Maintenance and Application Guide for Control Relays and Timers

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Technical Report

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R E P O R T S U M M A R Y

Maintenance and Application Guide for Control Relays and Timers

Reliable performance of control and timing relays is vital to the efficient operation of nuclear plants. This guide provides utilities practical, cost-effective methods for a control relay and timer maintenance program. It can help utilities optimize test and maintenance intervals while limiting expenditures.

INTEREST CATEGORIES

Nuclear plant operations and maintenance
Plant electrical systems and equipment
Engineering and technical support
Diagnostic monitoring

KEYWORDS

Relays
Control relays
Instrumentation
Electrical equipment
Maintenance

BACKGROUND Current relay maintenance practices depend mainly on corrective maintenance upon failure. For a select population of relays, periodic surveillance testing is also performed to verify operability. Industry experience to date has pointed to a need for preventive maintenance and/or condition monitoring to eliminate the potential for common cause failures from aging degradation and to extend the service life of relays. EPRI's Nuclear Maintenance Application Center (NMAC) sponsored this guide in response to this need.

OBJECTIVES To provide maintenance recommendations, detailed inspection, and test guidance for control and timing relays.

APPROACH NMAC's project team reviewed several current nuclear industry practices and procedures, industry standards, regulatory research publications, manufacturers' recommendations, and industry papers to gain insight into practices related to control relays. A group of industry experts, manufacturers, and utility representatives were consulted throughout the project to ensure that the bases for the recommended practices were understood. The collective information was used to develop programmatic recommendations and detailed inspection and test guidance.

RESULTS This guide provides a general description of relays by classification and a brief explanation of the functions for the types of relays covered in the guide. It presents relay application considerations, including a discussion of several cases of misapplication that could affect relay performance. The guide discusses industry operating experience as well as degradation mechanisms and failure modes associated with control relays and timers.

The guide highlights required maintenance activities and matches them to application and environment. It recommends maintenance practices which can provide a basis for preventative, predictive, and corrective measures. It also identifies test equipment and tools required to perform specified maintenance activities.

EPRI PERSPECTIVE The recommended practices in this maintenance guide have been developed from a perspective of ensuring reliability of control/auxiliary relays and timing relays through an understanding of the mechanisms that cause them to age and ultimately fail. By understanding the fundamentals of relay design, application, aging processes, and failure modes, maintenance staff can develop and implement a successful maintenance program. This guide is also useful to personnel needing familiarization with control relays and timers as well an those responsible for ongoing electrical system operations.

Related publications include EPRI's "Protective Relay Maintenance and Application Guide" (NP-7216) and "Seismic Ruggedness of Relays" (NP-7147-SL).

PROJECT

RP2814-86

EPRI Project Manager: Wayne Johnson

Nuclear Power Division

Contractors: MOS, Inc.

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Maintenance and Application Guide For Control Relays and Timers

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Prepared by

MOS, Inc.
25 Piermont Dr.
Melville, NY 11747

Principal Investigators
S. (Sonny) Kasturi
Luis Galindo

Prepared for

Nuclear Maintenance Applications Center
1300 Harris Boulevard
Charlotte, North Carolina 28262

Operated by
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
W.E. Johnson

Nuclear Power Division

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Abstract

Reliable performance of control and timing relays is vital to the safe and efficient operation of nuclear plants. Failure of one or more relays can result in lost capacity and in extreme cases, the inability to perform required safety functions. Current relay maintenance practices depend mainly on corrective maintenance upon failure. For a select population of safety-related relays, periodic surveillance testing is also performed to verify operability. However, industry experience to date points to a need for preventive maintenance, and/or condition monitoring to eliminate the potential for common cause failures from aging degradation, and to extend the service life of relays. EPRI's Nuclear Maintenance Applications Center (NMAC) sponsored RP2814-86 to respond to this need by developing a guide that provides information for establishing an effective maintenance program for control/auxiliary and timing relays.

The recommended practices in this maintenance guide have been developed from a perspective of ensuring reliability of control/auxiliary relays and timing relays through an understanding of the mechanisms that cause them to age and ultimately fail. By understanding the fundamentals of relay design, application, aging processes, and failure modes, maintenance staff can develop and implement a successful maintenance program and thus ensure a high degree of confidence that relays can fulfill their intended design functions. In order to provide a strong understanding of relay fundamentals, this maintenance guide emphasizes how relays are selected for a specific application and how they behave, age, and ultimately fail.

Recommended periodic inspections and tests are described in detail. Furthermore, a basis for each recommendation is provided so the user can understand why the inspection or test is important. Inspections and tests are presented in a format that facilitates comparison with existing plant relay maintenance procedures.

The maintenance practices recommended in this guide were developed through a review of several current nuclear industry practices and procedures, industry standards, regulatory research publications, manufacturers' recommendations, and industry papers. Experts were consulted throughout the project to ensure that recommended practices have a well-defined base. The collective information from this review was used to develop maintenance recommendations and detailed inspection and test guidance.

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Introduction

In a nuclear plant, relays are used to provide:

- Isolation between a switch and a load
- Contact capacity amplification and multiplication
- Logic matrixing
- Timing and/or sequencing of actions
- Isolation of class 1E circuits from nonclass-1E circuits.

Relays are usually mounted inside cabinets, wall mounted boxes, and equipment enclosures. Except for a few isolated cases where relays are located in potentially harsh environments, relays and timers are usually located in mild environments.

Proper maintenance of relays is essential to the reliable and successful operation of all safety and control systems. By understanding the fundamentals of relay design, selection, application considerations, aging processes, failure modes, and mechanisms, maintenance staff can develop and implement an effective maintenance program. This, in turn, will provide assurance that the relays will have the capability to perform their design function on demand, including during and after a design basis event.

Purpose

The purpose of this guide is to provide recommended surveillance, inspection, test, maintenance, condition monitoring, and trending practices that approach the maintenance tasks from a reliability standpoint through an understanding of the mechanisms that can affect relay performance.

Organization

This guide is divided into seven sections and several appendices:

- Section 1 provides a general description of relays and provides an explanation of the types of relays covered in this guide.

- Section 2 presents the relay application considerations, including a discussion of several cases of misapplication, that could affect relay performance.

- Section 3 discusses the degradation mechanisms and failure modes associated with relays.

- Section 4 highlights the relay operating experience, including a discussion of the industry experience on relay failures.

- Section 5 covers the overall maintenance programmatic recommendations.

- Section 6 discusses the safety precautions and training needs for personnel performing relay maintenance.

- Section 7 covers the recommended surveillance, inspection, maintenance, condition monitoring, and trending activities for relays, including the frequencies for such activities.

The appendices include a listing of pertinent references, glossary of relay terms, background information, and a detailed discussion of some of the relay failure experience.

An index is included at the end of this guide to aid the reader in finding specific items of interests.

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1.0 Relays and Timers, Description and Use

A relay is a remote switching device. It responds to an input signal in a prescribed manner to cause a change in related circuits, (e.g., a relay responding to a control switch input to turn on or off a load). In this example, the relay serves to isolate the switch from the load. Other applications of relays include logic matrixing, introducing a time delayed, or sequenced or interval action of the switched load and amplification of contact capacity and number as discussed in more detail in section 1.1.

Thousands of relays and hundreds of timers are used in every nuclear power plant in applications for controlling equipment, or protecting equipment, personnel and public safety. Typical systems where relays and timers are used in nuclear power plant applications include:

- Reactor Protection Systems (RPS)
- Engineered Safety Features Actuation System (ESFAS)
- Circuit breaker control schemes
- Diesel generator load sequencing systems.

In almost all of these applications relays and timers, **hereinafter referred to as relays**, function as the heart of the control logic and protective schemes. Proper operation of these systems depends directly upon the proper selection, application, installation, operation and maintenance of the relays.

Of specific importance are the relays used in safety systems that provide reactor trip and accident mitigation functions because, relays present the greatest potential for challenges to the defense-in-depth built into these systems. Because these systems are designed to "fail-safe" in these applications, relays often sit idle in their energized condition. Such operation results in high operating temperatures and thermal stresses on the insulation systems and other components. Therefore, challenges can originate from the potential for common cause and common mode failures that inhibit active relay functions in redundant channels.

A comprehensive program of testing, maintenance, inspection and replacement supports plant safety and reliability requirements by providing a high level of assurance that relays will operate on demand as required, and that the potential for common cause and common mode failures are reduced. An understanding of the aging mechanisms, degradation and failure modes of relays is essential to the development and implementation of a comprehensive program of testing, maintenance, inspection and replacement.

1.1 Role of Relays and Timers

The basic function of a relay is to provide isolation between the load being switched and its associated control switch or other instrument switch. In nuclear plant applications, relays are used to provide one or more of the following functions:

- Isolation
- Contact capacity amplification and multiplication
- Control interlocks
- Logic matrix
- Time delay, sequencing, and interval actions
- Equipment and bus protection

The scope of this guide is limited to relays and timers that perform all but the last of the functions listed above. Relays that perform equipment and bus protection functions are known as protective relays. These are covered in EPRI/NMAC's *Protective Relay Maintenance and Application Guide* (NP-7216). Thus, except for a brief description of the equipment and bus protection function in this section, this guide focuses solely on control relays and timers.

1.1.1 Isolation

Isolation refers to the separation of the input and output circuits from each other. For example, if a control switch in a 125 Vdc circuit is used to actuate a motor connected to 480 Vac distribution system, a relay is used to isolate the closing coils in the load control circuit from the switch (See Figure 1-1) to ensure personnel and equipment protection in the control room. Another example unique to nuclear plants, is the use of a relay to provide isolation of the class 1E motor control circuit (See Figure 1-1) from the associated nonclass 1E annunciator circuit that provides an alarm upon a motor trip.

Relays make it possible to use (low voltage) control and logic circuits which provide added safety for operators and lower cost from a design and installation point of view.

1.1.2 Contact Capacity Amplification and Multiplication

Relays are used to provide amplification of the current and voltage rating of switching device contacts and contact multiplication. Figure 1-1 demonstrates how a relay is used to amplify contact capacity. Relay and closing coil voltages are the same. The relay is used to amplify the current and/or voltage capacity of the pressure switch contacts which are usually rated for low currents, typically 0.5 amps at 125 Vdc for a straight in-line type pressure switch, or 0.1 amps at 24 Vdc if the pressure switch is a bi-stable type device from a process control loop. The relay is intended to accommodate the current drawn by the closing coil and other components in the starting circuit. The current drawn by the relay coil is within the contact capacity of the pressure switch. If additional pressure switch contacts are needed for use in other circuits, the relay can provide the required number of additional contacts. This is called contact multiplication.

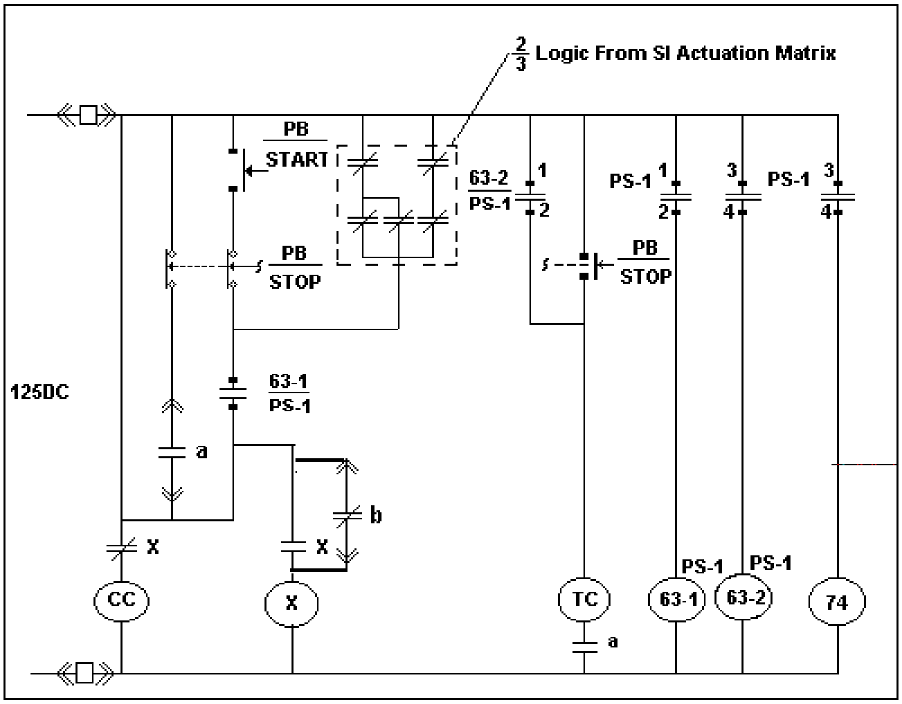


Figure 1-1 Typical Motor Control Schematic Wiring Diagram

1.1.3 Control Interlocks

In this application, a relay contact is used to provide a permissive or trip function when certain conditions are met. The relay contact 63-1/PS-1 (See Figure 1-1) provides a permissive interlock to ensure that the motor is started only if the suction pressure is above a certain value and a trip interlock to stop the motor if suction pressure falls below a certain value.

1.1.4 Logic Matrix

In this type of application which is somewhat unique to nuclear plants, relay contacts are used to generate logic such as two-out-of-three, two out-of-four, or one-out-of-two-twice. These types of logic systems are used in the reactor protection and the engineered safety features actuation systems. The purpose of this type of logic is to ensure against a single failure from negating the system functional capability, and to prevent spurious operation. In Figure 1-1, note that the start of the pump upon the presence of a safety injection signal is performed using a two-out-of-three logic.

1.1.5 Time delay, Sequencing, and Interval Actions

In these applications, a relay is used to:

- introduce a delay in the circuit completion or actuation of the load, e.g., initiate closure of reactor building emergency ventilation system upon high radiation, but only after a time delay of four seconds.

- sequence a set of loads or perform a set of actions in an established sequence, e.g., shed all the loads connected to the safety bus and bring on a set of loads in a pre-established sequence on the safety bus after the diesel generator has started and its breaker to the bus is closed.

- cycle a load or an action for a pre-specified duration at a specific interval, e.g., open a valve and keep it open for five minutes every hour on the hour.

1.1.6 Equipment and Bus Protection

In this application, relays are used to sense faulted conditions such as a ground fault, overcurrent, or undervoltage, and initiate protective actions to provide personnel and/or equipment protection. One example of this application is the starting of the on-site diesel generator upon sensing a loss of off-site power through an undervoltage or degraded voltage condition on the emergency bus.

1.2 Types of Relays

Relays are available in many forms, construction type, and technology. An understanding of the types of relays used in the nuclear industry is essential to the development of a comprehensive inspection, surveillance, and monitoring program to achieve the desired level of relay reliability.

1.2.1 Control and Auxiliary Relays

From an application sense, relays are classified by their function in these three categories:

- Protective Relays
- Auxiliary Relays
- Control Relays

Protective relays are those normally used to provide protection of equipment (e.g., transformer, motor, bus, and cabling), and personnel protection from the effects of fault conditions such as overload, underfrequency, undervoltage, and overcurrent. The purpose of the protective relay is to detect fault conditions and initiate protective actions such as tripping the load or isolating the bus from the faulted section or transferring the power source.

The classification "auxiliary relays" stems from their original use as a supplementary switching device to multiply the contacts and boost the load rating for the protective relays.

A control relay is the same as an auxiliary relay and derives its name from its use, i.e., used to control a load or circuit status based on the status of one or more given input(s). For example, in Figure 1-1, the relay 63-1 is usually designated as a control relay because it provides a permissive interlock to assure that adequate suction pressure exists before starting the pump motor.

The terms "control relays" and "auxiliary relays" may be used interchangeably because the only difference is in their functional use and not their construction or capability. For ease of discussion and consistency, throughout this document, the term "relay" is used to denote control relays, auxiliary relays and relays that provide timing functions. Whenever the term "control relay" is used, it is intended to mean a control or auxiliary relay.

Relays may be classified in three categories by the technology employed in their design:

- Electromechanical
- Solid State
- Hybrid

Electromechanical relays may be further classified under the following categories depending upon their construction, function, and/or principle of operation:

- General purpose relays
- Contactors
- Dry-Reed Relay
- Mercury-wetted Reed Relay
- Latching Relay

1.2.1.1 General Purpose Relay

General purpose relays are those used for control interlock or contact multiplication or logic matrix purposes in applications that involve control circuit voltages such as 120 Vac, 125 Vdc, or less. They are available in open or sealed type constructions and in a variety of coil rating, contact rating, and configuration. Mostly, these are of the clapper or hinged-armature type. This type of relay consists of a coil, a fixed core, and an armature plate (See Figure 1-2).

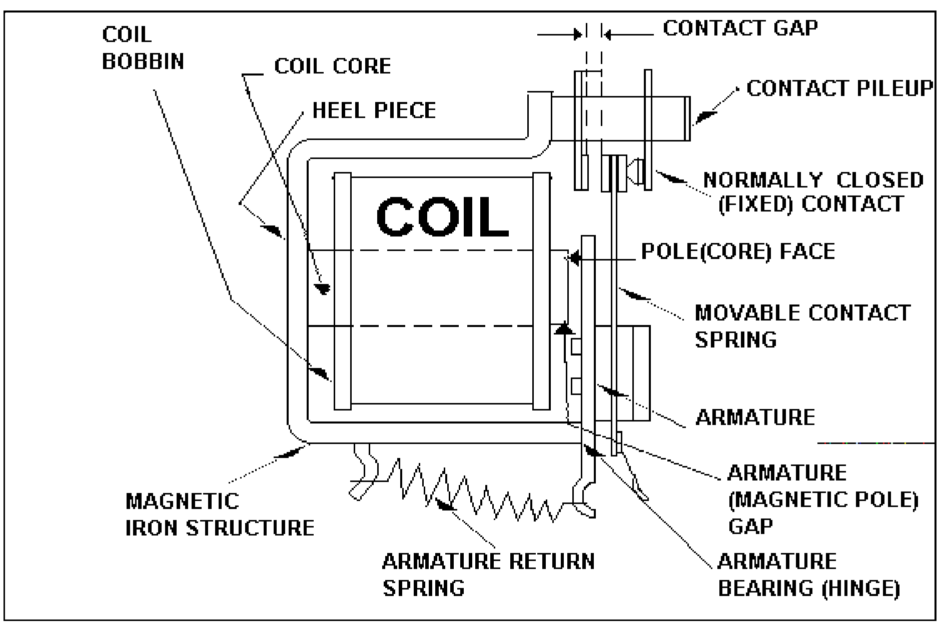


Figure 1-2 Line Drawing of a Hinged-Armature Relay

The stationary contacts are secured to the base of the relay and the movable contacts are secured to the armature plate over an insulator. The armature plate is restrained by a spring to hold it away from the core when the coil is de-energized. Upon energizing the coil, the core becomes magnetized and pulls the armature in completing the magnetic circuit, thus closing or opening the contacts. The magnetic force must be sufficient to overcome the spring force and hold the armature down. When the coil is de-energized the magnetic circuit is broken and the magnetic flux collapses gradually. When the spring force is greater than the magnetic force, the armature is pulled away thus breaking the electrical contact. The hinged-armature relay can be constructed to provide up to 6 sets of Form C, single pole-double throw contacts, with each contact rated up to 30 amps at 120 Vac (e.g., GE HFA series, HGA series).

1.2.1.2 Contactor

A Contactor is just a heavy duty relay used in power circuit applications. It is usually a double make or double break device that is of the solenoid actuated type construction. A solenoid type relay consists of a coil with an armature that travels into and out of the core in a perpendicular manner (See Figure 1-3).

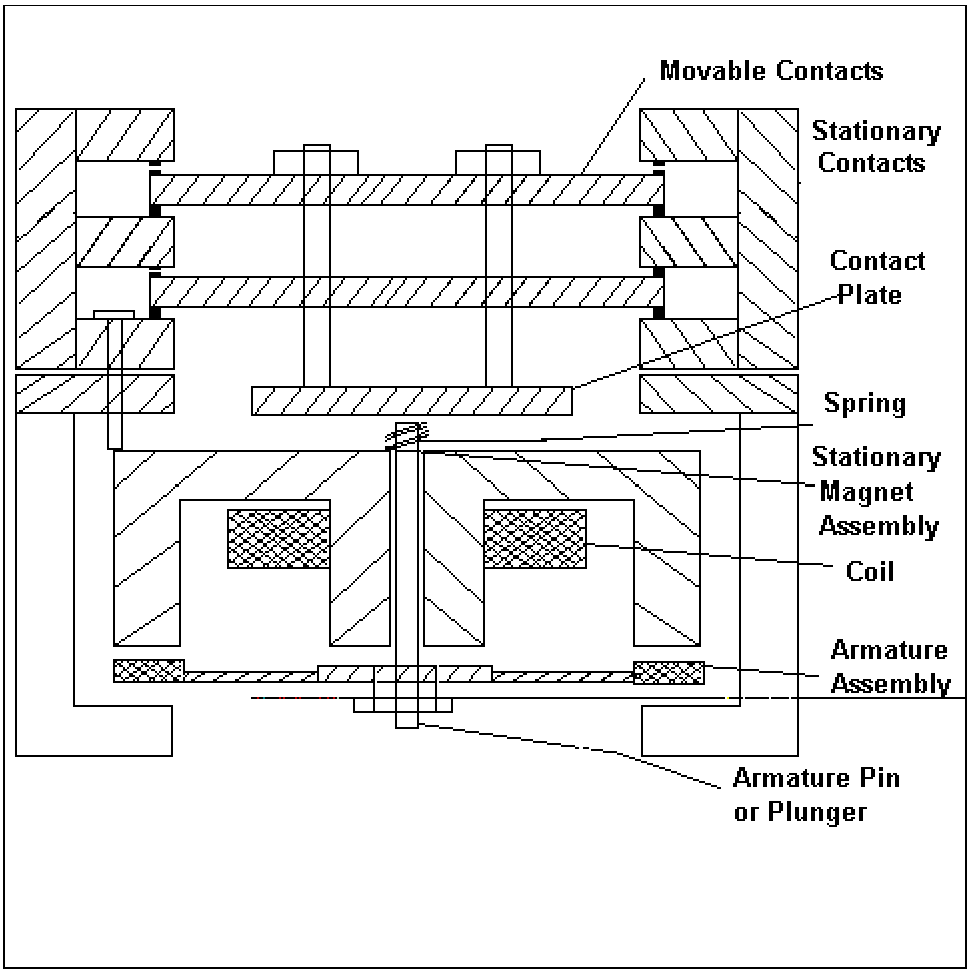


Figure 1-3 Line Drawing of a Solenoid Type Relay

The movable contacts are attached to the armature. This type of construction is generally utilized in applications that require wider contact gap and powerful closing or opening force. Such would be the case for relays used in power circuits that interrupt or close large currents usually at voltages higher than 120 Vac or 125 Vdc, generally 220 Vac or dc and above. Because the contact gaps are wider and the contacts do not travel in an arc, these relays can be designed for much higher contact closing or opening forces with little or no contact bounce. While the discussion of Contactors is beyond the scope of this guide, the solenoid type relays are discussed because, some manufacturers do use the solenoid type construction (e.g., Clark PM Type) for control relays. This type of construction provides the required electro-magnetic force when multiple contact sets of a sizable rating are used or the capability to withstand significant seismic vibrations and shock is required.

1.2.1.3 Latching Relay

Typically, a latching relay is a dual coil type relay with an operate-coil and a reset coil. When the operate-coil is pulsed, the normally open contacts close and the normally closed contacts open. The new contact status remains until the reset-coil is energized to reverse the contact positions. A latching relay can be of electrical or manual reset type. In a mechanical reset type, a push button, usually mounted on the relay, is provided to reset the contacts.

Some electrically reset type latching relays contain only a single DC coil. Contacts are latched in place by applying the coil voltage such that magnetic attraction pulls in the armature to change the contact status. To release the latch, the coil voltage polarity is reversed to kick the armature out by reversing the direction of the magnetic forces.

1.2.1.4 Dry-Reed Relay

This type relay consists of a coil and a pair of partly overlapping metal blades of a magnetic material in a hermetically sealed glass tube as shown in Figure 1-4.

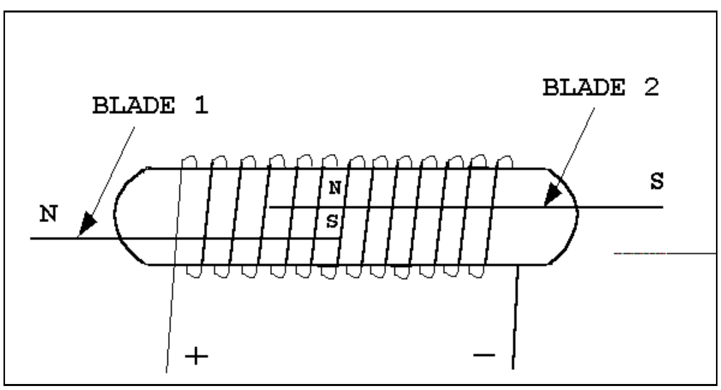


Figure 1-4 Line Drawing Of A Dry-Reed Relay

The overlapping edges are usually plated with a precious metal to provide low contact resistance. The ends of the blades are brought outside with a seal at the glass around the blade. The inside of the glass tube is either kept under vacuum or filled with an inert gas. When the coil is energized, the individual blades magnetize with opposing polarity. Unlike poles attract each other, thus making the contact. Generally, dry-reed relays are used in low current and low voltage applications that require high operating speed.

1.2.1.5 Mercury-Wetted Reed Relay

A Mercury-wetted Reed Relay is a reed type relay. It consists of a pair of glass-encapsulated reed contacts immersed in a pool of mercury at their base (See Figure 1-5). The mercury flows up the reed by capillary action and wets the contact surface of the end of the reed as well as the contact surfaces of the stationary contacts. This permits a mercury-to-mercury contact to be maintained. This relay can be designed for contact ratings up to 5A at 480 Vac, and higher operating speed (typically 2 milliseconds) than its dry-reed counter part.

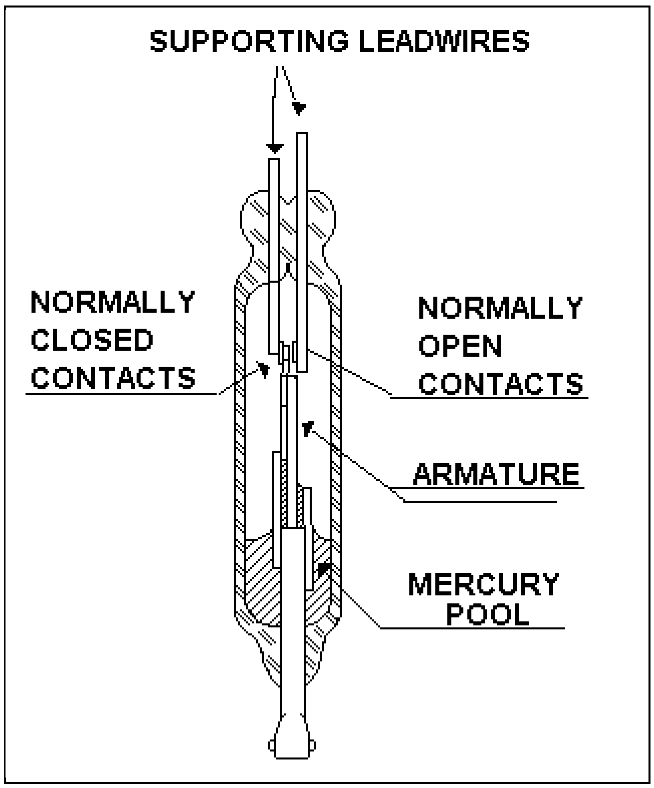


Figure 1-5 Line Drawing Of A Mercury-Wetted Reed Relay.

1.2.1.6 Solid State Relay

A Solid State Relay (SSR) is an all electronic relay that has no moving parts. It is built with diodes, transistors, TRIACS, silicon controlled rectifiers (SCR) and thyristors. An SSR includes the following three component circuits (See Figure 1-6).

- Input circuit
- Isolator
- Output switching circuit

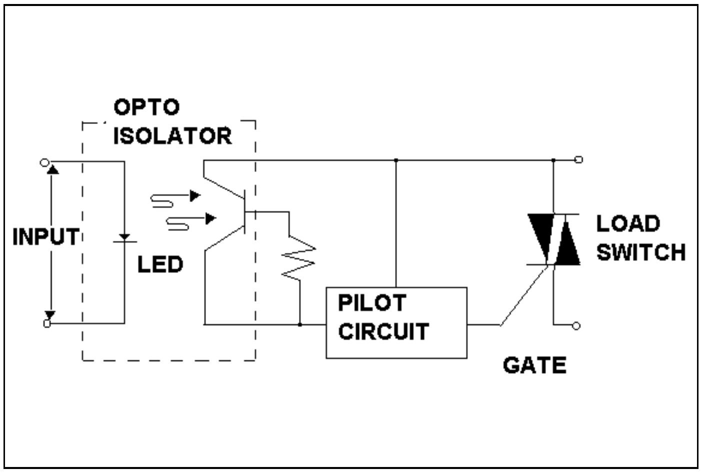


Figure 1-6 Schematic of an Optically-coupled Solid State Relay

There are two basic types of solid state relays:

- Optically coupled
- Transformer coupled

In an optically coupled SSR, a Light-Emitting Diode (LED) is turned on when a control voltage is applied to the input circuit. The LED conducts and converts electrical energy into light. A photo- receptor located a few millimeters away receives the light and goes into conduction which in turn permits the gate current to flow in the output load switch. The photo-receptor functions as the isolator between the input and output circuits.

When a transformer is used in lieu of an LED and a photo-receptor to couple the input and output circuits, then the SSR is called a transformer coupled device. A transformer coupled SSR is used when a higher output voltage (>600V Peak) capability is needed. If good input/output isolation is the main criterion, then an optically coupled SSR is better suited.

The output switch is a power switching diode device depending upon the specific application as listed below:

Silicon-Controlled Rectifier (SCR)	dc applications
Triode AC switch (TRIAC)	ac applications
Bipolar transistors	dc and low current ac applications
Power Field Effect Transistors (FET)	ac/dc applications.

An SCR is a unidirectional diode whose turn on is controlled by a gate. A TRIAC is equivalent to two SCRs connected inverse parallel. Like an SCR, a TRIAC is gate controlled and will cease conduction when the current through the gate is insufficient to maintain conduction. Power FETs are the latest in technology for switching applications. In operation they resemble a voltage controlled resistor.

The advantages of a solid state relay include:

- no moving parts to wear out
- bounce-free switching and chatter-free operation
- no contacts and thus no arcing or flashing
- very high operating speed
- latching, logic, circuit protection and timing functions can be integrated into a single device, often with field programmable capability
- zero voltage turn-on and zero-current turn-off techniques can result in low levels of EMI and RFI
- better seismic and shock withstand capabilities
- higher levels of reliability than their Electromechanical counterparts
- smaller size for comparable capabilities than their electromechanical counterparts
- lower life cycle costs.

Even with all these advantages, SSR use in nuclear plant control and safety systems is very minimal because of the design vintage of their instrumentation and control systems and the licensing implications of adopting changes. In a few of the recent vintage plants, SSR applications include UPS systems, DG sequencing, and some timing and RPS logic functions. This situation is likely to change over the next decade as instrumentation and control system upgrades are implemented. Thus, there is a general lack of operating and maintenance experience data on SSR's from nuclear industry information sources. Therefore, this guide includes only some general maintenance recommendations on SSR's.

1.2.2 Timers

Timers as a category refer to relays that perform time delay, interval timing, or sequencing functions.

1.2.2.1 Time Delay Relays

Time delay relays are available as electromechanical relays with timing units attached or as fully electronic units. An electromechanical time delay relay consists of a relay with an attached pneumatic, electronic or mechanical timing device. Energizing or de-energizing the timing device will delay change in the position of the relay contacts for a preset time.

The pneumatic time delay relay consists of a spring-loaded solenoid plunger, a solenoid coil, diaphragm, and an adjustable orifice. For the "TDPU" unit, energizing the solenoid coil draws the solenoid plunger and the diaphragm away from the orifice, drawing air through the orifice to fill the cavity above the diaphragm. Upon energizing the coil, the spring on the plunger is initially compressed but immediately begins returning the plunger to its de-energized state while forcing the air above the diaphragm cavity through the adjustable orifice at a rate proportional to the time delay selected. The contact arrangement is such that a change of state of the contacts occurs only upon full travel of the plunger and not at any intermediate position.

The mechanically actuated time delay relay consists of a relay mechanism, a mechanical clutch, timing motor, and appropriate timing cams. In the on-delay configuration, when power is applied to the device (energized), the clutch engages the motor, which begins to rotate the cam toward the zero time position. The instantaneous contacts transfer from one position (open or closed) to the other. The delayed contacts are maintained in their initial state until completion of the timing cam rotation, at which time they change state. The cam also trips the motor circuit so that the motor stops; however, the clutch remains engaged until de-energized. When the clutch is de-energized, it resets the cam to its zero position.

Time delay relays have two modes of operation, i.e., time delay to pickup (TDPU) or time delay to drop out (TDDO) (See Figure 1-7).

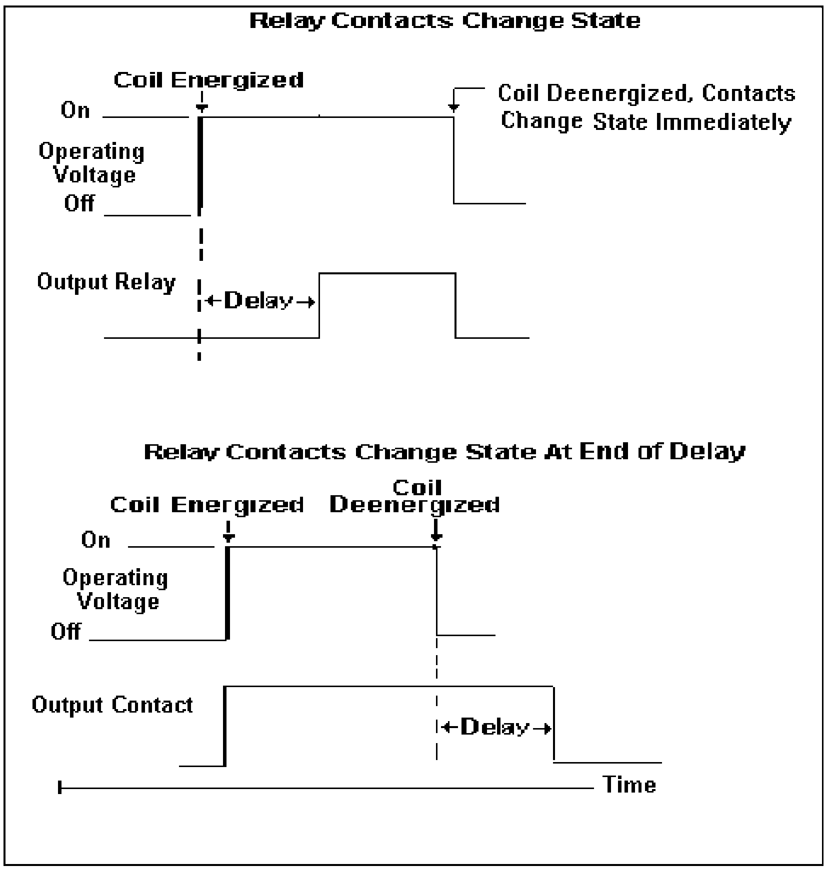


Figure 1-7 Time-Delay Relay Pick-up And Time-Delay Drop-out Representation

1.2.2.2 Time Delay to Pickup (TDPU)

Upon application of control power, time delay period begins. At the end of the time delay, relay contacts switch. When control power is removed, relay contacts return to their original state. If the control power is removed during the timing operation, the relay contacts remain in their original state, and the timer resets.

1.2.2.3 Time Delay to Dropout (TDDO)

Upon application of control power to the coils, relay contacts switch. Upon deenergizing the relay coil, time delay period begins. Upon completion of the time delay, the relay contacts switch back to their original state. If control power is applied prior to the end of the time delay period, the timer resets and the relay contacts remain in their current state.

1.2.2.4 Electronic Timing Relays

Electronic timing relays may be an electromechanical relay with attached electronic timer or a solid state relay with a timing circuit built into the input end. Electronic time delay relays are commercially available as both attachments for existing control relays or as independent, fully contained units. The electronic time delay unit normally consists of a dc power supply, a series resistor-capacitor network, a trigger or gate circuit, and an output device (control relay). When power is supplied to the dc power supply, the capacitor begins to charge through a resistor for a sufficient period of time to reach the voltage required to trigger the gate circuit. The gate circuit in turn energizes the output relay which completes the timing function. The electronic time delay relay will remain in this state until the power is removed from the dc power supply.

1.2.2.5 Interval Timers

Interval timers, also called Repeat Cycle timers, are available in mechanical and electronic types. The mechanical units have a motor, clutch, and cam arrangement. Energizing the relay starts a synchronous motor, which rotates a timing cam with pre-cut notches or teeth corresponding to the on-off time interval desired. The cam rotation results in contact make and break. An electronic cycle timer is a solid state relay with a Resistance-Capacitance (RC) oscillator time base connected at the load switching TRIAC or SCR gate circuit. The on and off states are generated by a time-base RC Oscillator with precision capacitors and adjustable potentiometer. The on and off durations are selected by varying the potentiometer setting. Opening the control circuit input resets the timer.

1.2.2.6 Sequencing Units

Sequencing units are also available as mechanical or fully electronic types. The mechanical types are analogous to the interval timers except that the cams have as many notches as there are sequencing steps. Similarly, an electronic sequencing unit has multiple timing circuits at the output end, each with its own adjustable potentiometer. Programmable controllers and microprocessor controlled units are also available. These units have the added advantage of field modifiable software controlled timing and duration adjustments.

1.3 Rating of Relays

1.3.1 Coil Rating

Typically relays are rated based on their coil operating voltage and the contact load carrying capacity. Generally, control/auxiliary relays used in nuclear plant applications are rated for operating coil voltages ranging from 24 Vdc to 125 Vdc, or 120 Vac. In nuclear plants 120 Vac and 125 Vdc represent the majority of the applications.

1.3.1.1 AC vs DC Coils

A relay coil is rated either for DC or AC voltages, not both. A DC coil should never be used in AC application. An AC coil is designed with a shader ring to ensure that as the current crosses zero and the magnetic field collapses, the relay does not de-energize. The shader ring is a piece of copper situated so as to separate a portion of the core or pole face and enclose it in a copper loop. This loop produces a lag in the timing of the ac magnetic flux in the shaded portion of the pole face with respect to that in the unshaded portion. Thus, as the core flux crosses zero, the shaded portion still continues to exert magnetic attraction on the armature, holding it to the core. If a DC coil is used in an AC application, the relay would tend to energize and de-energize at double the power line frequency i.e., 120 times per second.

An AC coil may be used in a DC application *but only after* derating the coil operating voltage. The derating is required to account for the reduced coil power rating of the AC coils.

1.3.2 Contact Rating and Forms

Relay contacts are normally rated in terms of their resistive current switching capability at the rated voltage. A general statement such as "the contact is rated for 15 amps at 24 Vdc," usually found in manufacturers' catalogs, means that the contact can switch 15 amps resistive load at up to 24 Vdc. The corresponding rating for inductive loads may only be 6.0 amps.

> NOTE: If this contact is used to switch current in the milliampere range, even at 24 Vdc, the contact may not function properly.

Proper performance of a contact depends upon many factors, including:

- materials of construction
- geometry
- force between contacts, also called contact pressure
- amount of slide or wipe of the contacts
- amount of rolling of the contacts
- resiliency of the supporting structure holding the contact button.

Therefore, a complete relay specification must include the relay coil rating and the contact rating for the specific application.

1.3.2.1 Contact Forms

The switching combinations available on a relay may be defined in terms of the number of poles, number of throws, normal contact position, and sequence of contact make and break. For example, a single pole single throw normally open contact means that the contact has one pole and one throw and with the relay de-energized the contact is normally open. This contact is usually called a Form A contact. In this case the contact either makes or breaks and no sequence is involved. On the other hand with the relay coil de-energized a single pole double throw contact has a normally open and a normally closed contact. When the relay coil is energized, the movable contact opens one contact and closes the other. Such contacts are designed for the normally closed contact to open before the normally open contact closes (break before make). This type of contact is called a form "C" contact. Another design of the double throw contact is one in which the normally open contact closes before the normally closed contact opens (make before break). This type of contact is called a form "D" contact. The contact configurations are usually given a Form letter designation. Figure 1-8 provides a sample listing of the relay Contact Form designations and corresponding symbols as established by the American National Standards Institute (ANSI) Standards C83-16-1971 and Y32.2-1975.

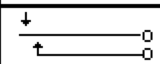
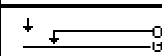
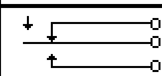
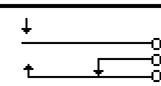
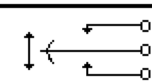
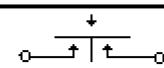
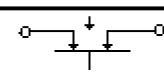
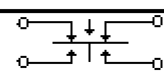
Form	Description	ANSI Symbol
A	Make or SPST- NO	
B	Break or SPST- NC	
C	Break before Make or SPOT (B-M), or Transfer	
D	Make-Before-Break, or SPOT (M-B), or "Continuily transfer"	
K	Single pole, Double throw Center off, or SPOT-NO	
X	Double break, SPST-NO-DM	
V	Double break Contact on arm SP ST NC DB	
W	Double break, Double make, STDT-NC-NO (DB-DM)	

Figure 1-8 Sample of Relay Contact Form Designations & Symbols

2.0 Relay Application Considerations

Proper application of relays depend upon identifying the applicable circuit configuration, contact requirements, and service conditions and matching these requirements with the manufacturer's relay specifications. Because of the diversity of relay application conditions and the wide variety of relays available, no widely applicable rules are available for relay selection. This section provides some guidance for selecting a relay for a specific application. The same considerations can be used as a checklist to determine if a relay failing in an application has been properly selected.

2.1 Selecting a Relay

A suitable relay for a specific application is selected by first determining the coil operating conditions, contact requirements, physical requirements, and the application environment and then comparing them with the relay manufacturer's specifications. In the following paragraphs, concerns that are not obvious in addressing these considerations are briefly explained.

2.1.1 Coils

Selecting the correct coil for a given application is usually an exercise of matching the available coil specifications with the purchaser's specification. To ensure that the coil is selected properly, the following items should be addressed when establishing the relay specification for a specific application:

a. Voltage rating and tolerance
b. Pickup/dropout voltage
c. Operating temperature
d. AC vs DC coils
e. Surge suppression and protection
f. Other design considerations

2.1.1.1 Voltage Rating and Tolerance

Coil operating voltage and tolerance for normal, abnormal and extreme operating conditions should be considered. There may be large deviations in the nominal coil voltage applied to the relay due to bus voltage degradation and power surges (e.g., Tripping a major load from a bus). The float voltage on the DC buses may be significantly higher than the nominal voltage for extended duration.

2.1.1.2 Pickup and Dropout Voltage

Pickup, dropout, holding, and non-pickup voltages at expected nominal operating temperature and extremes of operating temperatures should be addressed. Pickup and dropout voltage of a relay depends, among other considerations, upon the coil ampere turns, coil resistance, and mechanical forces from the armature and contact blocks. For instance, if room/enclosure cooling failed, the coil temperature may rise to a point where the increased coil resistance would cause the relay to pickup or drop out.

Standard practice in the relay industry is to design AC coils to ensure pick up at about 85% of the nominal rated voltage and DC coils to pick up at about 80% of the nominal rated voltage. If the application demands another pick value (e.g., 70% bus voltage required in certain safety-related applications), the user must specify the same. In some relays (e.g., GE-HFA), for a given coil, the pickup voltage can be adjusted in the field within a certain range through the mechanical adjustments provided. In others where such adjustments are not available, when the pickup voltage is off-spec, the coil may need to be changed out. In such cases, when a required pickup voltage is specified, the manufacturer will usually test each coil to verify that it has the correct pickup capability. Therefore, when purchasing replacement coils, it is necessary to specify the required pickup voltage and to verify that it is met. Remember also that pickup voltage must be measured with the coil installed in the specific relay in which the coil will be used. Another point to consider is that the pick voltage increases with increased coil temperature. This is important if the relays may be called upon to pickup at reduced voltage levels shortly after it has been deenergized (e.g., load shedding and pick up).

Similarly, any specific dropout voltage requirements must also be specified and verified. Normally, the manufacturers' catalogs do not contain a guaranteed dropout voltage.

2.1.1.3 Operating Temperature

Coil insulation must be able to withstand the cumulative effect of heating. Coil insulation, although not generally stated in the manufacturers' catalogs, may be classified based on the NEMA insulation classification system as follows:

Class A 105°C with 40°C ambient and a maximum temperature rise of 65°C.
Class B 130°C with 40°C ambient and a maximum temperature rise of 90°C.
Class F 150°C with 40°C ambient and a maximum temperature rise of 110°C.
Class H 180°C with 40°C ambient and a maximum temperature rise of 140°C.

Most commercially available relays have class A or B rated coil insulation. Review of the industry relay failure experience indicates that selecting the coil with proper insulation rating may not always have received sufficient attention from the plant designers. Although, it is not generally the current industry practice, it is preferable to specify the insulation class required when purchasing replacement coils, and verify the same as a minimum through a manufacturer's certification.

The effects of any volatiles (e.g., plasticizer, phenolic plastics, halogenated fumes) from the insulating or potting compounds that may deposit on the contact surfaces or surrounding parts should also be evaluated. This is of particular importance for relays used in continuously energized applications since the heat generated in the relay coils tends to cause the release of such volatiles over time.

2.1.1.4 AC vs DC Coils

A relay coil is rated either for DC or AC voltages, not both. A DC coil should never be used in AC application. If a DC coil is used in an AC application, the relay would tend to energize and de-energize at double the power line frequency i.e., 120 times per second. This results in contact chatter which would cause early contact failure.

An AC coil may be used in a DC application *but only after* derating the coil operating voltage. The derating is required to account for the reduced coil power rating of the AC coils. Power is given by $P = E^2 \div Z$, where Z is the impedance which is the result of the coil dc resistance and the coil reactance. The derated coil voltage for AC coil when operated on DC is calculated using the following relationship:

$$V = \{(\text{maximum power rating of the coil})(\text{DC coil resistance})\}^{1/2}$$

AC powered relays are generally less tolerant of overvoltages because the relay coil impedance can rapidly decrease as the magnetic core saturates due to the higher peak voltage, resulting in large coil currents and overheating. If a turn (or turns) on an AC coil should become shorted, it may act like a shorted secondary winding of a transformer. This can result in rapid heating of the coil and a significant increase in coil power requirements.

The AC voltage waveform is assumed to be a sine wave. Deviations from a sine wave create a DC component and can result in coil overheating because of the decrease in coil impedance. Such situations can occur in relays powered from vital buses supplied by uninterruptible power supplies which approximate sine waves from a series of step changes, or from constant voltage transformers which alter the waveshape to maintain a constant voltage.

2.1.1.5 Surge Suppression and Protection

Relay coils store energy. When an AC coil is de-energized, this stored energy does not present a problem because the current crosses through zero causing a faster magnetic flux collapse. In a DC coil, because the current never crosses zero, an inductive surge is generated resulting in high voltages. For example, a 125 Vdc coil can experience a surge voltage as high as 5,000 Volts. This stored energy and the resulting high voltage will appear and dissipate directly across the contact (i.e., the switch) that breaks the relay coil circuit. Therefore, when selecting a relay for DC application one must consider the proper arc suppression scheme, such as a diode installed across the coil. Usually, the need for surge suppression is identified and addressed in the field. Surge suppression can affect relay operating time since the currents circulating within the coil-diode loop tends to decrease the magnetic flux in the coil gradually. Therefore, the selection of the proper surge suppression scheme is often a trade-off between the operate or drop-out time vs the amount of energy that can be dissipated. Types of arc suppression techniques include installing resistors, varistors, series resistor-capacitors, diodes, or zener diodes across the coil. Consideration should be given to the effects of a coil failure and suitable precautions such as fuse protection to limit the energy and clear the fault.

2.1.1.6 Other Design Considerations

Depending upon the specific application at hand, other design considerations such as repeatability of relay operating time, rest time, qualified life and seismic capability should also be addressed.

2.1.2 Contacts

In a relay, the contacts are the most likely component to fail or degrade due to misapplication. This is no surprise given the various types of loads and switching conditions that can occur. It is difficult to define accurately the contact load requirements under normal and abnormal conditions. The contact specifications may not be fully understood, and the ability to relate relay specifications to actual conditions can be very difficult. Improperly chosen relay contacts can result in shortened relay life caused by welded contacts, high resistance contacts or improper circuit operation. The user generally specifies the number of contacts, configuration and rating for a given application. To ensure proper relay selection and maximum life of relays, the user should also pay attention to the following:

a. Type of loads switched
b. Duty type
c. Contact material

2.1.2.1 Type of Loads Switched

Contact ratings are usually specified for a resistive load at a rated voltage, frequency (i.e. rate of switching), and number of operations. Contact AC ratings apply only for the frequency specified. For example, if a contact rating is specified for 400 Hz, its 60 Hz switching capability is usually much less. Deviation from rated conditions can occur in many ways, some of which are not so obvious. For example, a contact may be able to switch high currents reliably but not low currents; single phase application can differ from three phase applications; grounding the case of a relay can reduce its contact rating. The type of load is significant to contact life. Incandescent lamps and capacitive loads (e.g., equipment with power supplies) have high inrush currents. Inductive loads may not produce high inrush currents but will cause arcing when turned off and may require arc suppression. Loads in the milliamp or microamp range will require special contacts (e.g., gold plated or gold alloy) for proper operation. DC loads tend to sustain arcing because the voltage does not cycle through zero. Hence, they can be more difficult to turn off.

2.1.2.2 Duty Type

The load rating, tolerance to contact bounce, and the expected duty cycle dictate the selection of the contact material and thus, the contact life. Contacts that do not frequently switch loads may become oxidized or covered with contaminants. Contacts that remain closed continuously will generate the most heat. Using a relay with multiple contacts all normally loaded, in a continuously energized application represent one of the worst case scenarios. Such relays will tend to run very hot. Contacts that are frequently switched and those that are used to switch heavy loads will require a material that can withstand contact erosion during arcing.

If one contact cannot switch a load, paralleling contacts will not help because the contacts will not switch simultaneously. Paralleling contacts can improve reliability and reduce contact heating when one contact can switch the load. Similarly, series contacts cannot increase the specified switching voltage because both contacts will not switch simultaneously. Series contacts can improve reliability and increase the dielectric strength by providing redundant contacts and increased contact separation.

Relays used in seismically qualified applications need contacts with adequate contact pressure margins to ensure chatter-free operation during an earthquake.

2.1.2.3 Contact Material

Matching the contact material for the specific application is vital to ensure proper relay operation and maximum contact life. Review of the industry failure experience data indicates this to be an area that has not received its due attention by the plant designers. A variety of contact materials such as silver, silver cadmium oxide, gold, palladium, rhodium, mercury, and tungsten are used. This subsection provides a brief discussion of the contact materials and their use in order to assist maintenance personnel in root cause evaluation of failures and identification of misapplication to prevent unwarranted relay failures.

Silver is probably the most commonly used contact material for light to medium current (1 to 10 amps) applications. It has high electrical and thermal conductivity and is relatively low in cost for a precious metal. It is easily formed, and resists oxidation and tarnishing except when sulfur is present. It is an established fact that in most industrial and urban areas, air is rich in gaseous sulphur compounds. Silver reacts with the gaseous sulphur in the air to form silver sulfide, a grayish black coating known as tarnish which increases contact resistance. Adequate contact wiping, sliding, or pressure can easily eliminate or burn off this film.

Silver is often combined with other materials such as cadmium, palladium, and nickel. Silver cadmium oxide is used in medium to high (5 to 25 amperes) current range applications. Its thermal and electrical conductivity is almost as good as silver, but it is more resistant to erosion and welding.

Gold, gold alloy, or gold plated contacts are used in low voltage/low current or dry circuit applications because of their resistance to tarnish and oxidation. Inert in nature, gold resists surface film formation. Because it is soft, it tends to stick or cold weld. It is not recommended for currents above 0.5 ampere.

Palladium in combination with gold has been used effectively in low level switching circuits because it resists cold welding and polymerization. Adsorption of hydrocarbon vapors from sources such as paint fumes, phenolic plastics, and some magnet wire insulation results in a film formation on the contact surfaces. Polymerization is the conversion of this film into a hydro-carbon material which, during arcing of the contacts, can result in a solid carbonaceous coating or ring on the contact surfaces. Polymerization can lead to contact failure through uniform surface erosion and high resistance.

Rhodium has excellent resistance to corrosion and oxidation. It resists cold-welding, and has excellent contact resistance stability. It is used as a contact material in reed relays for switching currents from 10 mA to 1.5 amperes.

Mercury is probably one of the most interesting of contact materials. Its wetability and surface tension helps it retain an extremely stable and uniform contact resistance. Contact resistance can be as low as 2 millohms in high current applications or as high as 200 milliohms in low current applications. It has a long life and can provide bounce free switching. The contact surfaces are renewed by fresh mercury every time they are operated. Mercury-wetted contacts can switch currents from 1 mA to 100 amperes. However, experience in the nuclear industry has shown that mercury-wetted contacts may be unreliable (sticky contacts) in continuously energized relay applications.

2.1.3 Service Environment

Complete specification of the expected service environment for the relays is vital to ensure proper relay selection and long life. Environments of interest include the following:

a. Temperature
b. Humidity
c. Radiation
d. Vibration, seismic shock
e. Dust, corrosive vapors, salt spray
f. Environmental protection (e.g., sealed)

The relay operating service environment should be carefully identified and evaluated. Specific items to be evaluated when specifying the environments are discussed in the following paragraphs.

2.1.3.1 Temperature

What are the normal and abnormal ambient temperature during operation? Is the environment different if air conditioning fails or cabinet doors are left open? When a number of relays are mounted inside a relay cabinet as in reactor protection system (RPS) cabinets, it is necessary to evaluate carefully the heat loads during various modes of operation. With a substantial number of relays continuously energized as in fail-safe designs, the heat rise in the cabinets can result in coil overheating and premature coil burnouts, (See section 3 and Appendix D for a discussion of real world problems).

2.1.3.2 Humidity

High humidity environments (e.g., Fuel Pool Operating Floor, Service Water Bays) can enhance electrolytic corrosion of windings, contacts, lead wires and terminals, and decrease the dielectric withstand capability of the contacts. Relays in normally de-energized applications are more vulnerable to such effects than those in normally energized applications. Installation of space heaters and/or relays with hermetically sealed construction may be needed. A relay with a dust cover is not an adequate substitute for an application that requires a sealed construction.

2.1.3.3 Vibration and Shock

Continuous high vibration levels can affect relay performance and enhance wear-out of mechanical linkages and springs. If the relay must properly function during and after an earthquake, the expected amplification of the floor motion at the location of the relay and the permissible level of contact chatter during the earthquake should be specified.

2.1.3.4 Dust, Corrosive and Chemical Vapors

Dusty, salty, hydrogen-rich, or corrosive vapors in the air can accelerate aging degradation of the relay contacts and mechanical parts, and affect coil heat transfer. In a hydrogen-rich atmosphere, sealed relays must be used. A dust cover may be all that is needed if explosive mixture is not present and the environment is relatively dust free as in relay rooms or control room.

2.1.4 Physical Considerations

Physical characteristics such as dimensions, weight, mounting orientation, mounting style, and termination types should be addressed. Mounting orientation may affect the seismic performance of relays. Screwed and slip pin (e.g., plug in sockets) terminations may vibrate loose and cause terminal overheating and arcing. Plug-in type relays may need to be secured firmly with special clips or brace bars to ensure that they stay in place during and after an earthquake.

2.2 Misapplication of Relays and Timers

Generally, application problems are the result of differences in real life application conditions, such as, load characteristics, operating temperature and bus voltage conditions, when compared with those

a. as specified by the engineer, and/or
b. as rated by the manufacturer

Potential misapplication problems that could arise because of these differences, which could lead to premature relay failures are discussed in this section.

2.2.1 Understanding Contact Rating

Unless otherwise specified explicitly, the manufacturer's rated contact capacity means the resistive load that can be switched at the rated voltage and frequency (i.e., rate of switching) for the specified number of relay operations. For example, one manufacturer specifies the contact rating as follows.

> "The current-closing rating of the contacts is 30 amperes @ 6-24 Vdc. The current-carrying rating is 12 amperes DC continuously or 30 amperes DC for 1 minute."

This information means that, when used for 6-24 Volts DC application, the contacts are capable of carrying a maximum of 30 amps for a maximum duration of 1 minute, or continuously carry a maximum of 12 amps. This statement does not mean that the contacts are capable of switching currents from zero to 30 amps reliably, i.e., it does not say anything about the capability of the relay contacts to function properly when switching currents in the milliampere range at say 24 Vdc. Also, the statement does not imply an equivalent ac rating of the contacts. Such information should be obtained from the manufacturer.

2.2.2 Low Level Switching

When standard contact materials such as silver or silver cadmium are used in low current applications, the contact voltage is insufficient to sustain arcing which serves to burn off the oxidation and sulphidation residues on the contact surfaces. It could lead to failure of the relay due to contact high resistance. The fact that a contact can reliably switch 30 ampere does not necessarily mean it can reliably switch 30 milliamperes. The suitability of the contact material and contact pressure should be evaluated before using a relay with the contacts rated at 30 amperes as discussed above in a low signal (e.g., 4-20 ma instrument signal switching for transfer of indications from the control room to the remote safe shutdown panels) current switching applications. Several cases of misapplication related to low level switching have been reported, [59].

2.2.3 Dry Circuit Switching

A circuit that does not make or break load currents is called a dry circuit. An example of a dry circuit application is the 2-out-of-4 or 1-out-of-2 twice logic contact arrays used in the RPS and ESFAS systems. In such an application, although the contact may convey its maximum rated current, it is likely to experience premature failure from high resistance contact. The reason for this type of failure is again the inability to burn off the oxidation and sulphidation residues, because contact wipe and contact bounce do not occur during arcing and softening of the contact surfaces.

2.2.4 AC vs DC rating

Sometimes the AC and DC contact ratings are used interchangeably. A contact rated for 120 Vac 30 amperes can reliably switch 30 ampere at 120 Vac, but only a tenth as much i.e., 3 amps at 125 Vdc. When this DC rating is exceeded, relay failure caused by contact welding or pitting and high resistance will result, [59]. The DC rating at high DC voltages depends on many factors such as contact gap, contact material, relative humidity, presence or absence of arc chutes or magnetic blowouts, and contaminating chemicals in the atmosphere.

2.2.5 Arc Suppression

DC loads are more difficult to turn off than ac loads because voltage never passes through zero. As the contact opens, an arc is struck and may be sustained by the applied voltage unless the arc length becomes too long to sustain itself. The arc energy can seriously wear away the contact.

Unlike resistive loads, inductive loads like solenoids and chokes may not produce high in-rush currents. But when inductive loads are turned off, the stored energy in the magnetic field must be dissipated across the opening contacts. This results in sustained arcing across the contacts which, if not suppressed, could lead to contact erosion and welding. Arc suppression techniques using R-C networks, diodes, varistors, zener diodes across the contacts, can help. Selection of the proper arc suppression technique depends upon the load type. For example, use of a diode across the load is a common and inexpensive technique. But it is not suitable if the input polarity can be reversed under certain conditions, or if the circuit is vulnerable to high voltage transients in the normal polarity. Most of the arc suppression techniques will also introduce a small delay in the operate time. If the relay operate time is critical, then the arc suppression scheme should be evaluated for compatibility with this requirement.

2.2.6 Operating Temperature

Relays are typically designed to operate in an ambient temperature range of -20°C to +55° C. The overall operating temperature of a relay will also be affected by the heat generated when current flows through the relay coil. As mentioned in Section 2.1.1.3, selection of a relay for a particular application depends on the insulation class of the coil. This however is only the first consideration. Other heat sources or the inability to remove heat from a relay will affect relay performance and ultimately relay service life.

2.2.6.1 Electromechanical Relays

Relays are normally mounted inside cabinets and enclosures in a grid form, also known as gang mounting (See Fig. 2-1). The enclosure is designed to assure sufficient air flow through it to keep the temperature rise within the enclosure low (usually 15^{o} F). Engineers usually calculate the expected heat load in the cabinet assuming that a certain percentage of (sometimes assuming all) relays are normally energized, and that each relay contributes a certain number of BTUs. Sometimes, this may result in inadequate ventilation because of the inability to estimate the individual relay heat load which is a function of, not only the coil operating status, but also other factors such as mounting configuration, number of contacts used, number of contacts continuously carrying the load, and contact load as a percentage of its rated load. This problem becomes more significant in the facility change process as new relays are added or spare contacts in existing relays are used. Several cases of inadequate heat removal leading to premature failure (usually of the coil burnout type) of relays have been documented. An effective way to address this problem is to perform a field survey of the enclosure heat rise under different operating conditions and verify that the ventilation through the cabinet is sufficient to ensure that relay coil operating temperatures are within their design limits.

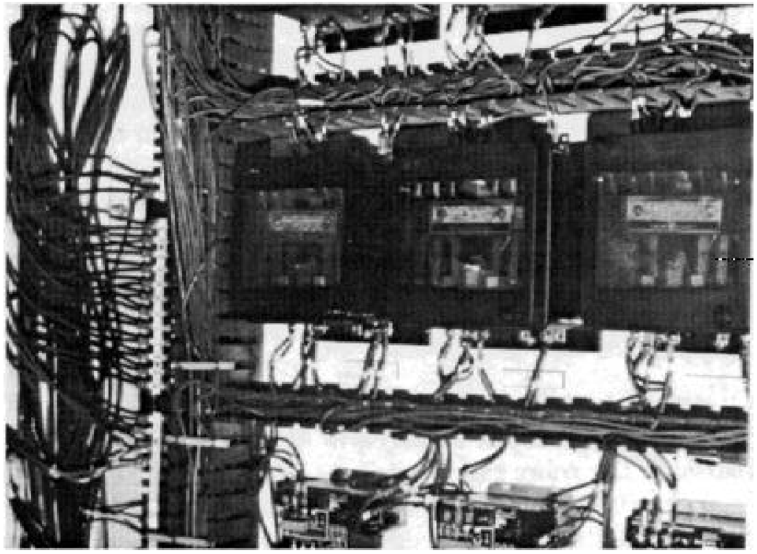


Figure 2-1 Photo Of Gang-mounted Relays

2.2.6.2 Solid State Relays

The single most important consideration in the application of an SSR is the junction operating temperature of the output switching device. All SSR's have well defined load current carrying capability related to their junction operating temperatures. In terms of their operating temperature rating, Power FET's rank the highest, up to 150^{o} C, SCR's being next, up to 125^{o} C, and TRIAC's last, 95 to 125^{o} C. However, most optically coupled SSR's are rated for maximum continuous working temperature of 115^{o} C based on LED limitations. Some transformer coupled SSR's are rated for temperatures up to 200^{o} C.

The junction operating temperature is related very closely to the ambient temperature. Figure 2-2 shows a typical curve for an SSR load current vs. ambient temperature. Similar to the electromechanical relay discussed above, it is essential to ensure that the design and actual conditions are closely matched.

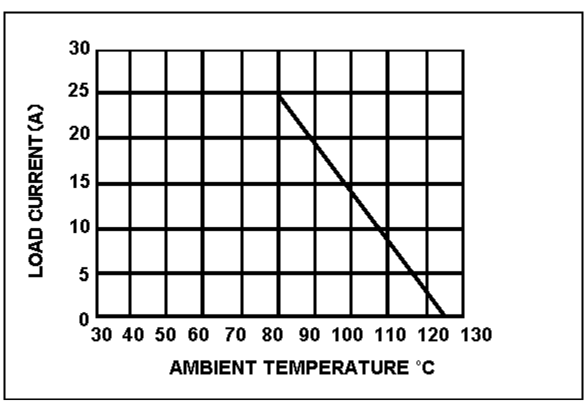


Figure 2-2 Maximum Allowable Current Vs. Ambient temperature

2.2.7 Coil Operating Voltage

Relay coils are rated for operation at specified voltages. Generally, relay coils are designed for a nominal rating of ± 10%. For example, let us consider a coil with a resistance of 2040 Ω and rated voltage of 125 Vdc. When this coil is used in a DC system where the bus voltage is normally maintained at 135 Vdc, the coil is operating at near its maximum rated voltage. All other conditions being equal, the coil power dissipation and hence the heat rise will increase by about 15% since the power dissipation varies as the square of the applied voltage ($Power=E^2/R$). Hence relays used in constantly energized application, when subject to such overvoltage conditions for prolonged duration are more likely to experience premature coil failure. This increased heat throw off should also be accounted for in establishing the ventilation air flow requirements as discussed previously.

2.2.8 Paralleling of Contacts

When a load greater than the rating of a contact needs to be switched, sometimes designers parallel two contacts to split the load between contacts. This approach should not be used in switching loads through relay contacts because, unless the two contacts close absolutely simultaneously, one contact will bear the full load leading to contact welding and failure.

3.0 Degradation and Failure Modes

3.1 Relays Used in Nuclear Plants

Relays used in the currently operating US nuclear plants fall into the following categories listed in decreasing order of the respective population :

Control/Auxiliary Relays

- Electromechanical, Hinged-Armature Type
- Electromechanical, Solenoid Type
- Electromechanical, Rotary Type
- Electromechanical, Dry-Reed Type
- Electromechanical, Mercury-wetted Reed Type
- Solid State Relays

Timers

- Pneumatic Timer attached to an elctromechanical relay
- Electronic Timer attached to an elctromechanical relay
- Electronic Timer relay

The majority of relays used in nuclear plants are used in 120 Vac or 125 Vdc applications. The next most common coil operating voltage levels are 48 Vdc and 24 Vdc. Some control/auxiliary relays are used in 208/240 Vac levels. Industry average estimates for population of relays and their function/use are given below:

1)	Control/auxiliary relay population per plant	2500 to 4000(1)
2)	Timing relay population per plant	250 to 400(1)
3)	Safety related population per plant	25% to 35%(1) of items 1 & 2
4)	Relays in normally energized applications	40% of items 1 & 2
5)	Relays covered by Tech. Spec. Surveillance	50% of item 3
6)	SSRs as % of total population	< 1/2 %

(1) Range reflects the plant vintage differences in systems and equipment

Table 3-1 lists the manufacturer and model number of relays used in nuclear plants. This list was compiled from a survey of the utilities conducted during this project, information collected from NPRDS, and by plant visits or telephone conversations. This survey also identified some of these relays as high maintenance items. Review of the overall industry failure data from the NPRDS confirmed that the relays identified by the individual plants as high maintenance item were indeed so. This information was used to develop the recommended maintenance actions and their periodicity (See Section 7).

Table 3-1 List of Manufacturer and Model for Commonly Used Relays

Manufacturer	Model or Model Series
Allen Bradley	700
Amerace/Agastat	7000, E7000, GP, SCCL, BCSA, SCBR, ETR, FTR
Clare	SF520
Cutler Hammer	D26, D23, D87
Deutsch	4A
Eagle Signal	CT, CX, BR
Electro-Switch	LOR, LOR/ER
General Electric Co	HEA, HGA, HFA, HMA, HAA, CR 120, CR 2820
Gould/ITE	J13
Joslyn Clark	PM5U, PM4U, PMT
MSD-Struthers Dunn / Magnecraft Electric Co.	211, 219, 214, 84XX
Potter & Brumfield	KRP, KRU, MDR
Rochester Instruments	ET-12XX, R10
Square D	RSD14, NR, NH, CI 8500
Westinghouse	ARD, AR, NBFD, NBF, MG-6, SG

3.2 Relay Components

An electromechanical relay consists of three basic units enclosed in a casing which may be nonmetallic or metallic:

- Coil subsystem
- Contact subsystem
- Mechanical linkages

The coil subsystem includes the coil, coil insulation, coil lead wires, bobbin or spool, core, core components, and if included ac to dc conversion rectifier components, and surge/arc suppression components, such as diodes, varistors and capacitors. The contact subsystem includes the fixed and movable contacts, armature, armature insulation, contact fingers or blocks, and lead wires to the contacts. Mechanical linkages include the springs, and armature or plunger travel adjustment screws. If the relay is a plug-in type, it will also include a socket and mating relay connector base.

In an elctromechanical timer, in addition to the basic relay, a timer attachment is included. This timer can be a mechanical, pneumatic, or electronic unit.

A solid state relay consists of circuit components, such as diodes, thyristors, LEDs, resistors, capacitors and inductors mounted on a printed circuit board and enclosed in a metallic or nonmetallic housing. If the SSR is a hybrid type, it will also include an output electromechanical relay.

3.3 Materials of Construction

In order to understand what goes wrong with any of these relays with time in-service, it is necessary to study the components, their design and materials of construction. The basic materials of construction are similar for the different types of electromechanical relays. Tables 3.2, 3.3 and 3.4 list the materials of construction used in most of the relays found in nuclear plants. Additionally, these tables also contain information about the age degradability of the materials of construction.

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Table 3-2 Typical Materials of Construction for Electromechanical Relays

Relay Components	Material of Construction	Age Degradable?	Comments
Relay case	Phenolic, Lexan(2) Aluminum, Steel	Yes No	
Coil wire	Polyamide-imide insulated copper magnet wire	Yes	Insulation degrades with time in service
Coil spool	Zytel (1), Nylon, Lexan (2) Fibre Glass Phenolic	Yes	
Coil coating or covering	Polyester Tape Fiberglass Tape Varnish Epoxy	Yes Yes Yes Yes	
Core Assembly	Steel and copper	No	Copper separator dots may wear from vibration
Contact assembly	Phenolic Zytel(1) Delrin(1) Nylon Metal	Yes Yes No	
Contacts	Silver, Sliver cadmium alloy Gold, Gold Alloy, Gold-plated Silver, Nickel or Nickel alloy	Yes Yes Yes	Contacts wear with time in service caused by corrosion and metal transfer
Contacts	Mercury-wetted	Yes	Prolonged operation in normally energized mode can cause sticky contacts
Terminals and screws	Brass, cadmium plated brass	Yes	Corrosion and arcing damage when loose
Armature plate and springs	Steel	Yes	Springs relax with time
Lead wires	Teflon(1), Silicon rubber, Tefzel (1) Metallic braids	Yes	Lead wire insulation ages relatively slowly and may be sensitive to radiation. Metallic braids like the ones in GE HFA relays may experience fatigue breaks.

1. Trademark of E. I. duPont de Nemours & Company
2. Trademark of GE

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Table 3-3 Typical Materials of Construction for Electromechanical Timing Relays

Relay Components	Materials of Construction	Age Degradable?	Comments
Case	Steel, aluminum Lexan(2), Phenolic	No Yes	
Timing motors	Magnet wire with fornal varnish	Yes	Insulation ages with time in service
Relay contacts	Silver, Sliver cadmium alloy Gold, Gold Alloy/plated Silver Nickel or Nickel alloy	Yes Yes Yes	Contacts wear with time in service due to corrosion and metal transfer
Contact carriers	Delrin(1), Zytel(1) Phenolic, Nylon	Yes	
Terminals and Screws	Brass, cadmium plated brass	Yes	Corrosion and arcing damage when loose
Cams	Delrin(1) Metal	Yes Yes	Metallic cams wear due to friction
Timing Circuits	Resistance-Capacitance net-works with diodes, transistors and ICs	Yes	Applies to electronic timing units
Timing diaphragm and stems	Silicon rubber Teflon, Nylon	Yes	Applies to pneumatic timing units

1. Trademark of E. I. duPont de Nemours & Company.
2. Trademark of GE
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Table 3-4 Typical Materials of Construction for Solid State Relays

Relay Components(2)	Materials of Construction	Age Degradable?	Comments
Relay case	Phenolic, Lexan(1) Aluminum, Steel	Yes No	
Circuit components	Silicon, germanium, carbon, semiconductor materials, Aluminum	Yes	
Terminals and screws	Brass, cadmium plated brass	Yes	Corrosion and arcing damage when loose
Lead wires	Teflon(1) insulation Silicon rubber insulation Tefzel (1) insulated Metallic braids	Yes	Lead wire insulation ages relatively slowly and may be sensitive to radiation. Metallic braids like the ones in GE HFA relays may experience fatigue breaks

1. Trademark of GE
2. For hybrid SSRs and transformer-coupled SSRs portions of Table 3-2 will also apply.

3.4 Stresses and Degradation Mechanisms

Generally relays, especially those used in safety related applications are located in areas where mild environmental conditions (i.e., moderate temperature, humidity, radiation) exist. These are called mild environment areas. For relays, even these environments combined with the operating duty can cause significant aging stresses. These stresses may be classified into four categories: Environmental, thermal, mechanical and electrical. These stresses will tend to cause some relay materials to degrade with time. The symptoms of such degradation may include changes in response time (e.g., change in operate time of control relays or change in the time delay setpoint for time delay relays), in coil characteristics (e.g., coil resistance, inrush and holding currents, and insulation resistance), or in contact characteristics (e.g., resistance across closed contacts, dielectric capability). In the following sections each of these four categories of stresses, associated degradation mechanism and the manner in which the resultant degradation may manifest itself are discussed. The methods for detecting and evaluating the symptoms of degradation are described in Section 7. Table 3-5 presents a summary of the stresses discussed in the following subsections, the type of aging that results, and the ultimate effect of the stress on relay operation.

Table 3-5 Stresses and Effects on Relays

Stress Type	Effect on Component	Failure mode
Elevated Ambient Temperature	Coil insulation degradation	Coil burnout
Humidity	Corrosion of contacts, leakage path to ground Winding electrolytic corrosion	High resistance contacts Coil burnout
Dust and Dirt	Physical interference, increase in friction, buildup of an insulating layer on contacts Affect heat transfer on SCRs, Triacs & Thyristors Affect coil heat transfer	High resistance contacts Mechanical component wear and misalignment Affect pickup voltage and seismic capability Output switching element junction overheating and failure in SSRs
Chemical contaminants	Contact activation	Prolonged contact arcing and contact welding
	Contact Polymerization, Sulphidation of silver or silver alloy contacts	High resistance contacts
Prolonged continuous energization (conduction)	Enhanced rate of insulation degradation Coil bobbin material embrittlement	Coil failure, possible physical obstruction of movable parts from failing debris Increased leakage and eventual output failure Pickup and dropout voltage shift.
Inductive surge	Dielectric breakdown and corona attack on coil insulation	Coil open circuit
Prolonged over voltage operation	Higher coil operating temperature Higher junction operating temperature	Coil burnout Increased leakage and output switching element failure of SSRs
Excessive contact bounce	Excessive arcing	Contact erosion and welding
Loose connections	Arcing & heating of contacts	Contact welding Terminal insulation breakdown Intermittent relay operation
Vibration	Material fatigue and misalignment	Intermittent contacts, breaking of the contact to case connections, mechanical obstructions from debris, pickup and dropout voltage shift from misalignment
High cycling rate	Wear of moving parts, contact erosion, coil insulation dielectric breakdown	Binding of armature, intermittent contact operation, coil burnout failure.
Dormancy (lack of operation)	Organic material set and adherence to adjacent material	Binding of movable parts
	Buildup of sulphidation on silver/silver alloy contacts, buildup of insulating film on the contacts.	High resistance contacts

3.4.1 Environmental Stresses

Environments for relays can be grouped into two categories: 1. normal and abnormal operational environments, and 2. design basis event environments. The stresses from each of these may affect the relay performance in different ways. The stresses from normal environments will very likely produce a gradual degradation of performance through their effects on the materials of construction. These effects will be of a lasting nature. The aging degradation from normal environments may result in only random failures, thus posing little or no safety consequences. The stresses from design basis environments such as a seismic event, especially when applied to an already aged relay, may impact performance in a sudden or immediate manner. The resultant degradation may or may not be lasting in nature. The result can be common cause failures of multiple relays in a short time interval, which could challenge the defense-in-depth built into safety systems.

3.4.1.1 Normal and Abnormal Environments

Normal and abnormal operational stresses are those that stem from the ambient conditions present during shutdown, normal, abnormal, and anticipated operational transients of the power plant. Environmental stresses that contribute to the degradation of relays are heat, radiation, humidity, dirt, dust, corrosive or sulphurous fumes, and other chemical contaminants.

Ambient temperature can affect the operating temperature of a relay coil and other relay parts, such as the timing element and the armature return spring. In an SSR, the ambient temperature can affect the heat transfer through the heat sinks provided for the output switching elements. Continuous operation at a higher than rated ambient temperature can result in :

- insulation degradation and shorted turns in coils; embrittlement of coil bobbins, lead wire insulation and other insulators; and/or relaxation of armature springs in an electromechanical relay.
- failure of the photo-receptors, LEDs and/or instability of the output TRIACS and SCRs caused by increased leakage currents in an SSR.

Relays used in normally energized (normally conducting state for SSRs) applications are more vulnerable to this degradation mechanism than their counterparts in normally de-energized application.

Humidity can accelerate winding corrosion, cause contact material degradation due to corrosion, reduce the dielectric capabilities of contacts, and cause short circuits if sufficient condensation occurs on electrical paths. Humidity can also promote hydrolysis of polyimide magnet wire insulation. This is of particular concern to the relays in normally deenergized applications.

Dust and dirt can increase friction on moving parts and contribute to wear of the relays. In an SSR, dust and dirt can deposit themselves in the flutes of the heat sinks and reduce the heat transfer. Chemical contaminants may cause premature breakdown of relay materials as well as contribute to oxidation or activation of contacts. It should be noted that in nuclear power plants, relays are generally of the enclosed type (i.e., as a minimum with a dust cover), and are located in relatively clean environments, thereby reducing the potential for degradation due to environmental contaminants.

3.4.1.2 Design Basis Event Stresses

The most significant design basis event for relays used in nuclear plants is a seismic event. Relays are located in mild environment areas, such as the control room, cable spreading room, electrical control cabinet, and circuit breaker rooms. They are not located in rooms where spray or steam environments are expected. They may be subjected to moderately higher temperature and humidity conditions during design basis events, but these conditions are not expected to be significantly different from normal conditions nor are they expected to last for long periods. Some relays in nuclear plants may be subjected to low levels of radiation during normal conditions and moderate levels of radiation during accident conditions. These conditions are plant-specific. For example, some plants have motor control centers that contain relays located in an auxiliary building.

For some relays, capability to withstand a seismic event and perform within specification may change with age. For instance, altered clearances in the armature linkages resulting from aging, can cause a sticky armature, armature spring pop up, or insufficient contact pressure when the relay is subject to vibratory and shock forces from an earthquake. Structural failure of relay components or electrical failures is not expected. Momentary contact chatter may occur, particularly if the relay is deenergized during the event. The relays are not damaged by the contact chatter during a seismic event. However, persistent contact chatter can initiate trip signals or inadvertent operation of systems and require operator action to restore normal operation.

3.4.2 Thermal Stresses

One of the two dominant stresses in electrical relays results from coil heating (junction heating in the output switching element for SSRs) resulting from prolonged energization of the relay coil. The effect on the coil and other nonmetallic materials is material degradation caused by thermally accelerated chemical (oxidative type) reactions. The coil operating temperature is a function of the I^2*R heating, coil loading, and the effectiveness of the heat transfer between the coil and the environment. Heat transfer between the coil and the environment can be affected by the contact loading conditions.

An often unrecognized thermal stress is imposed on relays housed in electrical cabinets. While the relay or switchgear room may have a low ambient temperature (70^oF to 80^oF), cabinets containing many continuously energized relays may have an internal temperature that is 20^o to 40^oF above the room ambient. The elevated cabinet temperature will increase the operating temperature of relay components and accelerate their deterioration.

3.4.3 Mechanical Stresses

The mechanical stresses for relays consist of cyclic operational stresses, loose connections, wear, and relay socket fit. High cyclical operation of relays may result in mechanical fatigue on spring-loaded components. Loose connections in the electrical paths for the relay coil and contacts may result in increased currents, arcing, and heat generation contributing to premature failure. Wear of moving parts and contacts can reduce mechanical tolerances. These changes in tolerances can result in increased current through the relay coil when it is required to operate or arcing of relay contacts due to poor mating. Frequent removal and insertion of relays with socket bases can cause wear to the relay socket contacts and result in air gaps between the socket and relay contact, causing open circuits.

Constant floor vibration or vibration in equipment enclosure (e.g., pump room) can cause misalignments and altered clearances in the mechanical linkages. Springs tend to relax over time when they are subjected to repeated operation at elevated temperatures. Such conditions can affect the relay performance through mechanisms such as sticky plunger, sticky armature, increased time interval between the open/close of the first to the last contacts, and inadequate contact pressure. Mechanical stresses can also adversely impact the seismic capability of the relays.

3.4.4 Electrical Stresses

During the normal operational life of relays, energization at nominal design voltages does not impart any significant stress on the relay. However, after degradation from one or more of the stresses discussed in the previous subsections, energization of relays even at nominal design voltages may result in relay failure.

Interruption of the supply voltage to dc coils can result in an inductive surge or inductive kick leading to a high voltage (in excess of 5kV for a 125 Vdc coil) appearing across the relay coil. Such high voltages can cause dielectric breakdown of weak points in the coil insulation system, e.g., voids or bubbles in the coil wire varnish, magnet wire insulation embrittled by prolonged energized operation. Breakdown of the coil insulating material can lead to cascading insulation failure. The leakage current causes increased temperatures in the insulation, which reduces the insulation resistance and leads to greater leakage current in the coil. Eventually, the insulation breaks down and the coil sustains a short circuit.

Operation of electrical relays at increased voltage levels (even for short periods) tends to accelerate the aging of relays caused by elevated temperatures resulting from voltage increases. Nominal self heating of the coil is dependent upon the applied voltage and the coil resistance. The heat generated can be calculated using the equation:

$$0.57 * E^2/R \text{ BTUs [94]}$$

where

E is the applied voltage to the coil,
R is the coil resistance at the operating temperature.

Supply voltage variation can affect the heat generated in the coil. The supply voltage for the dc relays in a nuclear plant can be as high as 140 Vdc. A survey of the plants indicates that the normal dc bus voltage is in the range of 130-135 Vdc. For coils rated for a nominal voltage of 125 Vdc, this amount of supply voltage increase can translate into about 15% additional power dissipation. Generally, DC coils are much more tolerant of higher operating voltages because of the reduction in current caused by increase in the resistance at elevated temperatures. Still continuous overvoltage application can and will reduce the relay life as a result of degradation of coil insulation and other insulating components, such as the coil bobbin and the armature separator insulating plate.

AC coils are less tolerant of coil overvoltages. Increased operating voltage will cause an increase in the magnetic saturation of the iron components, resulting in a significant decrease in reactance. The net result is decreased impedance and increased coil current and coil overheating.

In nuclear plant safety-related applications (e.g., RPS, ESFAS), most of the relays are either normally energized or deenergized for a period of time followed by actuation of the relays for testing or genuine system demand. Normally, this type of relay operation should not result in a high rate of cycling that would have significant impact on the life of coils or contacts.

However, since most of the RPS and ESFAS tests are performed with the actuation circuit bypassed, the tests may result only in opening or closing a dry circuit. Such operation is insufficient to ensure contact self-cleaning, which occurs when contact wipe and arcing takes place. Therefore, over time, the relay contact performance will be affected through a high resistance condition. A similar type of failure mechanism will also occur for contacts used in low-level switching applications if the contact materials are not properly matched with the application.

In other active contacts, each time a contact makes or breaks a load, the contact surfaces suffer degradation as a result of arcing and melting of the contact metals. While some arcing is necessary and desirable, excessive arcing can result in contact erosion leading ultimately to contact welding, high resistance, or open contact conditions. The extent of the arcing and metal transfer between contacts during arcing is dependent upon many factors, including load voltage, current, contact gap, contact bounce, melt voltage of the contact material, and the operating time of the relay. In a relay that has experienced in-service stresses discussed previously, changes in some or all the parameters that affect contact arcing will occur and cause enhanced contact erosion, leading ultimately to contact welding failure.

In atmospheres containing certain hydrocarbons (e.g. nuclear power plants located in close proximity to fossil power plants, petro-chemical plants, and refineries) contact arcing can cause carbonaceous deposits on contact surfaces. This phenomenon is known as "contact activation." This, in turn, leads to increasing the arcing duration and thus reduction in contact life caused by erosion. Different contact materials are subject to different levels of contact activation. Activation lowers the electrical field at which an arc will start and also lowers the minimum arc current. Arcing on activated contacts tends to produce uniform erosion over the contact surface rather than the hump and crater formation normally seen in worn contact surfaces.

3.5 Summary

The dominant stress factor that causes coil failure in relays is thermal stress which is additive in nature. Thermal stresses can originate from many sources, including mechanical misalignments and certain electrical phenomenon such as inductive surges which are unique to dc coils. The principal failure mechanism associated with thermal degradation is a cascading effect that is initiated in voids, bubbles or other weakened portions of the insulation in the coil. Continued application of the relay's nominal voltage will cause temperature rises in the voids or bubbles of the coil insulation. The temperature rise further reduces the dielectric strength of the material and causes local short circuits within the coil. Local short circuits cause higher currents to flow through the coil, increasing the coil temperature and resulting in additional insulating material breakdowns. Under this weakened condition, overvoltages such as those from inductive surges or equalize charge voltages in a dc bus can accelerate the insulation degradation. The eventual result is either turn-to-turn or layer-to-layer short circuits burning open the coil, or exceeding the temperature limits of other materials within the relay, thus causing softening or melting of these materials and possible binding of the armature. Relays used in normally energized applications are more vulnerable to thermal stress induced failure than their normally deenergized counterparts. This conclusion is supported by industry experience described in Section 4. Humidity and contaminants such as dirt and dust can compound the effects of higher operating temperatures in energized applications, thus accelerating the degradation rate. Coils in normally deenergized applications will also be affected by humidity and other contaminants through mechanisms such as winding corrosion.

Assuming proper selection for the application, the dominant stresses that affect contact performance are mechanical and environmental. The failure mechanisms associated with these stresses are mechanical misalignments and/or deposits on contacts. The eventual result is contact failure from welding due to excessive arcing or high resistance due to insufficient contact wipe and self cleaning. This conclusion is supported by industry experience described in Section 4.

4.0 Relay Operating Experience

This section presents a discussion of the experience with relay failures that are indicative of the stresses identified in Section 3. The sources of information utilized for the discussion of the relay failures presented in this section include the NPRDS data system, information from LERs, and vendor advisories. The failure experience is discussed in order of component, starting with the relay case and working down through the relay mechanism to the relay base. Failure experience with time delay relays are discussed at the end of the basic relay discussion. This discussion is limited to electromechanical relays only because no experience data is available from the industry databases and the NRC generic communication sources on SSRs because of their very low population.

4.1 Mechanical Damage

Relay cases could be subject to failure as a result of impact loads or vibration fatigue. The primary source of impact loads would be human error when the relay cases are inadvertently struck. Only a few cases of this nature were found in industry experience data sources. A few incidents of improper installation of the relay case in GE HGA relays led to relay failures from stuck armature or damaged lead wire insulation in [13]. Relay case failures present the opportunity for several failure modes. The first failure mode consists of mechanical binding that results from a case fracture. Pieces of the relay case could enter the relay mechanism and impede operation of the relay. The other failure mode resulting from relay case failure is caused by contamination. Dirt or dust entering the relay can result in binding of moving parts or deposits on contact surfaces that interfere with contact performance. In addition, moisture contamination and condensation can result in short circuits or short to ground of the coil lead wires or the load circuits switched by the relay contacts.

Plug-in type relays, i.e., those having a relay and a socket base, have been found to loosen and have sufficient space between the relay plug-in pin and the socket contact leading to an open circuit [3,7]. This phenomenon could be the result of loosening of the fit between the contact surfaces because of wear from the removal and replacement of the relay from the socket, vibration moving the socket base contacts, or displacement of the relay socket contacts by improper or forced insertion of the relay into the base. Plug-in type relays are also susceptible to increases in the resistance of the relay pins and the relay base socket contacts as a result of corrosion since the relay pins and the relay base socket are generally exposed to the ambient environment.

4.2 Coil Failure

Review of the industry failure data shows that coil failures represent about 40% (See Figure 4-1, 2) of all relay failures in the nuclear power industry. Some makes and models of relays used in normally energized applications exhibit higher coil failures than others. In terms of the type of relays, the hinged armature (HA) construction, which is estimated to constitute over 60% of the control/auxiliary relays used in the industry, shows a higher coil failure rate than do the solenoid and rotary type construction (See Figure 4-3).

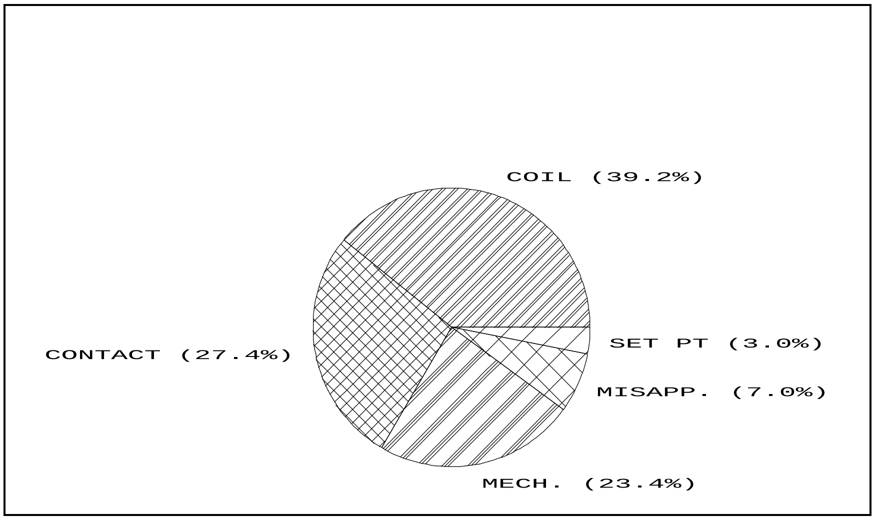

Figure 4-1 Breakdown of Failure Modes (energized)

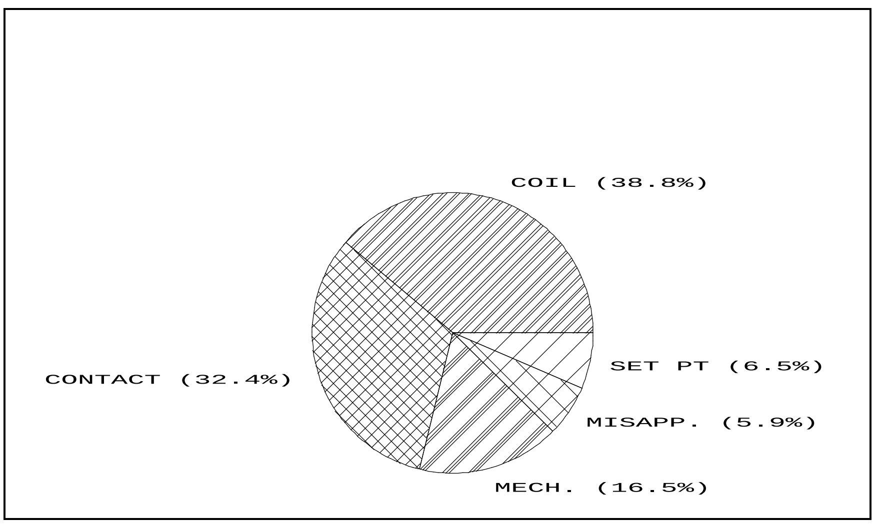

Figure 4-2 Breakdown of Failure Modes (deenergized)

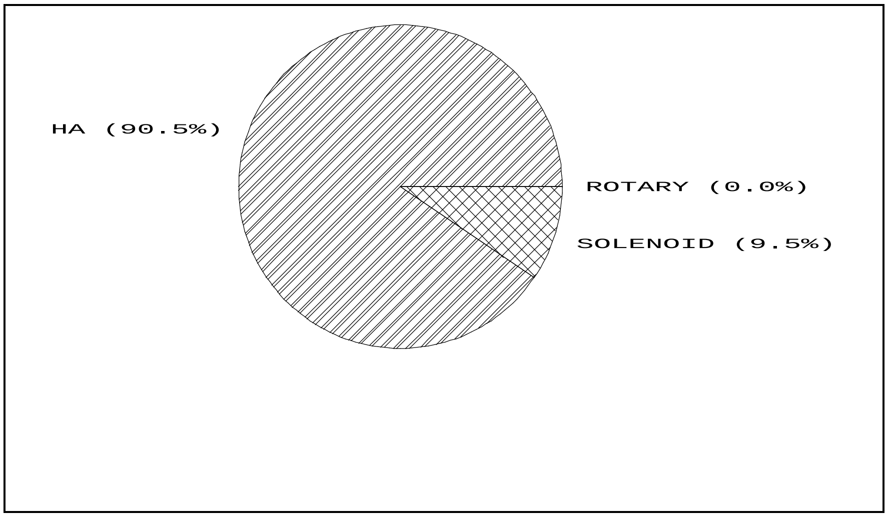

Figure 4-3 Coil Failures by Relay Type (energized)

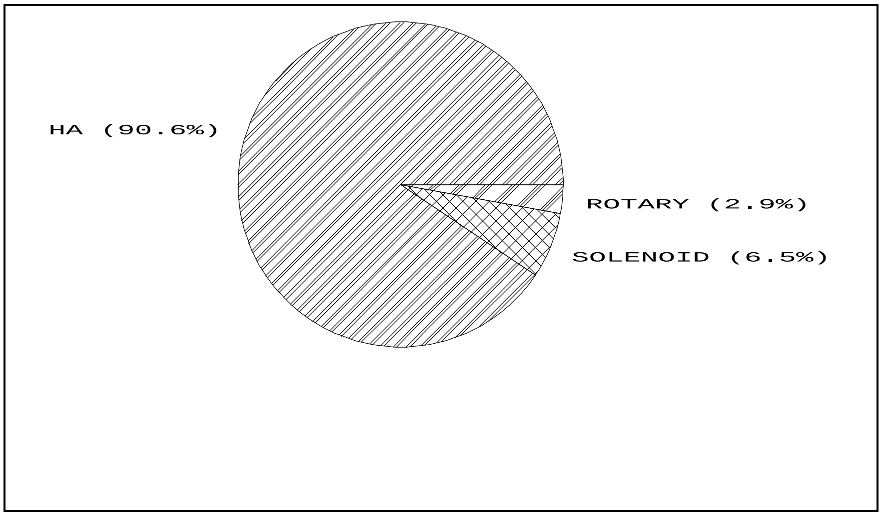

Figure 4-4 Coil Failures by Relay Type (deenergized)

A primary stress on all types of relays is coil heating resulting from continuous or long-term energization and from elevated ambient temperatures in relay cabinets. One failure analysis [96] of an auxiliary relay used as a control relay in a nuclear power plant safety system found that the temperature of the relay in the coil area rose more than 100^{o} F (55^{o} C) above the ambient temperature at the end of a 2-hour period. The relay tests conducted by Wyle Laboratories [97] verify that relay coil temperature rise can range from 50^{o}C to 120^{o}C. The high temperature imparts significant stress on the insulation systems in relay coils as well as on any nonmetallic components within the relay case. Gang mounting of relays in a relay cabinet/enclosure compounds [45] this condition.

Coil failures from continuous energization have been reported for both Westinghouse NBFD [53,54] and General Electric HFA relays [20 to 28].

Another significant stress on dc relay coils occurs during circuit interruption. Interruption of the supply voltage to the coil results in inductive surge. A large voltage (upwards of 5000 Volts for a 125 Vdc coil) may be produced across the coil on interruption of the current flowing in a dc coil. The surge will be the greatest at the moment of interruption. The transient voltage will be dissipated by arcing across the contacts switching the coil or through the coil over a short time. The inductive surge has been known to damage and destroy relay coils when the circuit interruption occurred too frequently or when the circuit interruption occurred in an aged coil whose insulation is degraded. Coil failures of the NBFD relays [49 and 50] were postulated to have resulted from such inductive surges in already aged coils.

The overvoltage surges cause breakdown of the coil wire insulation, especially at weak points in the insulation (e.g., voids and bubbles in coil wire varnish), which in turn causes short circuits within the coil. Internal coil shorts leads to heating which in turn causes the conductor of the coil to burn open.

The dc-powered armature-type relay is susceptible to another aging mechanism that does not occur in other relay types. In a dc-powered armature-type relay, energizing the relay coil draws the armature closer to the magnetic core armature pole, but leaves a small air gap between the two components. Overtravel of the armature so that the air gap between the armature and the magnetic core pole is eliminated, results in substantial increases in the coil current, and thus increased ohmic heating of the coil. A spacer, sized to equal the required gap in the magnetic circuit minimizes the problem. Contamination or buildup of deposits in the air gap presents a similar problem. Undertravel of the armature (produced by interferences in the air gap) also increases the coil current and can lead to high temperature failure of the relay coil or nonmetallic parts. NPRDS failure data contained numerous entries of failures where the originator of the data described them under the category "aging failure or end of life type failure." Review of the attendant description shows that several of the failures may have occurred due to armature Overtravel or Undertravel.

An unanticipated failure in control relays was identified in [4] as an end-of-life or age-related failure. The failure occurred as a result of continuous energization of the relay coil and manifested itself as a mechanical interference problem. The failure was caused by shrinkage of the relay case as the plastic cured. The phenomenon, called post-mold plastic shrinkage, resulted in reduction in clearances for moving parts and, in some cases, mechanical interference, which precluded correct operation of the relay. The post-mold plastic shrinkage appears to have been caused by the heat generated from continuous energization of the relay coil. Other thermal stress related coil failures have involved embrittlement failure of coil bobbins that either manifested as mechanical interference with the armature movement or shorted coil turns from loss of coil support. The result was coil burnout from overheating.

4.3 Contact Failures

Contact failure is the second most dominant mode of relay failure, accounting for just over 35% of all relay failures in the industry [Figure 4-1, 2]. The rate of contact failures seems to be unaffected by the coil operating status. For solenoid type relays, contact failures appear to be the dominant failure mode [Figure 4-5, 6] as opposed to coil failures for the hinged-armature construction. It also appears that a majority of contact failures may be occurring in dry-circuit or low-level switching applications as would be expected.

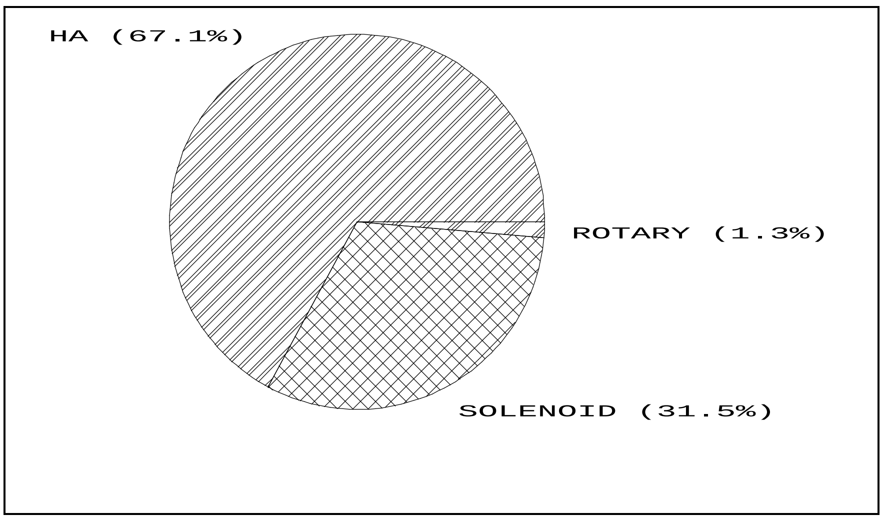

Figure 4-5 Contact Failures by Relay Type (energized)

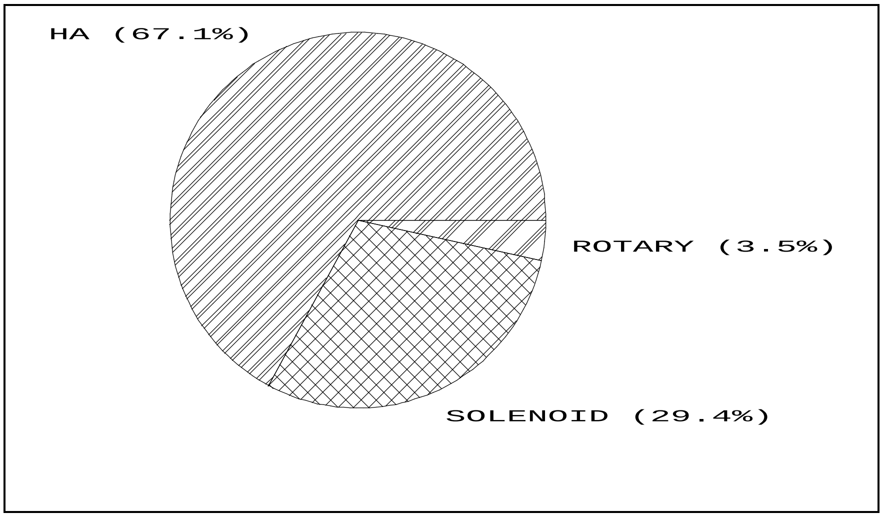

Figure 4-6 Contact Failures by Relay Type (deenergized)

Arcing and corrosion of contacts is a significant aging mechanism for relays. Arcing will occur in all load switching applications; in fact some arcing is necessary and desirable to provide contact cleaning action. Excessive arcing is usually associated with breaking of inductive loads or large resistive loads. Excessive arcing can burn or pit relay contacts, which results in reduced contact mating surface. In turn, the smaller seating surface increases the resistance of the contacts and adds to heating of the contacts, causing burning and further arcing, eventually leading to contact welding or high resistance or open contact type failure.

Corrosion of contacts increases the contact resistance. The increased resistance of the relay contacts results in increased contact bounce duration during make/break with prolonged arcing and contact erosion. Increased heating of the contacts will also occur when carrying the load. The result will be welding of the contacts or high resistance or open contact conditions.

Oxidation of contacts used in very low-level switching applications can produce sufficient insulation to prevent conduction and inadequate self-cleaning. As the buildup of oxidation products continues, the contacts will eventually fail in a high resistance mode.

Outgassing products from nonmetallics such as the cam, contact carrier, or the casing in the vicinity of the contacts can lead to a slow build-up of an insulating film on the contact surfaces. Each time the contact arcs, this film will polymerize on the contact surface leaving a solid coating on the contact surfaces. Intermittent contact failures of the Potter & Brumfield MDR rotary relays [58 to 60] have been postulated to have occurred because of this phenomenon. Similar cases have also been reported [46,47], for the Westinghouse ARD type relays. In this case, melting epoxy or the potting compound used in coil insulation polymerized on the contact surfaces.

4.4 Mechanical Failures

Mechanical failures in relays can occur in one or more of the following forms:

- Stuck plunger in a solenoid type relay
- Stuck armature and/or contacts in a hinged armature type relay
- Stuck rotor in rotary type relay
- Obstruction of the movement of the movable contacts from debris or dust accumulation
- Armature spring relaxation leading to prolonged contact bounce and excessive arcing and eventually, inability to change contact position.

Several cases of such failures have been recorded [24 to 29] in the industry in all types of control/auxiliary relays. Some early vintage HFA relays have experienced armature blocking by the debris from the Nylon and Lexan coil bobbins embrittled from overheating. For the HFA relays certain unique mechanical failure mechanisms exist. The first is the braiding that provides electrical connection between the terminal studs and the contact fingers. Operational cycling can lead to fatigue failure of these braids. When the casing is taken out and put back during maintenance, the braiding must be properly tucked in place, or it can affect armature motion. The second is the movable contact fingers. The fingers (i.e. the leaf on which the movable contacts are attached) tend to relax and change the contact gap and wipe after some time in service. Such conditions could promote contact arcing, erosion and affect the seismic functional capability of these relays. Note that in relays, the amount of time in service may cause degradations not necessarily caused by number of operations within the same time.

4.5 Timing Unit Failures

The pneumatic time delay relay is exposed to stresses unique to this type of device. The diaphragm in the relay is susceptible to embrittlement from heat generated by the coil. Dirt accumulation in the timing orifice area or in the air cavity can cause setpoint drift. For pneumatic time delay relays that use filters to prevent contaminants from entering the device, buildup of dust on the filter can reduce the air flow through the device and affect timing, while placing an additional strain on the operating mechanism. Several incidents have been reported [2,3], where the diaphragms in Agastat pneumatic time delay relays were susceptible to bleed-out of fluid from the diaphragm material when exposed to high temperatures, which could result in contamination of the relay O-rings and cause setpoint drift.

4.6 Evaluation of Relay Failure Databases

The data from the USNRC's Licensee Event Report (LER) system and the Institute of Nuclear Plant Operators' Nuclear Plant Reliability Data System (NPRDS) were analyzed. Data quality limitations and reporting requirements for each of these systems were considered in the analysis. Only certain failures of safety-related equipment are reported in the LER system. The reporting requirements are determined by each plant's license and Technical Specifications. The NPRDS data system reports most safety-related failures, but complete NPRDS information is available for a shorter period than LER data. The following data analysis is qualitative in nature and does not represent formal statistical evaluation.

Many of the failures, regardless of their type, were discovered during the performance of technical specification surveillance testing, thus providing the confidence that the potential for undetected failures, especially those of the common cause type, is minimal.

Approximately 780 failure records from the NPRDS and LER databases were utilized in performing the failure data analysis. This record set was selected from a total of 3700 + records after a review of each record for completeness and useability of the information. About 40% of the records were discarded because, they did not pertain to a relay failure. Other records that were deficient in one or more of the following were also discarded, leaving 780 failure records that were useable:

- Manufacturer and Model number unavailable
- Date of occurrence unavailable
- Failure information is incomplete

The 780 records reviewed does indeed provide a representative data set because they contained records:

- from nearly all of the operating and some previously operating but now retired plants
- from 1973 to 1991
- that represented nearly all of the make and models used in quantities in the industry
- that represented all of the make/model relays on which an NRC generic communication existed or a vendor advisory existed
- for approximately 60,000 relays in total component counts of these make and model from the NPRDS.

The data review was performed using the following sequence of steps:

1. Categorize the relay by its design type

2. Identify the initial criticality data of the plant and calculate age to failure.

3. Categorize each failure into one of the five failure mode categories listed below:
   - Coil failure
   - Contact failure
   - Mechanical failure
   - Misapplication
   - Setpoint drift.

4. Perform the arithmetic after normalizing the data to account for the number of plants in operation each year.

Based on this analysis the following conclusions may be drawn:

- The failure rate for all the relays regardless of type or application, has been on a steady increase up to about age 10 and then begins to level out. This might be because of the replacement of the relays as they fail. Sorting the data by individual make and model grouping confirmed the same, but showed that the average age to failures of the various make and model ranged from 6 years to 17 years depending upon the relay type and whether normally energized or deenergized in service.

- For most relay make and models, Amerace GP relays being one salient exception, normally energized relays have a *slightly lower average age at failure* than the normally deenergized relays. Thus, for most of the relays, the failure rates in normally energized applications are comparable to those in normally deenergized applications. However, the data for the Amerace GP series relays suggests that the age at failure for the normally energized case is abolut one half of that for the normally deenergized case.

- For both energized and deenergized applications, the dominant failure modes are coil and contact failures (See Figures 4-1, 4-2).

- Review of the data by the type of relay shows that the hinged armature type has a higher propensity for coil failures than the Solenoid & Rotary types for which dominant failure mode is contact failure (See Figures 4-4, 4-5).

5.0 Maintenance Philosophy and Program

Guidelines and recommended maintenance practices presented in this guide apply to the following types of relays:

- Electromechanical, Control and Auxiliary relays
- Electromechanical Timers
- Solid State Relays

This maintenance guide presents recommended practices with a view toward ensuring reliability of relays through a better understanding of the mechanisms that cause relays to age and ultimately fail. Understanding the fundamentals of relay design, application, selection, aging processes, and failure modes, helps the maintenance staff to develop a successful maintenance program and will provide a high degree of assurance that relays can fulfill their intended design functions.

This maintenance guide emphasizes that relay performance depends upon proper application and maintenance. An effective maintenance program cannot be developed without an understanding of relay application, performance, and the ways a relay can be harmed. The sections listed below will provide maintenance personnel with the necessary foundation to form the technical basis for the recommended maintenance practices contained in section 7:

- Section 1: a detailed description of the different types of relays, their operating principles, and use in nuclear plants

- Section 2: relay selection and application considerations and misapplication situations

- Section 3: aging mechanisms and failure modes for relays

- Section 4: operating and failure experience of relays and the results of the industry failure experience data review.

The inspections and tests recommended in Section 7 are based on the information in the above sections. These are discussed in the context of what each inspection or test accomplishes in relation to the identified degradation and failure modes. Inspections and tests are also presented in a format that would facilitate comparison with existing plant maintenance procedures.

The information presented in this maintenance guide should provide maintenance personnel with a solid grasp of the fundamentals which enable them to develop and implement a successful relay maintenance and replacement program. **However, it is stressed that there is no single "right" maintenance program that applies equally to all relays.** The degree of maintenance invested into a particular relay type depends on its safety function, the potential effects of failure or degradation, and the desired level of demonstrated reliability. Plant personnel should use the recommendations in the following sections to evaluate their maintenance practices and adjust them for specific applications.

5.1 Relay Information Sources

The recommended practices in this maintenance guide were developed from the following sources of information:

- Industry standards
- Industry papers
- Manufacturers' literature
- Regulatory research documents
- Plant procedures for testing and maintenance of relays.
- Industry experience data from NPRDS and LERs

The National Association of Relay Manufacturers (NARM) Handbook contains recommendations for design, installation, inspection, and testing. Appendix C provides an overview of the existing NARM standards. There are several IEEE standards that provide guidance for the application of protective relays. However, at present there is no industry standard devoted to the maintenance of control and auxiliary relays and timing relays. This may be because the common industry practice of replacing the relays that become defective. The NARM standards [88-90] contain guidance for design verification, factory acceptance, and qualification tests of electromechanical and solid state relays.

This maintenance guide has relied on the maintenance recommendations based on industry experience, NARM testing guidance, and NRC research reports. It is not intended to replace any industry standards; instead, it should be viewed as a supplement to existing industry guidance. This maintenance guide makes the following contributions to a control relay maintenance program:

- An overview of control relay design and construction fundamentals at a level appropriate for maintenance departments
- A discussion of aging and degradation mechanisms for relays in relation to recommended maintenance practices
- A technical basis for each recommended inspection and test
- Descriptions of what each inspection or test does and does not accomplish
- Recommendations in a format that can be readily compared with existing plant maintenance program documents

5.2 Maintenance Program Objectives And Development

5.2.1 Maintenance Philosophy

Relays are installed to provide control and safety interlock functions. All relays do not arbitrarily require the same level of periodic inspection, testing and maintenance. The maintenance program should include a review of the design basis for each relay or group of relays and the relay's role in the safe and reliable operation of the plant. The following are examples of application differences that should be considered:

- Not all relays have equal safety importance. Relays that perform safe shutdown functions or other Class 1E functions certainly require a higher level of reliability than relays providing auxiliary control and alarm functions.
- Individual relays may require different maintenance attention because of their locations, environments, or operating status. For example, a normally energized relay located in a room/enclosure with a year-round average temperature greater than 105^{o}F probably requires closer attention than the same type of relay installed in the control room with a year-round average temperature of 70^{o}F.
- **All relays are not alike**. Different relay designs have unique degradation and failure modes that should be considered. The maintenance program should treat the following types of relays differently:

  – Electromechanical hinged-armature relays
  – Electromechanical rotary relays
  – Electromechanical Solenoid relays
  – Electromechanical or pneumatic timer relays
  – Solid state relays and timers

- Relays with known degradation, e.g., time delay relays susceptible to setpoint drift, and continuously energized relays that have frequent coil or coil bobbin failure because of temperature should receive more detailed inspections so that the effect of the degradation on performance is understood and can be minimized

The maintenance program philosophy should be based on ensuring component reliability, not simply instituting maintenance requirements in response to manufacturer's recommendations or industry standards. The basis for any maintenance recommendation and the potential contribution of any maintenance practice to relay reliability should be fully understood.

5.2.2 Program Objectives

The objectives of a relay maintenance program are similar to the objectives of other equipment maintenance programs. An effective relay maintenance program should:

- Maintain each relay in a high state of readiness as determined by an acceptable level of reliability.
- Demonstrate compliance with applicable regulatory and industry requirements.
- Demonstrate that each relay can fulfill its design function.
- Provide performance trending for relays to predict when a relay may be approaching failure and will require refurbishment or replacement.
- Establish streamlined practices and procedures that minimize the complexity and administrative burden of implementing the program without compromising other objectives.
- Implement efficient and cost-effective maintenance practices that yield measurable results and avoid costly practices that provide little or no payback.

5.2.3 Maintaining The Design Basis

The design basis of each relay or relay group must be fully understood before applicable maintenance and test requirements can be established. By understanding the design basis for each relay, the maintenance department can tailor the periodic inspection, test, and maintenance requirements to achieve the desired level of reliability.

5.2.4 Practical Considerations

The maintenance program should take into account relevant practical limitations. Not all relays have equal importance and thus should not receive the same maintenance. An arbitrary decision to standardize all maintenance to the same level and periodicity as that specified or implied in the Technical Specifications or other plant specific regulatory commitments for safety-related relays can place an inordinate burden on the maintenance department. Each maintenance department has limited resource which should be applied in a manner that obtains maximum payback in overall plant reliability. The following items should be considered when establishing the maintenance program for relays:

- Installed relays have different reliability histories. This historical performance and failure experience should be used to establish the proper maintenance interval and maintenance actions.
- Test, inspection, and maintenance procedures should be streamlined and efficient. Overly complex and cumbersome procedures are inefficient and costly. Procedures that are too brief may not provide adequate guidance for the required maintenance and may increase the potential for unwarranted plant transients and trips. Procedures can be streamlined by considering the following:

  – What administrative controls must be satisfied and what level of documentation is needed?
  – Are separate procedures required for each relay or relay group, or is one procedure for a given class of relays more appropriate?
  – What training is needed to support the program?

5.2.5 Personnel Training

Proper training of personnel is an integral part of a successful maintenance program. No procedure, no matter how well written, can compensate for poor training. Development of complex procedures is often considered the solution to any maintenance-related problem. Unfortunately, attempting to compensate for a lack of training by adding more and more detail to procedures does not necessarily solve the real problem, and can result in less effective procedures in the long run. Properly trained personnel can directly support an efficient, streamlined program. Improperly trained personnel inevitably make mistakes and overlook problems. As a minimum, personnel working on relays should receive the following training:

- Personnel and equipment safety precautions for work on relays
- Fundamentals of relay operation and maintenance
- Proper use of test equipment
- Potential plant impacts when working on relays

- Procedure(s) to be used for performing relay maintenance
- Degradation and failure modes observable during periodic inspections
- Proper data collection and recording practices to support data trending

5.2.6 Performance Trending

All relay inspection and test data should be compared with previous relay performance and failure data. Although the results from each inspection and test are worthwhile for evaluating the current state of a relay, the data becomes even more valuable when compared with previous results to reveal performance trends.

Trending of relay failure and performance is crucial to a successful relay reliability program. During the life of a power plant, all installed relays will eventually require replacement. If properly collected, recorded and evaluated, trending information allows the maintenance staff to predict well in advance when a relay may no longer have the capability to meet its design requirements. A replacement relay can be installed in a planned and organized manner rather than in a crisis mode. Trending data can also support the basis for declaring an individual relay or relay group operable, and the development of a justification for continued operation when a potentially generic degradation (e.g., coil bobbin failure in GE/HFA relays, sticky contacts in Potter and Brumfield MDR relays) has been identified.

The maintenance program should emphasize accuracy, consistency and completeness in the collection and recording of inspection and test data to support a trending program.

5.2.7 Operator's Role In Monitoring Relays

Operators should identify abnormal relay or relay enclosure/cabinet conditions during shift tours. These tours are not intended to take the place of systematic in-depth relay inspection or testing; they are only meant to identify conspicuous problems. The operators should request further investigation by maintenance personnel for any of the following conditions:

- Unusually high or low relay enclosure/cabinet temperatures
- Unusually loud humming or noisy relays
- Obvious signs of relay damage such as mechanical damage or broken glass, arcing, charred wire insulation, misting on the windows, or smokey odor.

Control room alarm response procedures should direct the operator's response for any of the following conditions:

- Flickering alarms or indicating lights
- Repeated blown fuses

The response to any of the above conditions should address system operability requirements as well as relay operation such as chattering or intermittent contacts, shorted turns in relay coils and shorts to ground.

5.3 Recommended Maintenance Practices and Periodicity

Maintenance, in the form of periodic inspections, periodic tests, preventive maintenance, and corrective maintenance is necessary for **some** relays. For others, a well implemented program of corrective maintenance, failure trending and/or scheduled replacement may be all that is needed. The required level of maintenance and their periodicity for safety-related relays used in the plant protection systems such as RPS, ESFAS, and certain other safety functions are usually defined by a plant's Technical Specifications as an inherent part of the associated safety system test. The required maintenance and their periodicity for other safety-related and non-safety-related relays is often left to the judgment of the maintenance staff unless set by other plant commitments or design criteria.

Table 5-1 presents an overview of the recommended periodicity for the inspections and tests applicable to the types of relays (except the GE HFA relay) covered by this maintenance guide. Table 5-2 provides an overview of the recommended periodicity for the inspections and tests applicable to the GE HFA relays only which is treated as a special case. The bases for the inspection and test recommendations are discussed in detail in Sections 7. Tables 5-1 and 5-2 depict baseline recommendations, not requirements. The specific inspections and tests performed or the periodicity should be modified, as appropriate, after consideration of the following:

- Safety function or importance of the relays
- Technical specification requirements
- Environment, e.g., temperature and humidity to which the relay is exposed
- Plant-specific relay failure and performance experience
- Plant-specific commitments

The periodicites in Tables 5-1 and 5-2 apply to those relays that have been evaluated and a plant has determined that they belong in the preventive maintenance program. Those that do not present a challenge to plant safety or performance may be addressed by corrective maintenance efforts.

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Table 5-1 Recommended Inspection, Test and Maintenance for Relays in General

	Inspection or Test	Recommended Periodicity	Section
	Surveillance		
1	Operability Verification Testing	Annual[1]	Section 7.1
	Inspection		
2	Visual Inspection	1 to 3 Months	Section 7.2
3	Detailed Visual Inspection & Refurbishment	5 Years[2]	Section 7.2
	Maintenance		
4	General Cleaning and Contact Cleaning	5 Years[2,5]	Section 7.3
5	Contact Wipe & Gap Check & Adjustment	5 Years[2,5]	Section 7.3
6	Pickup & Dropout Voltage Check & Adjustment	5 Years[2,5]	Section 7.3
	Condition Monitoring		
7	Thermal Survey	12 to 18 mo[3]	Section 7.4
8	Trending "As Found" Setpoint Data	12 to 18 mo[4]	Section 7.4

(1) Required only for those relays that are not covered by Tech. Spec. Surveillance requirements and are not operated at least once a year.

(2) May be performed at a rate of 20% per year starting with the oldest. Should also be performed if there are any changes to the internals such as changing the contact arrangements or contact blocks.

(3) Recommended only for relays in normally energized applications. After initial baselining, it is sufficient to perform this only for those relays that operate at or near their coil insulation temperature rating.

(4) Applies only to timing relays.

(5) Does not apply to reed-relays.

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Table 5-2 Recommended Inspection, Test and Maintenance for the GE HFA Relays

	Surveillance, Inspection or Maintenance	Recommended Periodicity	Section
	Surveillance		
1	Operability Verification Testing	Annual[1]	Section 7.1
	Inspection		
2	Minimum Latch Engagement for Latching Relays	One time[2]	Section 7.5.2
3	Leaf Spring Tension Check for Latching Relays	One time[2]	Section 7.5.2
4	Mechanical Binding of Moving Contact Fingers	One time[2]	Section 7.5.2
5	Check for Correct Coil Bobbin Material	One time[2]	Section 7.5.2
6	Mechanical Binding of the Armature Stop Tab	One time[2]	Section 7.5.2
7	Visual Inspection	1 to 3 Months	Section 7.2
8	Detailed Visual Inspection & Refurbishment	5 Years[3]	Section 7.2
	Maintenance		
9	General Cleaning and Contact Cleaning	5 Years[3]	Section 7.3
10	Contact Wipe & Gap Check & Adjustment	5 Years[3]	Section 7.3
11	Pickup & Dropout Voltage Check & Adjustment	5 Years[3]	Section 7.3
	Condition Monitoring		
12	Thermal Survey	12 to 18 months[4]	Section 7.4
13	Trending "As Found" Setpoint Data	12 to 18 months[5]	Section 7.4

(1) Required only for those relays that are not covered by Tech. Spec. Surveillance requirements and are not operated at least once a year.

(2) These are one time checks that should be performed only once for the relays currently installed in storage and only if these inspections have not already been performed at various times when the respective vendor advisory was issued.

(3) May be performed at a rate of 20% per year starting with the oldest. Should also be performed if there are any changes to the internals such as changing the contact arrangements or contact blocks.

(4) Recommended only for relays in normally energized applications. After initial baselining, it is sufficient to perform this only for those relays that operate at or near their coil insulation temperature rating.

(5) Applies only to timing relays

6.0 Personnel and Equipment Safety Precautions

Relays are used in dc and ac applications. Often work on relays may have to be performed with some portions of the circuits energized.

The electrical shock hazards associated with dc power can be more severe than those associated with ac power for equivalent voltages and currents. A short circuit between the live terminals can result in electrical shock hazards and unwanted or undesirable equipment operation.

Only authorized personnel who have been trained on relay fundamentals and maintenance procedures should be allowed to perform maintenance activities on a relay.

Relay procedures may be performed with the plant in any operating mode. Relay test inspection and maintenance procedures often involve an infrequent activity. Therefore, depending upon the plant condition at the time of the activity, potential is great for reduced margins of safety or the introduction of unwarranted transients, or actions if the activity is performed incorrectly. The manufacturer's literature should be reviewed for applicable personnel and equipment safety precautions.

6.1 Personnel Safety Precautions

The following additional basic safety precautions should be exercised for working with relays and associated circuits:

- Care should be exercised to prevent electric shock and/or equipment damage.
- Use only insulated tools to prevent accidental shorting across live connections or to grounds. As a general rule, the length of the exposed metal for any tool should be as short as practical. Never lay tools or other metal objects on relays. Shorting, fire or personal injury could result.
- Always review the associated wiring diagrams to make sure that all related circuits are properly identified, deenergized if practical, and properly separated if energized.

6.2 Equipment Safety and General Precautions

The following additional basic equipment safety and general precautions should be exercised for working with relays and associated circuits:

- Relays should be tested in place unless otherwise dictated by access or clearance available.
- Never use spray solvents to clean contacts or relay components. Certain cleaners may be incompatible with the nonmetallic components. Solvents can attack and even crack the plastic and other nonmetallic relay parts.

- Use only approved greases on relays. Unapproved greases can attack plastic materials or solidify and cause improper relay operation of the relay.
- Do not use an emery cloth, sandpaper, or metal file to clean contacts these tools can damage the plating on the contacts.
- Use only burnishing tool for contact cleaning.
- Provide proper wire lay for lead wires inside relay dust covers to prevent excessive strain on the insulation, or wires causing armature or contact leaf/block binding.
- Always properly tag any leads lifted.
- Follow your plant procedures.
- Procedures should include plant impact statement/and cautions for lifted leads and de-energized circuits.

7.0 Recommended Maintenance Practices

Relays generally provide years of dependable service. However, they are susceptible to degradation mechanisms that affect performance. Failure of relays can have plant-wide repercussions. Hence, it is important that they are maintained in a state of readiness.

For some relays, a program of surveillance, inspections and preventive maintenance is necessary as a supplement to the corrective maintenance and failure evaluation programs. For others, a well developed corrective maintenance program supplemented by failure trending and/or scheduled replacement may be sufficient. For any given relay or group of relays, the choice should be made based among others on application, function, operating status and cost, as discussed in section 5.

This section presents recommendations on what constitutes Surveillance, Inspections and planned Maintenance (SIM) for relays. For each recommended SIM item, this section also presents:

- the purpose
- degradation and/or failure that may be detected
- key considerations in performing the item
- recommended periodicity including the rationale
- precautions and limitations.

The SIM recommendations presented in this section are based on:

- review of the relay operating experience (section 4)
- a review of the relay failure and the underlying mechanisms (section 3)
- the information collected from a utility survey conducted during this project and from discussions with utility maintenance staff (section 4)
- a review of the current industry practices and procedures
- manufacturers' maintenance Instruction Manuals and Service Advisories
- the guidance available from EPRI and NRC research reports.

Users of this guide are advised to supplement the guidance herein with those from the specific relay manufacturer's literature.

The central objectives of the SIM recommendations presented in this section are:

- to ensure a high level of relay reliability, especially as they age
- to preclude unwarranted plant transients and trips
- to enhance plant safety and availability.

To this end, this guide avoids drawing any strict boundary between relays used in safety-related and nonsafety-related applications.

7.1 Surveillance

Surveillance requirements in the form of operability verification testing are defined in the plant technical specifications for the relays used in RPS, ESFAS and certain other safety-related applications. For timing relays, surveillance also requires verification and calibration of the timing. The periodicity for these surveillance requirements vary from one month to once a cycle, although a majority of them fall in the one to three month intervals.

The purpose of this operability verification test includes the following:

- to verify the capability of the relays to energize or deenergize as required, within the time specifications, if applicable, and make or break the circuits that are switched
- to identify and correct any failures or deficiencies that may exist and can potentially affect the safety functional capability of the safety systems.

The test interval is established to ensure a high probability that the relays will operate as required between two successive tests.

The degradation and failure modes that can be identified by such operability verification are:

- defective coils such as burned-out or open coils
- mechanical failures such as binding
- open or damaged electronic components such as diodes and SCRs
- (to a limited extent) contact failures

Proven and time-tested procedures for conducting the operability verification tests of relays have been integrated into the respective system level test procedures. Therefore, descriptive steps for performing such tests are not included in this guide. However, a few key aspects that are worth considering in improving these tests are discussed in the following paragraphs.

In many cases, particularly in the RPS and ESFAS applications, operability verification tests are normally conducted without actually making or breaking the circuits that are switched; that is, the relay contacts are dry switched. The test configurations used are necessary to prevent unwarranted plant transients during testing. The relay operation is usually verified by the actuation of one or more of the contacts that initiate an alarm or an indicating lamp, or, in some cases, by visual inspection. Such operability verification testing, therefore, does not always ensure:

- contact cleaning from the self-wiping action
- all the contacts of a relay are indeed changing status and can make, carry, or interrupt the required circuit current.

Either of the above could lead to undetected failure(s) that may only be detected during a system challenge. To eliminate this potential condition, at least once during each refuelling the system testing configuration should be set up to verify that the each relay contact will make/break the circuit it is switching. An alternative to this method would be to verify by using an ohmmeter that each contact assumes the correct position (i.e., open/close), and that the contact resistance is acceptably low. The recommended periodicity is based on the ability to configure the system as required to minimize the potential for unwarranted plant transients and costs.

Other important items to note about the operability verification tests currently being performed include:

a. By themselves, such verification provides little or no information about the condition of the relays and their ability to perform satisfactorily during the interval between tests. In other words, verification of the relay performance capability at the time of the testing does not automatically provide assurance that it will perform later. Such assurance is particularly important for relays in aged condition.

b. Current industry practice generally limits operability verification tests to items covered under plant technical specifications. Therefore, not all safety-related relays, let alone nonsafety-related relays, are covered by this surveillance program. Reliable operation of the relays used in nonsafety systems such as the feedwater, main steam, and turbine generator systems is equally important to assure high plant availability.

Inspection, planned maintenance and condition monitoring recommendations discussed in sections 7.2 through 7.5 address item "a" above. The following recommendations are appropriate for addressing item "b":

1. Compile a list of relays used in safety-related applications not covered by technical specification, or other applications that are critical to plant availability (e.g., turbine generator, feedwater pump, and reactor coolant pump control and protective interlocks), but are not exercised in their expected operational mode at least once a year.

2. For these relays, implement an operability verification test program. Such operability verification is best performed using procedures that result in system level testing if practical. Otherwise testing individual relays and contacts will suffice. Operability verification should be performed regardless of the normal operating status of the coils.

7.2 Inspection

The inspection activities recommended below are intended to provide a general assessment of the condition of the relays and guide decisions related to replacement of entire relay or parts.

- Monthly or quarterly visual inspections
- Detailed visual inspections once in 5 years.

Monthly or quarterly relay inspection is intended to be a general visual inspection which looks for the obvious, such as smoky deposits, odor, charred parts, loose connections, broken case, or excessively arcing or corroded contacts. These inspections **are not intended** as a stand-alone activity, **rather as a part of the operability verification tests** such as the monthly or quarterly surveillance tests. The degradation mechanisms addressed by these inspections are overheating, contact wear, and visible mechanical damage. Removal of the cover or casing just for the purpose of performing these inspections is neither intended nor required.

Detailed visual inspection is intended to identify conditions indicative of impending failure. Detailed visual inspections should be performed at least once in five years. These inspections may be performed in a phased manner on 20% of the relays each year, preferably starting with the oldest in service. Detailed inspections should include the following items, included in a checklist:

- Evidence of thermal degradation that may manifest itself in one or more of the following ways:
  - Cracked coil bobbin
  - Smoky odor
  - Loose coil insulation flakes or particles inside the case
  - Misty windows (resulting from outgassing from coil insulation or bobbin material).

- Evidence of mechanical damage as indicated by:
  - Loose particles inside the casing
  - Arcing termination
  - Missing or loose seismic restraints such as clips or brace bars
  - Increased gap between the socket top and the relay base for plug-in relays
  - Cracked case
  - Missing or loose relay mounting screws
  - Broken or about-to-break contact connection braiding in GE HFA relays.

- Evidence of contact damage as indicated by:
  - Excessive buildup of grayish film or black ring on the contact surfaces
  - Excessive pitting or corrosion as seen by pips and craters on the contact surfaces
  - Arcing contacts

- Evidence of damage from environmental stresses as indicated by:
  - Misty windows, (mostly in normally deenergized relays)
  - Corrosion products on contact surfaces or other mechanical parts.

The detailed inspection is a visual inspection. It should be performed after deenergizing and disconnecting the relay with the relay cover/casing off. Detailed visual inspection should also include manually manipulating the armature and moving parts to verify smooth and friction free operation. The results of the detailed inspections should be documented and reviewed to identify the need for replacement of parts such as the coil or contact assembly, and refurbishment of relays. In addition, the information collected can also be used to identify potential misapplication or design deficiencies that could be corrected through appropriate plant modifications. For example, evidence of excessive corrosion product buildup in relays located in a specific cabinet might point to a need for a space heater inside the cabinet to maintain a drier ambient condition.

7.3 Maintenance

Preventive maintenance is performed on a planned or scheduled interval as a deterrent measure. Corrective maintenance responds to a failure or malfunction, and repairs the item. For relays, maintenance refers to a collection of activities (listed below) that may be performed either singly or in combination depending upon the specific relay.

(1) Cleaning
(2) Alignment/adjustment
(3) Calibration

This section provides recommendations for each of the activities listed above. Regardless of whether they are performed as a part of the planned or corrective maintenance, these activities have a purpose and require performance in a certain manner with certain precautions.

7.3.1 Cleaning

For relays, cleaning is an important step. Cleanliness can affect relay performance in many ways. Cleaning consists of:

- General Cleaning, and
- Contact Cleaning.

7.3.1.1 General Cleaning

General cleaning helps arrest coil overheating resulting from poor heat transfer between the coil and the environment and ensures free movement of the mechanical parts. It involves the removal of dust or dirt that may have accumulated in the active relay components, such as the coil, armature, springs, and fixed and movable contacts in an electromechanical relay. In an SSR, heat sinks should also be cleaned. A thorough general cleaning of the relays should be performed every time the relays are subject to detailed inspection, or as a minimum, once in 5 years.

CAUTION:	Do not use any cleaning solvent Do not use high pressure air or vacuum hose.

Use a soft bristle brush for general cleaning.
Make sure that no bristles from the brush are left in relay mechanical parts, circuit board or contacts.
If the relay case or cover is removed to clean the relay internals, restore the cover tightly.
If the case has air inlet and vent holes or slots, clean them free of dust or dirt.
If there is a filter cloth or paper in the air inlet/vent slots, clean or replace it.

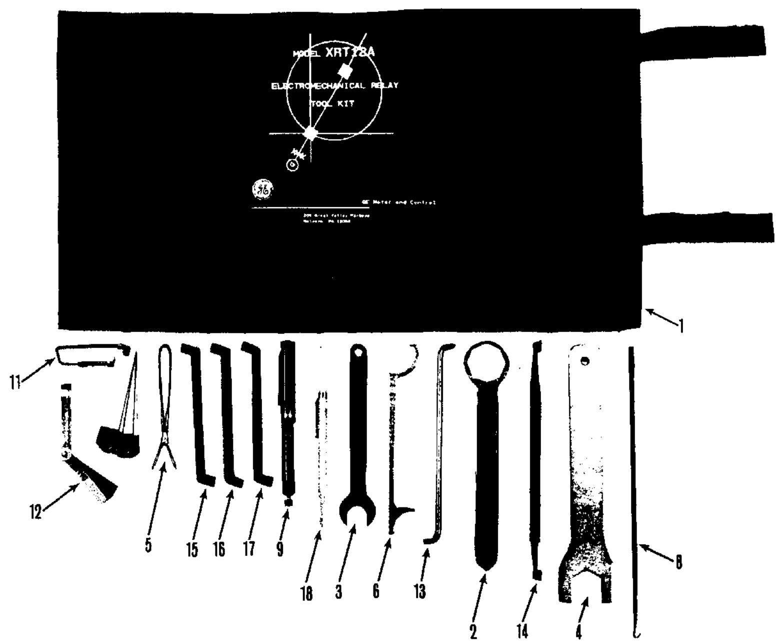
7.3.1.2 Contact Cleaning

Contact cleaning helps keep contact resistance and voltage drop low, and prevent excessive arcing. It involves the cleaning of the contacts to remove dirt, and sulphidation, corrosion, or activation products. Contact cleaning is required only if during visual inspection the contact surfaces show accumulation of:

- dust, dirt or debris
- Grayish film which is the sulphidation product, normally seen on silver and silver alloy contacts
- Black carbonaceous deposit on the contact, normally the result of contact activation
- Reddish brown oxide deposit, normally the result of corrosion from high ambient humidity.

A burnishing tool similar to the one shown in Figure 7-1 should be used for cleaning contacts.

CAUTION: Do not use any cleaning solvent or aerosol type chemical cleaners. Do not use emery, sand or any other abrasive coated paper or cloth.



1 Heavy Gauge Vinyl Pouch
2 Spec. 15/16" Box Wrench
3 Spec. 1/2" Open-end Wrench
4 Spec. 13/16" Open-end Wrench
5 Spec. 5/8" Spanner Wrench
6 Spec. Spanner Wrench
7 Contact Leaf Adjuster*
8 Push/Pull Spring Hook
9 Contact Burnisher
10 Extra Blades for Burnisher*
11 Angle Feeler Gauge Set
12 Straight Feeler Gauge Set
13 Contact Leaf Adjuster
14 Contact Leaf Adjuster
15 Armature Adjuster
16 Armature Adjuster
17 Armature Adjuster
18 0.085" wide Pot. Adjuster

* (not shown)

Figure 7-1 Relay Adjustment Tools (Courtesy GE)

7.3.2 Alignments/Adjustments

Relay alignments/adjustments consist of one or more of the following:

(1) Pickup and dropout voltage check and adjustments
(2) Contact wipe and gap check and adjustments

The alignments/adjustments listed above applies fully only to the GE Type HFA, HGA, and HEA relays because most of the other industrial relays used in the nuclear industry do not have provisions for field adjustment of some or all of these parameters. GE HFA relay maintenance recommendations are discussed in section 7.5.

7.3.2.1 Pickup and Dropout Voltage Check and Adjustment

For relays used in safety-related applications, the voltage at which relays pickup can be critical especially during emergency conditions when the available bus voltage may be quite low. Pickup and dropout voltages change with time in service because of:

- Accumulation of dirt, debris, and dust in the mechanical parts leading to blockage and higher friction
- Wear and misalignment of mechanical parts leading to increased friction in the mechanical linkages
- Coil resistance changes caused by shorted turns or heat rise
- Changes (e.g., replacement or addition of contact blocks) made to the relay internals.

For dc relays, the change in pickup voltage with temperature can be very significant because of the coil resistance varies with temperature. For ac coils, this is not the case, hence the changes in pickup voltage may not be quite so pronounced as those for dc relays. **Unless a specific pickup value is specified**, the coils are generally designed by the manufacturers to meet the following pickup voltage values:

ac coils for up to 240 Vac rating = 85% of nominal rating with the coil at 25^{o}C
dc coils for up to 125 Vdc rating = 80% of nominal rating with the coil at 25^{o}C

If the relays were originally purchased with a specific pickup voltage other than the manufacturer's standard values noted above, then that value should be used to verify proper operation of the relay. If the system voltage drop calculations have identified a specific pickup voltage requirement for relays, then that value should be used to verify proper operation of the relay.

Generally, the exact dropout voltage may not be quite so critical. However, since safety systems are designed to fail safe (i.e., deenergize to actuate), the dropout voltage should be greater than 10% of nominal voltage so that prompt completion of the safety function(s), once it is initiated, can be assured.

Therefore, for all relays, particularly for relays with DC coils, the pickup and dropout voltages should be checked, and, if practical, adjusted at least once in five years or whenever changes are made to the relay internals.

The choice of five year periodicity is based on industry operating experience with relays as reported in the NPRDS system, current industry practice, and discussions with the manufacturers and utility maintenance personnel. These checks and adjustments may be performed at a rate of 20% of the relays each year starting with the oldest. In most cases, these tests may be performed with the plant in any operating or shutdown mode, although it will require removing the relay from service.

How to Check and Adjust?

Test equipment required:

- Digital multi-meter (e.g., Fluke 8020A or equal)
- Digital probe type thermometer (e.g., Omega HH 20 series or equal), or an infrared thermometer (e.g., Raytech Ranger II Plus or equal).
- Variable AC and/or DC voltage source as required

Steps to check pickup voltage:

CAUTION: Pickup voltage adjustments should be performed only after mechanical adjustments if any, are completed.

1. Disconnect the relay from service

2. Allow the relay operating coil to stabilize for 30 minutes so that the operating coil reaches its steady state temperature. Then measure the operating coil temperature using a temperature probe in contact with the armature copper ring or using an infrared instrument.

3. Note the coil temperature T_1

CAUTION: The relay cover must be on during stabilization.
The relay must be in its installed orientation during check and adjustment of the pickup voltage.

4. Energize the coil by applying 50% of the rated nominal voltage.

5. Raise the voltage gradually until the relay picks up.

6. Note this voltage reading. This is the pickup voltage with the coil near its ambient temperature T_1.

7. Raise the coil voltage to the nominal operating voltage level and allow it to stabilize for 30 minutes.

8. Measure the coil temperature again and record this temperature T_2.

9. Deenergize the relay.

10. Without much elapsed time, re-energize the coil by applying 50% of the rated nominal voltage.

11. Raise the voltage gradually in until the relay picks up.

12. Note this voltage reading. This is the pickup voltage with the coil at or near its operating temperature T_2.

13. For ac coils, the measured pickup values at T_1 and T_2 should be nearly (< 5% variation) the same. If not, it is likely that the coil or the relay needs to be replaced. Proceed to Step 18.

14. For dc coil relays, calculate the minimum and maximum pickup voltages at coil temperatures T_1 and T_2 using the following equation [94] using a tolerance band of ± 1.5%:

$$PU_{min} = V_{nom} [V_{punom} - 1.5 + 0.004 (T_i - 25)]$$

$$PU_{max} = V_{nom} [V_{punom} + 1.5 + 0.004 (T_i - 25)]$$

V_{punom}	=	Required pickup voltage expressed as a % of the nominal voltage
V_{nom}	=	Coil nominal rated voltage
T_i	=	Temperature at specific coil operating condition T_1 or T_2
T_1	=	Steady State coil temperature when deenergized at near ambient in ^oC
T_2	=	Steady State coil operating temperature when energized in ^oC
PU_{min}	=	minimum pickup voltage at temperature T_i
PU_{max}	=	maximum pickup voltage at temperature T_i

15. If the measured pickup voltage at both temperature conditions fall within the respective minimum and maximum values then the relay is operating properly, proceed to Step 26. If not continue.

NOTE: Pickup voltage lower than required may be indicative of shorted turns or relaxed spring, whereas a higher than required pckup voltage may be indicative of coil high resistance, loose connections, or mechanical obstructions.

16. If the relay has provisions for adjusting the pickup voltage, adjust the pickup voltage following the manufacturer's instructions and recheck the pickup voltage.

17. If the relay does not have any provision for adjusting the pickup voltage then continue.

18. Allow the relay and the coil to cool to room temperature.

19. Perform detailed visual inspection per section 7.2.

20. Perform general cleaning per section 7.3.1.

21. Using the DMM, measure the coil resistance and record.

22. Compare it with the manufacturer's coil resistance specification.

23. If the coil resistance is within ± 5% of the original manufacturer's specification value, then recheck the pickup voltage. If the pickup voltage is still out-of-spec, then replace the relay.

24. If the coil resistance is not within ± 5% of the original manufacturer's specification, then replace the coil.

25. Repeat steps to check the pickup voltage.

Steps to check the dropout voltage:

26. Energize the relay coil at its nominal voltage. Observe the relay pickup.

27. Gradually lower the coil voltage until the relay drops out.

28. Note the dropout voltage.

29. If the dropout voltage is greater than 10% of the nominal voltage, the test is acceptable. If the dropout voltage is below 10%, then check the relay for mechanical obstructions or wornout separator between the pole face and the armature. Clear any obstructions and retest. If the separator is wornout, then replace the separator and repeat the test. If the problem still persists, replace the relay.

Note: For latching relays, in lieu of the dropout voltage, the pickup voltage of the reset coil should be checked.

Note: For the GE Type HFA relays which do have provisions for checking and adjusting the pickup voltage, see section 7.5.

7.3.2.2 Contact Wipe and Gap Setting

Optimum relay contact performance during normal operation and earthquakes depends upon proper contact wipe and gap. The contact wipe (i.e., pressure) and gap can change with time in service, or whenever pickup voltage adjustment is made, or whenever changes to the internals of the relay are made.

However, for many of the relay types used in the nuclear industry, the contact gap and wipe cannot be checked easily let alone adjusted. Therefore, for these types of relays, if a contact problem were to develop, cleaning the contacts, replacing the spring(s), and/or the contact carrier(s) through a trial and error process, and verifying that the relay functions properly is all that can be done. Hence, the current industry practice of replacing the relay in lieu of field repair is the most cost effective and should be continued.

Note: For the GE Type HFA relays which do have provisions for checking and adjusting the contact gap and wipe settings, see section 7.5.

7.3.3 Calibration

Calibration applies only to timing relays. Calibration consists of adjusting the time delay(s), timed intervals, and/or sequencing as applicable. The first and the most important item is to ensure that the timing setpoints and associated tolerance bands are specified by the engineering department. Acceptance criteria in relay maintenance and surveillance procedures should be established based on these tolerance bands and test equipment capabilities and limitations.

The plant Technical Specifications contains requirements for checking and calibrating the timing for most of the timing relays used in safety-related applications. For these relays, no additional calibration is required.

For those that are not covered by the Technical Specifications, but whose proper operation is critical to plant safety and/or availability, it is recommended that the timing setpoint be checked and adjusted once in three years. The choice of the three year periodicity is based on industry operating experience with relays as reported in the NPRDS system, current industry practice, and discussions with the manufacturers and utility maintenance personnel. In most cases, these tests can be performed with the plant in any operating or shutdown mode, although it will require removing the relay from service.

The exact method of adjustment depends upon the timing device used. Follow the manufacturer's instructions for the specific type. Special considerations to bear in mind when developing procedures of calibration of timing relays include the following:

- Timing adjustments should be performed in-situ, if practical. If it is done on a bench, then the adjustment must be done with the relay mounted in its as-installed orientation. After installation in-situ, the timing must be rechecked before returning the relay to service.

- Timing setpoints may be affected by coil heating.

7.4 Condition Monitoring

A well developed condition monitoring program can ensure timely identification of problems in relays that are indicative of impending failures. Based on these indicators, corrective actions such as replacing the coil, or changing out the contact blocks, can result in improved reliability of relays and extended operating life. It would also have the benefit of avoiding unplanned outages and/or transients caused by unexpected relay failures. As discussed in earlier sections, heat is the principal stress that contributes to aging degradation and failures of relays.

A thermal survey is an effective condition monitoring method to address the effects of this principal stressor. This survey can identify relays that are continuously subject to high thermal stresses. It can also pinpoint loose terminations that can lead to intermittent operation, or continuously arcing contacts that can lead to reduced contact life. Thermal surveys can also assist identifying misapplication such as gang mounted relays with inadequate heat dissipation [45], or continuous operation at higher than rated nominal coil voltage [59].

For timing relays, trending the "As-Found" setpoints from each calibration is also recommended. A continuously increasing/decreasing trend is indicative of a setpoint drift problem that would likely require a changeout of the relay. EPRI Technical Report TR-103335 [117] provides additional discussion on evaluating setpoint trend data and data analysis.

Other methods of condition monitoring, such as, trending of coil resistance, pickup voltage, and inrush current measurements which are discussed in the NRC research report on aging assessment of relays [97], are not recommended because they are not considered to be cost effective.

For relays used in normally energized (conducting in SSRs) applications, a thermal survey using an infrared temperature instrument should be undertaken. A thermal survey consists of measuring the operating temperature of the relays, particularly that of the coil in an electromagnetic relay and the output element, such as the SCRs or Triacs in a solid state relay.

An initial survey should be performed on all normally energized/conducting relays with the plant in normal power operation. The results should be reviewed to identify relays that are operating at greater than 194°F or 90°C (130°C for the GE Century series HFA relays). For these relays, the survey should be repeated once a year. The temperature data from the survey should be trended to assess the condition of the relay.

In the next two sections, tips on performing an IR survey on relays and using the results therefrom are discussed. For additional information on implementing an IR survey program, the reader should consult EPRI Report NP-6973 [98] on infrared thermography.

7.4.1 Tips on Performing Thermal Survey

- In an electromechanical relay, take temperature readings along the centerline of the coil as far as practical.
- In an SSR, take temperature readings with the gun aimed at the output element(s) and then at the heat sink.
- Make sure that the coil or the output element or the heat sink completely fills the Instantaneous Field Of View (IFOV) of the instrument.
- Take measurements at perpendicular angle to minimize reflections.
- Take readings with the cover/casing on.
- To ensure accuracy, determine the target emmitance values for the different make and model of relays and use them consistently.
- Take the readings as close to the relay as practical.
- For relays of the same make and model, use the same distance to the target and emittance settings.

- For each relay item, take at least three readings, one each looking in from front and at 45^o from left and right. If the data shows wide variation, additional readings may be required.
- Use a line diagram of the target and document the positions and target distances from where the reading were taken. Future readings should be taken from the same positions to ensure valid comparison.

7.4.2 Tips on Using Thermal Survey Readings

- If the initial survey indicates a coil temperature greater than 105^{o}C, then check the coil operating voltage to make sure that it is at nominal rating ± 2% . If the coil operating voltage is acceptable, then investigate the relay coil insulation rating. Unless otherwise specified (e.g., HFA Century Series relays use 180^{o}C rated coils), the relay coils are either Class A (105^{o}C) or in a few cases, Class B (130^{o}C) rated. If practical, the coil should be replaced with one rated for the service temperature. In some cases, it may not be practical to do so because the manufacturer may not have a higher temperature rated coil available for the specific relay. For economic reasons, he may not be able to supply a new one designed for higher temperature rating. In such cases, other alternatives such as replacing the relay with another one suited for the application temperature; or pursuing operating temperature reduction through increased air flow through the cabinet or enclosure in which the relay is mounted, or other means, should be considered.
- For SSRs, if the initial survey shows that the temperature at the output element is higher than 105^{o}C, consult the manufacturer about the type of output element used and its temperature rating. See section 2.3.6 for a discussion of the operating temperature limits for SSR output elements.
- A sporadic high temperature reading may be caused by higher than rated nominal coil operating voltage. This should be ascertained by measuring the relay coil operating voltage.
- In an electromechanical relay, a gradually increasing temperature trend would indicate one or more of the following conditions:
  - the coil is developing shorted turns
  - the heat dissipation from the relay is being affected
- In an SSR, gradually increasing temperature trend would indicate that:
  - the output element is leaky and degraded
  - the heat dissipation is being affected
- For the relays included in an ongoing thermal survey program, after the initial baseline, the following action level classification may be used:

Table 7-1 Recommended Problem Classification Levels

Action Level	Temperature difference	Recommended Action
ADVISORY (Level 1)	1 to 5°C	Item to watch. Perform a survey again within the next 3 months. If the temperature rise continues or shows increasing trend, initiate corrective maintenance work request to attend to the problem at the next available opportunity.
SERIOUS Level 2	6 to 15°C	Item to watch. Initiate monthly survey. If the temperature rise continues or shows increasing trend, initiate corrective maintenance to attend to the problem as soon as practical.
CRITICAL Level 3	> 15°C	Initiate corrective maintenance immediately. May require coil replacement.

The problem classification levels recommended above are more conservative than those general levels recommended in EPRI Report on Infrared Thermography, NP-6973, Rev. 1, because relays being mostly commercial grade items, the available design safety margin is low.

7.5 Inspection & Maintenance Recommendations for GE HFA Relays

The GE HFA relays are widely used in the industry in control and auxiliary relay applications. This particular relay has been the subject of NRC generic communications, particularly in the last few years reflecting the effects of aging of the relays and consequent failures. As a result, certain planned maintenance and one-time inspection recommendations have evolved.[1] They are documented in GE Service Information Letters and Service Advisory Letters[2] [30, 37 to 39]. This section provides a compilation of these and a few additional items deemed appropriate to improve the reliability of these relays and extend their operating lives. These are in addition to the surveillance and inspections discussed in Sections 7.1 and 7.2.

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1 Some of these one time inspections apply only to relays manufactured during specific time frames. Consult the SIL or SAL for applicability.

2 Service Advisory Letters, also known as SALs are issued by the GE division that manufactures the product. They carry a three digit number. Service Information Letters, also known as SILs are issued by the GE Nuclear Energy Group. SILs carry a two digit number. SILs may be on a GE manufactured or other manufacturer's products.

7.5.1 Planned Maintenance

Two specific planned maintenance recommendations from GE are mechanical adjustments to set the contact wipe and gap, and electrical adjustment to set the pickup voltage. These adjustments are intended to optimize relay performance and life by addressing the aging related degradation mechanisms such as operational cycling and insulation degradation that could affect relay performance.

7.5.1.1 Contact Wipe and Gap Adjustment

The GE Type HFA relay contains provisions for adjusting the contact gap and wipe settings. GE Service Information Letter, SIL 44 Supplements 4 & 5 [36, 38 & 39] states that the gap and wipe settings must be checked and adjusted periodically or whenever any change is made to the relay internals. In addition, the proper setting of these parameters are necessary to assure the seismic capability of the relays.

The contact gap and wipe settings should be checked and if necessary, adjusted at least once in five years or whenever changes are made to the relay internals. In most cases, these tests may be performed with the plant in any operating or shutdown mode although it will require removing the relay from service.

How to do it?

Test equipment required:

- Multi-meter, (e.g., Fluke 8020A or equal)
- Thickness gages 0.022", 0.039", 0.077", 0.093"
- DC power supply and indicating lamps or a pre-wired relay test lamp box.

Setting the Contact Wipe for Normally Open (NO) Contacts

1. Deenergize the relay and disconnect all wires.

2. Connect a set of indicating lamps through a low voltage DC power source across each of the NO Contacts as shown in Figure 7-2.

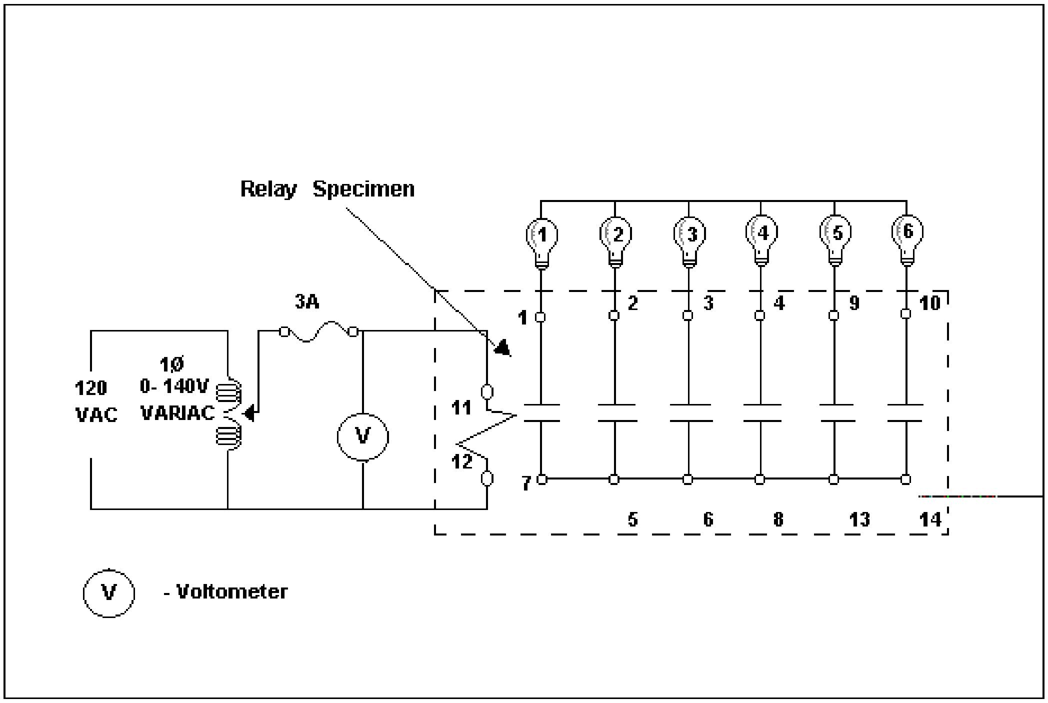

Figure 7-2 Test Connections for Contact Alignments

3. Place a 0.039 " thickness gage between the coil pole piece and the armature plate. See items "K' and "L" in Figure 7-3

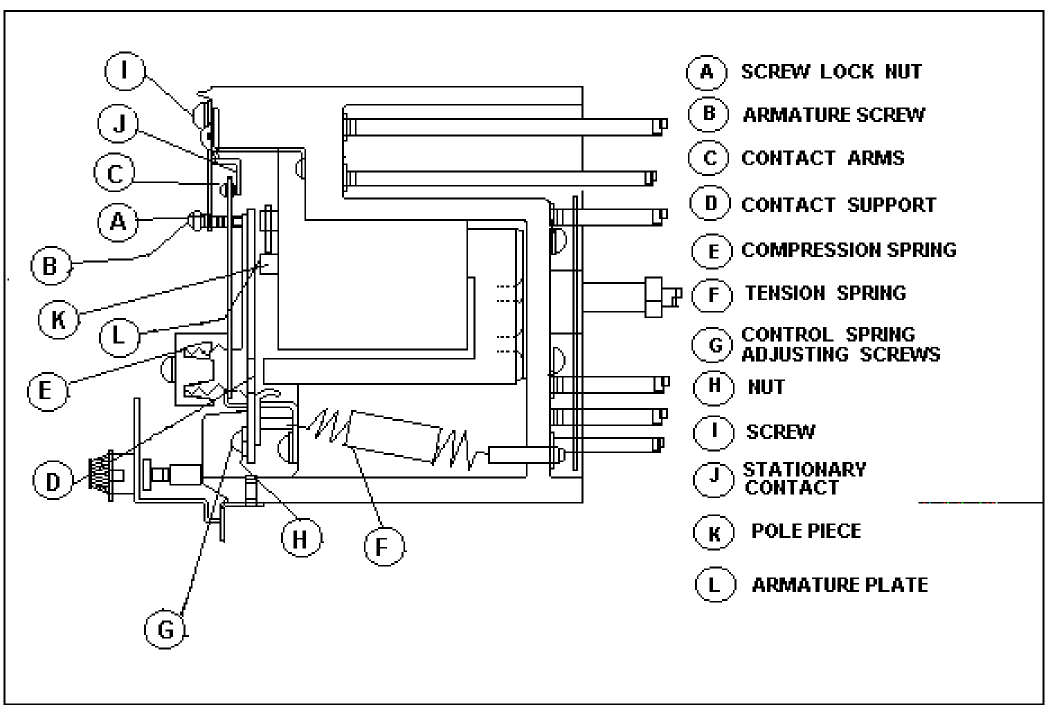

Figure 7-3 Cut View of the GE HFA Relay

4. Press down on the armature plate.

5. All lights should light up. If they do, go to Step 7. If one or more lights do not, then those contacts need adjustment, continue.

6. While keeping the armature plate pressed down, using the contact bender (Figure 7-1), bend the contact arm of the movable contact until the light just comes on. Continue this for each contact.

7. Place the 0.077" thickness gage between the pole piece and the armature plate as shown by items `K' & `L' in Figure 7-3

8. Press down on the armature plate

9. None of the lights should come on. If so, the adjustments are correct. If any of the lights come on, then the wipe on that contact is excessive. Readjust the movable contact arm with the bender until the light goes off.

10. Repeat Step 1 through 9 again and iterate this process until both minimum and maximum wipe settings are met.

Setting the Contact Gap for NO Contacts and the Wipe for NC Contacts

1. If there are no NC contacts used in the relay, then perform only Steps 2 through 5. If there are NC contacts used, then skip and perform steps 6 through 13.

2. Connect the indicator lights to NC contacts using a scheme similar to that shown in Figure 7-3.

3. Measure the contact gap by placing a 0.22" thickness gage between the movable and fixed contacts, items `C' and `J' in Figure 7-3, with the relay in deenergized condition.

4. If the gap is larger or smaller, then adjust the gap by adjusting the armature stop screw.

5. If the contact gap is adjusted, then repeat the steps discussed previously to verify that the wipe settings for the NO contacts are still within specification.

6. Place a 0.039" thickness gage between the stop screw and the armature plate, item `B' and `L' in Figure 7-3.

7. Allow the tension of the control spring to seat the armature firmly against the gage.

8. All of the NC contact lights should remain lit showing contact continuity. If one or more of the lights are not lit, then the respective movable contacts should be bent until the light just comes on.

9. Place a 0.077" thickness gage between the stop screw and the armature.

10. Allow the spring tension to seat the armature against the thickness gage.

11. None of the lights should be lit. If one or more of the lights are lit, then bend the movable contacts using the contact bender until the light just goes out.

12. Repeat steps 6 through 13 to ensure that the minimum wipe specification is still met.

13. Iterate until the minimum and maximum wipe specification are met.

7.5.1.2 Pickup and Dropout Voltage Setting

The pickup voltage can be adjusted on GE Type HFA relays. GE Service Information Letter, SIL 44 Supplements 4 & 5 [36, 38 & 39] states that the pickup voltage must be checked and if required, adjusted periodically or whenever any change is made to the relay internals. The exact dropout voltage may not be quite so critical, and no specific recommendation from GE is known. However, since the safety systems are designed to fail safe (i.e., deenergize to actuate), the dropout voltage should be at least greater than 10% of nominal voltage so that prompt completion of the safety function, once it is initiated, can be assured.

For the HFA relays, particularly for relays with DC coils, the pickup and dropout voltages should be checked, and if practical adjusted at least once in five years or whenever changes are made to the relay internals. The choice of five year periodicity is based on information gathered from industry operating experience with the HFA relays as reported in the NPRDS and the LER data systems, current industry practice, and discussions with the manufacturers and utility maintenance personnel. These checks and adjustments may be performed at a rate of 20% of the relays each year starting with the oldest. In most cases, these tests may be performed with the plant in any operating or shutdown mode although it will require removing the relay from service.

How to Check and Adjust?

Test Equipment Required:

- Digital multi-meter (e.g., Fluke 8020A or equal)

- Digital probe type thermometer (e.g., Omega HH-20 series or equal), or an infrared thermometer (e.g., Raytech Ranger II Plus or equal)

- Variable AC and/or DC voltage source as required

Steps to Check Pickup Voltage:

CAUTION: Pickup voltage adjustments should be performed only after mechanical adjustments if any, are completed.

1. Disconnect the relay from service

2. Allow the relay operating coil to stabilize for 30 minutes so that the operating coil reaches its steady state temperature.

3. Measure the operating coil temperature using a temperature probe in contact with the armature copper ring at the pole piece, or using an infrared instrument.

4. Note the coil temperature T_1

CAUTION: The relay cover must be on during stabilization
The relay must be in its installed orientation during checking and adjustment of the pickup voltage.

5. Energize the coil by applying 50% of the rated nominal voltage.

6. Raise the voltage gradually until the relay picks up.

7. Note this voltage reading. This is the pickup voltage with the coil deenergized and near its ambient temperature, T_1.

8. For 120 ac relays, the measured pickup value at T_1 should be 73 to 81 % (87.6 to 97.2 volts) of nominal voltage. If not, it is likely that the coil or the relay needs to be replaced. Proceed to Step 11.

9. For dc coil relays, calculate the minimum and maximum pickup voltages with the coil deenergized at temperature T_1 using the following equation [39]:

$$PU_{min} = V_{nom} [55 + 0.0024 (T_1 - 25)]$$

$$PU_{max} = V_{nom} [61 + 0.0024 (T_1 - 25)]$$

V_{nom} = Nominal rated voltage of the coil
T_1 = Steady State coil temperature when deenergized at near ambient in ^{o}C.
PU_{min} = Minimum pickup voltage at temperature T_1.
PU_{max} = maximum pickup voltage at temperature T_1.

10. If the measured pickup voltage at the measured temperature falls within the calculated minimum and maximum values then the relay is operating properly. Proceed to Step 19. If the pickup voltage does not fall within the calculated range, then continue.

11. Perform detailed visual inspection per section 7.2.

12. Perform general cleaning per section 7.3.1.

13. Using the DMM, measure the coil resistance and record.

14. Compare it with the original coil resistance specification.

15. If the coil resistance is within ± 5% of the original manufacturer's specification value, then it is acceptable. Proceed to step 16. If the coil resistance is not within ± 5% of the original manufacturer's specification, then replace the coil.

16. Repeat steps to check the pickup voltage and continue with Step 17 if required.

Steps to Adjust Pickup Voltage

17. Grasp the control spring adjusting screw and lift the adjusting nut about 1/16" above the armature tail piece.

18. Viewing the relay from the front, turn the nut clockwise to increase the pickup voltage or counterclockwise to decrease the pickup voltage until the pickup voltage is within acceptable range.

19. Record the pick up voltage

Steps to Check the Dropout Voltage

20. Energize the relay coil at its nominal voltage. Observe the relay pickup.

21. Gradually lower the coil voltage until the relay drops out.

22. Note the dropout voltage.

23. If the dropout voltage is greater than 10% of the nominal voltage, the test is acceptable. If the dropout voltage is below 10%, then check the relay for mechanical obstructions or wornout separator[3] between the pole face and the armature. Clear any obstructions and retest. If the separator is wornout, then replace the separator and repeat the test. If the problem still persists, replace the relay.

Note: For latching relays, in lieu of the dropout voltage, the pickup voltage of the reset coil should be checked.

[3] The separator refers to the dimple, or a screw or a slug of copper attached to the pole face or the armature to create an air gap. In some relays, this may be a piece of plastic attached to the armature at its point of contact with the pole face. The purpose of the separator is to create an air gap so as to ensure that residual magnetic forces do not prevent the armature from dropping out when the coil is deenergized.

7.5.2 Special One Time Checks and Adjustments

7.5.2.1 Minimum Latch Engagement for Latching Relays

GE SIL 190.1 [40], recommends that HFA relays with latching mechanisms, should be checked for proper latch engagement. This is done by measuring the distance between the top of the molded contact carrier and the top of the relay armature to ensure adequate contact carrier clearance. This distance should be a minimum of 1/32 inch. If the minimum distance requirement is not met, relays used in class 1E applications **must be** replaced. For relays in non-class 1E applications, it is acceptable to remove a small portion of the molded support by filing as follows:

a. Remove the armature assembly from the relay.
b. Disassemble the armature assembly, maintaining the proper orientation of contact springs and moving contacts.

c. File approximately 1/16" from the top of the contact carrier.

d. Reassemble the armature assembly, maintaining original orientation of contact springs and moving contacts, and recheck for at least 1/32 inch clearance.

e. Reinstall armature assembly in relay.

Note: After such repairs, mechanical and electrical adjustments will be required.

7.5.2.2 Leaf Spring Tension for Latching Relays

GE SIL 190.1 [40], recommends that HFA relays with latching mechanisms, should be checked for sufficient leaf spring tension. This is done by fully depressing the armature against the pole piece. Check to see if the latch is fully rotated by pulling up on the latch assembly. If the latch is fully rotated, there should be no motion of the latch, since it should be held in place by spring tension. If full latch rotation is not present, relays used in class 1-E applications must be replaced. For non-class 1E applications, it is acceptable to reform the leaf latch springs as follows:

a. Remove latch assembly by removing the 10-32 screw at the top of the assembly.

b. Re-form leaf latch spring to have less curve (flatter spring.)

c. Reassemble latch assembly and check for full rotation.

Note: After such repairs, mechanical and electrical adjustments will be required.

7.5.2.3 Mechanical Binding of the Moving Contact Fingers

Some HFA latching type relays were found to have less than adequate clearance between the armature stop tab and the magnetic coil assembly, and insufficient latch engagement. This condition leads to binding and improper relay operation. GE SIL 192.1 [42, 43], recommends that the movable contact finger assembly inside the phenolic support assembly in HFA relays should be checked for binding. This is done as follows:

1. Ensure contact to be checked is normally open. If contact to be checked is normally closed, it will be necessary to remove the stationary contact piece to provide clearance to perform the check.

2. Gently pull each moving contact, one at a time, outward toward the front of the relay until the finger touches its stop, then depress it toward the back of the relay while holding the armature assembly in place, until no further finger movement is possible.

3. Gradually remove the force applied. When all force is removed, the moving contact should return to its original position. A binding contact will not return to its original position. The point of binding will be where the pigtail is formed to the contact finger. If binding is experienced in relays used in class 1E applications, they must be replaced. For relays in non-class 1E applications, it is acceptable to replace just the affected contact and armature assembly as follows:

   a. Remove the screw and lock washer holding the moving contact pigtails to the base for each of the six moving contacts.

   b. Lift the control spring adjusting screw out of the armature slot and let it move to a rest position.

   c. Slide out the existing contact and armature assembly and replace it with a new assembly.

   d. Fasten the moving contact pigtails to the base with the existing screws and lock washers.

   e. Form the pigtails in a loop without any kinks.

   f. Replace the control spring adjusting screw in the armature slot.

> Note: After such repairs, mechanical and electrical adjustments will be required.

7.5.2.4 Check for Correct Coil Bobbin

The coil bobbin material in the high temperature coil assemblies currently being supplied for the Century series HFA relays is TEFZEL, color light beige or light grey. This material is the correct one for all applications. If the color of the coil bobbin material in any relay is cream white, then it is made of Nylon, if the color is black or clear, then it is made of Lexan. In relays used in class 1E applications, if the Nylon or Lexan spool coil assembly is found, it **must be** replaced with the new coil assembly with TEFZEL coil bobbins [29, 35, 36 & 39]. The essential steps for performing this includes the following:

1. To assure correct assembly, note the location and orientation of parts and assemblies before removing them from the relay.

2. Remove the relay cover, if not removed earlier, then release the control spring by lifting the control spring adjusting nut and screw out of the slot in the armature tail piece. Mark the nut at the 12 o'clock position for reference during re-installation. (This is necessary in order not to disturb calibration.)

3. Lift the moving contact/armature assembly out of the relay to uncover the magnetic assembly.

4. Disconnect the two (2) relay coil leads and remove the stop bar.

5. Remove the four (4) magnetic assembly mounting screws from the back of the relay.

6. Remove the old magnetic assembly.

7. Install the new magnetic assembly.

8. Install the four (4) magnetic assembly mounting screws from the back of the relay and torque the screws to 18-20 in-lbs.

9. Reconnect the two (2) relay coil leads.

10. Insert the moving contact/armature assembly in the relay to cover the magnetic assembly.

11. Loosen the right side screw of the contact assembly (nameplate) one turn only.

> CAUTION: Removing both screws will result in the contact assembly coming apart.

12. Remove the left screw entirely and swing the old name plate up and out of the way.

13. Mount the new name plate and then install the left screw.

14. Tighten both screws.

15. Replace the control spring and the adjusting nut into the hex recess with the reference mark at the 12 o'clock position. Check the control spring adjusting nut to assure that it is seated in the hexagonal recess in the armature tail piece.

7.5.2.5 Mechanical Binding of the Armature Stop Tab

Check relay for mechanical binding of the armature stop tab with magnetic coil assembly as follows:

1. Loosen the four (4) magnetic assembly mounting screws located at the rear of the relay case.

2. Allow the magnetic assembly to move down as far as possible with the relay in the upright position, then re-tighten the screws to 18-20 in-lb. (This sets the magnetic assembly in the most disadvantageous position.)

3. Close the armature by hand and gradually release. Verify that the armature moves freely, seats properly, and returns to the open position when released. If binding is experienced in relays used in class 1E applications, the relays **must be** replaced [112]. For non-class 1E applications, it is acceptable to replace just the armature in order to maintain proper moving contact spring orientation. Armature replacement is performed as follows:

   a. Disengage the control spring from the armature by pulling the control spring adjusting screw out and then down.

   b. Remove the six (6) screws fastening the contact braided leads to the lower terminals of the case.

   c. Tilt the lower portion of the armature and contact assembly out from the relay and slide the entire assembly down and out.

   d. Remove one of the two screws holding the nameplate and moving contact assembly to the armature.

   e. Loosen the remaining screw.

   f. Rotate the armature 90 degrees from its normal position.

   g. Replace the screw that was removed in 'd' above, through the contact assembly, and fasten with an 8-36 nut.

   h. Remove the other screw (loosened in 'e' above).

   i. Fasten the contact assembly and nameplate assembly to the new armature with the removed screw.

   j. Remove the 8-36 nut (added in 'g' above) and rotate the armature until the moving contact assembly and nameplate holes line up with the remaining hole in the armature.

k. Reinstall the loose screw and tighten the assembly to 16-20 inch pounds.

l. Install the new armature into the relay by reversing Steps a, b, and c.

Note: After such repairs, mechanical and electrical adjustments will be required.

Surveillance, inspection and maintenance recommendations provided in this section are based on an evaluation of industry operating experience with relays, and the underlying failure mechanisms and modes discussed in Sections 3 & 4.

7.6 Summary

For most control/auxiliary relays surveillance, inspection and maintenance recommendations consists of:

- Operability verification testing at least once a year unless the relays are subject to testing in accordance with the Technical Specifications.
- Detailed visual inspection and cleaning once every five years.
- Checking pickup and dropout voltage once during five years.

For timing relays, in addition to the above, checking and adjusting the time set points once every three years in recommended.

For the GE HFA type relays the following specific one time, and periodic inspection and maintenance recommendations apply:

One time inspection and maintenance:

- Minimum latch engagement for latching relays
- Leaf spring tension check and adjustment for latching relays
- Checking the movable contact fingers for binding
- Upgrading the coil bobbin to Lexan bobbin
- Checking for, and clearing any armature stop tab binding conditions

Periodic inspection and maintenance:

- Checking and adjusting the contact wipe and gap setting
- Checking and adjusting the pickup and dropout voltage setting

For *all* normally energized relays, an initial thermal survey is recommended to identify possible misapplication, installation deficiencies, or relays that are operating with higher than average coil operating temperatures. Based on the results of the initial thermal survey, periodic thermal surveys limited only to those relays that are operating with coil temperatures above 90^{o}C (130^{o}C for GE Century series HFA relays) should be undertaken to assure timely identification of potential approach to failure.

For *all* timing relays, in addition to thermal surveys, setpoint trending is recommended. Lastly, evaluation of the industry operating and failure experience with relays indicates that most of the commercially available electromechanical relays used in the nuclear industry, when properly applied and operated have an average age of about 15 years (in some cases e.g., Agastat GP series relays, lower than 15 years). Therefore, it appears that a prudent and cost effective approach would be to systematically replace relays once every 15 years or other estimated life appropriate to the specific relay type and application (See Table 4-1). A relay aging test program conducted [118, 119] by the Beznau power plant in Switzerland on Westinghouse BFD series and some Brown Boveri relays essentially came to the same conclusion. Beznau has apparently implemented a program to replace relays aged 10 years or more.

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Appendix B Glossary

Armature Gap: The distance between armature and pole face.

Auxiliary Relay: A relay that operates to assist another relay or device in the performance of a function, (also called control relay).

Contact: The portion of current-carrying members at which electrical circuits are opened or closed.

Contact Activation: Refers to the process of carbon deposit formation on contact surfaces during arcing due to the presence of certain hydrocarbons in the atmosphere.

Contact Bounce: Internally caused intermittent and undesired opening of closed contacts, or closing of open contacts of a relay, caused by one or more of the following:

(1) Impingement of mating contacts
(2) Impact of the armature against the coil core on pickup or against the backstop on dropout
(3) Momentary hesitation or reversal of the armature motion during the pickup or dropout stroke

Contact Bounce Time: The time interval from initial actuation of a contact to the end of bounce.

Contact Chatter: Externally caused, undesired vibration of mating contacts during which there may or may not be actual physical contact opening. If there is no actual opening but only a change in resistance, it is referred to as dynamic resistance.

Contact Follow: The further specified movement of the contact tips (points) when making and after they have just touched and while they are travelling in the same direction as that of the moving contact member. (IEC)

Contact force: The force which two contact tips (points) exert against each other in the closed position under specified conditions. (IEC)

Contact Gap: The gap between the contact tips (points) under specified conditions, when the contact circuit is open. (IEC)

Contact Operate Time: Time from initial energization of the relay coil to the first opening of closed contact or first closing of open contact, prior to bounce.

Contact Release time: Time from initial de-energization of the relay coil to the first opening of a closed contact prior to bounce.

Contact Weld: A contact failure due to fusing of contacting surfaces to the extent that the contacts fail to separate when intended.

Contact Roll: When a contact is making the relative rolling movement of the contact tips (points) after they have just touched. (IEC)

Contact Wipe: When a contact is making, the relative rubbing movement of contact tips (points) after they have just touched. (IEC)

Cycling: The minimum number of hours during which a relay may be switched between the off state and the on state at a fixed, specific cycle rate, load current, and case temperature without failure.

Defense-in-Depth: A term generally used in the context of nuclear plant design. It refers to the multiple layers of defense employed in the plant design to protect the health and safety of plant personnel and the public.

Double-break Contact: Contact combination in which contacts on a single conductive support simultaneously open electrical circuits connected to the contacts of two independent contacts. This provides two contact air gaps in series when the contact is open.

Double-make Contact: A contact combination in which contacts on a single conductive support simultaneously close electrical circuits connected contacts of two independent contacts and provide two contact air gaps in series when the contact is open.

Dropout: A monostable relay drops out when it changes from an energized to an unenergized condition. (IEC)

Dropout Value: As the current or voltage on an operated relay is decreased, the value at or above which all relay contacts must restore to their unoperated positions.

Dry-circuit Contact: A contact that carries current but neither opens nor closes while its load circuit is energized.

Electro-mechanical Relay: An electrical relay in which the designed response is developed by the relative movement of mechanical elements under the action of a current in the input circuits. (IEC)

Hybrid Electromechanical (HEMR): A relay with isolated input and output in which electromechanical and electronic devices are combined to perform a switching function with an electromechanical output. Switching characteristics are dictated by electromechanical relay specifications.

Hybrid Solid State Relay (HSSR) : A relay with isolated input and output in which electromechanical and electronic devices are combined to perform a switching function with a solid state output.

Hydrolysis: The chemical reaction between the ions of water and polymer materials resulting in depolymerization and a change of electrical and mechanical properties [121].

Isolation: The value of insulation resistance, dielectric strength and capacitance measured between the input to case, output to case, inputs and outputs, and output to output as applicable.

Junction Operating Temperature: The temperature at which a semiconductor junction operates.

Latching Relay: A relay that maintains its contacts in the last position assumed without the need of maintaining coil energization.

Logic Relay: Refers to relays that operate at low operating voltage and have low contact capacities used in decision making circuits, e.g., coincidental presence of multiple inputs.

Mechanical Time-delay Relay: A relay in which operate or release action is delayed by a clockwork, escapement, bellows, dashpot, or other mechanical device.

Normally Closed Contact: A contact combination which is closed when the armature is in its unoperated position.

Normally Open Contact: A contact combination that is open when the armature is in its unoperated position.

Operate Time: The time interval from coil energization to the functioning of the last contact to function. Where not otherwise stated, the functioning time of the contact in question is taken as its initial actuation time (that is, it does not include contact bounce time). For a solid state or hybrid relay in a non-operated state, the time from the application of the pickup voltage to the change of state of the output.

Optically-coupled: A term used in conjunction with solid state relays whose input to output isolation is achieved by the use of short length optical path.

Pickup Value: As the current or voltage on an unoperated relay is increased, the value at or below which all contacts must function.

Plunger Relay: A relay operated by a movable core or plunger through solenoid action.

Protective Relay: A device whose function is to detect defective lines or apparatus or other power system conditions of abnormal or dangerous nature and to initiate appropriate control action.

Polymerization: When used in the context of relay contact performance, polymerization refers to the formation of a solid polymer coating on the contact surfaces due to chemical combination of the contact metal with gaseous compounds of certain chemicals (e.g., sulphur, halogens).

Reed Relay: A relay using glass-enclosed, magnetic reeds as the contact members.

Rotary Relay: A relay whose armature is rotated to close the gap between two or more pole faces, (usually has a balanced armature).

Shading Ring: A shorted turn surrounding a portion of the pole of an AC electromagnet that delays the change of the magnetic field in that part, thereby tending to prevent chatter and reduce hum.

Solid State Relay (SSR): A relay with isolated input and output whose functions are achieved by means of electronic components and without the use of moving parts.

Silicon Controlled Rectifier (SCR) An alternative name for reverse blocking triode thyristor (see Thyristor) [121]

Time Delay: Refers to a time interval purposely introduced in the performance of a function [121]

Time Delay to Pick Up (TDPU): TDPU refers to an arrangement wherein relay contacts switch after a preset time delay after the relay coil is energized.

Time Delay to Drop Out (TDDO): TDDO refers to an arrangement wherein relay contacts switch immediately upon energizing the relay coil, but switch back (i.e., drop out) only after a preset time delay after the coil is deenergized.

Transformer-coupled: A term used in conjunction with solid state relays whose input to output isolation is achieved by the use of a transformer.

Triode AC Switch (TRIAC): Refers to a gate controlled semiconductor device, usually called a thyristor triode, used to switch ac loads.

Varistor: A two-terminal resistive element, composed of an electronic semiconductor and suitable contacts, that has a markedly nonlinear volt-ampere characteristic [121]

Voltage, rated coil: The coil voltage at which the relay is intended to operate for the prescribed duty cycle.

Appendix C Overview of Related Industry Standards

Industry standards define accepted practices for design, application, installation, operation and/or maintenance of equipment and systems. The following sections discuss the relay standards/guides and their applicability.

C.1 National Association of Relay Manufacturers [1]

C.1.1. Engineers' Relay Handbook, Fourth Edition

This handbook provides a tutorial on relay design and selection. It also contains guidance on the selection, application, and testing of electromechanical and solid state relays.

C.2 Electronic Industries Association [2]

C.2.1 EIA/NARM Standard EIA-407-A, July 1978

EIA/NARM Standard EIA-407-A, "Testing Procedures for Relays for Electrical and Electronic Equipment," provides procedures for inspecting and testing electromagnetic relays for the applicable mechanical, electrical, and environmental requirements. It is intended for relays used in military and commercial applications.

C.2.2 EIA/NARM Standard RS-473, March 1981

EIA/NARM Standard RS-473, "Definitions and Terminology for Relays for Electronic Equipment," provides definitions, classifications, terminology, notation and performance characteristics for relays. It covers general purpose relays, solid state relays and relays used in military applications, electronic circuits, unusual environments, and airborne equipment.

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[1] National Association of Relay Manufacturer's, Milwaukee, Wisconsin 53217.

[2] Electronic Industries Association, 1772 Eye Street, Washington DC 20006.

C.2.3 EIA/NARM Standard RS-443, April 1979

EIA/NARM Standard RS-443 for "Solid State Relays," establishes a reference for determining and defining parameters required to specify ac Solid State relays and Hybrid Solid State Relays which employ a single isolated input and are designed for switching of ac lines up to a maximum of 500 H-2, 300 Vac and 50 amperes. It also provides uniform methods and techniques for measuring the specification parameters.

C.2.4 EIA/NARM Standard for Dry Reed Relays, EIA RS-436

EIA/NARM Standard RS-436 for "Dry Reed Relays," establishes a reference for determining and defining parameters required to specify dry type reed relays. It also provides uniform methods and techniques for measuring the specification parameters.

Appendix D Overview of NRC and Vendor Documents

Section 3 provided an overview of relay aging characteristics, degradation mechanisms, and failure modes. Section 4 presented and overview of the industry failure experience on relays and how they correlated with the degradation mechanisms discussed in Section 3. This appendix presents a summary of the results of the NRC-sponsored relay aging research/testing and other relay problems identified by NRC Generic Communications (e.g., Notice, Bulletin) and Vendor Advisories (e.g., GE Service Information Letter, Westinghouse Technical Bulletin).

D.1 NRC Sponsored Relay Aging Research

The Nuclear Plant Aging Research (NPAR) program was initiated by the NRC to investigate aging effects on installed equipment in nuclear power plants. The general objectives of the NPAR program, as explained in NUREG-1144 include the following:

- Identify and characterize the aging and service-wear effects associated with electrical and mechanical components, interfaces, and systems likely to impair plant safety.
- Identify and recommend methods of inspection, surveillance, and condition monitoring of electrical and mechanical components and systems that will be effective in detecting significant aging effects before loss of safety function so that timely maintenance and repair or replacement can be implemented.
- Identify and recommend acceptable maintenance practices that can be undertaken to mitigate the effects of aging and to diminish the rate and extent of degradation caused by aging and service wear.

The NPAR program included a two phased research and testing effort on the aging and reliability of relays. Two NUREGs that address the age-related degradation of relays are listed below:

NUREG/CR 4715, "An Aging Assessment of Relays and Circuit Breakers and System Interactions."

NUREG/CR 5762, "Comprehensive Aging Assessment of Circuit Breakers and Relays."

The conclusions presented in these NUREGs that apply to relays are discussed in the following sections.

D.2 NUREG/CR 4715, "An Aging Assessment Of Relays and Circuit Breakers and System Interactions"

NUREG/CR 4715 provides the results of an evaluation of aging effects and failures of relays and circuit breakers. Presented below are the significant conclusions documented in this report:

- The overall population of relays indicates an increasing trend in failures from the 7th through the 11th year, attributed mainly to failures of control and time delay relays that have similar failure trends.
- The predominant failure mechanisms relate to setpoint drift for timing relays, coil burnout, binding and contact problems for control and timing relays.
- Normally energized relays fail approximately 60 percent more often than normally de-energized relays.
- The most significant failure mechanism associated with normally energized relays is thermally induced damage of organic coil and housing components.
- Most control and time delay relay failures are detected during functional tests of the associated systems which are required by the plant surveillance programs. Testing and evaluation for prediction of continued operability and evaluation of the level of deterioration are not being performed.
- The number of different types of failures identified is sufficient to support the need for a strong maintenance and test program to prevent multiple age related failure of relays from affecting multiple safety trains.
- While the failure rates do not appear to be high relative to the population size, some of the failures are common mode types, indicating that multiple simultaneous failures could occur if the failures remain undetected.
- Further research and evaluation of the feasibility of improved inspection, testing and surveillance methods for relays should be undertaken.

Table 3-5 in this guide incorporates the aging mechanisms and failure modes for relays and timers identified in this guide as appropriate.

D.1.2 NUREG/CR -5762 "Comprehensive Aging Assessment of Circuit Breakers and Relays"

This phase of the study involved testing several samples in a laboratory. The test specimen used included new, aged in-service, and artificially aged relays, and relays with specific degradations simulated. Laboratory tests were supplemented with field evaluation of certain maintenance and surveillance practices. The objectives of this phase included verifying the effectiveness of the current surveillance, maintenance and test techniques to identify the condition of the relays and potential approach to failures; and demonstrating the feasibility of implementing improved inspection, surveillance, and monitoring methods to provide the data required for effective condition assessment. The report documenting the results of the test program presents the following conclusions:

- Current industry practices which included visual inspection, pick up and drop-out voltage checks are not sensitive to most of the degraded conditions. In fact, if relay coils have shorted turns, pick up voltage tests can give misleading information.

  Improved inspection, surveillance and monitoring methods that include a combination visual inspection, infra-red pyrometry, vibration testing, and acoustic testing are sensitive to some degraded conditions.
- Infrared temperature measurement was considerably more sensitive to the degraded conditions of dirt accumulation, overheat, shorted coil turns, and loose connections than current practice of pick up and drop out voltage testing.
- For control relays, the methods of infra-red temperature measurement and vibration testing are recommended to be added to the current practices.
- For some timing relays inrush current measurements may be more sensitive to degraded conditions of dirt accumulation, overheat, contact damage and shorted coil turns. Therefore, for timing relays, inrush current measurement in addition to the above is recommended.

D.2 NRC Generic Communications and Vendor Advisories

Over two dozen NRC Generic Communications (e.g, Notice and Bulletin) and an equal number of Vendor Advisories have been issued on relay problems. A complete listing of all these documents is included in Appendix A. In this section, some of the significant relay problems addressed in these documents are discussed. The relays and the problem topics chosen are based on a review of the NPRDS data and the results of a survey of the utilities conducted as a part of this project.

D.2.1 MDR Rotary Type Relays

MDR relays which are manufactured by Potter & Brumfield relays are designed to meet the requirements of Military specification MIL-R-19523. Their contacts are rated for 500,000 operations. The MDR relays are used in some nuclear plants in portions of the Reactor Protection System. The RPS monitors many parameters throughout the plant and initiates a reactor-trip upon exceeding parameter limits. The MDR relays provide the interface between the RPS and a variety of equipment such as valves, motor starters, and annunciators. A typical plant that utilizes MDR relays in the RPS design has about 100 of them in normally energized applications. MDR relays are also used in other normally de-energized applications, with power applied to the coil only for short periods to operate the relay. This is in contrast to the operation in the RPS where the relays are used in the "fail-safe" mode by keeping the relay energized during normal plant operation and removing power to allow the relay to drop out and initiate a trip signal.

Several failures have been reported on this relay [54,55]. The failure modes were sticky rotor and intermittent operation of the contacts.

The relay design consists of a rotary armature which when energized rotates through a 30^{o} angle and operates several banks of contacts. Two coil springs return the armature when power is removed. Investigation of the failures disclosed that the sticky rotation was due to deposition of foreign material in the area of the bushings and armature shaft. In areas where the foreign material was found, the metallic surfaces also showed signs of corrosion. The foreign material deposits and the corrosion products prevented the armature from rotating back to its de-energized position upon removal of power. The problem was apparently caused by the heat generated by prolonged application of power to the coil which in turn caused outgassing from the insulating and potting materials used in the fabrication of the coil. The intermittent contact operation was attributed to the possible chemical reactions i.e., contact activation on the fixed and movable contacts from the outgassing (e.g. chlorine).

The relay redesign by the manufacturer incorporated several changes between 1986 and 1990 to address these problems and others. Changes included replacement of those materials identified as causing the outgassing. Chloride containing materials which were thought to have caused the corrosion were eliminated. Some brass parts of the relay were replaced with stainless steel parts. Subsequent testing and in-service experience thus far indicates that the design changes implemented may have solved the relay failure problem.

Separate from the failures discussed above, other instances of misapplication reported (A.56) include:

- using contact dc and ac ratings interchangeably
- using contacts rated for high load for low level switching.

D.2.2 Mercury-wetted Relays

Mercury-wetted relays are used in some designs of the Reactor Protection Systems (RPS) because of their speed and bounce-free switching capabilities. Failures of mercury-wetted relays from two different vendors have been reported (61, 62). The relays were used in continuously energized applications. Failures involved the closed contacts remaining closed after the relays were de-energized and vice versa. It was found that periodically de-energizing the relay tended to mitigate the problem. An investigation of the problem postulated that the failures may be due to "oxygen contamination of the H_2 atmosphere normally found in the vials," but the exact root cause of the problem could not be determined.

Because the same types of failures occurred with two different makes of mercury-wetted relays, it was concluded that there was a generic problem with operating this type of relays in the continuously energized mode. Therefore, the mercury-wetted relays were replaced with dry contact type relays.

Mercury-wetted relays are used in other applications such GE Turbine Electro-hydraulic Control System. When their contacts fail, they must be replaced, rather than attempting a repair by tapping the circuit boards. Such actions can only result in a temporary solution to the problem. After consulting with the manufacturer, it is preferable to replace them with dry-contact type relays.

D.2.3 HFA Series Relays

The HFA relays are of the hinged-armature type auxiliary relays manufactured by the General Electric Company. With an estimated nuclear industry population of over 40,000, this relay probably represents the most widely used control/auxiliary relay.

Several failures have been reported over the past 25 years. Many of them are primarily caused by manufacturing or material deficiencies that show up only with age in service. Many of the failures occurred after the relays had been in service for about 10 years. The NRC Generic Communications and GE Service Information Letter type communications have documented the following types of problems:

1. **Coil burn-out failures due to corrosion of windings.** Several cases of coil failures were reported [22, 21, 22, 23] after the relays have been in service about 10 years. Cause was attributed to electrolytic corrosion from halogens released from a class of nylon bobbins exposed to high humidity conditions. DC coils operated in continuously energized, or intermittent operation were considered to be more prone to failure than AC coils. Initial corrective action proposed by GE was to replace the coil with new coils which included a Lexan bobbin. Later, the Lexan material also proved to be susceptible to failures under high temperature environment. The second stage corrective action included replacement of the coils with TEFZEL bobbins, or the relays with the new Century series relays. The model number for the Century series relays includes three numerals (HFA121XXX) following the letters HFA, whereas, the old HFA relays contain only two numerals (HFA12XXXX).

2. **Coil bobbin cracking failures leading to loose debris blocking the armature.** This series of failures [24 to 29, 33, 34] is merely a continuation of the problem with the coil bobbin material previously identified. The failures were determined to be from high temperature aging induced embrittlement of the Lexan or Nylon material. The bobbins are currently made of TEFZEL material. GE's recommended corrective action was to replace the coil assembly with ones that contain TEFZEL coil bobbins or to replace the relays with the new Century series relays.

3. **Potential for jeopardizing seismic qualification due to improper adjustment of contact gap and wipe settings**. During a seismic qualification testing, GE identified [30, 31] that the seismic capability of the hinged armature type relays depended upon proper adjustment of contact gap, armature gap and contact wipe settings. GE's SIL 44 Supplement #4 identified the need for periodic contact gap and wipe settings and provides a recommended procedure for performing these adjustments. Wipe settings should be adjusted to yield a gap of 0.039" between the armature section under stop screw and the pole piece for normally open contacts, and 0.039" between the stop screw and the armature for normally closed contacts. The contact gap should be adjusted to be 0.220" ± 0.015". The recommended periodicity was not defined in the SIL 44 Supplement. Industry practice appears to be to use a frequency of once in five years and whenever a change to the internals, such as, changing the contact configuration or contact replacement is made.

4. **Periodic checking and adjustment of pickup voltage.** Based on field experience GE emphasizes [35, 36, 38, 39] the need to periodically test and adjust the pickup voltage on HFA relays. Pickup voltage can change with time in service or if any changes to the internals are made. GESIL 44, Supplement No. 5 contains the recommended procedure for adjusting the pickup voltage. The pickup voltage for

dc relays is to be set between 57 to 60% of nominal voltage, and for ac relays it is to be set between 73 and 81 % of nominal voltage. The recommended periodicity was not defined in the SIL 44 Supplement. Industry practice appears to be a five-year frequency and whenever a change to the internals such as changing the contact configuration or contact replacement is made.

5. **Movable contact finger binding.** A manufacturing process deficiency during a certain period resulted in contact arms being wider because the tolerance was exceeded. GE [41, 42, 43, 44] recommends replacement of the affected class 1E relays and changeout of the contact armature assembly for non-1E applications. Further, the GE also states that changes to the manufacturing process have been made to preclude recurrence.

6. **HFA Relays with latching mechanisms may not have the required minimum latch engagement** . A minimum latch engagement of 1/32" inch is required. The probable causes for this condition are insufficient clearance between the top of the relay armature and the top of the molded moving contact carrier and/or insufficient tension by the formed leaf spring that rotates the latch to its fully engaged position. GE SIL 190-1 [40] recommends checking for the latch engagement and replacing the 1E relays that do not meet the 1/32" requirements. For nonclass 1E relays, the adjustments can be performed onsite using the GE recommended procedure outlined in GE SAL 190-1.

D.2.4 AR/ARD Relays

AR and ARD relays are manufactured by Westinghouse Electric. These relays are used as slave relays in Westinghouse Solid State Protection System and as control/auxiliary relays in many other applications throughout the nuclear industry. Several failures have been reported for this relay over the past 15 years. Many of the failures occurred after the relays had been in service for about 10 years. Significant failures are discussed in the following paragraphs.

One of the two types of AR relays used in SSPS not seismically qualified: Originally Type ARLA latch relays manufactured by Westinghouse Electric were used as slave relays in the Solid state Protection Systems (SSPS) of Westinghouse PWRs and in several other applications in other nuclear plants. These relays perform their latching function by mechanical means and were seismically qualified. The type ARMLA relays, which were available as replacements for the ARLA, are not seismically qualified. These relays perform the latching function by magnetic means. Westinghouse supplies a special seismically qualified replacement (Part No. 2388A31). Type ARMLA relays used in qualified safety related applications should be replaced. Westinghouse Technical Bulletin NSD-TB-82-03 [48, 49] provides a means for identifying the unqualified units that may have been used.

Aging failure of ARD relays: Older type ARD relays manufactured by Westinghouse Electric use a sand-based coil potting compound. Aging degradation of this material was found to affect relay performance in all three modes (operating, transition and non maintenance/surveillance program for mild environment to extend their qualified life.

Misapplication AR relay contacts: In its technical Bulletin on AR relays **[45]**, Westinghouse addresses the potential for misapplication AR type relay contacts. In some cases, circuits with high DC inductive loads (e.g., Target Rock or Valcor SOV coils) may have been designed using contacts with inadequate DC interrupting capabilities. This condition can cause continued contact arcing after the contacts are opened. Such arcing can degrade non-metallic components in the immediate vicinity. Westinghouse recommends arc suppression techniques, such as, using a free-wheeling diode in parallel with the coil or connecting two contacts in series.

Another Technical Bulletin [48] discusses the potential for misapplication of contacts caused by a confusion in the Westinghouse "Quick-Selector" Catalog 25-000 11th edition. The 12th edition of the Catalog corrects this by changing the contact rating from NEMA N600 to NEMA P600. Westinghouse also recommends that the user determine reportability under 10CFR21 based on an evaluation of the specific applications in the plant.

D.2.5 BF/BFD Relays

NBF and NBFD (a modified version of the BF/BFD industrial control relays) relays are manufactured by Westinghouse Electric. These relays are used in the Reactor Protection and Engineered Safety Features System in many early Westinghouse PWR plants and as control/auxiliary relays in many other applications throughout the nuclear industry. One significant age related failure that began occurring after the relays had been is service for 10 years, is discussed below:

Potential for undetected coil failures in NBFD relays: NBFD relays are used in reactor protection systems in both normally energized and de-energized dc applications. Coil failures have been reported [49, 50, 51, 52] in relays used in the reactor protection system and in some plants, in other normally energized applications. Failures were postulated to be the result of inductive surges in aged coils. To prevent a potential safety hazard from undetected failures, Westinghouse recommended both short term and long term actions by the users. The short term recommendations included: (a) verifying coil continuity for normally de-energized applications after each energize-deenergize cycle for testing, prior to returning the relays to service, and (b) verifying armature pull-in for the energized applications after each deenergize-energize cycle for testing prior to returning the relays to service.

For the long term, Westinghouse recommended replacing the coils in affected relays, i.e., those with coils manufactured before January 1981. Newer coils use a nylon insulating material which has been confirmed by tests to be capable of withstanding the high voltage spikes.

Appendix E Dictionary of Abbreviations

ANSI	American National Standards Institute
BTU	British Thermal Unit
DG	Diesel Generator
EPRI	Electric Power Research Institute
ESFAS	Engineered Safety Features Actuation System
EMI	Electro-Magnetic Interference
FET	Field Effect Transistor
HA	Hinged Armature
INPO	Institute of Nuclear Power Operations
IEEE	Institute of Electrical & Electronic Engineers
IFOV	Instantaneous Field Of Vision
IR	Infra Red
LED	Light Emitting Diode
NARM	National Association of Relay Manufacturers
NEMA	National Electrical Manufacturers Association
NMAC	Nuclear Maintenance Application Center
NC	Normally Closed
NO	Normally Open
NPRDS	Nuclear Plant Reliability Data System
NRC	Nuclear Regulatory Commission
RPS	Reactor Protection System
SCR	Silicon Controlled Rectifier
SSR	Solid State Relay
RFI	Radio Frequency Interference
TRIAC	Triode AC switch
TDDO	Time Delay Drop Out
TDPU	Time Delay Pick Up

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