ELECTRIC POWER RESEARCH INSTITUTE

Nuclear Maintenance Applications Center: Guidelines for the Development of Circuit Breaker Specialists

2012 TECHNICAL REPORT

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Nuclear Maintenance Applications Center: Guidelines for the Development of Circuit Breaker Specialists

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Product Description

Circuit breakers are critical to the continued operation of industrial facilities, including power plants. However, there is no consistent process in place in the utility industry to ensure the proper professional and technical development of individuals who are responsible for these components as facilities age. This report, developed by the Electric Power Research Institute (EPRI) and the Circuit Breakers Users Group (CBUG), provides a tiered approach for development of future Circuit Breaker Specialists by establishing skill sets that encompass the knowledge areas most commonly needed by individuals who operate and maintain electrical equipment.

Background

Circuit breaker expertise is often possessed by many individuals at a nuclear power plant. Depending on the organizational structure of the utility, different individuals may be called upon to provide technical expertise regarding the design, procurement, operation, and maintenance of electrical system components in general, and circuit breakers in particular. This report recognizes this fact, and tries to ensure that regardless of which persons are selected to become Circuit Breaker Specialists, a clearly defined success path is established for their professional and technical development.

Objectives

The objectives of this report are to lay out the many different skills and knowledge areas that are needed to become an effective Circuit Breaker Specialist, and to provide guidance for a career development plan.

Approach

To develop the knowledge areas and the progression of skills in the three skill sets presented in the report, guidance was sought from individuals at utility organizations who are responsible for maintaining electrical systems and the circuit breakers installed in those systems. Equipment manufacturers and existing Circuit Breaker Specialists were also consulted.

Results

The recommendations within this report are provided in a progressive fashion to allow users to benefit from the information while minimizing the risk of job impacts resulting from insufficient knowledge of, or improper exposure to, equipment. This report is not intended to validate or invalidate qualifications but to provide a framework for further individual development. It is expected that each organization will review this report and identify the subset of information that it can apply to meet site and industry objectives. The report presents three progressive skill sets, with cross-references to recommended training options and alternatives to assist in achieving the Circuit Breaker Specialist requirements of each organization.

Applications, Value, and Use

Because the skills involved are broad and varied, it takes many years to become an effective Circuit Breaker Specialist. This report presents the mechanical and electrical attributes that must be understood in order to properly maintain circuit breakers and the systems in which they are installed, and to maximize their life expectancy. It is the responsibility of each user of this report to apply the appropriate recommendations to meet his or her own training commitments and requirements.

Keywords

Component engineer
Circuit Breaker Specialist
System engineer
Testing
Training

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Section 1: Introduction and Background

1.1 Purpose and Intended Use

1.1.1 Purpose of the Report

This guide presents a collection of recommendations to be used within a utility's program to develop the necessary job skills for an individual working in a role that is termed in this document as a *Circuit Breaker Specialist*. The guide identifies three progressive skill set levels of a Circuit Breaker Specialist and describes corresponding topics, knowledge areas, development opportunities, and training options.

It is the responsibility of the individual users of this guide to incorporate the appropriate recommendations specified in the guide in ways that are consistent with their own sites' personnel development plans as well as training commitments and requirements.

The EPRI Circuit Breakers Users Group (CBUG) has developed this guide to identify basic plant knowledge, obtainable through training activities or opportunities, that upon completion of the course or attainment of the skill set can be used to develop a site Circuit Breaker Specialist who meets site and industry expectations. This goal is consistent with and supports the CBUG mission statement, which states the following:

> The primary mission of the Circuit Breaker Users Group is to provide an industry forum for issues relating to switchgear and circuit breakers. This mission is accomplished through meetings, workshops, working groups, training, the EPRI website, industry preventive maintenance basis development, and an e-mail distribution list.
>
> The circuit breaker users groups meet annually to identify and address circuit breaker technical and programmatic issues. These meetings provide utility personnel with opportunities to review operating experience, conduct utility roundtables, and discuss tools and techniques with peers, manufacturers, and service providers. EPRI provides an up-to-date e-mail network of industry personnel responsible for circuit breaker maintenance. EPRI and NMAC member utilities utilize this network for benchmarking and industry surveys.

1.1.2 Use of the Report

The recommendations within this guide are provided in a tiered fashion to allow users to benefit from the information while minimizing the risk of job impacts resulting from insufficient knowledge or improper exposures. This guide will neither validate nor invalidate any particular site qualifications.

It is expected that each site will review this document and identify the parts that they can best apply in order to meet site and industry needs. The resultant product is tiered qualification cards (Skill Sets 1 through 3), with a cross-reference of recommended training options with alternatives to meet the qualification card requirements of each individual site.

1.2 Background and Cornerstone Industry Documents

1.2.1 Background Information

Circuit breaker personnel are known by various titles: component engineer, breaker technician, and breaker specialist, to name a few. Duties and responsibilities are often spread across several departments, including maintenance, operations, engineering, and design and procurement. This guideline is intended to be used as a resource for developing tiered qualification criteria, recommended mentoring sessions, demonstrative skill sets, and training options to meet individual site and industry needs.

1.2.2 Cornerstone Circuit Breaker Program Documents

The following four documents have become the cornerstone of circuit breaker programs at nuclear power plants:

- EPRI technical report 1000014, *Circuit Breaker Maintenance Programmatic Considerations*
- INPO SOER 98-2, “Circuit Breaker Reliability”[1]
- NRC IN 99-13, “Insights from NRC Inspections of Low- and Medium-Voltage Circuit Breaker Maintenance Programs”
- NRC letter to EPRI (reproduced in Appendix A of this report)

These four documents contain a wealth of guidance and lessons learned—information that should be effectively communicated through the training and plant activities described in this report during the professional development of the Circuit Breaker Specialist.

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[1] Access to INPO reports and materials is restricted to organizations authorized by INPO. The information is confidential and for the sole use of the authorized organization.

1.3 Report Scope and Contents

Figure 1-1 illustrates the scope and contents of this report.

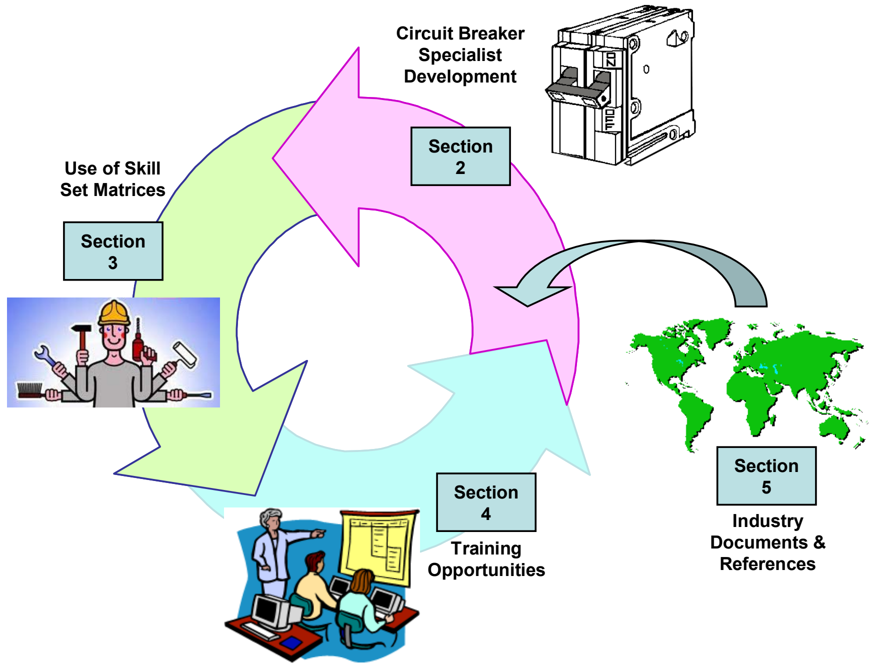


Figure 1-1
Report scope and contents

Following the introductory material provided in this section, an overview of the Circuit Breaker Specialist development process is provided in Section 2. The primary focus of the report is the detailed skill set development guidance provided in Section 3. The tables in Section 3 summarize numerous skill sets and development opportunities for each level of development, and provide cross-references to various training opportunities (detailed in Section 4) and site and industry documents and references (detailed in Section 5).

1.4 Overview of Circuit Breaker Design

A circuit breaker is an electromechanical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic functions are to provide power to a circuit under normal conditions and to automatically interrupt continuity under short-circuit or overload conditions. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit breakers are made in varying sizes, ranging from small devices that protect an individual component up to large switchgear designed to protect high-voltage circuits feeding major systems within the nuclear power plant.

1.5 Definitions of Key Terms and Acronyms

1.5.1 Key Terms

The following definitions are for terms commonly encountered by the Circuit Breaker Specialist and are based on definitions most often associated with IEEE Std C37.100-1992 (R 2001), "IEEE Standard Definitions for Power Switchgear."

advance angle — In an automatic synchronizer, the angle in degrees prior to phase coincidence that the generator voltage waveform will change relative to the bus voltage waveform during the period of time between initiation of breaker closing and the actual closing of the circuit breaker contacts. This can be expressed by the following equation:

$$\Phi_A = 360 * \Phi_S * T_B$$

Where: Φ_A is the advance angle in degrees

Φ_S is the slip frequency in Hertz

and T_B is the breaker closing time in seconds.

arc resistance (of a fault) — The component of the fault impedance that is caused by the current flowing through ionized air. At the fault location, R_{arc} = V. There is no significant reactive component. The arc resistance accounts for the heating effect of the arc.

automatic synchronizing system — A relaying scheme with one or more elements that 1) takes into account the closing time of the controlled breaker to calculate when the advance angle is proper to initiate closing, 2) causes the breaker contacts to close when a zero phase difference between the sensed voltages occurs, 3) monitors and controls the frequency and voltage of the generator. *See* manual synchronizing system, semi-automatic synchronizing system.

auxiliary current transformer — A current transformer used in the secondary circuit of another current transformer to provide, for example, additional current ratio and phase angle adjustment or circuit isolation.

current differential — A protection technique in which the currents entering and leaving the protected zone or area are compared. If the net result is not zero, a fault could exist within the protected zone, and the current difference can be used to operate the associated relays.

direct underreaching transfer trip (DUTT) — A form of pilot protection in which each underreaching trip unit trips the local breaker(s) and sends a direct transfer trip signal, by way of a communication channel, to the remote breaker(s), which are then tripped with no local supervision and no intentional time delay.

directional comparison protection	A form of pilot protection in which directional relay (or element) action at the two line terminals is compared with the aid of a communication channel. The line breakers are tripped when the directional relays at both terminals sense the fault to be in the trip direction. The major relay schemes used are directional comparison blocking, directional comparison unblocking, and permissive overreaching transfer trip.
dropout (of a relay)	The level of the measured quantity at which a sensing device will just reset. *See* pickup (of a relay), reset (of a relay).
fault impedance	The impedance at the point of the fault, which can include the impedance of the arc, the fault initiating object, and the tower footing resistance.
ground fault (transmission and distribution protective relays)	An insulation failure between an energized conductor and ground.
hardware failure	Inability of a relay to perform properly because of the malfunction of one or more physical components, which must be replaced to correct the malfunction.
high-impedance fault	A generic term used in protective relaying to identify a fault condition in which the fault current magnitude is significantly lower than that caused by a bolted fault.
high-impedance ground fault	*See* high-impedance fault.
high-resistance fault	A high-impedance fault in which the reactive component is small in comparison to the resistive component.
inadvertent energizing	Accidentally energizing a generator that is off-line, with the field de-energized.
manual synchronizing system	A control scheme whereby an operator controls the generator voltage, frequency, and breaker closing. A group of instruments provides the information required to make the closing decision. The operator's action may be supervised by additional devices that prevent incorrect closures. *See* automatic synchronizing system, semi-automatic synchronizing system, synchronism check relay.
operator window (operator synchronizing window)	A predetermined range of voltage, phase angle, and slip frequency within which an operator can safely initiate closing of a circuit breaker to synchronize a generator to the system. *See* automatic synchronizing system, manual synchronizing system, semi-automatic synchronizing system.
permissive overreaching transfer trip (POTT)	A directional comparison pilot relaying scheme in which the communication channel is keyed to a trip signal by an overreaching relay. Tripping occurs when both a trip signal is received and a local overreaching relay operates.

phase angle regulator (regulating transformer) A high-voltage phase shifter used for power flow control, usually equipped with an exciting winding and a series winding, requiring special relaying consideration differing from conventional transformer relaying.

pickup (of a relay) The level of the measured quantity at which a sensing device will just operate. *See* dropout (of a relay), reset (of a relay).

principle failure (of a relay) Inability of a relay to perform properly because of an inaccuracy or error in the relay concept or algorithm. To correct the principle failure, the relay must be conceptually redesigned.

reset (of a relay) The state of a relaying function at which the output is in the same state as when the relay is completely de-energized and unlatched. *See* dropout (of a relay), pickup (of a relay).

semi-automatic synchronizing system A relaying scheme that has aspects of both the manual and the automatic synchronizing systems in that either one or the other will match the generator or close the breaker, but not both. *See* automatic synchronizing system, manual synchronizing system.

slip frequency The difference in frequency between two systems or between a generator and the system. Slip frequency is per unit slip times rated frequency. For a generator or motor, per unit slip is equal to the difference between the rated speed, Ns, and the actual speed, N, divided by the rated speed.

slug A metallic link or switch blade inserted in a fuse holder or mounting in an electrical circuit to eliminate the fusing function.

trip window (unblocking or channel failure) A trip permission output generated (usually within 4–6 milliseconds) by a receiver after loss of channel of 100–150 milliseconds duration. This trip window is generated only on the loss of channel and not when the channel is restored. The receiver logic requires that guard be restored and stable before the trip window can again be generated.

tripping modes This term describes the sequence of operations of the devices that must trip in a relay scheme.

unblocking A form of permissive overreaching transfer trip modified so that the receiver will generate a trip time window that will permit local tripping if the local relay sees a fault and a loss of channel. *See* trip window, permissive overreaching transfer trip.

1.5.2 Acronyms

ANSI – American National Standards Institute

AOV – air-operated valve

ASME – American Society of Mechanical Engineers

ASTM – American Society for Testing and Materials

CBT – computer-based training

CBUG – Circuit Breakers Users Group

CFR – Code of Federal Regulations

CT – current transformer

DC – direct current

EASA – Electrical Apparatus Service Association

EFE – equipment failure experience

EPRI – Electric Power Research Institute

EQ – equipment qualification

ESP – engineering support personnel

ETTM – engineering technical training module

FME – foreign material exclusion

FMEA – failure modes and effects analysis

IEEE – Institute of Electrical and Electronics Engineers

INPO – Institute of Nuclear Power Operations

JIT – just-in-time

KT – Kepner-Tregoe

LEMUG – Large Electric Motor Users Group

MOV – motor-operated valve

NDT – nondestructive testing

NEIL – Nuclear Electric Insurance Limited

NEMA – National Electrical Manufacturers Association

NETA – International Electrical Testing Association

NFPA – National Fire Protection Association

NMAC – Nuclear Maintenance Applications Center

NRC – Nuclear Regulatory Commission

NUPIC – Nuclear Utility Procurement Issues Committee

O&M – operations and maintenance

O&MR – operations and maintenance reminders

OE – operating experience

OEM – original equipment manufacturer (supplier)

OJT – on-the-job training

OSHA – Occupational Safety and Health Administration

PT – potential transformer

QA – quality assurance

SEN – Significant Event Notifications

SER – Significant Event Reports

SME – subject matter expert

SOER – Significant Operating Experience Reports

WANO – World Association of Nuclear Operators

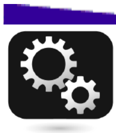
1.6 Key Points

Throughout this report, key information is summarized in "Key Points." Key Points are bold-lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Key Point is to emphasize information that will allow individuals to take action for the benefit of their plant. The information included in these Key Points was selected by NMAC personnel, consultants and utility personnel who prepared and reviewed this report.

The Key Points in this report are organized according to four categories: O&M Costs, Technical, Human Performance, and Supervisory Observation. Each category has an identifying icon, as shown below, to draw attention to it when quickly reviewing the guide.

Key O&M Cost Point
Emphasizes information that will result in overall reduced costs and/or increase in revenue through additional or restored energy production.



Key Technical Point
Targets information that will lead to improved equipment reliability.

Key Human Performance Point
Denotes information that requires personnel action or consideration in order to prevent injury or damage or ease completion of the task.

Key Supervisory Observation Point
Identifies tasks or series of tasks that can or should be observed by maintenance first line supervisors to improve the performance of the maintenance staff and improve the reliability of the component.

Appendix B contains a listing of all key points in each category. The listing restates each key point and provides a reference to its location in the body of the report. By reviewing this listing, users of this guide can determine if they have taken advantage of key information that the writers of this guide believe would benefit their plants.

Section 2: General Discussion: Development of the Circuit Breaker Specialist

Key Human Performance Point
The development of skills required to be proficient at the various aspects related to circuit breakers is a lifelong endeavor.

The Circuit Breaker Specialist is not only concerned with various electrical systems but must also have component-level knowledge of the devices themselves.

This guide provides direction to individuals who are new to circuit breakers and electrical systems; however, because the skills involved are so varied, the document can also serve as a refresher or reference for experienced individuals. The intent of the guide is to focus the Circuit Breaker Specialist's development by identifying knowledge areas that should be acquired as the Circuit Breaker Specialist's career advances.

2.1 Typical Competencies and Skills

The following list presents typical skills and competencies that are commonly possessed by individuals performing component specialist functions. They should not be interpreted as minimum requirements for qualification or certification purposes, but rather as a benchmark for use within each licensee's plant-specific program.

- Communication skills
  - Good verbal skills for communicating component conditions and work activities
  - Good rapport with OEMs and ability to interface with component refurbishment vendors
  - Ability to collaborate and coordinate with numerous organizations within and outside the utility
  - Report writing skills
  - Knowledge of site/fleet procedures
- Technical competencies and skills
  - Knowledge of component design parameters, design characteristics and margins, equipment manufacturing capabilities, component operations and maintenance, equipment performance, and equipment reliability
  - Ability to make appropriate use of operating experience (OE)

- Capacity to support industry initiatives regarding components
- Skill at troubleshooting component problems
- Proficiency at retrieval of historical equipment performance data
- Recognized standing as a subject matter expert (SME) and the single point of contact for the assigned component/line of components
- Good problem-solving skills
- Effectiveness in performing equipment root cause analysis

▪ Human performance competencies and skills

  - Engaged, professional, and knowledgeable specialist demeanor
  - Ability to interface with numerous organizations within the utility and to ensure that roles and responsibilities are respected and understood
  - Good business acumen

▪ Planning/organization competencies and skills

  - Attitude of strong ownership of the area of expertise
  - Ability to maintain focus on long-range equipment reliability goals while simultaneously addressing emergent component performance issues
  - Ability to retain a long-term focus for the health of the component

2.2 Typical Engineering Support Personnel Qualification

The scope and level of engineering support personnel (ESP) training for the component specialist will vary from plant to plant. Table 2-1 provides an example of the typical scope of ESP training available for component specialists and the knowledge areas of the ESP that are typically needed by component engineers. They should not be interpreted as minimum requirements for qualification or certification purposes, but rather as a benchmark for use within each licensee's plant-specific program.

Table 2-1
Typical engineering support personnel skills and knowledge areas

Typical ESP Knowledge Area
10 CFR 50.59 Screening/Evaluation
Appendix R
Cause Analysis Process
EQ Program
Investigation and Troubleshooting Process
Maintenance Rule
Methods to Evaluate Component Performance
Methods to Evaluate System Performance
Motor-Operated Valve Program
NRC Interface
Operability Determination
Organizational Familiarization
Postmaintenance and Modification Testing
Predictive/Condition-Based Maintenance Program
Preventive Maintenance Program
Problem Identification and Resolution
Procedure Commitment Database
Procedure Program
Processing of Work Orders
Rotating Equipment

There are additional continuing/position-specific training areas that may be relevant to some component specialists. These specialty areas include the following:

- Performing vendor oversight activities
- Specification development
- Failure modes and effects analysis
- Thermography
- Equipment reliability process implementation (for example, INPO AP-913[2])
  - Component-specific maintenance activities (level of awareness)
  - Case studies (using operating experience and developing lessons learned)

[2] Access to INPO reports and materials is restricted to organizations authorized by INPO. The information is confidential and for the sole use of the authorized organization.

2.3 Detailed Description of Circuit Breaker Specialist Skill Sets

Key Human Performance Point

At most utilities, circuit breaker expertise can reside among component specialists (often referred to as component engineers), system engineers (sometimes referred to as system managers), and design engineers. Any of these individuals can be an excellent candidate for developing circuit breaker technical expertise and assuming the role of subject matter expert when circuit breaker issues arise.

2.3.1 Candidates for Circuit Breaker Specialist

Circuit breaker expertise is often possessed by many individuals at a nuclear power plant. Depending on the organizational structure of the utility, different individuals may be called upon to provide technical expertise regarding the design, procurement, operation, and maintenance of electrical system components in general, and circuit breakers in particular. This report recognizes this fact, and tries to ensure that regardless of which persons are selected to become Circuit Breaker Specialists, a clearly defined success path is established for their professional and technical development.

2.3.2 Skill Sets and Related Topics

For the purposes of this report, three skill sets have been identified for the Circuit Breaker Specialist: Basic, Intermediate, and Advanced. Figure 2-1 illustrates the various topics at both the system and component levels that the Circuit Breaker Specialist would be expected to know at each of the three levels of experience.

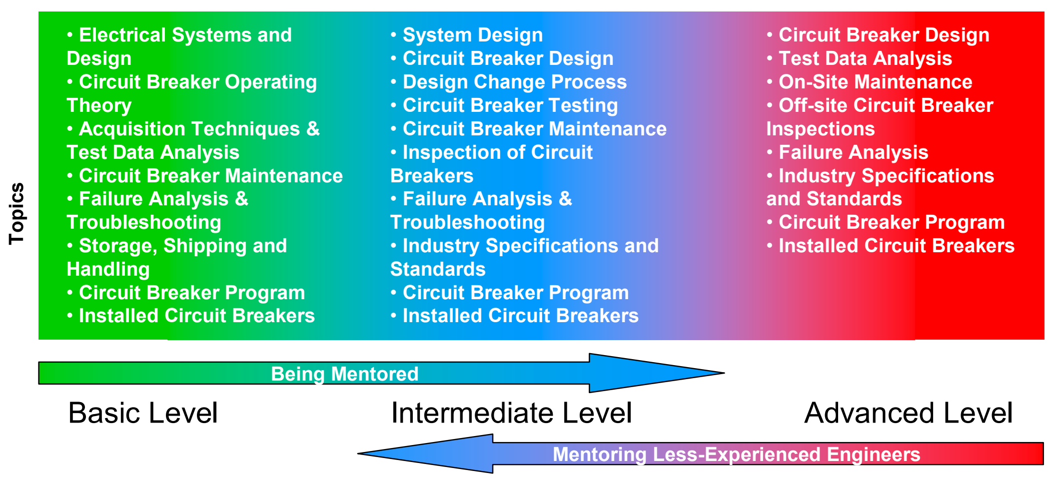


Figure 2-1
Recommended topics for each level of experience

Specific guidance for developing Circuit Breaker Specialists is provided in Tables 3-1 through 3-3 of this report. For the purposes of this report, and as depicted in Figure 2-1 and the Section 3 tables, the following color scheme is used:

- Basic Level – Depicted in green font and/or shading
- Intermediate Level – Depicted in blue font and/or shading
- Advanced Level – Depicted in red font and/or shading

2.3.3 Means for Acquiring the Necessary Skills

There are several methods that can be used to enhance the acquisition of skills for the development of the specialist. Two key areas that can enhance this development are mentoring and equipment exposure with hands-on opportunities.

Key Human Performance Point
Mentoring can greatly accelerate the development of a Circuit Breaker Specialist.

2.3.3.1 Being Mentored and Mentoring Less-Experienced Engineers

As reflected in Figure 2-1, mentoring can greatly accelerate the development of a Circuit Breaker Specialist. Mentoring is a relationship built on trust, and one of its primary goals is to make a person new to a field more confident in his or her abilities and talents. Mentoring normally involves a member of the same profession with more experience and connections, helping a new person become more confident in their chosen field. Although there is some focus on the skills, the main focus in mentoring is on offering a long-term, ongoing process—it is usually a developed relationship, based on shared experience.

Key Supervisory Observation Point
Experienced Circuit Breaker Specialists or supervisors acting in the mentoring role should ensure that performance and learning are measured during opportunities for direct observation of component maintenance activities.

The mentor often passes on not only tangible knowledge, but also philosophy, advice, and experience. The mentor may also provide introductions to people or organizations that can enhance the knowledge of a Circuit Breaker Specialist.

A person who wants to develop skills related to maintaining electrical equipment should find as many opportunities as possible to witness the disassembly, testing, refurbishment, and repair of electrical system components in general, and circuit breakers in particular. Also, since ensuring that components operate properly is a primary responsibility, opportunities to witness the application of other skill sets such as installation, maintenance, operation, testing, and failure analysis should be sought out by the individual who would become a Circuit Breaker Specialist. These skills are essential when one is attempting to determine what can be done to circuit breakers and what level of effort it will require.

Key O&M Cost Point
The effectiveness of the circuit breaker program should be reflected in the reliability of the electrical system components in general, and circuit breakers in particular.

2.3.3.2 Hands-On Opportunities

In the development of any specialist, the individual needs to be dedicated predominantly to a particular system and its components. A Circuit Breaker Specialist should be the single point of accountability and have responsibility for the circuit breaker program(s). Since the program(s) require resources and finances, the circuit breaker program owner (Circuit Breaker Specialist) will have to justify why certain tests, maintenance activities, and refurbishment time intervals have to be followed. The more knowledgeable the Circuit Breaker Specialist is, the easier it is to technically justify the action taken to make the site/fleet/corporate program successful. Hands-on developmental opportunities for each level of development are provided in the Tables 3-1 through 3-3 of this report.

2.3.3.3 Training Opportunities

Training opportunities that should be considered for the Circuit Breaker Specialist are listed in detail in Section 4.

2.3.3.4 Library of Technical References

It is important that a comprehensive circuit breaker library (either electronic, hard copy, or both) be compiled so that the necessary reference information will be readily available. A significant amount of information has been developed over the past years on circuit breaker system design, failure identification, mechanical repairs, testing, refurbishment specifications, procurement specifications, and environmental qualification. Documents that should be considered for inclusion in a circuit breaker library are listed in detail in Section 5.

2.3.3.5 Typical Organizational Interfaces

Appendix C of this report provides detailed insight into the various organizational interfaces typically encountered by the Circuit Breaker Specialist. This appendix describes typical functions and interfaces with the following organizations:

- Operations and Maintenance Interfaces
  - Preventive/corrective maintenance organizations
  - Predictive maintenance organizations
  - Plant operations
- Engineering Interfaces
  - Systems engineering
  - Design engineering
  - Procurement engineering and the supply chain
- Other Plant Interfaces
  - Training organization
  - Work/outage planning
  - Radiation protection
  - Safety
  - Human performance
  - Environmental
  - Work/outage scheduling
  - Document control
  - Plant management review committee
  - Procedure writers
  - Finance/accounting for O&M and capital budgets
  - Procurement engineering
  - Oversight and regulatory affairs

- Interfaces with Organizations External to the Utility
  - Refurbishment service suppliers
  - Component manufacturers
  - Industry users groups
  - The U.S. Nuclear Regulatory Commission (NRC)
  - Nuclear Electric Insurance Limited
  - The Institute of Nuclear Power Operations (INPO)
  - The World Association of Nuclear Operators (WANO)

Section 3: Use of the Skill Set Matrices

The skill sets are intended to be used as a recommended career development guide to assist sites in developing primary and backup Circuit Breaker Specialists. The matrices contain a comprehensive list of skills and knowledge areas that should be learned over time. To a varying extent that is dependent upon the individual and organization goals, acquiring these skills and knowledge will require considerable time.

As stated in Section 2, it is expected that the primary Circuit Breaker Specialists and the backup will become knowledgeable in the topics listed in Skill Set 1 (Basic) and Skill Set 2 (Intermediate). It is recommended that the primary Circuit Breaker Specialist will become proficient in Skill Set 3 (Advanced). The topics in the skill sets do not have to be covered in the order they are listed. However, some of the topics in Skill Set 3 will be better comprehended by experienced Circuit Breaker Specialists.

It is important that a career path be developed to maintain individuals in the electrical discipline for a considerable amount of time in order for them to become Circuit Breaker Specialists. It will be essential for these persons to possess developed skills and provide mentoring to others entering the electrical field, or there will be very few Circuit Breaker Specialists in the future. Although the recommended level of training, site involvement, industry participation, and knowledge listed in this document requires a significant investment, the return on the investment in the development of the Circuit Breaker Specialist more than pays for itself when even one major component failure that would have affected site production is averted.

The tables presenting the skill sets are divided into three columns:

- The **Topics** column identifies high-level topics, each of which may have several associated knowledge areas. Skill levels are designated as Basic, Intermediate, and Advanced. As noted in Section 2 of this report, electrical expertise can reside among component specialists (often referred to as component engineers), system engineers (sometimes referred to as system managers), and design engineers. Any of these individuals can be an excellent candidate for developing electrical technical expertise and becoming the subject matter expert when electrical issues arise.
- The **Skill Set** column expands on each topic in an attempt to identify the most important knowledge areas that need to be learned by the Circuit Breaker Specialist. This column essentially directs Circuit Breaker Specialists to the most important areas that they should be involved in or have commanding knowledge of.
- The **Development Opportunities** column provides recommendations on site-specific activities the Circuit Breaker Specialist should be involved in to gain knowledge of each listed topic. Some of these recommendations will involve observing work being performed, some will be hands-on, and some will involve working with other groups to better understand their job functions and/or processes.

Training opportunities. Specific training courses are listed in Section 4 of this report. It should be noted that the training courses listed are not all-inclusive and may not always be available. Some training recommendations will require outside training, while other training courses can be brought to the organization. Most of the training recommended will have a cost associated with it but also brings benefits to the organization in the form of increased knowledge by the Circuit Breaker Specialist.

Site and industry references. The full names of pertinent reference documents are listed in Section 5 of this report. The documents listed are in the public domain or can be purchased. As stated earlier, many documents pertaining to performing maintenance, operating, testing, refurbishment, repairing, rewinding, procuring, storage, and so on of electrical equipment have been developed within the past 10 years. It is important the Circuit Breaker Specialist know where to find information within these references, and it is preferable that this information be readily accessible. The selection of documents listed in Section 5 was based on the experience and knowledge of the authors. The list is not all-inclusive and can be adjusted as needed by the user.

As stated earlier, this document is not intended to take the place of on-site component engineer development programs. Rather, it provides a Circuit Breaker Specialist with a development plan to enhance the skills and knowledge of the individuals assigned to the equipment. The intent is that future Circuit Breaker Specialists will be trained in the many different mechanical and electrical attributes of system components in order to maintain a high level of equipment reliability and maximize life expectancy.

3.1 Skill Set 1 (Primary and Backup Circuit Breaker Specialists)

Upon attainment of this knowledge-based skill set, the individual will be qualified to perform tasks related to routine duties for a Phase 1 (Level 1) Circuit Breaker Specialist. It is expected to take approximately 2 years to complete the learning objectives to reach Level 1. Upon successful attainment of this skill set, the individual will be able to demonstrate mastery of the skills noted in Table 3-1.

Table 3-1
Basic knowledge areas

Topics	Skill Set	Development Opportunities
Electrical Systems and Design	Develop a general plant knowledge of systems Become familiar with the site-specific circuit breaker program Develop a basic knowledge of site-specific electrical theory and electrical safety training Develop knowledge of plant schematics Become familiar with the design and interaction of common system components such as bus and switchgear, motor control centers, and load centers	Review plant licensing and design basis documents Review site/fleet circuit breaker program documents and procedures Attend training courses as recommended in Section 4

Acquisition Techniques and Test Data Analysis	Understand testing methods and types of equipment (use of each type of monitoring equipment)
	• On-line
	    ○ Continuous (permanently installed technology)
	• Off-line
	    ○ Permanently and temporarily installed technology
		Become familiar with guidance documents (for example, EPRI and vendor equipment manuals)
		Become familiar with testing requirements (for example, regulatory, postmaintenance, acceptance, predictive, preventive, and so on)

Circuit Breaker Maintenance	Develop a basic knowledge of plant maintenance procedures • Testing procedures • Installation/replacement procedures • Repair procedures • Operating procedures Develop a basic knowledge of planned maintenance (preventive and predictive) and its purpose Develop a basic knowledge of corrective maintenance (scheduled and emergent) and its purpose • Repair and refurbishment specifications • OEM and plant drawings • Foreign material exclusion (FME) procedures • Purchase specifications • Repair/installation standards	Support plant walkdowns and monitoring Support circuit breaker installations Support vendor-supplied services Participate in off-site circuit breaker refurbishment/PM activities Provide escort and oversight of on-site vendors Support maintenance with circuit breaker PMs and testing Initiate the development of purchase documents for circuit breaker services and equipment

Table 3-1 (continued)
Basic knowledge areas

Topics	Skill Set	Development Opportunities
Failure Analysis/ Troubleshooting	Become familiar with evidence preservation Develop a basic knowledge of the principles of troubleshooting	Participate in the preparation of failure evaluation cause reports Observe maintenance troubleshooting activities of failed circuit breakers Participate in generating white papers, Maintenance Rule functional failure determinations, and operability determinations
Circuit Breaker Operating Theory	Critical parameters in circuit breaker design • Electrical • Mechanical Switchgear design and installation alignment Electrical cable specifications, design, connections, conduit standards, and splices Lubrication types and frequencies of use Breaker designs • Molded case • Metal clad ○ Air – magnetic, oil, vacuum DC breaker design • Use of shunts • Trip units ○ Oil dashpot, pneumatic, analog, solid state, digital (microprocessor based) • Testing DC trip units Frame types/sizes • Molded case 120V–600V • Insulated case • Metal clad Circuit breaker timing technology Secondary control circuit technology Zinc and silver coating technology	Review circuit breaker/switchgear vendor manuals, catalogs, and drawings Periodically attend CBUG meetings Review circuit breaker design standards (such as ANSI C37, IEEE, NEMA, and so on) Review manufacturer-published handbooks and web-based documents regarding circuit breaker design Review appropriate EPRI power plant reference series volumes regarding circuit breakers and cables Interact with circuit breaker specialists/SMEs Visit/tour vendor/manufacturer facilities Observe circuit breaker PM activities Observe manufacturing testing and inspection activities

Table 3-1 (continued)
Basic knowledge areas

Topics	Skill Set	Development Opportunities
Storage, Shipping, and Handling	Develop a basic knowledge of how circuit breakers are stored, shipped, and handled prior to installation in the plant Develop a basic knowledge of FME requirements for breakers while in storage	Observe receipt inspection activities and storage of circuit breakers Review procedures defining storage requirements for Level B equipment Observe various lifting and handling processes for circuit breakers Observe installation practices for circuit breakers
Circuit Breaker Program	Become familiar with the site circuit breaker program and related procedures Become familiar with cornerstone industry documents (as listed in Section 1 of this report) Be able to extract breaker maintenance data from the controlled records database	Understand the content and purpose of the site circuit breaker health report Provide support to the site circuit breaker subject matter expert Review circuit breaker PM tasks and frequencies Review corrective actions taken affecting the circuit breaker program
Installed Circuit Breakers	Become familiar with the site circuit breaker database and how installed circuit breakers are identified and managed within the database	Assist with the maintenance of the site circuit breaker database Assist with tracking locations of circuit breakers (typically by serial number) Assist with entering tracking data acquired during maintenance into the database

3.2 Skill Set 2 (Primary and Backup Circuit Breaker Specialists)

Upon attainment of this knowledge-based skill set, the individual will be qualified to perform tasks related to routine duties for a Phase 2 (Level 2) Circuit Breaker Specialist. It is expected to take approximately 3 years to complete the learning objectives to reach Level 2, from the time of initial assignment. Upon successful attainment of this skill set, the individual will be able to demonstrate mastery of the skills noted in Table 3-2.

Table 3-2
Intermediate knowledge areas

Topics	Skill Set	Development Opportunities
System Design	Develop knowledge of system designs Develop knowledge of circuit breaker failure modes Develop knowledge of system coordination protection schemes Understand the detailed design, interaction, maintenance, and operation of common system components such as bus and switchgear, motor control centers, and load centers	Assist and participate in site circuit breaker program revisions and self-assessments Assist or participate in failure analyses Review system design documents and schematics Continue to review appropriate EPRI power plant reference series documents
Circuit Breaker Design	Develop an advanced knowledge of circuit breaker theory and design • Critical parameters in circuit breaker design • Overcurrent trip device, design, and application • Travel and timing testing monitoring technology, design, and application • Switchgear design, application, and alignment (installation of circuit breakers and key interface points) • Interrupter technologies, design, and application (vacuum, SF6, air-magnetic, oil, and so on) • Electrical cable specifications, design, connections, conduit standards, and splices (EQ splices, high/low-voltage applications) • Breaker design and applications (seismic criteria, harsh vs. mild environment applications, DC operating voltage limitations) • Molded case circuit breaker design and applications • DC circuit breaker design and applications • Frame types and applications (replacements) • Voltage and current sensory/monitoring technology and application • Arc flash calculations and personal protective equipment requirements	Assist in the development of design/procurement specifications Read technical and regulatory documents (see Section 5 of this report for suggestions) Read vendor technical manuals and product literature Review plant-specific environmental qualification documents Review plant-specific arc flash calculations and/or NFPA 70E as applicable to design activities

Table 3-2 (continued)
Intermediate knowledge areas

Topics	Skill Set	Development Opportunities
Design Change Process	Understand site-specific requirements for design modification documents Meet site-specific qualification requirements as a preparer of 10CFR50.59 safety analyses	Support and review part equivalency evaluations Prepare change evaluation documents Prepare or provide input to Minor Modification documents Assist in preparing or provide input to Major Modification documents Draft changes to plant schematics and drawings Prepare 10CFR50.59 safety analyses and screens Assist in generating white papers, standing order documentation, Maintenance Rule functional failure determinations, and operability determinations
Circuit Breaker Testing	Develop knowledge to analyze, disposition, and track circuit breaker test data Understand limits and actions taken Address population performance issues (health reports) Maintain test equipment knowledge	Assist and recommend procurement of new maintenance or test equipment Set up and assist in facilitating monitoring equipment training courses Periodically review OEs with breaker technicians

Table 3-2 (continued)
Intermediate knowledge areas

Topics	Skill Set	Development Opportunities
Circuit Breaker Maintenance	Develop knowledge necessary to support on-site maintenance Understand the process for review and disposition of vendor-specific technical bulletins Develop knowledge of the scope of shop tests and repair procedures	Revise and/or create new maintenance procedures Assist in planning, scheduling, and disposition of preventive, predictive, and corrective maintenance activities Conduct on-site circuit breaker inspections and installations Participate in the review and acceptance of purchase test data packages Lead surveillances and evaluation of gathered data (that is, reactor protection trip and molded case circuit breakers) Draft changes and approvals of OEM drawings and vendor manuals (as required) Assist with on-the-spot changes and disposition approvals Review breaker and parts obsolescence issues Engage in breaker maintenance interaction in plant shop area (weekly)
Inspection of Circuit Breakers	Develop knowledge necessary to support off-site circuit breaker inspections Be able to provide vendor oversight	Assist in the development of repair/refurbishment and purchase specifications as required Reconcile and disposition nonconformances Review and approve off-site circuit breaker refurbishment data packages Assist in assuring that repair/refurbish/installation industry specifications and standards are met

Table 3-2 (continued)
Intermediate knowledge areas

Topics	Skill Set	Development Opportunities
Failure Analysis	Become knowledgeable with the failure analysis for circuit breaker-related failures	Participate in the development of failure analysis reports Assist in evidence post-mortem testing Prepare root cause reports Assist in the development of troubleshooting guides
Industry Specifications and Standards	Build upon the knowledge of cornerstone documents and become familiar with the following industry documents: • ANSI C37.20 standard • NEMA AB 1, AB 4 • IEEE 1534 • OSHA 1910, Subpart R • NFPA 70E • Protective clothing technology • NEIL – Program Requirements	Read and review documents listed in Section 5 of this report, including EPRI technical reports that interpret industry standards (such as EPRI TR-104513 and EPRI 1009832) Review vendor technical bulletins (Service Information Letters, Service Advice Letters, Tech Bulletins, Information Notices, and so on) Develop and/or review site-specific responses to vendor technical bulletins and industry specifications/standards
Circuit Breaker Program	Develop a thorough understanding of the site circuit breaker program and related procedures	Develop and maintain the site circuit breaker health report Develop and maintain the site circuit breaker program procedures Provide support to the site circuit breaker subject matter expert
Installed Circuit Breakers	Develop a thorough knowledge of the site circuit breaker database and how installed circuit breakers are identified and managed within the database	Maintain the site circuit breaker database Track locations of circuit breakers (typically by serial number) Enter tracking data acquired during maintenance into the database

3.3 Skill Set 3 (Primary and Backup Circuit Breaker Specialists)

Upon attainment of this knowledge-based skill set, the individual will be qualified to perform tasks related to routine duties for a Phase 3 (Level 3) Circuit Breaker Specialist. It is expected to take approximately 4.5 to 6 years to complete the learning objectives to reach Level 3, from the time of initial assignment. A Level 3 specialist will have mastered all of the Level 1 and 2 items in addition to the skills noted in Table 3-3.

Table 3-3
Advanced knowledge areas

Topics	Skill Set	Development Opportunities
Circuit Breaker Design	Understand how to conduct a systems certification class Meet site-specific requirements as a reviewer of 10CFR50.59 safety analyses Develop a thorough and detailed knowledge of circuit breaker design technologies	Manage the site circuit breaker program Prepare, review, and approve part equivalency evaluations Prepare, review, and approve change evaluation documents • Minor Modification documents • Major Modification documents Perform/approve changes to plant schematics and drawings Review 10CFR50.59 safety analyses and screens
Test Data Analysis	Develop knowledge necessary to become a subject matter expert (SME) for circuit breaker test data analysis	Generate white papers, standing order documentation, and Maintenance Rule functional failure determinations, and/or assist in equipment operability determination
On-Site Maintenance	Develop knowledge sufficient to act as SME of on-site maintenance and be responsible for the technical content of the following: • Circuit breaker maintenance procedures • Circuit breaker purchase/repair test data packages • Owner of circuit breaker purchase specifications • Maintenance procedures, scope, and frequency • OEM drawings • Engineering changes or modification packages • Outage support and scheduling interface • EQ program document changes related to breaker replacements • 10CFR21 and defective parts impact evaluations Develop knowledge necessary to manage the PM Basis database Evaluate new testing methods and technology	Coordinate with and serve as liaison with management regarding circuit breaker and switchgear related issues Act as project manager of on-site circuit breaker inspections and installations Control, and revise as necessary, breaker and switchgear repair/refurbishment procedures Control, and revise as necessary, breaker and switchgear repair/refurbishment specifications Initiate and revise required EQ documentation for breaker replacements Reconcile and disposition nonconformances Initiate changes to maintenance activities and frequencies as needed, to address degradation and breaker failures Perform trend reviews of circuit breaker maintenance and failure histories to identify potential generic issues that may indicate degradation or common breaker failure modes Track circuit breaker overhaul status and availability

Table 3-3 (continued)
Advanced knowledge areas

Topics	Skill Set	Development Opportunities
Off-Site Circuit Breaker Inspections	Develop a thorough and detailed knowledge of shop tests and repair procedures sufficient to act as SME of the following: • Off-site repair/refurbishment • Off-site vendor oversight • Circuit breaker and switchgear design modification and repair • Support for NUPIC audits	Lead surveillances and evaluation of gathered data Lead and manage off-site repairs/refurbishment Perform QA inspections When possible, participate as a technical specialist during external (NUPIC) audits of circuit breaker manufacturers
Failure Analysis	Develop a thorough knowledge of circuit breaker-related failure mechanisms and how to analyze each type of failure	Act as lead for circuit breaker-related issues Act as lead for development of troubleshooting plans Lead failure analysis activities Perform evidence post-mortem testing Lead root cause investigations Present findings to industry peers Assist in the issuance of external OE documents Support other sites' failure analysis teams
Industry Specifications and Standards	Develop a thorough knowledge of industry issues regarding circuit breaker design, analysis, testing, procurement, application, and failure Interface with NEIL auditors with regard to the circuit breaker program Support generation and revision of industry-specific circuit breaker guidance documents (EPRI publications)	Participate in the development of industry specifications and standards Lead and approve reliability improvement initiatives Support/interface with NEIL auditors with regard to circuit breaker program and changes Assist in facilitating interface with industry peers on EPRI standards and implement the appropriate changes either to the EPRI standards or the plant program

Table 3-3 (continued)
Advanced knowledge areas

Topics	Skill Set	Development Opportunities
Circuit Breaker Program	Develop a thorough understanding of the site circuit breaker program and related procedures (for example, program procedures, training procedures, operating procedures, and emergency operating procedures)	Maintain site circuit breaker health report Act as circuit breaker subject matter expert and mentor
Installed Circuit Breakers	Develop a thorough knowledge of the site circuit breaker database and how installed circuit breakers are identified and managed within the database	Maintain the site circuit breaker database Track location of circuit breakers (typically by serial number) Ensure that data acquired during maintenance is entered into the database

Section 4: Training Opportunities

The purpose of this section is to provide a summary of training opportunities that may be beneficial to an individual designated as, or serving in the role of, the Circuit Breaker Specialist at a nuclear power plant.

The training courses and instructional materials referenced in this report do not encompass the entire array of commercially available training that may be offered by manufacturers, third-party organizations, or industry associations (for example, ASME, IEEE, ANSI, and ASTM). The training listed in this report is limited primarily to those courses offered through EPRI at the time this report was published. A new Circuit Breaker Specialist is encouraged to investigate whether additional courses are available in the industry that are applicable to his or her job function.

The following listed training recommendations are to be used as a guideline in establishing a training matrix.

4.1 Basic Level

4.1.1 Recommended Training Courses and Seminars

The following training opportunities should be made available to the entry (basic) level circuit breaker specialist:

- Principals of AC Circuit Breakers (16 hours) – EASA or equivalent
- Electrical Theory Fundamentals (16 hours) – EASA or equivalent
- Mechanical Repair Fundamentals (16 hours) – EASA or equivalent
- ETTM Molded Case Circuit Breaker, CBT Module, Version 1.0 (EPRI product 1009318)
- Circuit Breaker Overcurrent Testing 101 (8 hours) – Field testing
  - Insulation resistance
  - Electrical contact resistance
  - Time testing
  - Travel testing

  - Control voltage testing (under voltage)
  - Functional operation of electrical interlocks (bell alarms, antipump relays)
  - Overcurrent testing (long time, short time, instantaneous, ground fault, and so on)
- Plant-Specific Circuit Breaker Testing (24 hours)
  - Circuit breaker electrical testing (timing testing, Doble testing, primary/secondary current injection testing, and so on)
  - Circuit breaker mechanical testing (trip shaft torque, travel, positive interlocks, spring discharge)
- Schematic Interpretation and Overview (4 hours) – plant-specific
- Breaker Drawings (OEM) Interpretation (8 hours) – outline, accessories, and so on
- General site-specific electrical safety training (typically CBT)
- Vendor-sponsored training on circuit breaker design, maintenance, and testing (8 hours) (Westinghouse, ABB, GE, Siemens, Eaton, and so on)
- Test equipment specific training for equipment used at the site (8 hours) (Doble, Megger, Hi-pot, and so on)

4.1.2 Participation in Industry Events, Workshops, and Meetings

- CBUG/EPRI working meetings (40 hours/year)
  - Attendance
  - Training
  - Working meetings
- Fleet/plant working group and conference calls (40 hours/year)
  - Participation
  - Benchmarking within industry/utilities (80 hours/year)

4.2 Intermediate Level

4.2.1 Recommended Training Courses and Seminars

The following training opportunities should be made available to the intermediate level circuit breaker specialist:

- Circuit Breaker Testing 102 – Shop Testing (8 hours)
- Advanced Plant-Specific Circuit Breaker Testing and Data Analysis (8 hours)
- Breaker Shipping, Handling, and Storage (4 hours)
- Plant-Specific Circuit Breaker Training for Technicians (8 hours)

- Motor/Transformer Protection
  - Knowledge of relay, breaker, transformer protection
  - Knowledge of CT, PT protection
  - Understanding of symptom-based troubleshooting
  - Apparent cause failure analysis of breakers
  - Attend LEMUG training workshops
  - Training course on electric motors
  - Partial discharge monitoring training

4.2.2 Participation in Industry Events, Workshops, and Meetings

- CBUG/EPRI Working Meetings (40 hours/year)
  - Participation
  - Working meetings
  - Training
  - Breakout sessions
- Fleet/Plant Working Group and Conference Calls (40 hours/year)
  - Participation
  - Cabling and terminations (4 hours) (Tan Delta Testing)
  - Failure analysis – site-specific training, including KT Analysis, FMEA, direct, fault tree, and so on (16 hours)
  - Class 1E circuits and circuit breaker qualification basics – including seismic and environmental (4 hours)
  - Quality programs (10CFR50 Appendix B, ANSI/ASME NQA-1, ISO 9001, EASA-Q) (4 hours)
  - OE training (30 hours – CBUG)
  - Visits to repair shop (OJT) (80 hours/year)
    - Assist in repair shop evaluations
    - Perform repair procedure review
- Participation in the evaluation and disposition of operating experience (OE) as it relates to site/fleet equipment

4.3 Advanced Level

4.3.1 Recommended Training Courses and Seminars

The following training opportunities should be made available to the advanced level circuit breaker specialist:

- DC Circuit Breaker Operation and Repair
- Advanced Data Analysis Course
- Advanced Circuit Breaker Design
- Load Protection, Coordination Training (8 hours)
- Thermography (4 hours) (FLIR Training)

- Basics of NDT (4 hours)
  - Eddy current
  - Dye-penetrant
  - Ultrasonic
  - Understanding of NDT and troubleshooting
  - Metallurgy
- Visits to Repair Shop (OJT) (80 hours/year)
- Circuit Breaker/Electrical Protection – Advanced (4 hours)
  - Symptom-based
  - Advanced motor protection – sizing and limits
  - Protection scheme development
  - Slip and timing relays
- Power Systems (8 hours)
  - Transformers, electrical distribution, and so on

4.3.2 Participation in Industry Events, Workshops, and Meetings

- CBUG/EPRI Working Meetings (40 hours/year)
  - Participation
  - Breakout sessions
  - Leadership
- Fleet/Plant Working Group and Conference Calls (40 hours/year)
  - Participation
  - Leadership
- NFPA Membership
- IEEE Membership
- Leadership in the evaluation and disposition of operating experience (OE) as it relates to site/fleet equipment
- Participation in INPO/WANO evaluations

4.4 Manufacturers' and Third-Party Training Opportunities

Listing of the following manufacturers/suppliers/organizations should not be interpreted as an endorsement of the training or the equipment furnished by these suppliers. The list is provided for consideration and illustrative purposes only, and is in no way a complete listing of suppliers offering training relevant to the prospective Circuit Breaker Specialist.

4.4.1 Circuit Breaker Manufacturers' Training Opportunities

The prospective Circuit Breaker Specialist may also consider training offered directly by manufacturers of circuit breakers, as some of these organizations routinely offer hands-on seminars and short courses regarding the design, specification, installation, maintenance, and operation of their equipment. The following manufacturers should be considered when pursuing training in this manner:

- ABB
- Allis Chalmers
- Cutler Hammer
- Federal Pacific – FPE
- General Electric – GE
- ITE
- Merlin Gerin
- Siemens
- Square D
- Westinghouse

4.4.2 Third-Party Organizations' Training Opportunities

Third-party training courses, seminars, and materials are often offered by non-OEM vendors and organizations. The following organizations should be considered when pursuing training in this manner:

- AVO
- Click Safety
- Doble
- EPRI NMAC
- Megger
- NETA
- NLI
- NTT Workforce Development Institute
- Schermco Industries
- Schultz Electric
- Tampa Armature Works
- Tan Delta

Section 5: Industry Documents and References

The purpose of this section is to provide a comprehensive list of references that may be useful to the Circuit Breaker Specialist. The section is divided into the following subsections:

- EPRI Technical Reports
- NRC Published Documents
- INPO Guidance and References
- Industry Codes, Standards, and References

Any references to commercially available products or services are made so as to provide the Circuit Breaker Specialist with the broadest list of references possible. Inclusion in this report does not imply EPRI's endorsement or recommendation.

5.1 EPRI Technical Reports

5.1.1 Introduction

Users of this report should be aware that the availability of some EPRI material referenced in this report may be restricted to members of the program or sector within EPRI that is responsible for the material.

Additionally, users should be aware of the following two types of EPRI products that may be useful as cross-references or as an alternative means for accessing EPRI technical reports and published material: product lists and technical libraries.

5.1.1.1 EPRI Product Lists

Some organizations within EPRI periodically update and publish a product list, with its own unique product identification number, that compiles titles of all of the current publications from that particular organization. The following three product lists may be helpful to the Circuit Breaker Specialist as another means of identifying relevant sources of guidance.

- *Instrumentation and Control Program: Complete Product List, June 2011*. EPRI, Palo Alto, CA: June 2011. 1023421.
- *Nuclear Maintenance Applications Center: Complete Product List, Spring 2012*. EPRI, Palo Alto, CA: June 2012. 1025737.
- *Plant Engineering: 2012 Complete Product List*. EPRI, Palo Alto, CA: April 2012. 1024901.

5.1.1.2 EPRI Technical Libraries

Some organizations within EPRI periodically update and publish on DVD a compilation of the full products named in their respective product lists. The advantage of having the DVD is that the user does not need Internet access in order to read a published EPRI document. The following three technical libraries may be helpful to the Circuit Breaker Specialist as another means of identifying relevant sources of guidance.

- *Instrumentation and Control: Technical Library 2010*. EPRI, Palo Alto, CA: June 2010. 1021374.
- *Nuclear Maintenance Applications Center: Technical Library 2011*. EPRI, Palo Alto, CA: April 2011. 1023148.
- *Plant Engineering: Technical Library 2010*. EPRI, Palo Alto, CA: June 2010. 1021364.

5.1.2 EPRI Technical Reports

ABB HK Arc Chutes Evaluation Guide. EPRI, Palo Alto, CA: May 2005. 1012004.

Circuit Breaker Maintenance Programmatic Considerations. EPRI, Palo Alto, CA: February 2001. 1000014.

Circuit Breaker Maintenance Volume 1: Low-Voltage Circuit Breakers, Part 1: ABB K-Line. EPRI, Palo Alto, CA: May 2000. NP-7410-V1-P1.

Circuit Breaker Maintenance Volume 1: Low-Voltage Circuit Breakers, Part 2: GE AK Models. EPRI, Palo Alto, CA: May 2000. NP-7410-V1-P2.

Circuit Breaker Maintenance Volume 1: Low-Voltage Circuit Breakers, Part 3: Westinghouse DB Models. EPRI, Palo Alto, CA: May 2000. NP-7410-V1-P3.

Circuit Breaker Maintenance Volume 1: Low-Voltage Circuit Breakers, Part 4: Westinghouse DS Models. EPRI, Palo Alto, CA: May 2000. NP-7410-V1-P4.

Circuit Breaker Maintenance Volume 2: Medium-Voltage Circuit Breakers, Part 1: ABB HK Models. EPRI, Palo Alto, CA: July 1995. NP-7410-V2-P1.

Circuit Breaker Maintenance Volume 2: Medium-Voltage Circuit Breakers, Part 2: General Electric Magne-Blast Circuit Breakers. EPRI, Palo Alto, CA: July 1995. NP-7410-V2-P2.

Circuit Breaker Maintenance Volume 2: Medium-Voltage Circuit Breakers, Part 3: Westinghouse DH and DHP Models. EPRI, Palo Alto, CA: July 1995. NP-7410-V2-P3.

Circuit Breaker Timing and Travel Analysis. EPRI, Palo Alto, CA: April 1999. TR-112783.

Considerations for Conversion or Replacement of Medium-Voltage Air-Magnetic Circuit Breakers Using Vacuum or SF6 Technology. EPRI, Palo Alto, CA: November 2003. 1007912.

Evaluation and Testing of ABB Circuit Breakers with Mobilgrease 28. EPRI, Palo Alto, CA: October 2001. 1003087.

Field Testing of Overcurrent Trip Units for Low-Voltage Circuit Breakers Used in DC Applications. EPRI, Palo Alto, CA: September 1994. TR-104513.

Guidance on Overhaul of ABB K-Line Circuit Breakers. EPRI, Palo Alto, CA: February 2001. 1000013.

Guidance on Overhaul of AK 15/25 Circuit Breakers. EPRI, Palo Alto, CA: August 2001. 1002759.

Guidance on Overhaul of Magne-Blast Circuit Breakers. EPRI, Palo Alto, CA: December 2000. 1000011.

Guidance on Routine Preventive Maintenance for Magne-Blast Circuit Breakers. EPRI, Palo Alto, CA: October 1998. TR-109641.

Guidelines for Effective Component Engineering. EPRI, Palo Alto, CA: December 2005. 1011896.

Life Cycle Management Plan for Circuit Breakers at Salem and Hope Creek Stations: Generic Version. EPRI, Palo Alto, CA: September 2003. 1009153.

Life Cycle Management Planning Sourcebooks, Volume 7: Low-Voltage Electrical Distribution Systems. EPRI, Palo Alto, CA: February 2003. 1007426.

Life Cycle Management Plans for Hope Creek and Salem: Feedwater Heater and Moisture Separator Controls, Circuit Breakers, and Station Air System. EPRI, Palo Alto, CA: September 2003. 1009155.

Molded Case Circuit Breaker Application and Maintenance Guide: Revision 2. EPRI, Palo Alto, CA: December 2004. 1009832.

Power Plant Electrical Reference Series, Volume 7: Auxiliary Electrical Equipment. EPRI, Palo Alto, CA: May 1989. EL-5036-V7.

Reduced Control Voltage Testing of Low and Medium Voltage Circuit Breakers. EPRI, Palo Alto, CA: July 1999. TR-112814.

Routine Preventive and Condition-Based Maintenance for Westinghouse DHP Circuit Breakers, Revision 1. EPRI, Palo Alto, CA: July 2001. 1002758.

Routine Preventive Maintenance for AK and AKR Type Circuit Breakers, Revision 1. EPRI, Palo Alto, CA: October 2001. 1003086.

Routine Preventive Maintenance Guidance for ABB HK Circuit Breakers. EPRI, Palo Alto, CA: December 1999. TR-109642.

Routine Preventive Maintenance Guidance for ABB K-Line Circuit Breakers. EPRI, Palo Alto, CA: May 2000. TR-113736.

Routine Preventive Maintenance Guidance for AK and AKR Type Circuit Breakers. EPRI, Palo Alto, CA: November 1999. TR-112938.

Routine Preventive Maintenance Guidance for Westinghouse DS Circuit Breakers. EPRI, Palo Alto, CA: September 2000. 1000246.

5.2 NRC Published Documents

5.2.1 Introduction

Selected regulatory references are listed in Section 5.2.2. The Circuit Breaker Specialist is encouraged to investigate other regulatory documents (such as Generic Letters, Information Notices, Reportable Events, and so on) to obtain additional information on specific topics. The Circuit Breaker Specialist should also be aware of the following quality assurance regulations, which address design, specification, procurement, installation, operation, and maintenance activities:

- 10CFR50 Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Facilities, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC.
- 10CFR50.2, Definitions, Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, DC.

- U.S. Nuclear Regulatory Commission. Quality Assurance Program Requirements (Operational). U.S. NRC Regulatory Guide 1.33, Revision 2, Washington, DC, February 1978.

5.2.2 Regulatory References

NUREG-0933, Main Report with Supplements 1–34: Section 3, New Generic Issues. Issue 49: Interlocks and LCOs for Class 1E Tie-Breakers (Rev. 3). U.S. Nuclear Regulatory Commission, Washington, DC.

NUREG-0933, Main Report with Supplements 1–34: Section 3, New Generic Issues. Issue 55: Failure of Class 1E Safety-Related Switchgear Circuit Breakers to Close on Demand (Rev. 2). U.S. Nuclear Regulatory Commission, Washington, DC.

NUREG-0933, Main Report with Supplements 1–34: Section 3, New Generic Issues. Issue 115: Enhancement of the Reliability of Westinghouse Solid State Protection System (Rev. 2). U.S. Nuclear Regulatory Commission, Washington, DC.

IN 99-13, Insights from NRC Inspections of Low- and Medium-Voltage Circuit Breaker Maintenance Programs. U.S. Nuclear Regulatory Commission, Washington, DC: April 1999.

IN 2007-34, Operating Experience Regarding Electrical Circuit Breakers. U.S. Nuclear Regulatory Commission, Washington, DC: October 2007.

5.3 INPO Guidance and References

5.3.1 Introduction

INPO products are not accessible to the general public, and reference to these documents in this report does not in any way change this policy. As a reminder, all references to INPO documents in this report are accompanied by the following notation: "Access to INPO reports and materials is restricted to organizations authorized by INPO. The information is confidential and for the sole use of the authorized organization."

The INPO web site should be consulted for the latest operating experience (OE) and other pertinent information related to specific equipment, system, and program issues. The web site provides ready access to many types of technical information, including (but not limited to) the following:

- Equipment Failure Experience (EFE)
- Just-in-time (JIT) Operating Experience
- Operations & Maintenance Reminders (O&MR)
- Significant Event Notifications (SEN)

- Significant Event Reports (SER)
- Significant Operating Experience Reports (SOER)
- Topical Reports

5.3.2 INPO References

"Circuit Breaker Reliability." INPO, Atlanta, GA: September 1998. SOER 98-2.[3] (Available only to INPO members.)

"Deenergized Breaker Charging Spring Motor." INPO, Atlanta, GA: January 1983.[3] (Available only to INPO members.)

"Reactor Trip Breaker Failures." INPO, Atlanta, GA: October 1983. SOER 83-8.[3] (Available only to INPO members.)

"Unavailability of Emergency Power Caused by Diesel and Breaker Control Circuitry Design." INPO, Atlanta, GA: June 1983. SOER 83-6.[3] (Available only to INPO members.)

5.4 Industry Codes, Standards, and References

5.4.1 General Availability of Reference Material

The information sources listed in this report represent a reasonable compilation of primary references that would be useful to the Circuit Breaker Specialist. It should be noted that there are many other industry references that could be informative to the Circuit Breaker Specialist and that the references provided represent documents that were available at the time of publication. Since that time, additional references will have been published, and some older references may no longer be available.

5.4.2 Industry Codes, Standards, and References Regarding Circuit Breakers

ANSI/IEEE 741-2007, IEEE Standard Criteria for the Protection of Class 1E Power Systems and Equipment in Nuclear Power Generating Stations.

ANSI/IEEE C37 Series, Circuit Breakers, Switchgear, Substations and Fuses.

ANSI/IEEE C37.06.1, Guide for High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis Designated "Definite Purpose for Fast Transient Recovery Voltage Rise Times."

ANSI/IEEE C37.10.1-2000, IEEE Guide for the Selection of Monitoring for Circuit Breakers.

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[3] Access to INPO reports and materials is restricted to organizations authorized by INPO. The information is confidential and for the sole use of the authorized organization.

ANSI/IEEE C37.12-2008, IEEE Guide for Specifications of High-Voltage Circuit Breakers (over 1000 Volts).

ANSI/IEEE C37.13-2008, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

ANSI/IEEE C37.16, Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors—Preferred Ratings, Related Requirements, and Application Recommendations.

ANSI/IEEE C37.17, Trip Devices for AC and General Purpose DC Low-Voltage Power Circuit Breakers.

ANSI/IEEE C37.29-1981, IEEE Standard for Low-Voltage AC Power Circuit Protectors Used in Enclosures.

ANSI/IEEE C37.50, For Switchgear: Low-Voltage AC Power Circuit Breakers Used in Enclosures—Test Procedures.

ANSI/IEEE C37.100-1992 (R 2001), IEEE Standard Definitions for Power Switchgear.

ATS Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems. ANSI/NETA, Boston, MA: 2009.

ETT Standard for Certification of Electrical Testing Technicians. ANSI/NETA, Boston, MA: 2010.

Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications. National Electrical Manufacturers Association, Rosslyn, VA: 2009. NEMA AB-4.

MTS Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems. ANSI/NETA, Boston, MA: 2011.

National Electric Code, NEC 2009.

NEIL insurance documents and requirements for circuit breaker programs.

OSHA 1910, Subpart R: Special Industries. Occupational Safety & Health Administration, Washington, DC: December 2011.

Standard for Electrical Safety in the Workplace. National Fire Protection Association, Quincy, MA: 2012. NFPA 70E.

Appendix A: Insights from NRC Circuit Breaker Maintenance Program Inspections

The following letter from the U.S. Nuclear Regulatory Commission to EPRI provides valuable insight into issues related to the effective maintenance of circuit breakers and has become a cornerstone document for the development of circuit breaker programs throughout the U.S. nuclear industry. It is fundamental for the Circuit Breaker Specialist to be familiar with these issues and ensure that they continue to be adequately addressed and implemented.

Electric Power Research Institute
ATTN: Mr. Jack Lance
1300 Harris Boulevard
Charlotte, NC 28262

SUBJECT: INSIGHTS FROM NRC CIRCUIT BREAKER MAINTENANCE PROGRAM INSPECTIONS

Dear Mr. Lance:

Because of concerns over the reliability of safety-related low- and medium-voltage power circuit breakers, the U.S. Nuclear Regulatory Commission (NRC) developed an action plan to determine whether regulatory action was needed to ensure that the breakers remained reliable components. As part of the action plan the NRC performed inspections of eight licensee circuit breaker maintenance programs using a special inspection module (Temporary Instruction 2515/137, Revision 1). In addition to those inspections, the staff also performed inspections of original equipment manufacturers and third party vendors that perform breaker refurbishments.

The purpose of this letter is to transmit the insights gained from NRC inspections at nuclear power plants and circuit breaker vendor facilities over the two-year period from 1997 to 1998. The inspection results indicate that the eight inspected licensee maintenance programs for medium-voltage (4 kV to 15-kV) and low-voltage (600-V and below) circuit breakers that supply power to safety-related equipment, are generally adequate and the circuit breakers are still reliable components. However, there are some areas of these maintenance programs that could be improved to ensure that circuit breakers continue to be reliable throughout their service lives. Information Notice (IN) 99-13, "Insights from NRC Inspections of Low- and Medium-Voltage Circuit Breaker Maintenance Programs," was issued on April 29, 1999, to summarize the inspection results for all licensees.

The enclosure to this letter provides a detailed discussion of the topics covered in IN 99-13 so that licensee personnel responsible for developing and implementing circuit breaker maintenance programs may take advantage of the information gathered from the inspection of licensee and vendor facilities. In addition to discussing the topics in IN 99-13 in greater detail, the enclosure also discusses corrective maintenance, refurbishment, and the maintenance rule. The enclosed insights are for information only, so that licensees may consider them when making improvements to their circuit breaker maintenance programs, and are not meant to be construed as new regulatory requirements.

The historical background of the circuit breaker reliability issues that led to the NRC performing the maintenance program inspections is enclosed. Following the background, the insights gained from the NRC inspections are described. The insights have been divided into the following categories: (1) general programmatic issues, (2) preventive maintenance, (3) corrective maintenance, (4) licensee/vendor interface, (5) control voltage calculations, (6) operating experience review, (7) refurbishment, and (8) maintenance rule.

If you have any questions concerning any of the material in the attachment to this letter please contact one of the cognizant staff members listed at the end of the attachment.

Ledyard B. Marsh, Chief
Events Assessment, Generic Communications and Non-Power Reactors Branch
Divison of Regulatory Improvement Programs
Office of Nuclear Reactor Regulation

Theodore R. Quay, Chief
Quality Assurance, Vendor Inspection, Maintenance and Allegations Branch
Division of Inspection Program Management
Office of Nuclear Reactor Regulation

Enclosure: Low- and Medium-Voltage Circuit Breaker Reliability Concerns

cc: J. Sharkey, EPRI
W. Subalusky, INPO
G. Fader, INPO
R. Burris, INPO
D. Modeen, NEI
J. Butler, NEI

Background: Low- and Medium-Voltage Circuit Breaker Reliability Concerns

The NRC issued Information Notice 98-38, "Metal-Clad Circuit Breaker Maintenance Issues Identified by NRC Inspections," on October 15, 1998, to alert licensees to issues identified by reactive NRC inspections at plants that experienced circuit breaker reliability issues in 1997. The nuclear power plants discussed in IN 98-38 either considered shutting down, extended an outage, or actually shut down because of concerns over common-mode failure of their safety-related circuit breakers. In response to those events, the NRC implemented a task action plan to evaluate whether any generic regulatory action was warranted to address power circuit breaker reliability problems. As part of the plan, inspections were performed at eight plants to determine the overall status of the industry's circuit breaker maintenance programs, using Temporary Instruction (TI) 2515/137, Revision 1, "Inspection of Medium-Voltage and Low-Voltage Power Circuit Breakers," issued on March 9, 1998. In addition to the TI inspections, several inspections of original equipment manufacturers and third party vendors were performed as part of the action plan.

Another part of the NRC task action plan was the monitoring of industry initiatives to address circuit breaker reliability issues. NRC representatives have attended portions of the Electric Power Research Institute's Nuclear Maintenance Applications Center (EPRI/NMAC) Circuit Breaker Users Groups over the last two years. The users groups, formed to develop maintenance and refurbishment guidelines for medium- and low-voltage power circuit breakers manufactured by General Electric, Westinghouse, and ITE/ABB, have been aggressively pursuing resolution of the breaker reliability issues and are developing guidance based on industry experience and vendor recommendations. The vendors, although reticent at first, have become increasingly involved over the last year. The EPRI/NMAC groups have already issued guidance for the General Electric Magne-Blast (4-kV) breakers, and plan to have the maintenance guidance for all of the 4-kV and 480-V breakers made by the three manufacturers issued by the end of 1999 or early 2000. Although the staff has not reviewed any of the final guidance documents, NRC representatives have seen some of the draft documents at the various users group meetings and they appear to be of high quality.

NRC staff also met with the Nuclear Energy Institute's (NEI) Circuit Breaker Task Force in December 1998. The NEI task force is made up of representatives from NEI, EPRI/NMAC, leaders of the EPRI/NMAC users groups, and the Institute of Nuclear Power Operations (INPO). The staff discussed with the task force a way to share the insights gained from the TI inspections that were performed in 1998. The staff and the NEI task force believe that it is important to share the inspectors' insights, as well as the inspection results, with the industry, especially since the EPRI/NMAC circuit breaker maintenance guidelines are being drafted and many licensees will be revisiting their maintenance programs to see where improvements can be made once the guidelines are issued.

Circuit Breaker Maintenance Inspection Insights

I. General Programmatic Issues

Licensee preventive maintenance procedures and practices could be improved by ensuring that all of the applicable vendor recommendations or industry operating experience are taken into consideration. Inspection results indicate that when licensees deviated from such recommendations and operating experience there was often no documented basis or rationale given. Although vendor recommendations may not be appropriate in some cases, it is important to have a sound engineering basis when deviating from those recommendations. Discussion with the vendor about the reasons behind their recommendations can help to ensure that a licensee has not overlooked something important when deciding to deviate from a vendor-recommended practice.

Control of the storage of lubricants and cleaning materials (including appropriate resealable containers or dispensers, shelf life, environment, segregation, etc.) is important. Some licensees had not identified shelf lives for lubricants and cleaning agents or solvents used in the maintenance of circuit breakers. Procurement and commercial-grade dedication documents did not always identify shelf lives where there were shelf lives associated with the materials. One licensee had identified a resealable container as a critical characteristic for dedication of a lubricant, but receiving documents did not reflect verification of that critical characteristic. Guidance for useful lives of these materials when in use after original containers had been opened (sometimes referred to as “pot life”) was not often established. Guidance for storage and handling of these materials after issue to maintenance personnel was typically not provided (e.g., requirements for storage environments, avoiding prolonged exposure to air or high temperatures, avoiding moisture or other contaminants, etc.). Supply issue procedures did not always require that lubricants be issued only on work orders for equipment for which the material was approved and in limited quantities. Maintenance procedures often were not specific about where certain lubricants or solvents should or should not be used on breakers.

A good training program for maintenance personnel should include: (1) specific qualification for various maintenance tasks on different types of breakers, (2) review of industry operating experience, (3) vendor-recommended modifications or upgrades, (4) vendor manual revisions, or (5) plant procedure revisions. At some plants, maintenance procedures did not cover inspecting breakers for specific problems identified in industry operating experience. Some licensees stated that they covered such items in training, but the inspectors found that specific items in question were seldom explicitly addressed in lesson plans. Also, maintenance personnel were not always familiar with some of the test equipment. At one plant, the electrical maintenance supervisor instructed electricians to perform runup reduced control voltage tests using a variable power supply and chart recorder, but the electricians were not familiar with the test equipment. After they experienced some difficulty with the equipment, instrumentation and control technicians were summoned to assist.

Unique identifiers on individual breakers are important for tracking breaker performance and maintenance history. Individual breakers at some plants do not have unique identifiers, and some of the licensees inspected did not know that group or series identifiers, such as shop order numbers, are not unique. Some licensees did not record both the breaker serial number, when present, or the cubicle number in maintenance records to allow for tracking of breaker location, performance, and maintenance history.

At most plants, the racking of breakers in and out of the cubicle (and local operation when required) is the job of Operations Department personnel. Operations personnel training and/or procedures could be improved by covering (1) verification and adjustment, if required, of cubicle interfaces in the connected position (or calling for Maintenance Department personnel to do this) and (2) functional testing in the connected position (i.e., starting, running, and stopping the load equipment when permitted by plant conditions) to verify post rack-in breaker operability in the fully connected position. This practice provides for verification of proper indications, closing spring recharging, and restoration of all electrical and mechanical interfaces and interlocks. These functions were sometimes covered to some extent by post-maintenance testing procedures. However, they were often not prescribed if for some reason a breaker was racked out (even if only to the test position), but no maintenance was performed on either the disconnected or racked-out breaker itself or its load equipment.

Having spare breakers on hand (particularly ones that have been refurbished and are certified for safety-related service) can allow flexibility for interchanging breakers in support of refurbishment, preventive maintenance, or in some cases, to replace a failed breaker in a timely manner, if necessary. Maintenance workers sometimes are under pressure to perform preventive maintenance within a short time in order to minimize the time that equipment served by a breaker (or the breaker itself) is out of service. Licensees have reported that much of this pressure is due to a provision of 10 CFR 50.65(a)(3) which recommends assessing and managing the risk associated with taking equipment out of service for planned maintenance. Having a ready spare to replace a problem breaker could alleviate some of the time pressures.

II. Preventive Maintenance

Some licensees did not always adhere to their own preventive maintenance schedules. At several plants breakers were found to be currently overdue for preventive maintenance with respect to licensee-established periodicity (as well as that recommended by the vendor), or were overdue on one or more occasions in the past.

Recording as-found breaker conditions and comparing them to previous as-found and as-left conditions can help maintenance personnel assess the amount of degradation since the last maintenance, or the effectiveness of the latest maintenance. As-found values of preventive maintenance parameters that could provide useful information include, the trip and close voltage, tripping current and times, insulation resistance, and contact resistance. These parameters should be measured and documented before making adjustments, cleaning, or operations that would tend to alter the as-found conditions. Consistently performing maintenance steps in a prescribed sequence designed to minimize preconditioning (because it cannot be completely eliminated) should provide more valid, comparable or trendable results.

Some vendor manuals prescribe functional testing of circuit breakers (i.e., closing and tripping electrically) at the minimum (and maximum) vendor-specified voltage for the closing solenoid, closing spring release solenoid, or tripping solenoid (e.g, Westinghouse MPM-DS). Others simply provide the voltage range within which the solenoids are designed to operate without explicitly prescribing testing at those extremes of solenoid design capability. However, reduced (i.e., less than nominal) control voltage testing as one means of (1) verifying current operability at the minimum expected (design-basis) or calculated control voltage available at the breaker, (2) confirming past operability, (3) determining margins to unsatisfactory performance, or (4) obtaining diagnostic, predictive, or trendable performance data, has not been routinely performed at all plants in the past. Some licensees have recently begun to obtain quantitative, trendable data on the minimum "pickup" voltages for the control devices which also reflects the condition of breaker tripping and closing mechanisms; or at least to determine if such data are trendable and useful in diagnostic condition assessment or performance prediction.

Although reduced control voltage testing is not a regulatory requirement, testing the most important breakers at reduced voltage may provide added assurance that these breakers would remain operable under worst-case conditions. Breakers such as the EDG output breaker, offsite power source breakers, or other breakers (including some loads that are sequenced on early or that remain connected to vital busses) may be required to close with minimum design control voltage under conditions such as initial recovery from a prolonged station blackout before battery chargers become available. However, certain others (e.g., later sequenced ECCS equipment breakers) that could see minimum design control voltage under some conditions may never be required to operate to perform any of their safety functions at less than nominal voltage because, for example, they are not required to close until after the standby emergency ac power source (e.g., a diesel generator) has restored power to the battery chargers, and hence vital 125-Vdc bus voltage, which is most often used for safety-related breaker control power, is restored to nominal (unless for a given plant, the failure of the only available battery charger must be assumed under the single failure criterion).

Note that most closing spring charging motors on safety-related breakers would not normally be required to operate at reduced voltage because in most design basis event scenarios, e.g., LOOP-LOCA, charging motors, which operate immediately after closing in most cases, would have already recharged their breakers' closing springs upon the initial closing after the vital bus(s) (and hence the battery chargers) have been re-energized on the standby emergency ac power source (e.g., a diesel generator). Even in the LOCA followed by a delayed LOOP scenario, which is not within the design basis of most plants, the charging motors of emergency core cooling system (ECCS) breakers would operate after their breakers closed upon ECCS initiation while normal power was still available. They would not need to operate again to allow their breakers to open upon loss of power and reclose one time as ECCS loads are automatically reenergized by, for example, an emergency diesel generator) load sequencer. Nevertheless, there may be certain instances that could require a charging motor to operate at reduced voltage (unless manual recharging is being relied upon). For example, during recovery from station blackout, if the EDG breaker or first offsite power supply breaker should fail to latch closed, and/or remain closed on the first try, the motor would need to operate at whatever control voltage was available to recharge the closing spring for subsequent attempts at closing, if warranted. While the motor would then operate at lower than normal speed, manufacturers, e.g., General Electric, have said that it is not deleterious for them to be tested at reduced voltage if deemed necessary.

Insulation resistance testing was being performed at some plants using inappropriate test voltage. Often the acceptance criteria required that the resistance be higher than some minimal value such as a thumb rule taken from rotating machinery testing practice, which is one megohm/(kV) + 1 megohm. However, having a very high value (e.g., 1000 megohms, or more, @ 2500 volts-dc for 5-kV equipment, as recommended by the National Electrical Testing Association) as an acceptance criterion (with results below this level requiring some action such as notifying the maintenance manager or cleaning) could facilitate early identification and timely correction of a degrading trend before a breaker failed to meet the minimum acceptable value. Also, some licensees did not require technicians to record the actual values measured, but only required them to indicate that the resistance was greater than some acceptance value, which as previously stated, was often too low. This practice was not conducive to meaningful data recording and evaluation of insulation performance and degradation.

III. Corrective Maintenance

Procedures or guidance to aid control room personnel who might have to deal with various types of breaker failures in the various modes of plant operation could prove useful. Although it may not be practical to develop detailed procedures for such failures, some general guidance on how to cope with failures of important breakers could be developed. Such predetermined operational considerations and off-normal operating guidance could be very helpful to operators, both from the standpoint of facilitating promptly placing the plant in a safe and stable condition and, to the extent possible at the same time, permitting the isolation of the affected breaker in order to preserve the as-failed conditions. For example, some plants have experienced failures of breakers to open (or open fully) on demand, a much less common, but typically more complicated problem than failures to close. Having predetermined off-normal operating guidance for this contingency could have minimized the time the affected plants had to remain in an unanalyzed condition while operators formulated the strategy for coping with the situation. In one case, having the coping strategies for a stuck-closed residual heat removal (RHR) pump breaker thought out ahead of time might have provided additional time for consideration before an unplanned plant shutdown was deemed necessary. In this case, knowing how much excess initial load the emergency diesel generator (EDG) could actually handle safely (because one of the subsequent automatically sequenced loads, the RHR pump, could not be disconnected from the affected vital bus), might have obviated the need to declare the emergency diesel generator inoperable, at least initially. Knowing how long it was actually safe to run the affected pump on minimum recirculation flow if, for instance, local temperatures or other parameters could be monitored, could have enabled operators to easily and promptly determine how much time was available to shift loads, lock out alternate sources, and de-energize the affected bus, so that some inappropriate and ineffective measures to open the breaker with the bus energized under time pressure (which resulted in damage to the breaker and violation of personnel electrical safety precautions) might have been avoided.

Procedures or guidance covering isolation, quarantining, and troubleshooting of failed circuit breakers by local visual examination, documentation (logging), and evaluation of the state of indications or the transitions observed in indications, or carefully documenting as-found conditions could be useful. Few licensees have developed symptom-based breaker troubleshooting plans to aid in determining the root causes of failure. Although such procedures are not explicitly required by NRC regulations, they could facilitate failure analysis and corrective actions, while minimizing the time that the electrical distribution system may have to remain in an abnormal lineup. For example, such plans might include predetermined strategies to determine the actual position of the contacts, the state of the closing spring, the state of the tripping or closing (or closing spring release) latches; to determine whether an opening or closing operation was electrically initiated, whether the breaker's failure to open, close, or remain closed (i.e., if it went "trip free") on demand was mechanical, or whether there might have been an electrical failure such that the closing or opening sequence was never initiated. In the past, instead of performing logical, coordinated failure analysis, some licensees performed routine preventive maintenance on a failed breaker and, if successful, placed the breaker back in service, only to have it, or another breaker in a similar condition, fail for the same, still undetected reason at a later time.

A knowledgeable and experienced breaker technician may be able to identify factors contributing to a failure from just a visual examination of the breaker in its cubicle or cell, but may not always be readily available. However, most on-duty technicians should be able to make basic determinations aided by a well-thought-out troubleshooting guide. Once the breaker is disturbed or removed from the cell, valuable information may be lost. Also, being aware of the latest industry operating experience or vendor information can be very useful in troubleshooting efforts. Certain contributing factors can sometimes be easily verified or discounted if the technician is alerted to the various problems identified by previous failures in the industry or at a specific plant.

Some licensees have developed (or contracted for) special diagnostic techniques, such as video boroscopy; high-speed videography; and time, motion and current data recording. These techniques have proven invaluable in analyses of certain unusual breaker failures when problems were intermittent and routine inspections and tests were inconclusive or ineffective in revealing the root causes. Such special techniques would not be expected to be employed routinely, but in several cases they have been the only methods that were successful in identifying the cause of the failure.

IV. Licensee/Vendor Interface

Licensees committed to implement vendor interface programs to address Item 2.2 of Generic Letter 83-28, “Required Actions Based on Generic Implications of Salem ATWS Events,” issued July 8, 1983, and later, GL 90-03, “Relaxation of Staff Position in Generic Letter 83-28,” Item 2.2, Part 2, “Vendor Interface for Safety-Related Components,” issued March 20, 1990. The purpose of vendor interface programs, as stated in GL 90-03 was to ensure that licensees would receive all vendor technical manual updates or revisions in a timely manner and also all other relevant technical information in order to have the latest applicable information with which to operate and maintain the key safety-related equipment. Inspection results indicate that several aspects of licensee/vendor interface programs could be improved.

Circuit breaker and switchgear vendor manuals should be maintained current by periodically recontacting the vendor (by telephone) to ensure that the licensee has the latest vendor information, including updates to manuals, or other pertinent technical information bulletins, letters, and so on. In the past, some licensee recontact efforts have not been successful because of reorganizations, or name and location changes of several switchgear manufacturers, or by vendors who were unresponsive to periodic recontact attempts and requests for information by licensees. In the past year, however, the major circuit breaker vendors have begun participating in the EPRI/NMAC circuit breaker users groups and the licensee/vendor relationship appears to be improving.

Several licensee circuit breaker vendor interface program weaknesses were identified during NRC inspections, including (1) uncoordinated or conflicting procedures; (2) inaccurate or incomplete lists of key safety-related components; (3) inaccurate, incomplete, or out-of-date lists of vendor names and/or locations and cognizant personnel or the most appropriate contacts; (4) insufficiently detailed or specific periodic recontact form letters requesting information, often not sent to the most appropriate vendor department, location, or personnel; (5) insufficient followup on requests for information; (6) insufficient involvement by technically knowledgeable personnel; (7) organizational weaknesses, such as lack of priority, lack of centralized responsibility, and having separate distribution paths; or (8) poor administration.

Some licensee-identified areas of vendor interface program improvements include (1) periodic review of plant equipment to ensure that lists of key safety-related equipment are current; (2) establishing organizational and procedural interfaces and links to ensure that vendor interface personnel are kept informed of equipment changes or modifications; (3) establishing personal contact with the cognizant or most appropriate vendor personnel with the ability and willingness to provide the licensee with the needed information in a timely manner;

(4) substantial involvement in the process by personnel technically knowledgeable of the equipment and well acquainted with vendors' technical documentation and staff contacts; and (5) periodic comprehensive reconciliation with the vendor of lists of equipment and related technical publications or documentation, preferably by telephone and followup correspondence.

V. Control Voltage Calculations

As part of their implementation of NRC regulations, including General Design Criterion (GDC) 17, "Electric Power Systems," and GDC-18, "Inspection and Testing of Electric Power Systems," of 10 CFR Part 50, Appendix A; 10 CFR 50.63, "Loss of all alternating current power," and Criterion III, "Design Control," of 10 CFR Part 50, Appendix B, many licensees have performed calculations to determine the worst-case design-basis control voltage (nominally 125 Vdc) available at the trip solenoids, closing solenoids, or closing spring release solenoids on safety-related circuit breakers as part of the design basis of the vital electrical power distribution systems. These calculations have sometimes been performed in conjunction with sizing or capacity calculations for vital station batteries, and in conjunction with the development of station blackout coping analysis.

In some cases, although formal rigorous calculations for each circuit were not performed based on actual installed cabling, design engineers established the minimum allowable breaker control voltage for the plant as the vendor-specified minimum operating control voltage for the trip and closing solenoids. To translate this design basis requirement into design constraints for construction, they first assumed minimum source voltage (e.g., minimum vital station battery voltage without chargers, typically around 105 Vdc), then calculated the allowable maximum lengths and allowable minimum sizes for control cabling. During construction, when it became difficult to meet these design requirements in certain cable installations, some licensees used interposing (boosting) relays or used parallel current paths to reduce line resistance and hence minimize voltage drop to meet the design basis requirement that no less than the vendor-specified minimum solenoid voltage would be available to trip and close safety-related breakers.

However, the NRC inspections revealed that a few licensees had neither performed the calculations based on as-built systems, nor enforced alternative design constraints during construction. Several discrepancies were identified in licensee calculations, including: (1) not starting with the minimum battery voltage; (2) using an incorrect minimum battery voltage that did not take into account loading, state of discharge, and/or aging factors; (3) using incorrect current paths, cable lengths, conductor sizes, and/or ohms/foot values to determine overall cable resistance; (4) calculation of cable conductor resistance using ambient temperature values, but neglecting temperature rise due to heat from surrounding cables in a raceway or without having data to justify the non-conservative lower temperature assumption; and (5) using incorrect loading values in the final determinations of voltage drops.

VI. Operating Experience Review

Operating experience review programs should review applicable documents from all pertinent sources. These documents include NRC information notices (INs); INPO SEE-IN documents or Nuclear Network reports; and vendor information, such as service information letters (SILs) from General Electric (GE) Nuclear Energy, service advice letters (SALs) from GE product departments such as the former Specialty Breaker Plant (for Magne-Blast equipment) or GE Electrical Distribution and Control (for low-voltage switchgear equipment); and technical bulletins or nuclear service advisory letters (NSALs) from Westinghouse Nuclear Service Division or its predecessors.

This operating experience sometimes has not been reflected in licensee maintenance procedures for various administrative reasons, including that the information was not distributed to the appropriate licensee personnel or was not received by the plant at all.

However, in most cases, the greater problem involved incorrect determinations of applicability. The TI inspections revealed instances of industry operating experience information erroneously determined to be not applicable because of narrowly focused and/or superficial reviews and insufficient involvement by technically knowledgeable personnel. Problems generically applicable to several types of breakers were often not recognized because the plant's breakers did not have the same exact model designation as the one used as an example in the information notice or the vendor technical bulletin. In some cases, licensees failed to recognize specific applicability because reviewers were not familiar with their plant's equipment, did not perform adequate verification of installed equipment, or did not consult with more knowledgeable staff.

TI 2515/137, Revision 1, lists 62 NRC information notices and bulletins that deal with problems with low- and medium-voltage power circuit breakers. As many as one third of these were erroneously determined not to be applicable at one or more plants. Some examples of INs that were misclassified or received inadequate licensee review serve to illustrate this point.

IN 83-50, "Failures of Class 1E Safety-Related Switchgear Circuit Breakers," issued August 1, 1983, alerted licensees to the failure of breakers to close on demand after racking to the connected position. This IN emphasized problems with breaker-cubicle electrical interlocks and interfaces, but the message was generically applicable. Superficial review and disposition of this IN often resulted in lack of procedural steps in post-maintenance test instructions or operations department instructions, as discussed previously, to ensure that electrical and mechanical breaker-cubicle interlocks and interfaces have been restored (such as by functionally testing breakers whenever they are returned to the connected position, plant conditions permitting).

IN 84-46, "Circuit Breaker Position Verification," issued June 13, 1984, dealt with position verification of racked-in breakers. The breaker used as an example of the problem was a predecessor of the widely used 4.16-kV ITE/ABB type breaker now known by the "HK" designation, but the IN described it by its old ITE designation, "ITE Model 3." Use of the older nomenclature apparently led to several licensees' not realizing that they actually had breakers of the type discussed. In addition, several more licensees failed to realize that the problem and similar remedies were applicable to other types of breakers as well.

IN 90-41, "Potential Failure of General Electric Magne-Blast Circuit Breakers and AK Circuit Breakers," issued June 12, 1990, alerted licensees to failures of GE Magne-Blast (Type AM, vertical lift) breakers due to deteriorated Teflon®-impregnated fiberglass "Tufloc®" sleeve bearings in their Type ML-13 operating mechanisms. The IN did not point out that this problem was also applicable to Type AMH, horizontal drawout, Magne-Blasts with Type ML-13A mechanisms; nor did the subsequently issued GE SAL 318 series; because the internals of the ML-13 and ML-13A mechanisms are the same. Some licensees with AMH breakers assumed the IN and SAL were not applicable to them and did not attempt to verify that assumption with the vendor or the NRC.

IN 93-85, "Problems with X-Relays in DB- and DHB-Type Circuit Breakers Manufactured by Westinghouse," issued October 20, 1993, addressed a problem with sticking of the "X" or anti-pump relay used on some Westinghouse type low-voltage breakers. The IN used the Type DB-25 as an example because that was the model of breaker that failed and prompted issuance of the IN. The same type of relay is also used on Type DB-50 breakers. Some licensees with DB-50 breakers erroneously dismissed the IN as inapplicable, because the IN only mentioned the DB-25 breaker.

IN 97-53, "Circuit Breakers Left Racked Out in Non-Seismically Qualified Positions," issued on July 18, 1997, discussed the potential for some safety related breakers to be left in the racked out position, which could affect the seismic qualification of both the breaker and the switchgear. Some licensees did not properly evaluate the notice for applicability because no specific circuit breaker type or model numbers were given.

VII. Refurbishment

Some of the plants inspected did not have a schedule for breaker refurbishment (overhaul), even though the breakers had been in service for 15 to 20 years. Not all circuit breaker manufacturers have promulgated recommended time-based or operation-based refurbishment intervals or condition-based refurbishment guidelines, particularly for relatively less severe service conditions such as in nuclear power plants. However, industry experience indicates that generally, breaker performance begins to degrade after 12 to 15 years of service. Depending on the operating environment and the maintenance history, a particular breaker may need refurbishment either earlier or later than this range of service. At one plant that had a refurbishment schedule in place, not all applicable circuit breakers (in particular, dc supply breakers) were included in the schedule.

Refurbishments are accomplished by service shops affiliated with the original equipment manufacturer (OEM), independent (so-called third-party) contractors, or by licensees themselves, sometimes with outside assistance and/or training. Factors to be considered when choosing the most appropriate and expeditious means of refurbishment include: (1) OEM-affiliated facilities may have the most experience at servicing their particular brand of breaker, may have access to original design and manufacturing information, and may have the greatest ability to obtain genuine spare parts, but the cost may be higher and the OEM may not be able to meet a licensee's schedule if multiple refurbishments are needed in a short period of time; (2) a third-party contractor may be able to service breakers faster and at a lower cost but may not have fully qualified, experienced personnel for a particular type of breaker or may not have access to all of the original design information (which is a significant disadvantage when commercial-grade spare parts must be dedicated), and some third-party refurbishers have had difficulty obtaining OEM parts in a timely manner; nevertheless, some third-party refurbishers have developed elaborate reverse engineering processes, supplemented by extensive functional testing to compensate for their lack of original design data, and may be able to perform satisfactory dedications and refurbishments; and (3) in-house refurbishment may be the most cost-effective and it gives the licensee the most control over the process, but it may not be feasible for a licensee to allocate enough maintenance staff resources to keep up with the demand; in addition, licensee personnel (particularly considering turnover) may not perform refurbishments often enough to maintain proficiency and may require retraining by experienced contractor or OEM personnel.

Some licensees that have breaker refurbishments performed by OEM-affiliated service shops or by independent contractors, whether at the vendors' facilities or at the plant site, have found it helpful to have one or more of their own knowledgeable personnel observe the work, particularly the first time it is performed. Observation by licensee personnel can help ensure that the work is performed in accordance with the licensee's specifications.

Another area where the refurbishment process can be improved is the quality of the procurement documentation. Some purchase orders (POs) from licensees to the refurbisher simply stated that the breakers were to be refurbished, instead of prescribing detailed specifications for the work to be performed. Best results were obtained when technical and quality requirements were discussed in detail by the licensee and the refurbisher ahead of time, and then specified in the procurement documents or by reference to vendor proposals, licensee-approved vendor overhaul procedures, and so on. Effective POs also specified any agreed-upon modifications and upgrades, contents of condition and overhaul reports, disposition of old parts, and the licensee's quality release and/or receipt inspection acceptance criteria.

VIII. Maintenance Rule

The TI inspection results indicated that the scoping of breakers met the requirements of the maintenance rule. At most plants, in-scope breakers were classified in two categories: (1) incoming or feeder breakers, source output breakers, bus tie breakers, and supply breakers to transformers for lower voltage distribution buses were classified as part of one of the electrical power distribution systems, for example, the 4.16-kV vital system or the 480-volt shutdown boards, and (2) breakers that supply power to individual load equipment or motor control centers associated with a particular functional system (e.g., the residual heat removal system), the service water system, or the emergency diesel generator support system, were counted as part of that system. In some cases, a source output breaker might be counted as part of the source system (e.g., the diesel generator) as well as part of the connected distribution system.

In most instances, functional failures and maintenance-preventable functional failures were appropriately identified, and classified, and the affected system was shifted to a monitoring status under 10 CFR 50.65(a)(1) when warranted. However, there were some instances where multiple failures of similar types of breakers for similar reasons occurred within one year, but because the breakers were in different systems, and because one failure in each of those systems in a one year period did not exceed the licensee's established system reliability and availability criteria for demonstrating the effectiveness of preventive maintenance under 10 CFR 50.65(a)(2), the failures did not result in the placement of the affected systems in a 10 CFR 50.65(a)(1) status. Not shifting to 10 CFR 50.65(a)(1) status in these instances may have been appropriate for the system because the breaker failure would not typically be related to any attribute of the plant system, with the possible exception that some systems, by the nature of their operational modes, cause their associated breakers to be cycled more than others. However, the multiple, and sometimes common-cause, breaker failures did not result in the increased scrutiny and higher priority attention afforded by 10 CFR 50.65(a)(1) status.

To address this type of situation, some licensees established circuit breakers of similar types as separate classes of components across system boundaries in addition to their conventional classifications. This practice allowed the reliability and availability of similar types of breakers to be tracked at the "component type" level, independent of their load or distribution systems so that in the event of multiple and/or common-cause functional failures (some of which might be "maintenance preventable"), the affected class of breakers could be evaluated for monitoring under 10 CFR 50.65(a)(1), if warranted. Grouping circuit breakers as a separate class of components could aid in performing root cause evaluations (particularly if deficient maintenance was implicated) and also aid in formulating effective and comprehensive corrective action because other failures of breakers of the same type might have previously been attributed to a similar problem.

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Appendix B: Key Points

Key O&M Cost Point
Emphasizes information that will result in overall reduced costs and/or increase in revenue through additional or restored energy production.

B.1 Key O&M Cost Points

Page Number	Key Point
2-5	The effectiveness of the circuit breaker program should be reflected in the reliability of the electrical system components in general, and circuit breakers in particular.
C-5	Given the broad component health and performance data available to the Circuit Breaker Specialist, this individual should provide recommendations regarding possible design modifications and enhancements to improve equipment reliability or extend component life.
C-6	The Circuit Breaker Specialist should be a key contributor to establishing critical spares and completing bills of materials for his or her scope of components. The Circuit Breaker Specialist should also play a role in recommending qualified vendors for refurbishing existing components and potential suppliers of new replacement components.
C-6	To support the plant's ongoing training of maintenance and operations personnel, the Circuit Breaker Specialist should be sought as the subject matter expert regarding the component design and functionality, and as a primary source for recommending the type and scope of component-related training relevant to operations and maintenance personnel.
C-7	The Circuit Breaker Specialist should be the key contributor to defining the refurbishment work scope, preparing the specification and work instructions for the vendor, recommending testing/verification activities to ensure that the refurbishment was performed correctly, and establishing the appropriate performance and testing acceptance criteria that the vendor must achieve.
C-7	The Circuit Breaker Specialist should recommend potential equipment suppliers to the design and procurement engineering organizations, as appropriate, as soon as the decision has been made to replace an existing component no longer performing in accordance with design requirements.

Key Technical Point
Targets information that will lead to improved equipment reliability.

B.2 Key Technical Points

Page Number	Key Point
C-3	Interface with the preventive/corrective maintenance organization is an ongoing relationship that directly affects equipment reliability through consistent and effective maintenance activities.
C-5	The interface between the Circuit Breaker Specialist and the system engineer can be made more effective given the understanding that the system engineer has a more vertical view of the plant (that is, a view of one particular operating system), whereas the Circuit Breaker Specialist has a more horizontal view (that is, a view of one group of components, installed in many different operating systems).
C-8	Once a component manufacturer has been selected and has furnished the equipment, the Circuit Breaker Specialist should ensure that all necessary technical information accompanying the hardware is provided, that the information is accurate and current, and that the information is incorporated into appropriate plant procedures.

Key Human Performance Point
Denotes information that requires personnel action or consideration in order to prevent injury or damage or ease completion of the task.

B.3 Key Human Performance Points

Page Number	Key Point
2-1	The development of skills required to be proficient at the various aspects related to circuit breakers is a lifelong endeavor.
2-4	At most utilities, circuit breaker expertise can reside among component specialists (often referred to as component engineers), system engineers (sometimes referred to as system managers), and design engineers. Any of these individuals can be an excellent candidate for developing circuit breaker technical expertise and assuming the role of subject matter expert when circuit breaker issues arise.
2-5	Mentoring can greatly accelerate the development of a Circuit Breaker Specialist.
C-4	The Circuit Breaker Specialist should provide condition monitoring guidance to the predictive maintenance organization as a means of identifying and assessing component health.
C-4	The plant operations organization should have a close working relationship with the Circuit Breaker Specialist because together they form an important channel for sharing equipment performance data and condition monitoring results.

Key Supervisory Observation Point
Identifies tasks or series of tasks that can or should be observed by maintenance first line supervisors to improve the performance of the maintenance staff and improve the reliability of the component.

B.4 Key Supervisory Observation Points

Page Number	Key Point
2-5	Experienced Circuit Breaker Specialists or supervisors acting in the mentoring role should ensure that performance and learning are measured during opportunities for direct observation of component maintenance activities.
C-7	Once maintenance has been approved, either through standing procedures or for execution during an outage, the Circuit Breaker Specialist should work closely with the maintenance planning organization to assist in preparing the necessary work packages and maintenance work instructions.

Appendix C: Organizational Interfaces and Outputs

Figure C-1 illustrates in general terms the organizational interfaces for the Circuit Breaker Specialist at a typical nuclear power plant site. This figure, along with other guidance in this appendix, is based on material contained in EPRI Report 1011896, *Guidelines for Effective Component Engineering*.

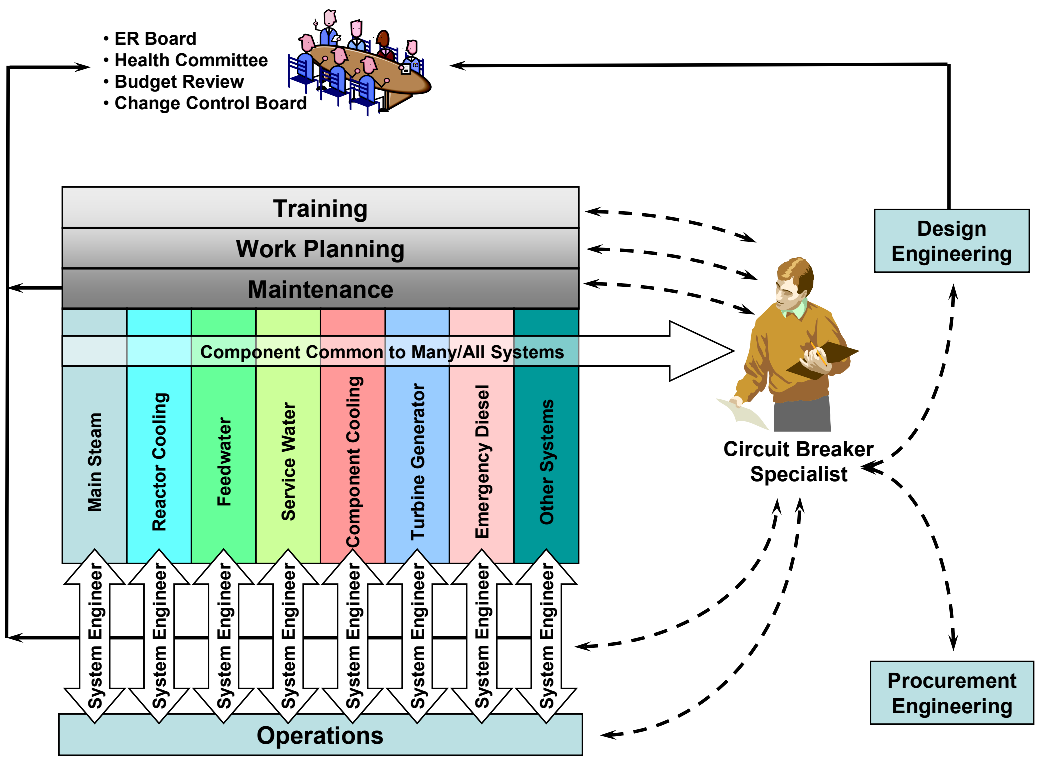

Figure C-1
Overview of organizational interfaces for the site-level Circuit Breaker Specialist

The figure illustrates the following key points regarding the typical interfaces for the Circuit Breaker Specialist:

- Component specialists such as the Circuit Breaker Specialist tend to interface mostly with maintenance, whereas system engineers tend to interface more with operations.
- A component specialist is responsible for a given component that may be installed in many systems (that is, the component transcends a single system); thus, interfaces tend to be more horizontal.
- At the site level, a component specialist indirectly contributes to long-range planning, most likely through the system engineering organization to the equipment reliability review board, the health committee, the budget review process, the change control board, and so on.

Although not shown in the figure, three other key points about the component engineering function are as follows:

- In larger utilities with multiple sites, the component specialists at the sites are often relieved to some degree of long-range planning issues. The component specialists at the corporate level tend to focus more on long-range issues, whereas the site component specialists are allowed to focus more on day-to-day component performance issues.
- Interfaces with programs typically depend on where a program resides within the utility/fleet/site/unit. In some cases the program manager may in fact be the component specialist.
- To optimize the effectiveness of how the component engineer interfaces with other organizations, the licensee should consider using various organizational performance measures (that is, emergent vs. long-term issues, amount of time spent among sites, training time vs. technical support time, outage support vs. long-range planning, and so on).

C.1 Operations and Maintenance Interfaces

Figure C-2 illustrates key interfaces between the Circuit Breaker Specialist and personnel from the operations and maintenance organizations. Because these two organizations have frequent contact with circuit breakers, the Circuit Breaker Specialist should seek feedback regarding component performance problems on a regular basis. The figure shows the need for two-way information exchanges between each of these groups and the Circuit Breaker Specialist. In some plants, the interfaces with these personnel is viewed as being more important than the interfaces the Circuit Breaker Specialist has with engineering organizations. Therefore, in these cases the Circuit Breaker Specialist is often assigned to the maintenance organization rather than to engineering.

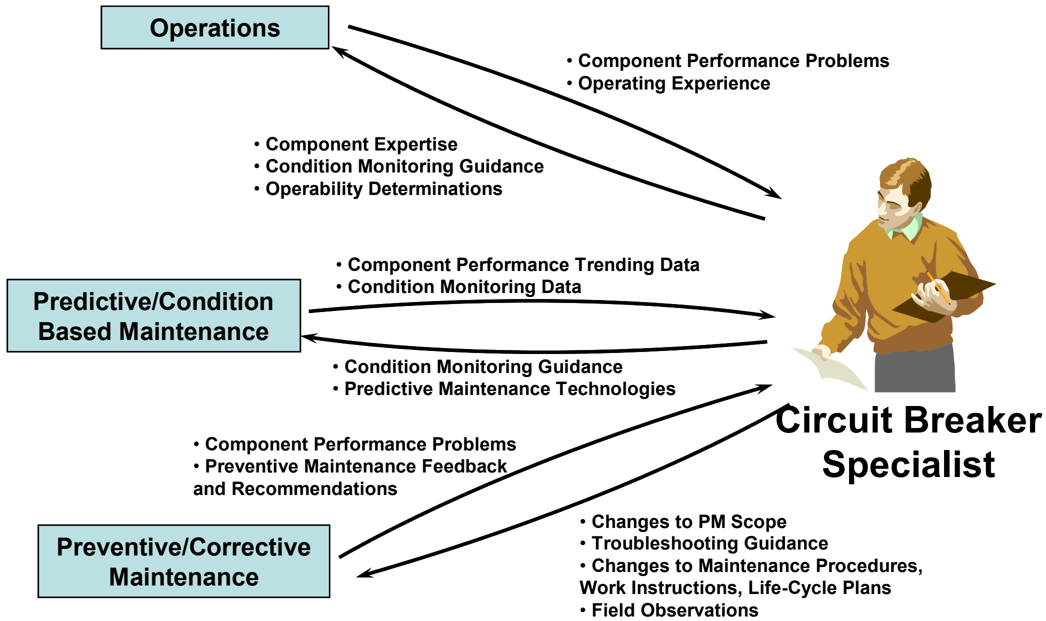

Figure C-2
Operations and maintenance interfaces for the Circuit Breaker Specialist

Licensees should ensure that procedures clearly identify these roles and responsibilities to ensure the most effective use of component engineering personnel.

Key Technical Point
Interface with the preventive/corrective maintenance organization is an ongoing relationship that directly affects equipment reliability through consistent and effective maintenance activities.

C.1.1 Preventive/Corrective Maintenance Organizations

The Circuit Breaker Specialist should be seen as a valuable source of information to make preventive and corrective maintenance instructions more effective, timely, and current based on knowledge of the component design, functionality, and failure mechanisms. The Circuit Breaker Specialist should also be the lead interface when a component performance problem has been identified and troubleshooting/corrective maintenance is needed.

The Circuit Breaker Specialist can offer technical expertise to maintenance personnel with regard to the troubleshooting and repair of the component, and this should lead to more effective resolution (elimination of rework) for component problems. Operating experience from the field should be factored by the component engineer into revisions of maintenance procedures, work instructions, and life-cycle plans. In many cases, field observations of actual conditions are important to making feedback processes most effective.

The Circuit Breaker Specialist should be receptive to learning about component performance problems from the preventive maintenance organization as input for changing maintenance activities and their frequencies. The Circuit Breaker Specialist should also seek feedback regarding the overall effectiveness of the maintenance performed and its impact on the reliability of the equipment.

Key Human Performance Point
The Circuit Breaker Specialist should provide condition monitoring guidance to the predictive maintenance organization as a means of identifying and assessing component health.

Key Human Performance Point
The plant operations organization should have a close working relationship with the Circuit Breaker Specialist because together they form an important channel for sharing equipment performance data and condition monitoring results.

C.1.2 Predictive Maintenance Organizations

Any changes in condition monitoring techniques, including the application of new technologies, should also be shared with the predictive maintenance group.

The Circuit Breaker Specialist should obtain condition monitoring data (short-term) and component performance trending data (long-term) from the predictive maintenance organization as input for component health reports. This data is valuable because it assesses component health based on the age of the equipment and can be a valuable tool for predicting remaining life of the component and for life cycle planning.

C.1.3 Plant Operations

The Circuit Breaker Specialist can offer technical expertise to the operators about the design and functionality of components. This should lead to more effective operation of the equipment. Operating experience from the field should be factored by the component engineer into revisions of maintenance procedures, work instructions, and life-cycle plans.

C.2 Engineering Interfaces

Figure C-3 illustrates a number of key interfaces with engineering organizations at a typical site.

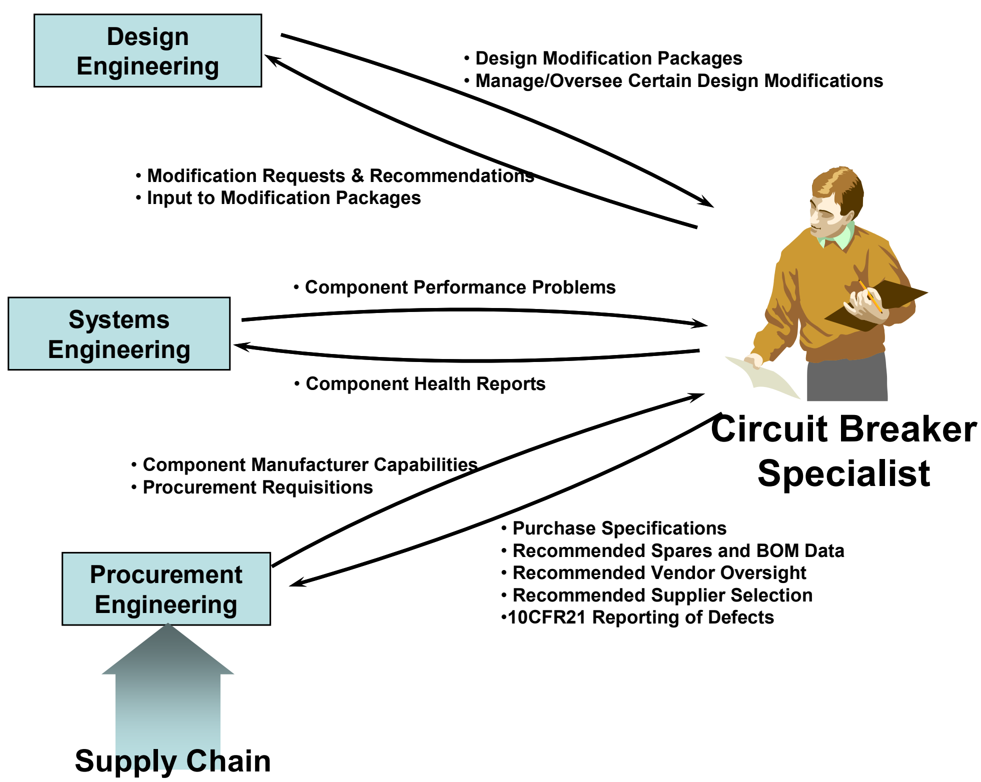

Figure C-3
Engineering interfaces for the Circuit Breaker Specialist

Key Technical Point
The interface between the Circuit Breaker Specialist and the system engineer can be made more effective given the understanding that the system engineer has a more vertical view of the plant (that is, a view of one particular operating system), whereas the Circuit Breaker Specialist has a more horizontal view (that is, a view of one group of components, installed in many different operating systems).

Key O&M Cost Point
Given the broad component health and performance data available to the Circuit Breaker Specialist, this individual should provide recommendations regarding possible design modifications and enhancements to improve equipment reliability or extend component life.

C.2.1 Systems Engineering

The Circuit Breaker Specialist should seek feedback regarding component performance from all system engineers responsible for systems containing a particular component. In the ideal scenario, the component performance feedback obtained from various system engineers should be consistent with the feedback received from the operations and/or maintenance organizations.

Component specialists, after compiling component health and performance data across various plant systems, should prepare the necessary component health reports and share the trends and issues with the appropriate system engineer(s).

C.2.2 Design Engineering

Once a design modification has been approved, the Circuit Breaker Specialist should work closely with the design engineer, with input from component manufacturer(s), regarding the scope and application of the proposed modification. In some cases, the Circuit Breaker Specialist may be required to seek potential component manufacturers if the decision has been made to replace the existing component with a suitable alternative. The Circuit Breaker Specialist may be asked to recommend a particular type or model of component in these cases as well. He or she should also provide input to the modification package to ensure that the replacement component is suitable for the intended application(s) and to determine whether the replacement component will adversely affect any design margins.

Once a design modification package has been developed, the component engineer may be required to manage or oversee the implementation of the modification, or as a minimum, review the design modification package to ensure technical accuracy.

C.2.3 Procurement Engineering and the Supply Chain

The Circuit Breaker Specialist's interface with the procurement engineering organization is similar in scope to the interface with design engineering except that in most cases the issues will apply to replacement parts/assemblies rather than to the entire component.

The Circuit Breaker Specialist should work closely with the procurement engineer in developing the necessary procurement documents (that is, purchase requisitions, specifications, and so on) as well as quality controls (that is, manufacturing surveillance plans, receiving inspection plans, witness/hold point test and inspection plans, and acceptance criteria).

Key O&M Cost Point
The Circuit Breaker Specialist should be a key contributor to establishing critical spares and completing bills of materials for his or her scope of components. The Circuit Breaker Specialist should also play a role in recommending qualified vendors for refurbishing existing components and potential suppliers of new replacement components.

The Circuit Breaker Specialist should also seek feedback from the procurement engineering organization, and possibly through the vendor quality assurance group, regarding the current capabilities of a given refurbishment vendor or equipment manufacturer. This interaction should ensure that only qualified suppliers are considered for bidding and subsequently asked to furnish replacement items or refurbishment services.

C.3 Other Plant Interfaces

Figure C-4 shows two other key interfaces with organizations at the plant site: training and work planning.

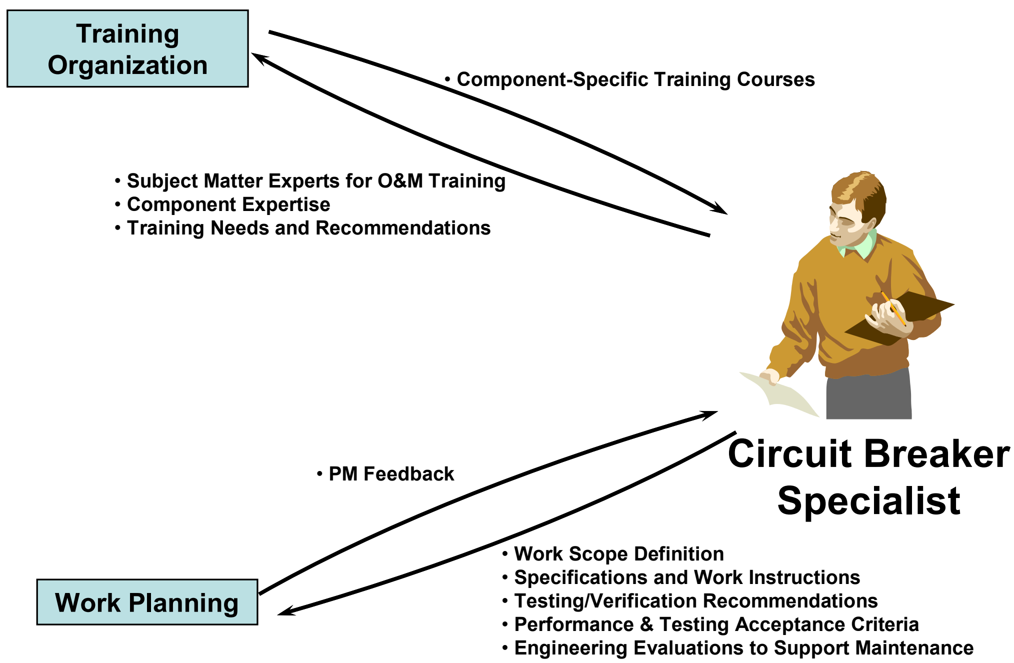

Figure C-4
Training and work planning interfaces for the Circuit Breaker Specialist

Key O&M Cost Point
To support the plant's ongoing training of maintenance and operations personnel, the Circuit Breaker Specialist should be sought as the subject matter expert regarding the component design and functionality, and as a primary source for recommending the type and scope of component-related training relevant to operations and maintenance personnel.

C.3.1 The Training Organization

Through continuous training, the Circuit Breaker Specialist has an excellent means to share plant-specific component performance trends and related maintenance activities needed to improve equipment reliability and extend component life.

At many sites, the Circuit Breaker Specialist is the individual who develops the training and conducts it. The Circuit Breaker Specialist should also consider the use of equipment manufacturers or maintenance/troubleshooting specialists to assist with training when appropriate.

Key Supervisory Observation Point
Once maintenance has been approved, either through standing procedures or for execution during an outage, the Circuit Breaker Specialist should work closely with the maintenance planning organization to assist in preparing the necessary work packages and maintenance work instructions.

C.3.2 Work Planning

The Circuit Breaker Specialist is often the most appropriate individual to establish, define, or revise work scope, and to recommend performance testing and acceptance criteria, because of this individual's level of technical expertise with the component group.

The Circuit Breaker Specialist should also seek feedback regarding the effectiveness of the maintenance through the work planning organization, in cases where it is more appropriate than getting the feedback directly from the maintenance organization.

C.4 Interfaces with Organizations External to the Utility

Figure C-5 illustrates key interfaces the Circuit Breaker Specialist should develop with organizations external to the utility. These include industry users groups, refurbishment service suppliers, and component manufacturers.

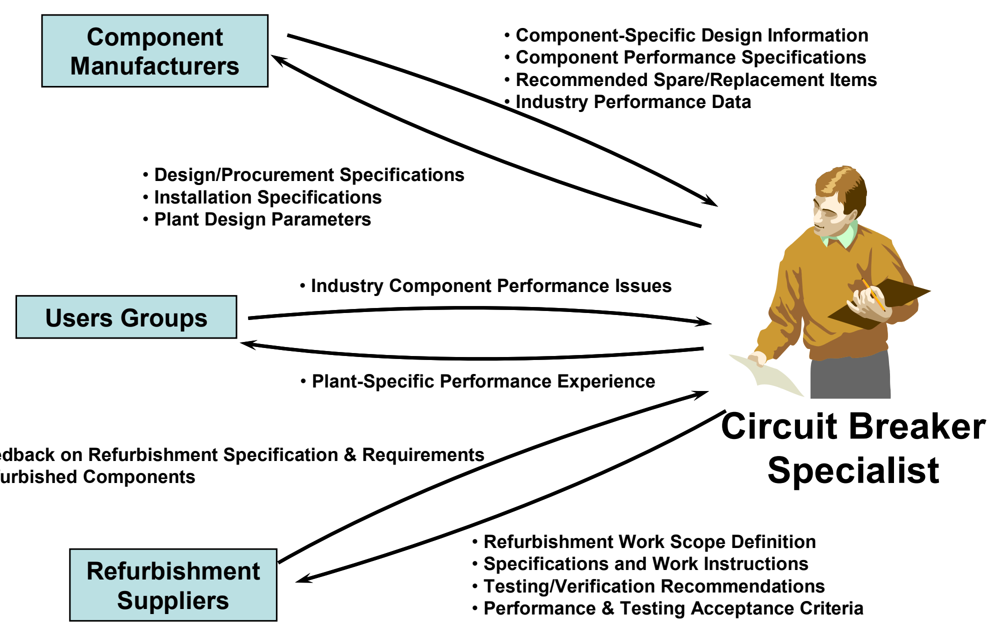

Figure C-5
External interfaces for the Circuit Breaker Specialist

Key O&M Cost Point
The Circuit Breaker Specialist should be the key contributor to defining the refurbishment work scope, preparing the specification and work instructions for the vendor, recommending testing/verification activities to ensure that the refurbishment was performed correctly, and establishing the appropriate performance and testing acceptance criteria that the vendor must achieve.

C.4.1 Refurbishment Service Suppliers

As components age, it often becomes necessary to refurbish them, either to extend their life or as an alternative to wholesale replacement with another component.

The Circuit Breaker Specialist should develop a means to capture refurbishment information so it can be applied generically, as appropriate, for the broadest application through the component line as possible. The Circuit Breaker Specialist should seek feedback from the refurbishment vendor regarding the accuracy, effectiveness, and workability of the specification and work instructions so improvements can be made to future refurbishment activities.

C.4.2 Component Manufacturers

Key O&M Cost Point
The Circuit Breaker Specialist should recommend potential equipment suppliers to the design and procurement engineering organizations, as appropriate, as soon as the decision has been made to replace an existing component no longer performing in accordance with design requirements.

As noted in the preceding section, the Circuit Breaker Specialist should be the primary point of contact between the plant and the manufacturer of a replacement component.

The Circuit Breaker Specialist, in concert with the design engineering organization, should prepare the bid specification and the request for proposal and should evaluate the bids for technical merit and suitability. Through these activities, potential equipment manufacturers should be provided with plant-specific design parameters. In cases where the component manufacturer is also required to install the equipment, the Circuit Breaker Specialist should work closely with design engineering and maintenance planning to develop the necessary demolition/installation specifications. This may include recommendations regarding spare/replacement items and replacement component/part design information. Over the long term, the component manufacturer should be sought for industry-wide component performance data, preventive maintenance enhancements, and obsolescence information.

C.4.3 Industry Users Groups

Key Technical Point
Once a component manufacturer has been selected and has furnished the equipment, the Circuit Breaker Specialist should ensure that all necessary technical information accompanying the hardware is provided, that the information is accurate and current, and that the information is incorporated into appropriate plant procedures.

Industry users groups, and the Circuit Breaker Users Group (CBUG) in particular, can be additional valuable sources of operating experience that the Circuit Breaker Specialist should consider. Typically, these users groups are a means to keep abreast of industry developments that may include any of the following:

- New technologies associated with the component
- Common failure mechanisms and their causes
- New or enhanced preventive maintenance techniques
- Suitable replacement items (subcomponents, parts, and components) for replacements due to obsolescence
- New regulatory requirements or industry operating guidance
- Modification experiences and lessons learned
- Early warning of component degradation

C.5 Program Interfaces

Because of regulations, industry operating guidance, or economy of scale, there are some component groups—such as circuit breakers—that are typically managed through a separate technical program at either the unit, the site, or the corporate level.

A program is defined as an organized set of activities, directed toward a common purpose or goal, that is carried out in order for an organization to fulfill its responsibilities. Generally, a program is used to accomplish routine tasks that are highly complex or whose success is reliant upon a high level of coordination between numerous organizations. The key attributes of a program include a mission, an owner (single point of contact), a defined sequence of activities and tasks, clearly identified responsibilities for those performing the tasks (stakeholders), and indicators to monitor program performance, health, and effectiveness. Key program attributes are generally documented in a plan or procedure.

An engineering program is a program created to enable an engineering organization to carry out its assigned engineering responsibilities, which are generally highly technical or complex in nature. A program health report is a document that is used to communicate the status of a given program at a nuclear utility, site, or power plant. The component engineer may in fact be designated as the manager for one or more of these programs, depending on the organizational structure at the plant site. If this is not the case, however, the Circuit Breaker Specialist should ensure that there are sufficient means for communicating component information to the program manager, and that the program supports continued reliable equipment performance.

C.6 The Circuit Breaker Specialist's Outputs and Deliverables

As shown in Figures C-2 through C-5, there are number of outputs that the Circuit Breaker Specialist may be required to deliver to a wide range of recipients. Table C-1 summarizes these output documents and identifies the organizations most likely to contribute information and to receive the final product.

Table C-1
Summary of the Circuit Breaker Specialist's outputs and deliverables

Output/ Deliverable	Organizations Contributing Information to Generate the Output Document	Organizations Typically Receiving and Using the Output Document
Condition monitoring plans and guidance	Predictive/condition-based maintenance, component manufacturer	Predictive/condition-based maintenance
Revisions to preventive maintenance procedures	Maintenance, operations, systems engineering, design engineering	Preventive maintenance
Component health reports	Maintenance, operations, systems engineering	Systems engineering, plant health board, fleet component health board

Table C-1 (continued)
Summary of the Circuit Breaker Specialist's outputs and deliverables

Output/ Deliverable	Organizations Contributing Information to Generate the Output Document	Organizations Typically Receiving and Using the Output Document
Root cause analyses	Maintenance, operations, systems engineering, design engineering, component manufacturer	Maintenance, operations, systems engineering, design engineering
Component life cycle management plan	Maintenance, operations, systems engineering, design engineering	Systems engineering, plant health board, fleet component health board, plant financial board
Component purchase, repair, and/or refurbishment specifications	Maintenance, systems engineering, design engineering, component manufacturer, procurement engineering	Refurbishment vendor, procurement engineering
Outage scope list	Maintenance, systems engineering, design engineering	Outage work scope planning board, outage planners and schedulers
On-line work schedule review	Maintenance, systems engineering, design engineering, operations	Work planning, maintenance
Troubleshooting instructions, guides, and/or plans	Maintenance, operations, systems engineering, component manufacturer	Maintenance
Maintenance work instructions and procedures	Maintenance, work planning	Maintenance, work planning
Replacement component equivalency evaluations	Design engineering, procurement engineering, component manufacturer	Procurement engineering
Training material	Maintenance, operations, systems engineering, design engineering, component manufacturer	Training
Input to operability determination and justification for continued operation	Maintenance, operations, licensing, systems engineering, design engineering, component manufacturer, industry peers	Operations

C.7 Reference

Guidelines for Effective Component Engineering. EPRI, Palo Alto, CA: 2005. 1011896.

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