spurious signals could cause a change of state which could trip breakers, change valve alignments or prevent pumps from starting when required, The consequence of these events would be that recovery actions by a plant operator from the control room or from local control panels may be required in order to return to the desired mode. Although relay chatter was identified as a credible failure mode in the early seismic PRAs, it was treated in a simplistic manner both from a systems standpoint and a from a fragility standpoint. The relay chatter was assumed to be recoverable and the relay fragilities were derived from generic test data. The depth of the relay issue was not fully understood until some time late and a fairly major research effort is underway within the industry to resolve the relay chatter concerns. In the seismic margin review methodology developed by the Expert Panel (Budnitz, et al 1985) the relay chatter issue was considered outside the scope.

A number of studies have recently been completed to examine the contribution of relay chatter to plant risk during a seismic event. Guidance has been given in the USI A-46 resolution program, the EPRI seismic margin methodology and its application to two trial reviews, and the Diablo Canyon PRA study. A number of test programs are currently underway to develop relay fragilities. These programs will identify which relays and breakers are particularly susceptible to seismic events.

The present report summarizes the relay chatter issues, the state-of-the-art in the treatment of relay chatter effects in seismic PRAs and margin studies and provides guidance on the seismic capacities of relays for the Severe Accident Policy Implementation. Relays needing particular attention are identified based on ongoing studies at the Electric Power Research Institute, Brookhaven National Laboratory and LLNL. The minimum scope of systems for which relay chatter effects may be important will be identified by systems analysts in the conduct of IPEEE.

1. INTRODUCTION

During an earthquake, relay chatter can affect the functionality of components required to bring the reactor to a safe shutdown condition. In a nuclear plant subjected to earthquakes, relays may chatter and send spurious signals to other electrical and control devices such as circuit breakers, motor starters or other relays. These spurious signals could cause a change of state which could trip breakers, change valve alignments or prevent pumps from starting when required. The consequence of these events would be that recovery actions by a plant operator from the control room or from local control panels may be required in order to return to the desired mode.

1.1 Description of Relays

A detailed description of relays is presented in Hardy and Griffin 1987. A relay is a device which, when energized by suitable inputs, responds to these inputs in a prescribed manner to indicate and/or isolate an abnormal operating condition. The two functional types of relays that are of principal interest for power plant systems are the protective relay and the auxiliary relay. IEEE 100 defines a protective relay as "a relay whose function is to detect defective lines or apparatus or other power system conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action." Protective relays protect components and circuits such as motors, blowers, air compressors, generators, centrifugal pumps and heaters from various types of abnormal conditions by tripping circuit breakers and switches. These relays protect against a short circuit, an overload, or other abnormal condition which causes the relay to open an auxiliary electric circuit and trip the associated switch or breaker. Auxiliary relays are devices which operate in response to the opening or closing of its operating circuit to assist another relay or device in performing a function.

Relays can also be classified on the basis of their operating mechanism. The relay operating mechanism is judged to be an appropriate basis for defining relay categories because the relay response to a vibratory loading is directly related to the configuration of the operating mechanism. The relay operating mechanism categories appropriate for seismic capacity purposes are given below together with brief descriptions of each.

1. Electromagnetic Attraction - Hinged Armature Type
2. Electromagnetic Attraction - Plunger Type
3. Electromagnetic Induction - Disk/Rotor Type
4. Electromagnetic Induction - Cup Type
5. Solid State
6. Pneumatic
7. Thermal-Acting Bimetallic Strip

The first two types of relays, hinged armature and plunger, operate on the principle of magnetic attraction. As shown in Figures 1-1 and 1-2, an armature is attracted to a coil or to the pole face of an electromagnet, resulting in the closing of a set of contacts. These relays may be used with either alternating current or direct current and are generally actuated by a single input quantity, either current or voltage.

Figures 1-3 and 1-4 illustrate the construction of the induction disk and the induction cup types of relays. The principle of operation is magnetic induction where torque is developed in a movable disk or rotor similar to torque produced in an induction motor. This principle can only be used with AC power. The induction disk relay operates with a metal disk of copper or aluminum rotating between the pole faces of an electromagnet. The induction cup relay uses a metal cylinder (with one end closed like a cup) which rotates in an annular air gap between the pole faces of electromagnets and a central core.

Solid state relays operate on a static basis similar to transistors and diodes. Pneumatic relays are fluid actuated and are generally associated with the protection and control of gaseous systems. Sudden pressure relays are examples of pneumatic relays. These are typically mounted on oil-filled transformer and reservoir tank. This relay operates when an internal fault creates a sudden pressure rise caused by either a gas build-up or oil surge. Figure 1-5 depicts the operating principal of the common Buchholz type sudden pressure relay. Thermal relays respond to thermal inputs and rely on displacements induced by a bimetallic strip.

1.2 Early Seismic PRAs

Relay chatter was identified as a credible failure mode in the early seismic PRAs. These early PRAs treated relay chatter in a very simplistic manner both from a systems standpoint and from a fragility standpoint. The depth of the relay issue was not fully understood until some time later and a fairly major research effort still exists within the industry to resolve the remaining relay chatter concerns.

1.2.1 Systems Considerations

Summaries of the systems aspects of the early seismic PRAs have been documented in several studies (Budnitz, et al., 1987 and Reed and Shiu, 1985). In the first probabilistic safety analyses conducted by utilities for Zion (Commonwealth Edison Company, 1981) and Indian Point (Power Authority of New York, 1982) relay fragilities were computed, but relay chatter effects were later dismissed as a credible mode of failure. Similarly, the Seismic Safety Margins Research Program (SSMRP) modeled the electrical components into the fault trees/event trees, but the assumption was made that relay chatter is always recoverable which is equivalent to omitting its treatment entirely in the analysis (Smith et al., 1981 and Bohn et al., 1983). The Limerick PRA (Philadelphia Electric, 1981 and Azarm, 1984) investigated the relay chatter issue in greater detail and concluded that the probability of failure on the part of the operator to reset the relays/breakers was greater than zero. The Limerick methodology treated operator errors under earthquake conditions as a possibility (due to the high-stress environment) which would result in the equivalent of a relay failure for those relays susceptible to chatter. Subsequent PRAs have considered relay chatter to be a realistic failure scenario and operator reset has not automatically been assumed to be possible. This effort on the review of relays in safety related systems has been shown to be fairly complex and extensive. A study done for Lawrence Livermore National Laboratory (LLNL) (Lambert, 1984) encompassed the review of over 500 electrical drawings to assess the earthquake induced relay effects on only a few nuclear systems in the plant.

1.2.2 Seismic Capacities of Relays in Early Seismic PRAs

In the early PRAs, fragility descriptions for relays were derived from test data obtained from the U.S. Army Corps of Engineers. These data consisted of a limited number of fragility tests and qualification tests conducted in support of the SAFEGUARD program.

In the SAFEGUARD program, comprehensive testing was undertaken to demonstrate acceptable reliability of power and process equipment installed in a hardened radar installation. A summary of the SAFEGUARD test program together with methodology utilized are presented in 3 reports (HNDDSP, 1972, 1973, 1975). The SAFEGUARD tests were designed to assess the reliability of the equipment when subjected to severe ground shocks resulting from nuclear attack.

In this program, off-the-shelf equipment was procured rather than procuring specially engineered equipment qualified for severe shock and vibration environments. The equipment was very similar to equipment installed in nuclear power plants and was procured in the same time frame as the procurement of equipment in older US plants. At that time, most manufacturers of commercial equipment were unsure of ultimate shock and vibration capacity of their products and did not have experience in qualification for shock and earthquake environments. It was therefore decided to conduct selected fragility and shock environment qualification tests on generic classes of equipment and develop the reliability of untested equipment by a pseudo-probabilistic methodology. Some 400 component and system tests were conducted in support of the qualification of some 30,000 critical items in the SAFEGUARD installation.

The tests of electrical instrumentation and control equipment often resulted in functional anomalies, such as relay chatter and breaker trip, which were common to many generic classes of equipment. The data were, consequently, used to develop fragility descriptions by failure mode, which could be combined for several generic classes of equipment.

Fragility descriptions for the following generic categories of equipment which contain relays were developed from the SAFEGUARD test data:

Switchgear
Instrument Panels & Racks
Control Panel & Racks
Relay Cabinets
Motor Control Centers
Breaker Panels

The SAFEGUARD program shock test environments were defined as undamped in-structure response spectra for various equipment locations. The spectra were not typical of earthquake spectra in that the shock spectra emphasized the high frequency, high spectral acceleration regions typical of blast loading and contained very little response to frequencies below about 5 Hz. Earthquake in-structure response spectra typically peak in the 2-10 Hz range with essentially zero amplified response beyond 20-25 Hz. The shock test data are felt, however, to have applicability to nuclear power plant equipment, especially that equipment that fails in a functional mode. It was generally observed during the shock test program that the lower frequency content of the shock spectra was the most significant contributor to malfunctions and certainly to structural failures. There is no positive way to separate out frequency effects from the test data since almost all tests were conducted with broadband shock spectra. A few tests were, however, conducted at single frequency input that demonstrated that electrical malfunction problems with large switchgear were due primarily to lower frequency input. The shock test data are not particularly applicable to equipment whose fundamental frequency is below 5 Hz. Fortunately, most equipment items of concern have fundamental frequencies considerably above 5 Hz and the shock test data are felt to be a good indicator of seismic resistance.

The terminology "shock test" was used in the SAFEGUARD program to describe a complex time history input of 2-5 seconds duration. The tests were not, as might be reasoned from the title, single shock pulse inputs. They were, instead, complex waveform tests which typically consisted of several superimposed sine beat inputs that would result in the required response spectrum. The predominant failure modes observed in the SAFEGUARD electrical and control equipment tests were relay chatter and breaker trip. The effects of chatter and trip do not necessarily result in equipment failure and must be addressed by the systems analyst.

The SAFEGUARDS test data were examined in the Seismic Safety Margins Research Program (SSMRP) (Kennedy et al., 1982). The relay chatter and breaker trip test results could not always be explained in a logical manner. Frequently, functional failures would occur at one test level but not at twice that level. If the test results on a particular item of equipment were more logical, i.e., the failure rate increased with acceleration level, cumulative distribution functions (fragility curves) could be derived directly from the test data. Unfortunately, this was not always the case, and insufficient data were available for any one generic category of equipment to average out the spurious behavior and result in a well-defined cumulative distribution function. Since two failure modes, relay chatter and breaker trip, were common to several generic categories of electrical and control equipment, the SSMRP study combined all test data to increase the database and result in more representative cumulative distribution function for failure modes common to several generic categories of equipment. Thus, the relay fragilities derived for the SSMRP and for the early PRAs (Zion and Indian Point) were all based on generic data which defined the capacities of the whole cabinet assembly when subjected to floor level accelerations. The resulting spectral acceleration capacities for cabinets containing relays was:

Median Spectral Acceleration Capacity	= 2.07 g
Random Variability	= 0.5
Uncertainty Variability	= 1.37

These variabilities are quite high, but they reflect the true nature of brittle failure modes like chatter on a wide variety of different relays. State-of-the-art PRAs should reduce this uncertainty by utilizing test data on the relays themselves and accounting for the amplification factor between the floor and the relay mounting location on the cabinet.

1.3 Diablo Canyon PRA

PG&E performed a relay chatter analysis to determine which relays are of interest by their possible unplanned change in state (PG&E, 1988). The objectives in that analysis were to:

- Identify contacts that affect components required for safe shutdown.
- Determine which contacts are subject to seismic relay chatter.
- Determine the consequences, if any, of contact chatter.
- If contact chatter is possible, determine how the operator can diagnose the problem.
- When the problem is diagnosed, determine the means available for the operator to correct the problem, such as resetting the control.

The process involved reviewing electrical schematic diagrams and other information and identifying each type of relay related to the systems of interest in risk assessment, relay contact type, its location within a building, as well as the normal and directed contact position, the possible result of chatter, and the consequences in terms of affected equipment. From this information, it was possible to screen out a very large group of relays that were considered susceptible to chatter with negative consequences. The resultant list of relays that could affect safe shutdown is presented in Table 1-1. Although specific relay model numbers and manufacturers were not available for this report, Table 1-1 gives valuable information in several areas:

- Denotes the types of systems for which relay evaluation would be required following the initial screening

- Identified the number of relays remaining after the initial screening

- Identified the physical locations (switchgear, panel, MCC, etc.) for these relays

- Identifies the results of the chatter

The seismic floor response spectra at Diablo Canyon are very high due to the postulated Hosgri earthquake (0.75 g peak ground acceleration) at the site. As a result, many plant-specific seismic vibration tests were done to meet the seismic qualification requirements placed on safety-related relays. Some relays were even modified to increase their capacity to resist seismic loads. The fragilities calculated for Diablo Canyon relays were, thus, based primarily on plant specific test data. This specific data had a much lower uncertainty associated with it than the uncertainty associated with the generic relay fragilities generated for earlier PRAs.

The fragility descriptions for Diablo Canyon critical electrical cabinets containing relays were based upon the documented results of their corresponding seismic qualification tests. The loss of function due to acceleration-sensitive failures (for example, relay chatter), when important, were generally based upon a conservative factor applied to the qualification acceleration test level. This factor was typically taken to be 1.5 and represents the margin to failure beyond the test level (Note: This is applicable only if no failures were observed at the test level). The structural capacities of the important electrical components were shown to be high, and thus have adequate factors of safety. The weakest of the electrical elements was in the 4160 V/480-V transformer which had a reported median and HCLPF capacities estimated (in terms of the average spectral acceleration) to be 5.34 g and 2.42 g, respectively.

Loss of function due to acceleration-sensitive failures were considered to be of sufficient importance to warrant fragility estimates for the following electrical cabinets:

Diesel Generator Control Panel
4-kV Switchgear
4-kV Safeguard Relay Panel
Main Control Boards
Hot Shutdown Panel

Except for the 4-kV switchgear, the chatter failure mode capacities, when evaluated by means of relay-specific Generic Equipment Ruggedness Spectra (GERS), are sufficiently high so as not to contribute significantly to plant seismic risk. The 4-kV switchgear, however, contains a large number of overcurrent relays, which were found to be primarily sensitive to vertical excitation. The median and HCLPF chatter failure capacities were estimated to be 3.53 g and 1.31 g (average spectral acceleration values), respectively (PG&E, 1988). The 4-kV switchgear chatter failure mode is recoverable by operator action, and the probabilities associated with operator action were included in the model of the system.

1.4 Seismic Margin Studies

Relay chatter has been identified as a potential failure mode affecting equipment functionality. The approach to the quantification of seismic margins in nuclear power plants (Budnitz, et al., 1985) did not address system effects from relay chatter, but rather recommended additional research work be performed to quantify these effects. Thus, the trial plant seismic margin review of the Maine Yankee Atomic Power Station (Ravindra, 1987) did not address relay chatter, but indirectly considered chatter effects when evaluating equipment functionality. However, subsequent to this work, an EPRI study (NTS Engineering, 1988) has proposed a recommended methodology for assessing the seismic ruggedness and the consequences of relay chatter if the plant is subjected to an earthquake greater than the design basis (seismic margin earthquake). The methodology parallels that of the USI A-46 generic implementation procedure, in that relays are identified and either determined to be susceptible to contact chatter or not. Development of corrective action plans and their implementation can be effected. The following presents this proposed methodology.

The EPRI methodology in evaluating the seismic margin of relays is developed as a series of steps whereby systems and relays are screened as to their criticality and sensitivity to seismic induced vibrations. A summary of these steps follows:

1. Determine the systems and components required to achieve and maintain the reactor in a safe shutdown condition following a seismic margin earthquake.

2. Determine the electrical power supply requirements, actuation and/or control circuits, and instrumentation needed to support the systems and equipment deemed essential in step 1.

3. Determine the potential effects of relay chatter to the specific equipment needed to maintain the plant in a safe shutdown condition.

4. Determine the specific electrical circuits in which relay chatter could be a problem (from step 3).

5. Perform a limited walkdown of critical control systems identified in steps 2-5 which have not been screened out.

6. Identify corrective actions for the remaining systems which could not be screened out.

7. Develop procedures for implementing the corrective actions.

Steps 1 and 2 identify the safe shutdown component list for the plant in question. This list consists of all components critical to the plant shutdown, but does not define all of the subcomponents contained within these components which are required. Step 3 defines these subcomponents i.e., specific relays whose chatter may have adverse effects on safe shutdown. Steps 4 and 5 are for the seismic capability assessment of these relays. Step 6 assesses whether an operator action can rectify the potential problems, and Step 7 entails relay replacement or new recovery procedures. Taken together, these seven steps represent a thorough assessment of the relay seismic adequacy issue as currently available.

Figure 1-6 presents these steps in the form of a flow chart.

Table 1-1: Diable Canyon Relays

Table 1-1: Diable Canyon Relays

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
1. Auxiliary Feedwater	51HH8/A,B,C	Prevent start of pump 1-2	SHH8-4-kV Switchgear cubicle 8
	51HF9/A,B,C	Prevent start of pump 1-3	SHF9-4-kV Switchgear cubicle 9
2. Auxiliary Saltwater	51HF8	Pump 1-1 stops	SHF8-Switchgear 4-kV bus F cubicle
	C-52HF8/CS	Pump 1-1 stops	CNAS-Control board ASW (VB1)
	R-52HF8/CS	Pump 1-1 stops	H01-Hot shutdown panel 1
	27XHFT	Pump 1-1 stops	SHF13-Switchgear 4-kV bus F cubicle
	43RHF88	Pump 1-1 stops	H01-Hot shutdown panel 1
	51HG6	Pump 1-2 stops	SHG6-Switchgear 4-kV bus G cubicle
	C-52HG6/CS	Pump 1-2 stops	CNAS-Control board ASW (YB1)
	R-52HG6/CS	Pump 1-2 stops	H01-Hot shutdown panel 1
	27XHGT	Pump 1-2 stops	SHF13-Switchgear 4-kV bus G cubicle
	43RHG6B	Pump 1-2 stops	H01-Hot shutdown panel 1

Table 1-1: Diable Canyon Relays (Continued)

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
3. Component Cooling Water	51HF12	Stop pump 1-1	SHF12-4-kV bus F switchgear cubicle
	43HF12	Stop pump 1-1	CNCC-Control board CCW
	C-52HF12/CS	Stop pump 1-1	CNCC-Control board CCW
	R-52HF12/CS	Stop pump 1-1	H01-Hot shutdown panel 1
	27XHFT	Stop pump 1-1	SHF13-4-kV bus F switchgear cubicle
	51HG12	Stop pump 1-2	SHG12-4-kV bus G switchgear
	43HG12/CS	Stop pump 1-2	CNCC-Control board CCW
	C-52HG12/CS	Stop pump 1-2	CNCC-Control board CCW
	R-52HG12/CS	Stop pump 1-2	H01-Hot shutdown panel 1
	27XHGT	Stop pump 1-2	SHG13-4-kV bus G switchgear cubicle
	51HH12	Stop pump 1-3t	SHH12-4-kV bus H switchgear cubicle

Diable Canyon Relays (Continued)

Table 1-1: Diable Canyon Relays (Continued)

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
3. Component Cooling Water (Continued)	43HH12/CS	Stop pump 1-3	CNCC-Control board CCW
	C-52HH12/CS	Stop pump 1-3	CNCC-Control board CCW
	R-52HH12/CS	Stop pump 1-3	H01-Hot shutdown panel 1
	27XHHT	Stop pump 1-3	SHH13-4-kV bus H switchgear cubicle
	421F-11CS	Close FCV-430, stop all flow	CNCC-Control board CCW
	421F-11/Close	Close FCV-430, stop all flow	SPF-480V MCC bus section 1F
	421G-28/CS	Open FCV-431, alter success criteria	CNCC-Control board CCW
	421G-28/Open	Open FCV-431, alter success criteria	SPG-480V MCC bus section 1G
	421H-16/CS	Close FCV-355, isolate Header C	CNCC-Control board CCW
	421H-16/Close	Close FCV-355, isolate Header C	SPH-480V MCC bus section 1H
	421G-36/CS	Close FCV-356, isolate flow to RCPs	CNCC-Control board CCW

Table 1-1: Diable Canyon Relays (Continued)

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
3. Component Cooling Water (Continued)	421G-36/Close	Close FCV-356, isolate flow to RCPs	SPG-480V MCC bus section 1G
	421H-18/CS	Close FCV-749, lube oil cooling	CNCC-Control board CCW
	421H-18/Close	Close FCV-749, lube oil cooling	SPH-480V MCC bus section 1H
	421F-23/CS	Close FCV-750, lose thermal barrier	CNCC-Control board CCW
	421F-23/Close	Close FCV-750, lose thermal barrier	SPF-480V MCC bus section 1F
	421G-23/CS	Close FCV-363, lube oil cooling	CNCC-Control board CCW
	421G-23/Close	Close FCV-363, lube oil cooling	SPG-480V MCC bus section 1G
	421H-17/CS	Close FCV-357, lose thermal barrier	CNCC-Control board CCW
	421H-17/Close	Close FCV-357, lose thermal barrier	SPH-480V MCC bus section 1H

Table 1-1: Diable Canyon Relays (Continued)

Table 1-1: Diable Canyon Relays (Continued)

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
4. Containment Spray	51HG7	Prevent pump 1-1 from starting	SHG7-Switchgear 4-kV bus G cubicle
	51HH9	Prevent pump 1-2 from starting	SHH9-Switchgear 4-kV bus H cubicle
	42-1G-48/CS	9003A to intermediate position	CNCS-Control board containment
	42-1H-6/CS	9003A to intermediate position	CNCS-Control board containment
	42-1G-48/aux	9003A to intermediate position	SPG-480V MCC
	42-1H-6/aux	9003A to intermediate position	SPH-480V MCC
5. Diesel Generator	OPT1-11	Lockout DG start (1)	GQD11-DG control panel
	OCT-11	Lockout DG start (1)	GQD11-DG control panel
	OPR-11	Lockout DG start (1)	GQD11-DG control panel
	JWTR-11	Lockout DG start (1)	GQD11-DG control panel
	ESR-11	Lockout DG start (1)	GQD11-DG control panel

Table 1-1: Diable Canyon Relays (Continued)

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
5. Diesel Generator (Continued)	OCR-11	Lockout DG start (1)	GQD11-DG control panel
	SDR-11	Lockout DG start (1)	GQD11-DG control panel
	51HF7	Block auto-start (1)	SHF7-4-kV switchgear bus F cubicle (one in each unit)

NOTE:

(1) Similar relays are of interest for the other diesel generators (that is, for diesels 12, 13, 21, and 22).

System	Relay ID	Chatter Result	Relay Location
6. Reactor Coolant System	PCV 474/CS	Start to open , automatically reclose	CNC2-Main control boards
	PCV 456/CS	Start to open , automatically reclose	CNC2-Main control boards
	PCV 455C/CS	Start to open , automatically reclose	CNC2-Main control boards

NOTE:

Block valve closure is not complete; valves may start to close but never close all the way.

Table 1-1: Diable Canyon Relays (Continued)

Table 1-1: Diable Canyon Relays (Continued)

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
7. Reactor Trip	NONE		

NOTE:

Reactor trip breakers will be tripped by seismic sensors; breakers may attempt to reclose but will be keep open by seismic trip signal and chatter in trip circuit.

System	Relay ID	Chatter Result	Relay Location
8. RHR	51HG8	RHR Pump 11 prevented from starting	SHG8-Switchgear 4-kV bus G cubicle
	51HH11	RHR Pump 12 prevented from starting	SHH9-Switchgear 4-kV bus H cubicle

NOTE:

Starting of pump does not hurt since nothing prevents miniflow recirculation. Also, all valves return to initial state so valve changes are not significant. The RWST low level relays are assumed not to lock in so that after the seismic event the RHR pumps would not be prevented from starting even if chatter involving these relays occurs.

Table 1-1: Diable Canyon Relays (Continued)

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
9. Safety Injection/ Charging (1,2)	51HF11	CH Pump 11 prevented from starting	SHF11-Switchgear 4-kV bus F cubicle
	51HG9	CH Pump 12 prevented from starting	SHG9-Switchgear 4-kV bus G cubicle
	51HF15	SI Pump 11 prevented from starting	SHF15-Switchgear 4-kV bus F cubicle
	L-52HF15/CS	SI Pump 11 starts	SHF15-Switchgear 4-kV bus F cubicle
	C-52HF15/CS	SI Pump 11 starts	CNSI-Control board SI (VBI)
	2HF15	SI Pump 11 starts	SHF15-Switchgear 4-kV bus F cubicle
	51HH15	SI Pump 12 prevented from starting	SHH15-Switchgear 4-kV bus H cubicle
	L-52HH15/CS	SI Pump 11 starts	SHH15-Switchgear 4-kV bus H cubicle
	C-52HH15/CS	SI Pump 11 starts	CNSI-Control board SI (VBI)
	2HH15	SI Pump 11 starts	SHH15-Switchgear 4-kV bus H cubicle
	42-1F-63/CS	VLV 8923A loss of RWST suction (3)	CNSI-Control board SI and a

Table 1-1: Diable Canyon Relays (Continued)

Table 1-1: Diable Canyon Relays (Continued)

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
9. Safety Injection/ Charging (1,2) (Continued)	42-1H-71/CS	VLV 8923B loss of RWST suction (3)	CNSI-Control board SI and a
	42-1F-49/CS	VLV 8821A prevent successful injection (4)	CNSI-Control board SI and a
	42-1F-31/CS	VLV 8821B prevent successful injection (4)	CNSI-Control board SI and a

NOTE:

(1) Valves 8835, 8974A, 8974B, and 8976 are not powered so they cannot change state.

(2) Charging pumps have oil pumps driven off motor shaft so it does not matter if auxiliary lube oil pump starts.

(3) Loss of RWST suction can fail pump if pump strats.

(4) Need to recover for successful injection at a later time.

Table 1-1: Diable Canyon Relays (Continued)

Relays of Interest to the PRA as a Result of Chatter by System

System	Relay ID	Chatter Result	Relay Location
10. 4kV/480V	51HF10	Breaker tripped; loss of 480V	SHF10-Switchgear 4-kV bus F cubicle
	51HG10	Breaker tripped; loss of 480V	SHG10-Switchgear 4-kV bus G cubicle
	51HH10	Breaker tripped; loss of 480V	SHH10-Switchgear 4-kV bus H cubicle
	51HF13	Breaker tripped; loss of 4 kV	SHF13-Switchgear 4-kV bus F cubicle
	51HG13	Breaker tripped; loss of 4 kV	SHG13-Switchgear 4-kV bus G cubicle
	51HH13	Breaker tripped; loss of 4 kV	SHH13-Switchgear 4-kV bus H cubicle
	51HF14	Breaker tripped; loss of 4 kV	SHF14-Switchgear 4-kV bus F cubicle
	51HG14	Breaker tripped; loss of 4 kV	SHG14-Switchgear 4-kV bus G cubicle
	51HH14	Breaker tripped; loss of 4 kV	SHH14-Switchgear 4-kV bus H cubicle

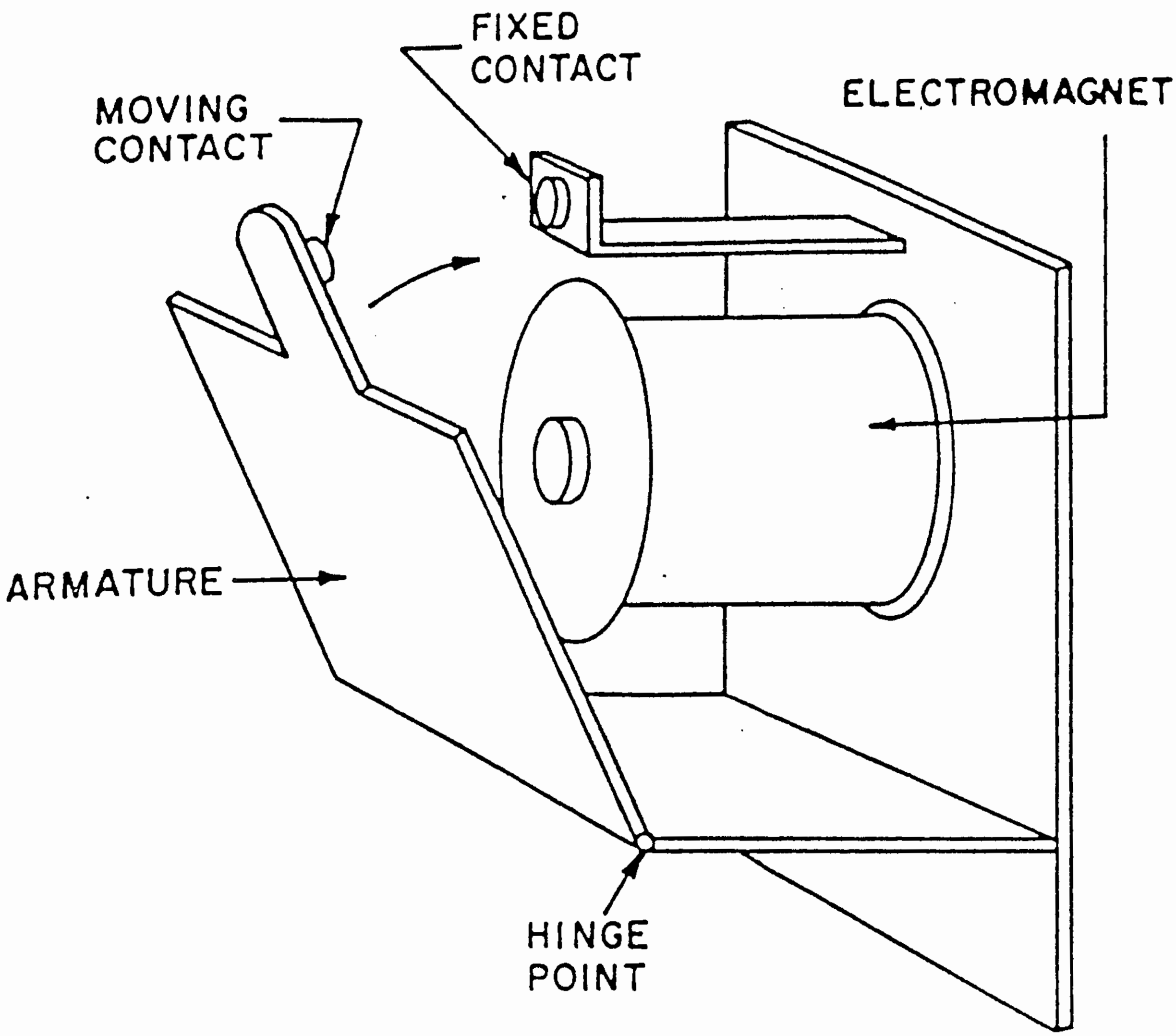

Figure 1-1: Hinged Armature Type Relay Operating Mechanism

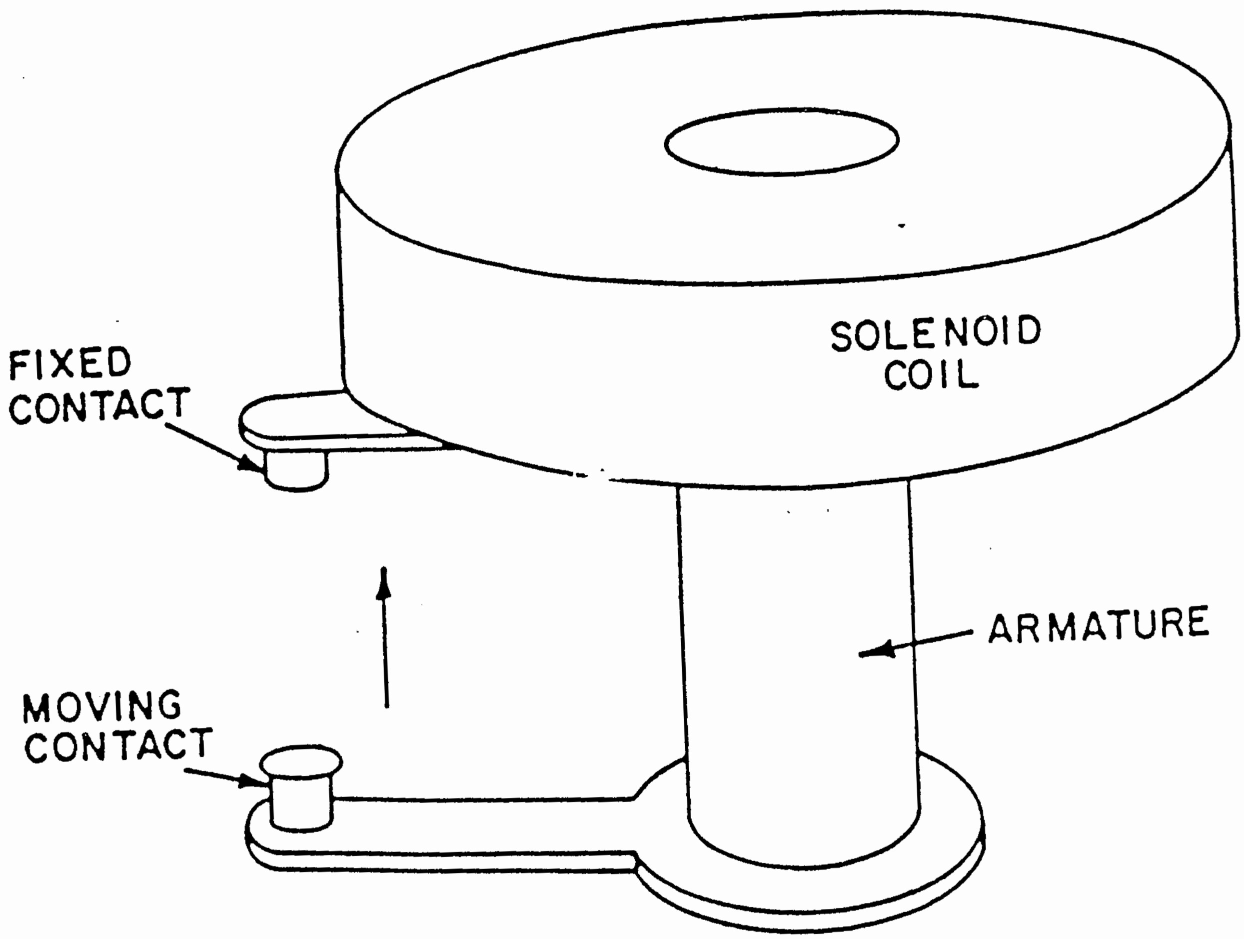

Figure 1-2: Plunger Type Relay Operating Mechanism

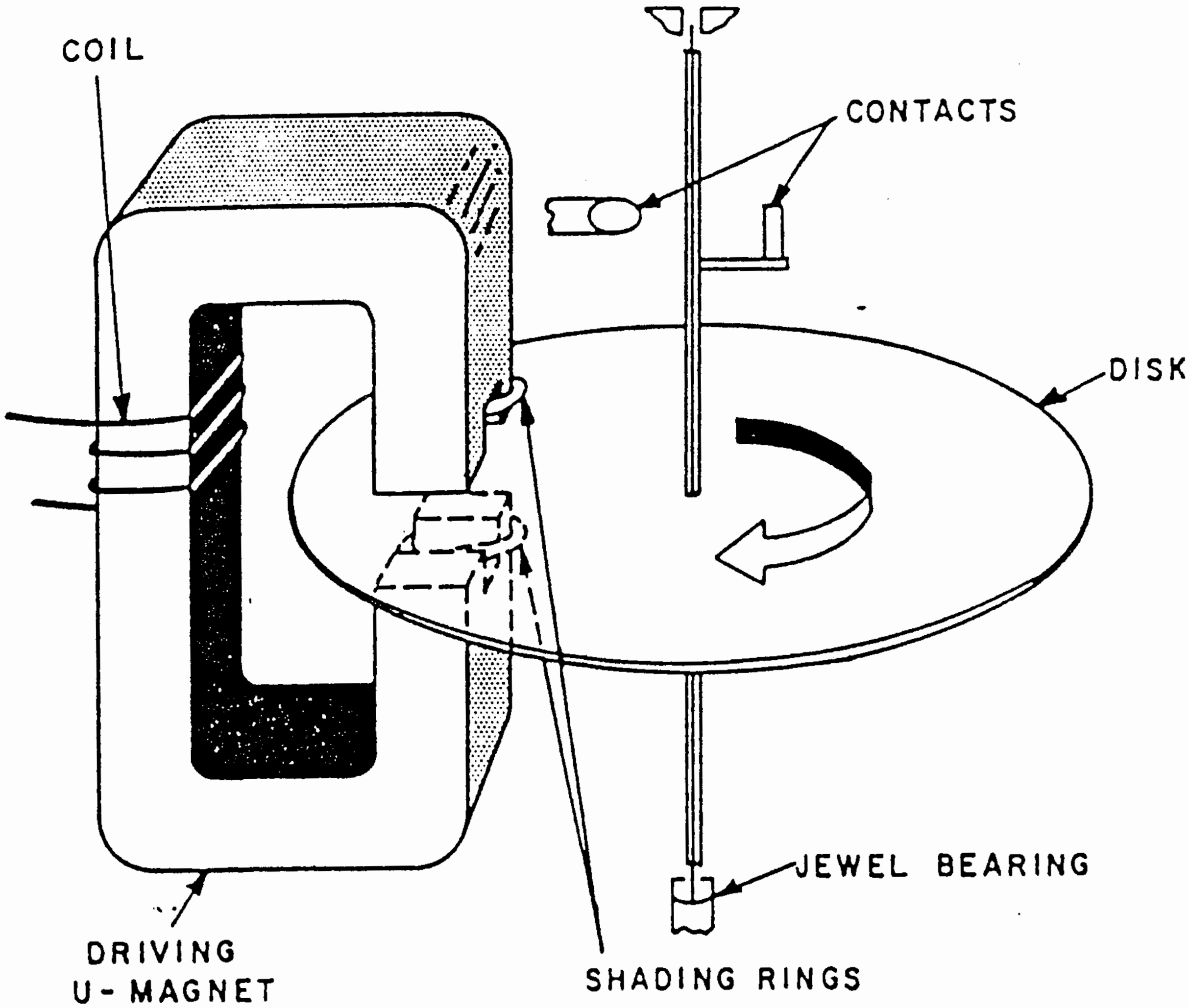

Figure 1-3: Induction Disk Type Relay Operating Mechanism

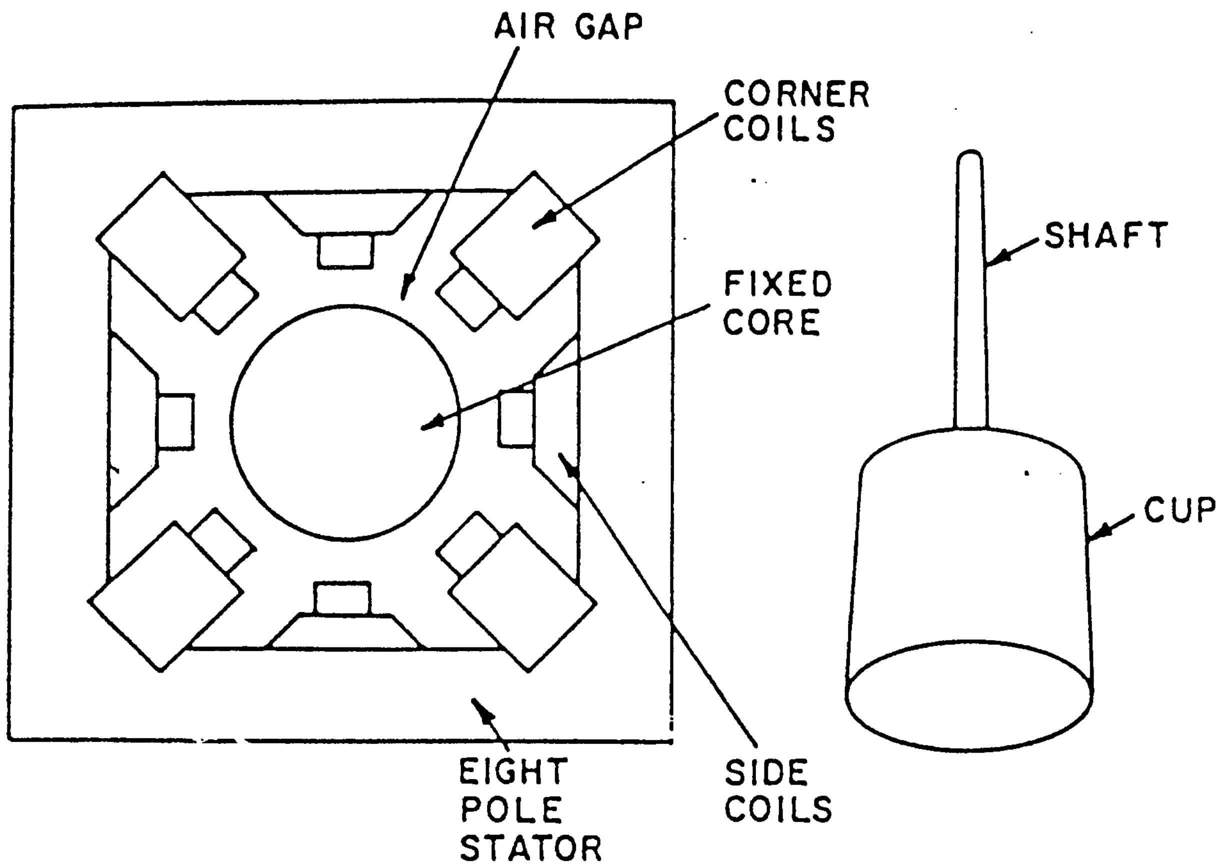

Figure 1-4: Induction Cup Type Relay Operating Mechanism

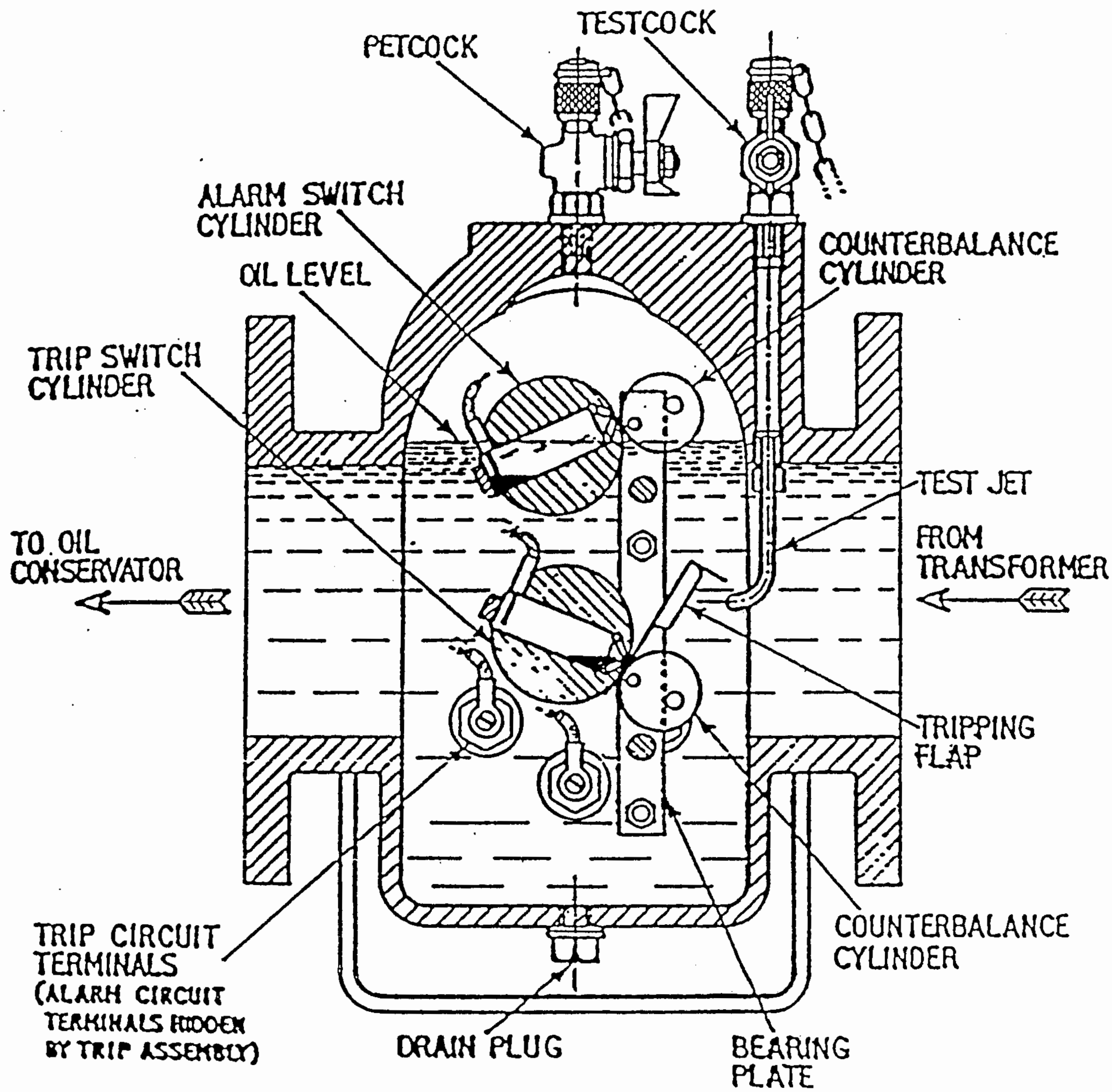

Figure 1-5: Schematic of Sudden Pressure Relay (Buchholz Type)

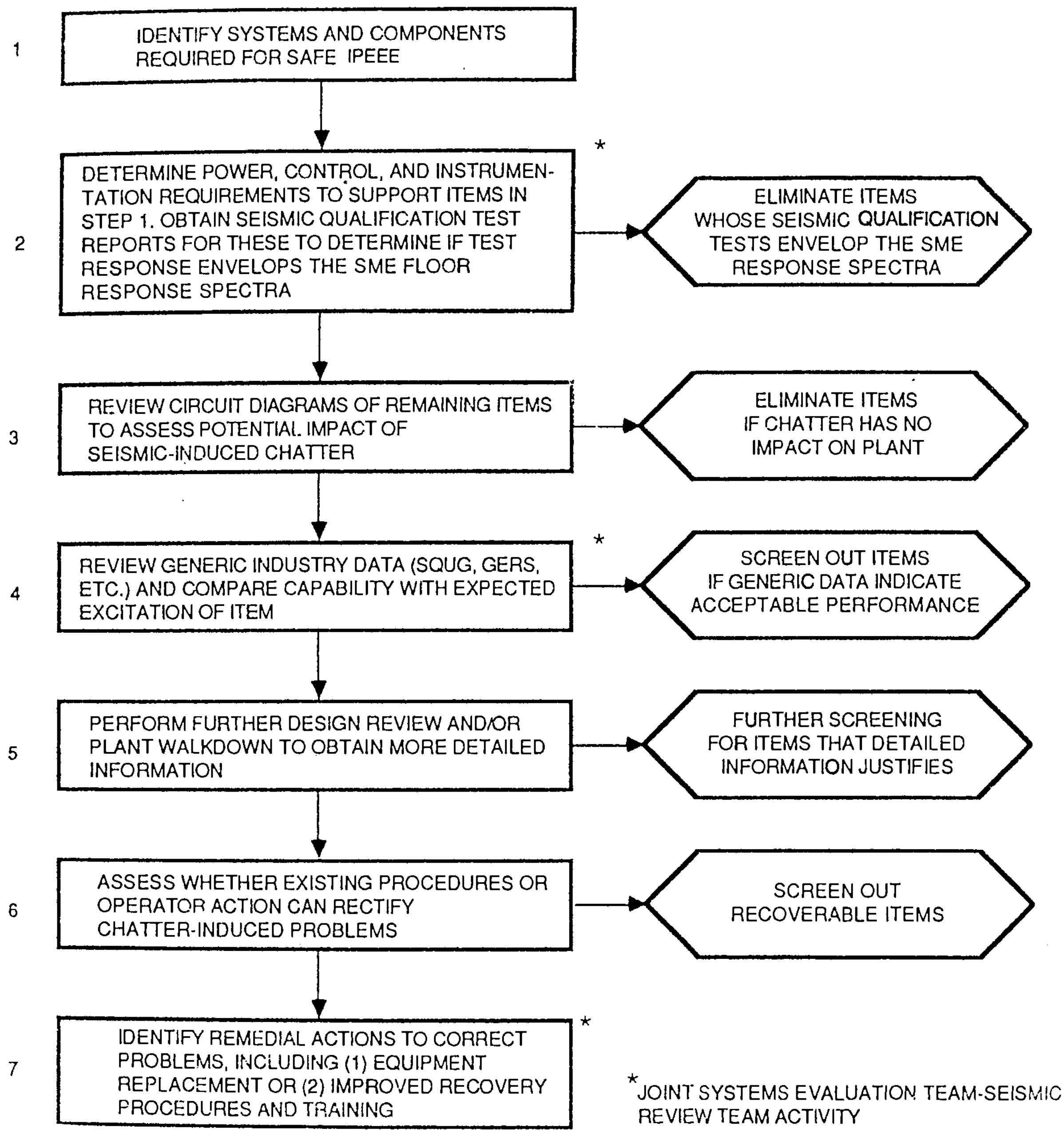

Figure 1-6: Steps in the Assessment of the Potential Effects of Electrical Relay or Contactor Chatter

2. SEISMIC CAPACITIES OF RELAYS

The seismic capacities of relays generally are derived from vibration test data conducted either individually on the relay or on a cabinet assembly in which the relay is mounted. Due to the complex dynamics involved in the chatter-type functional failures for relays, analysis methods are not considered appropriate. Earthquake experience data on relay performance is also not considered appropriate as the sole basis for a capacity calculation for the following reasons:

- The consequences of relay chatter in nuclear plant systems vs non-nuclear plant systems has not been adequately addressed.
- The inadvertent changes in function during/following earthquakes cannot always be observed in the experience database.

The database does provide unique "system" level seismic vibration results. Actual earthquake motions are transmitted into the components, and actual chatter durations which result in a change-of-state can be evaluated. The various methods available in determining relay seismic capacities are discussed below.

2.1 Earthquake Experience Data

Data on overall performance, specific failures, relay vulnerabilities, and other lessons learned from actual earthquake experience in power plants and other facilities which have undergone significant earthquakes have been documented in past studies (Hardy et al., 1986). This information is being used to identify unacceptable types of relays (e.g., specific relay models which are known to be susceptible to malfunctions or damage due to seismic shaking), unacceptable mounting arrangements, and other deficiencies. These unacceptable conditions are being evaluated in PRA's, seismic margin studies and in the resolution of USI A-46. The positive/success data from actual earthquake experience is also being utilized as a part of the relay screening procedure for the USI A-46 resolution program to verify the seismic ruggedness of an entire class, or sub-class, of relays up to certain acceleration limits. For example, it is possible that the experience data will demonstrate that certain classes of relays (e.g., energized auxiliary relays) are inherently rugged (both structurally and functionally) and require no further seismic evaluation for nuclear plants in moderate and low seismicity regions of the country (e.g., east of the Rocky Mountains). Relay experience data also provides valuable insights on operator response during actual earthquake conditions.

Hardy et al., 1986 specifically documents the performance of over 1,000 relays at selected data base sites; it is conservatively estimated that on the order of 5,000 relays exist in the total data base. These relays encompass a wide variety of types, models, manufacturers, mounting configurations, cabinet types, ages, system configurations and contact positions. In addition, the dynamic loads input to these relays are generated from a wide spectrum of soil conditions, peak ground accelerations and structural amplifications.

The results of earthquake experience data indicate that certain categories of relays are not adversely affected by earthquakes while other relay types can malfunction during an earthquake. The results of experience data show that the hinged armature, solid state, plunger and bimetallic strip relays have not malfunctioned (i.e., relay damage or spurious circuit breaker actuation) at the sites researched for Seismic Qualification Utilities Group (SQUG). The hinged armature and plunger relay types are used for auxiliary relay application in power plant systems. Earthquake experience data demonstrates that only a small percentage of data base relays contained in the remaining three relay categories (induction disk, induction cup and pneumatic sudden pressure types) have spuriously actuated during past earthquakes. Each of these three relay types are used in protective relay applications.

Spurious relay actuations result from either a vibration induced displacement of the moving contact which either opens or closes the contact or from a spurious signal from the associated protective or control circuit. There were 22 documented cases of spurious actuations of relays (Table 2-1) and five cases of relay damage in the experience data base review conducted for SQUG (Hardy et al., 1986). Each of these documented cases of spurious actuation or damage has been associated with protective relays. Of the 22 documented cases of spurious relay actuation, three were electromagnetic disk design, eleven were electromagnetic cup design, and eight were fluid actuated sudden pressure relays.

Induction Disk and Induction Cup Type Relays

Electromagnetic induction disk and cup relays have exhibited both spurious actuations and damage during past earthquakes. The operating mechanisms on both of these relay types are susceptible to horizontal vibratory input. The vertical shaft (axis of rotation) is mounted on precision jewel bearings which require only a small torque to rotate. It is therefore possible to make or break the contacts during an earthquake. The electromagnetic induction cup design has exhibited more spurious actuations than any other relay design. This is understandable since the contact operating mechanism for these relays is an eccentric cantilever protruding from the axis of rotation. Any significant acceleration perpendicular to this radial cantilever will rotate the contact and cause a spurious signal to be generated.

Sudden Pressure Relays

There have been eight documented cases of sudden pressure relays causing spurious actuations at data base sites. These sudden pressure relay actuations are caused by the seismic-induced sloshing of oil in transformers, and not by a malfunction of the relay itself (Figure 1-5). Depending on the particular application, these sudden pressure relays may either be connected to an annunciator circuit or they can be wired to trip the transformer off line. Sudden pressure relays can usually be reset in the control room, but for some designs they must be reset at the transformer. Due to the inherent design of sudden pressure relays and of the oil-fille and of the oil-filled transformers, these systems spurious actuations during earthquakes.

2.2 Qualification Tests

All safety related equipment in modern nuclear power plants are required to have had a seismic qualification performed before being accepted for use in the plant. The seismic qualification level is a function of the original seismic design basis for the plant site and also of the amplification of the ground spectra up to the equipment location. These qualification tests can very often be utilized as a basis for deriving fragilities for specific components, such as relays.

Since relay malfunctions in an earthquake do not lend themselves to an analytical solution, all of the qualification studies were performed using a vibration test of either the individual relay or of the entire cabinet housing the relay. Earlier tests used single frequency excitation. In fragility tests the acceleration level was progressively increased at each single frequency until malfunction occurred. For qualification tests, the frequency was progressively increased so that the relay was subjected to an entire frequency range. Sine beat inputs were used to reduce the amount of overexcitation typical of this type of test. Where the input frequencies are sufficiently close to assure that all component resonances are identified, these single frequency tests provide information which can be utilized to develop fragility levels. The effects of the multi-modes present in the component are conservatively estimated in deriving a fragility description referenced to a broad banded input spectrum.

More recent testing methods employ multi-frequency and multi-directional input accelerations. ANSI Standard C37.98 is a standard developed by the IEEE Power Systems Relay Committee to standardize the testing of relays. This standard recommends broad-band multi-frequency testing which produces a test response spectrum enveloping a spectral shape developed by the Committee. The spectral shape of the standard response spectrum from C37.98-1978 together with a sample test response spectrum (in this case a fragility response spectrum) is depicted in Figure 2-1. The shape of the spectrum was developed with the following reasoning:

- A flat peak spectral response between 4 and 16 Hz since this is expected to be within the natural frequency range of most of the nuclear plant panels to which they are mounted.

- Below 4 Hz the spectrum ramps to zero due to the low possibility of amplification in this frequency range.

- Above 16 Hz, there typically exists equipment and panel resonances; however, the seismic energy input in this range is significantly reduced and the resulting motion would be enveloped by the lower response spectrum amplitude levels in this range.

Section 2.3 contains further information relative to the ANSI/IEEE relay qualification criteria.

2.3 EPRI GERS Data

As part of an EPRI study (ANCO Engineers, 1987), Generic Equipment Ruggedness Spectra (GERS) have been developed in response to U.S. Nuclear Regulatory Commission (USNRC) Unresolved Safety Issue (USI) A-46, "Seismic Qualification of Equipment in Operating Nuclear Power Plants (Chang, 1984). The GERS represent a consolidation of available seismic test data on a wide variety of relays. The test data are used to develop the seismic ruggedness spectra (GERS) which define seismic acceleration levels below which relays can be expected to function without chatter or damage. The GERS provide seismic response spectra within which a class or subclass of relays has functioned properly during formal shake-table qualification tests.

In the EPRI study, the assessment of relay seismic ruggedness accomplishes several things:

1. Identification of the more common types of relay models and manufacturers.

2. Classification of relay types.

3. Evaluation of relay qualification tests and development of relay GERS.

Item 1 was addressed via a survey of relays in both control circuits and power protection circuits found in SQUG Utility Operating Plant Hot Shutdown Systems. The survey found the following with regard to relay function, mounting, and manufacturers:

- Function - distribution among functional characteristics was:

    - Timing - 29%
    - Latching and Locking - 22%
    - Sequencing - 16%
    - Other - 9%

- Mounting - socket or panel - mounted in accordance with manufacturer's recommendations; no unconventional relay mountings were reported.

- Manufacturers - as many as twenty different manufacturers were represented in each plant. Among these, three were identified as common:

    - General Electric
    - Westinghouse
    - Agastat

  A few of the plants indicated that 75% of their relays were General Electric or Westinghouse.

Two other industry surveys were conducted with generally consistent findings with the SQUG survey results presented above.

Relay designs were studied in order to establish common dynamic characteristics (such as contact mass, mounting arrangement and type) which might affect seismic ruggedness. The results were used to classify relays into like types (item 2). Three groupings with subclassifications are used in classifying the relays for GERS development:

- Contactors and motor starters
- Auxiliary
    - Electro-Mechanical
        * Panel mount
        * Socket mount
    - Pneumatic timing
    - Solid-State

- Protective
    - Electro-Mechanical
    - Solid-State

The relay GERS were developed using test data obtained in accordance with ANSI/IEEE C37.98 standards. The evaluation of the relay test data demonstrates that relay performance depends on the various relay types and models and the electrical performance which is influenced by the relay state and function. Five factors affecting relay performance emerged from the evaluation of the test data:

- Energized condition (operate mode)
- De-energized condition (non-operate mode)
- Normally open contacts
- Normally closed contacts
- AC or DC operation (coil)

Relay performance varies depending on the combined condition, (i.e., energized vs de-energized and normally open contacts vs. normally closed contacts). Given the above considerations, GERS were constructed for each condition. When possible, one screening GERS was used for all or several conditions. If the energized/de-energized seismic ruggedness levels differ substantially, two GERS were developed and if the normally open/normally closed contact performance differed substantially, both were used.

It should be noted that the test data used in developing the GERS is specific to the relay mounting location and does not represent potential amplification effects of the cabinet structure to the floor spectra. Additional studies are being conducted by SQUG, LLNL and BNL in establishing conservative generic equipment cabinet amplification factors to be used in conjunction with the relay GERS for assessing relay seismic ruggedness (see Section 3.2 of this report).

Seven GERS have been developed for relay categories and are intended to be used in assessing their seismic ruggedness. Table 2-2 lists the seven general GERS developed. The GERS have been established at levels below which chatter ($\leq$2ms duration) was known to occur. The low ruggedness relays have been excluded from determining these Table 2.2 values. These low ruggedness relays are defined in Table 3-1. Figures 2-2 and 2-3 illustrate two examples of GERS curves.

2.4 LLNL/Brookhaven Fragility Data

Current seismic fragility data for relays using existing test data has essentially followed two different approaches: (1) Whole equipment components are shake table tested and functionally monitored during and after the tests. The relays within these components are inherently addressed in the test results as the failure levels associated with contact chatter are identified during the testing process. (2) Individual seismic fragility tests are conducted for individual relays or classes of relays. The test results from this approach reflect the actual relay fragilities; however, this approach does not address in-cabinet amplification effects.

Both the Brookhaven National Laboratory (Bandyopadhyay, 1987) and the Lawrence Livermore National Laboratory (Holman, 1987) are performing studies on the seismic fragility of equipment components by using existing test data. While both laboratories are conducting whole equipment component seismic fragility studies, only Brookhaven is performing seismic fragility evaluations of individual relay types. The BNL study is considering typical relays associated with the safe shutdown logic of nuclear power plants.

The BNL test program (Wyle Laboratories, 1989) consisted of single-axis sine dwell testing, single-axis sine sweep testing, and single-axis, biaxial and triaxial random multifrequency testing. The sine dwell tests were performed to establish specimen unique fragility-level profiles for worst case axes, contacts, and test frequencies for each relay. Fragility level was defined as the maximum possible input acceleration at which chatter on the electrically-monitored relay contacts did not exceed a duration of two milliseconds. The sine dwell fragility levels were then utilized to derive the Required Response Spectrum shapes for the random multifrequency tests. The specimens were electrically powered and operated during the test program. Additionally, selected relay contacts of each relay were electrically monitored as required to define each relay's unique fragility characteristic.

The fragility results for several equipment component classes evaluated by both laboratories include:

- 4160 Volt Metal-Clad Switchgear
- Safeguard Relay Boards
- Potential Transformers
- Emergency Light Battery Racks
- Station Battery and Rack
- Motor Control Centers
- Switchboards
- Panelboards
- Power Supplies

The database of seismic fragility results for each equipment component class are prescriptive in nature. Each equipment class identifies certain parameters for use in establishing the applicability of the particular data set to the evaluated component. Typical parameters include the equipment description (sample number, size, weight, etc.), test description (single axis-single frequency, biaxial, etc.), functional tests performed and monitored (sub-components monitored and parameters measured), and extent of data applicability.

The fragility results are presented in terms of the median peak ground acceleration, average spectral acceleration (within a specific frequency range) and HCLPF capacity descriptors. Breaker, relay or contact chatter is noted for each test and becomes the level at which the fragility estimates are based. Table 2-3 presents a summary of fragility test results for switchboards.

2.5 Open Issues Relative to Relay Capacities

The relay capacity topic is currently still being researched on several fronts and there are several issues which have not been completely resolved. Two of the more prominent of these issues include relay vintage and chatter duration. The relay vintage issue involves the use of test data conducted for newer relays to develop fragilities for "identical" relays of an older vintage. Research into the changes in these relays over the course of time reveals that many relays have not changed from a capacity standpoint over the years, yet other models of relays have. The EPRI relay project is researching methods to identify those older relays for which the vintage issue is pertinent.

The chatter duration issue relates to the conservatism included in the specific relay tests conducted according to IEEE standards. Current testing criteria require the monitoring of chatter on all critical contacts and consider failure to occur at 2 milliseconds of chatter duration. 2 ms chatter duration is conservative in most relay logic configurations and an increase in allowable duration from 2 ms to the actual duration threshold (e.g. 10 ms) can, for some relays, increase the fragility level tremendously. This chatter duration question is difficult to resolve due to the complexity in testing complete systems to determine actual system failure levels, or in defining accurate chatter duration thresholds for each relay logic configuration. The EPRI program is also researching this issue of chatter duration, but it is not considered probable that the inherent conservatism in this low chatter duration will be resolved without considerable time, energy and resources.

Table 2-1

Spurious Relay Actuations Documented in the Earthquake Experience Database

Relay Type Function	Relay Type Structural	Number of Spurious Actuations
Auxiliary	1) Armature	0
Auxiliary	2) Plunger	0
Protective	3) Disk/Rotor	3
Protective	4) Cup	11
Auxiliary or Protective	5) Solid State	0
Protective	6) Pneumatic (fluid actuated)	8
Protective	7) Thermal	0
		22

Table 2-2

Summary of GERS for Relays*

Relay Category	Spectral Acceleration** Energized (G)	De-energized (G)
Contactor***	6.0	6.0 main contacts 4.0 auxiliary contacts
Pneumatic timing	10.0 4.0 transitional	6.0
Auxiliary Relay - Socket	10.0	4.0
Auxiliary Relay - Hinged Arm	10.0	5.0
Protective Relay 1	5.0	5.0
Protective Relay 2	14.0	8.0

* These values apply to a certain category of relay models. Refer to ANCO, 1987 for specific coverage details.

** Values are for $\leq$2ms chatter duration, 5% damping and the 4-16 hz frequency range.

*** The contactor values have changed to be 4.5g for both energized and unenergized conditions in the new ANCO, 1988 report.

Table 2-3

Summary of Switchboard Fragility Test Results

Test Specimen No.	Contact Chatter Monitored	ZPA in "g"	ASA @ 2% in "g"	Remarks
1	Breaker and N/O Relay > 2ms	1.0	2.0	No malfunction
2	Breaker > 1ms	1.0	-	No malfunction
		3.4	4.3	Mounting weld broke. No electrical malfunction
3	Relay and CB aux Contact > 20ms Power Circuit > 2ms	1.4	-	No malfunction
		2.5	6.9	Several relays chattered; no other malfunction
4	Breaker	4.1	10.3	No malfunction
5	Breaker > 1ms	3.4	4.3	No malfunction
6	Switch and Motor Starter (Inadequate Monitoring of Starter)	2.6	7.5	No malfunction
		4.1	10.4	Motor starter chattered

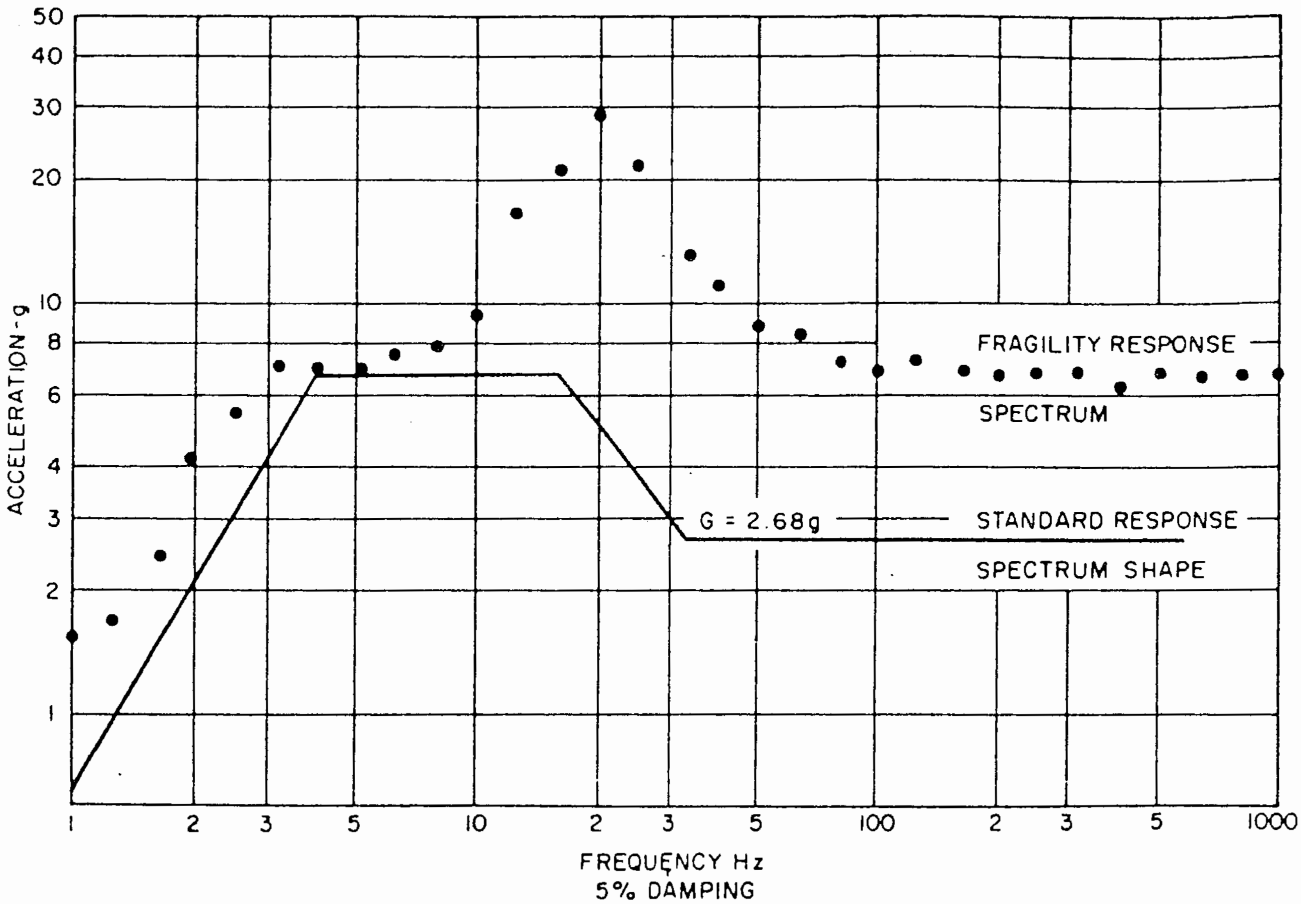

Figure 2-1: Standard Response Spectrum for Relays from ANSI/IEEE C37.98

RELAY MODEL	DATA CURVE	GERS
GP	1	C
ML	2	C
TR	3	B

ANSI/IEEE
'37.98-1978

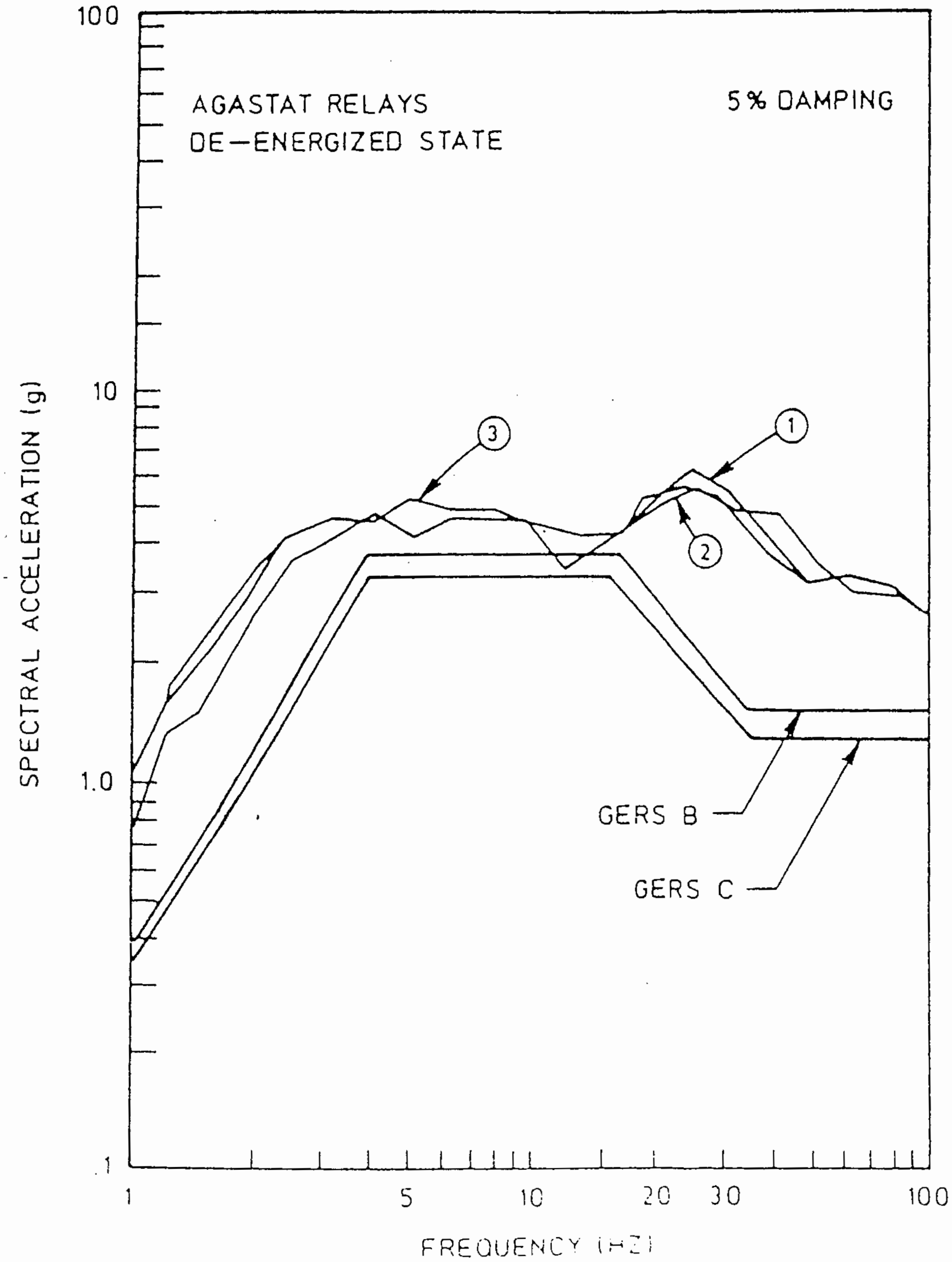

Figure 2-2: Comparison of GERS with Available Fragility Data for Agastat Relays in the De-energized State

ENERGIZED AUXILIARY RELAY (HINGED ARMATURE)
GERS IDENTIFICATION

RELAY MODEL	CONTACT CONFIGURATION	
	NORMALLY OPEN	NORMALLY CLOSED
HFA (AC/DC)	A	A
HEA	B	B
HMA (AC/DC)	A	A
HGA (AC)	B	B
HGA (DC)	C	B

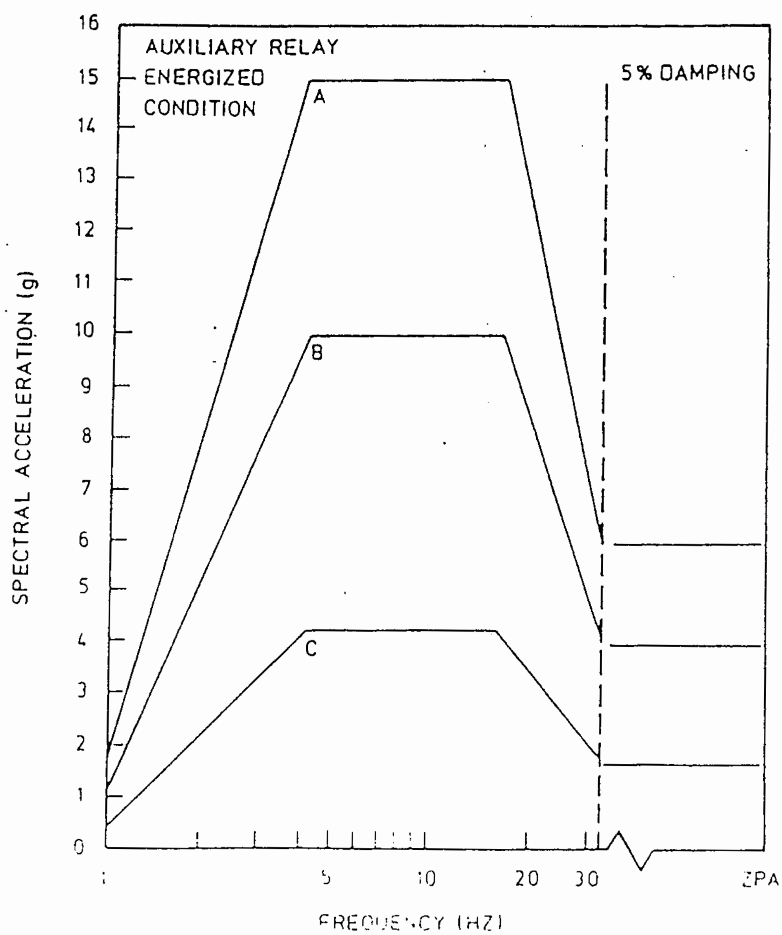

Figure 2-3: GERS for Auxiliary Relays (Energized)

3. USI A-46 RELAY RESOLUTION APPROACHES

3.1 Background

One of the important findings of early surveys of power plants which had experienced strong motion earthquakes was that electrical relays occasionally chattered during the earthquakes (sometimes causing trips of systems and/or equipment). Unfortunately, it was sometimes difficult, after the fact, to identify those relays which malfunctioned and those which did not. Nonetheless, it was clear from the past performance of conventional plants in strong earthquakes that major system unavailability or other abnormal plant performance, as a result of relay chatter or change of state, did not occur.

Faced with these findings, SQUG concluded that a different approach was required for the evaluation of seismic functionality of important electrical relays and similar contactors and switches to resolve USI A-46. A project was undertaken by EPRI (MPR, 1987) to develop an approach with a two-part screening process consisting of the following:

- A system and electrical circuit analysis which identifies those relays (and other contactors) whose function is essential during and immediately after an earthquake, and

- Evaluation of the seismic ruggedness of the essential relays using relay ruggedness data (e.g., GERS), together with guidelines to estimate the seismic demand at specific relay locations.

The relay screening procedures take credit for the fact that an earthquake, unlike other postulated design basis accidents, has a short duration (typically less than one minute) and that most safe shutdown equipment is not required to function during this brief period of shaking. For this equipment, relay functionality is important only for certain relays which could trip or otherwise disable important circuits. Even in these cases, relay functionality is not required if operator action is possible after the earthquake to restore any electrical circuits which may be tripped during the earthquake.

The relay evaluation approach has been used on two trial plants and has demonstrated the capability of reducing the number of relays in safe shutdown systems which require seismic qualification to a relatively small number (tens rather than hundreds or thousands). It should be noted that the Hatch trial plant seismic margin review expended considerable resources in reducing the relay list to a manageable number. We anticipate that this number of engineering hours will be reduced on future plants as the methodology is refined and as engineers better understand the trade-offs of qualifying relays versus replacing relays.

3.2 Relay Capacity Review

SQUG is currently exploring two different capacity evaluation options relative to the resolution of the relay issue on USI A-46. The first option is to use the EPRI GERS (see Section 2.3) as the capacity level for any relay identified in the plant safe shutdown list. If the demand response spectrum is enveloped by the GERS spectrum then the device is considered to be qualified for the purposes of the A-46 review. If the device spectra cannot be enveloped, then the relay needs to be replaced or the chosen safe shutdown path needs to be altered to exclude this relay.

Plant specific relay test data can also be utilized in place of the GERS data. This relay specific test data could come from qualification test data for the plant, information from relay manufacturers or from specific test the plant conducts to obtain relay fragilities.

The second option being considered by SQUG is a "focused scope" type evaluation where the relays are lumped into several different groups based on their seismic capacity levels. The first group includes the unacceptable relays which have low fragility levels or have demonstrated impact sensitivities. Relays in this category would be replaced without any further evaluation if they are critical to the safe shutdown of the subject plant. Table 3-1 from MPR, 1987 lists these unacceptable relays. The second category of relays encompasses the middle group of relays whose GERS levels fall above the unacceptable but below the high capacity relays. These relays would be judged to be acceptable for nuclear plant sites with lower design ground response spectra and, conversely, would be judged unacceptable for higher seismicity sites. The exact break point between these categories has not yet been established. The last category of relays encompasses the high capacity relays which would be judged acceptable for all sites based on their very high GERS levels. This focused scope approach has the advantage of eliminating the need to make specific comparisons between the device response spectra and the GERS spectra, and also eliminates the cabinet amplification issue.

In-Cabinet Amplification - One of the major issues still to be resolved for the A-46 review of relays and on any seismic evaluation program is the generation of in-cabinet amplification values for specific relay locations on specific cabinets. Testing and analytical methods of obtaining this information can be prohibitively expensive due to the quantities which may be required to be evaluated. In-situ test results may be overly conservative if the excitation level of the test is low. SQUG is studying the development of generic amplification factors for different types of cabinets. Proposals for factors of 3 for MCC's and 7 for switchgear are currently being considered by SQUG and the NRC based on response data on several MCC's and switchgear. The criteria for other cabinet types containing relays is also currently being developed and are scheduled to be finalized in early 1990.

An alternative to developing these cabinet amplification factors is the focused scope approach discussed above. SQUG has considered an approach which eliminates the cabinet amplification factor by specifying certain g level relays to be acceptable for situations where they are mounted on certain cabinets (e.g., 5 g GERS relays acceptable on MCC's and 8 g relays acceptable on switchgear). This approach has simplicity in its favor, but lacks the same level of confidence in its application unless the values are conservatively high.

Table 3-1
Unacceptable Relays (Appendix E of SQUG Relay Evaluation Procedure, MPR 1987)

Relay	Operating Mode*	References
GE CFD	All	1 (81-14/313, 82-26/348, 86-13/293),2, 3, 4, 5 (IN 85-82), 6
GE CFVB	All	2, 3, 6
GE CEH	All	2, 6
GE CPD	All	2, 6
GE IJD+ (none 1E)	All	2
GE PVD11 and PVD21	All	1 (84-20/352), 3, 4 (GE)
GE RAV11	All	4 (GE)
GE HGA	(DE, NC)	1 (84-18/331, 86-15/269, 87-11/250), 4, 5 (IN 88-14)
W HLF	All	2, 6
W HU (non 1E)	All	3, 6
W ITH	All	1 (81-44/346 and 81-37/346)
W ARMLA	All	5 (IN 82-55)
W PMQ	All	1 (85-16/247)
W SG	(DE, NC)	4 (ANCO)
ASEA ARMX-1	All	1 (88-06/387)
English Electric YCG+	All	2
Mercury Switches	All	1 (86-25/249), 2
Sudden Pressure Switches	All	2

REFERENCES:

1 LERS
2 Earthquake Experience Data
3 SAFEGUARDS Data
4 IEEE 501 Test Data
5 Notices, Bulletins, etc.
6 Induction Cup or Induction Cylinder Design
* DE = DE-energized
E = Energized
NC = Normally Closed Contact
NO = Normally Open
ALL = All Modes
\+ Susceptible to damage; damage has occurred to this relay in an earthquake and it must be assumed that it will be inoperable following an SSE level earthquake.

4. PROCEDURES FOR DERIVING FRAGILITIES FOR RELAY CHATTER EFFECTS

Seismic probabilistic risk assessments and seismic margin studies performed using the NRC margin approach require the generation of fragilities. As discussed in Section 1.2, fragilities were developed for early PRA's based on generic shock tests on cabinets containing relays. These fragilities had large variabilities due to the broad range of devices and cabinets contained in the test database. In addition, the vibration input duration did not match the input associated with a typical earthquake and, thus, assessing a credible fragility level was difficult. Specific qualification test data have proven to provide a much clearer picture of the relay fragility values. Specific relay test data eliminates much of the uncertainty associated with lumping the chatter thresholds of different types of relays together.

There are three different approaches recommended for developing fragilities of relays:

1) Specific Fragilities Based on Relay Test Data
2) Specific Fragilities Based on Cabinet Test Data
3) Generic Fragilities Based on Similarity

<u>Category 1</u> - The first category is the best method to develop fragilities if specific test data are available for the relay in question. The data could be obtained from qualification test reports, the GERS (see Section 2.3), the Brookhaven Data (see Section 2.4) or from other source of test results conducted on specific relays. The actual methodology for calculating fragilities has been presented in the literature numerous times (e.g., Kennedy et al., 1982) and will not be repeated in this report. The two main steps in the fragility process which are difficult in regard to relays are obtaining the seismic failure threshold and obtaining the appropriate in-cabinet amplification. The failure threshold can be obtained directly if actual fragility test results are available for the relay or it can be estimated by considering the successful test level to be a 95% confidence lower bound value and the median to be approximately 1.5 times above this value (Holman and Chou, 1987). The in-cabinet amplification factor can be determined on a cabinet specific basis (modal testing, analysis, etc.) or it can be estimated on a generic basis such as described in Section 3.0 for the A-46 program.

<u>Category 2</u> - This category includes those relays whose fragilities are to be developed using test data on cabinets with relays mounted in them. This form of test data has a distinct advantage in that the issue of in-cabinet amplification factors is avoided. Unfortunately, unless the test results are for the identical cabinet for which the fragility is being developed, a similarity assessment must be undertaken to ensure that the results are still valid. There is a wide range of test data available in this format including the EPRI GERS project, the Brookhaven fragility testing project and the LLNL fragility testing project.

Fragilities can be derived based on these data if similarity can be established between test specimen and component being evaluated. This similarity assessment has proven to be complex due to the wide variation of in-cabinet response which is a function of cabinet construction, anchorage configuration, position on a panel, elevation within the panel and frequency content of the input.

Category 3 - In situations where specific data are not available with which to develop a relay fragility based on the methods of Category 1 or 2 above, a generic approach is required. Development of a generic fragility requires a broad understanding of the operating mechanisms of specific relays and the mechanisms which result in chatter. An example would be the use of "Model A" GERS data to develop the fragility of a "Model B" relay. To do this the fragility analyst must demonstrate that the differences between the Model A and Model B relays were insignificant in relation to its seismic failure mode. Differences such as mounting configuration, casing material, wiring, etc. will typically not affect the chatter of the relay. Differences in relays which include the armature length or stiffness, the magnetic force holding the contact, the rotational spring rate or the type of operating mechanism would all affect the chatter levels of the relays. In these cases, an assessment would need to be presented as to the similarity in failure threshold arguments between Model A and Model B. Similarity between relays is an issue that is not yet fully understood and caution should be exercised in developing relay fragilities through similarity. Use of this category 3 methodology will also require the use of conservatism due to the inherent large uncertainties associated with a generic approach. As a result, this method is recommended only when other more specific avenues are not available.

5. PROCEDURES FOR TREATMENT OF RELAY CHATTER EFFECTS IN IPEEE

The procedures for treatment of relay or contactor chatter effects in the IPEEE depend on the approach taken for the seismic evaluation. The seismic evaluation approach could be a deterministic one or a probabilistic one; it could be a seismic margin review of the plant or a seismic PRA.

The basic procedure for treatment of relay chatter consists of the steps outlined in Figure 1-5 and would apply to both seismic margin review and PRA. However, the differences are in the evaluation of the seismic capacities of relays and in the considerations of operator recovery actions. The steps are:

1. Identify the systems and components in the plant essential from the IPEEE standpoint; these could be the ones required for safe shutdown, the ones in the plant safety functions listed in the NRC Seismic Margin Methodology (Budnitz, et al 1985, Amico, 1987) or the ones that the PRA analyst has included in the study.

2. Screen out certain components of the power, control and instrumentation support systems for Item 1 based on a study of the test response spectra used in the seismic qualification; in the margin studies, these spectra are compared with the floor response spectra calculated for the review level earthquake. In the PRAs, median capacity against relay chatter is estimated and compared with the median floor response calculated for the range of earthquake judged to contribute most to the seismic risk. The randomness and uncertainty in these estimates are considered.

3. Review the circuit diagrams of remaining items to assess the potential impact of seismic-induced chatter; eliminate items if chatter has no impact on plant.

4. Review generic industry data (SQUG, GERS, etc) and compare capability with expected excitation of item. This could be done for both the review level earthquake and the representative earthquake in a PRA. Screen out items if generic data indicates acceptable performance.

5. Perform further design review and/or plant walkdown to obtain detailed information. Further screening is done for items that detailed information justifies. The list of acceptable relays developed by SQUG could be used for this purpose. Also the procedure for estimating the seismic fragilities (Chapter 4) could be used. The relay seismic HCLPF capacities or seismic fragilities are used in the seismic margin review or PRA as described in

PRA Procedures Guide (1983) and Budnitz et al (1985), Prassinos et al (1985), EPRI (1987).

6. Assess whether existing procedures for operator action can rectify chatter-induced problems. In the seismic margin reviews, screen out those items that are judged to be recoverable at the review level earthquake. In the seismic PRAs, the probability of operator recovery action is taken into account.

7. Identify remedial actions if necessary to correct relay chatter problems, including (a) replacement of seismically poor relays, and/or (b) improved recovery procedures and training, (c) redesign of circuitry, (d) strengthening of cabinet to reduce amplification, (e) relocation of the relay to reduce demand.

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