SAIC-91/6687

Preventive Maintenance and Testing Guidelines for Electrical Power Systems and Equipment in Nuclear Power Plants

Prepared by
R. H. McFadden and R. Karimi/SAIC
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Science Applications International Corporation

An Employee-Owned Company

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ABSTRACT

This report contains guidelines for the preventive maintenance and testing of electrical power systems, subsystems, and equipment common to nuclear power generating plants, together with supporting information. The guidelines address preventive maintenance on essentially the entire ac and dc auxiliary electric power system found in a nuclear power plant, including both Class 1E or "Q-list" subsystems and equipment, and "balance-of-plant" (BOP) subsystems and equipment which are not classified as "safety-related." The BOP portion of the electric power system is covered because of the potential for failures therein to precipitate reactor trips, degrade the performance or reliability of safety functions, and challenge safety systems.

The guidelines have been derived from the recommendations of electrical equipment manufacturers, authoritative reference works and technical papers in the preventive maintenance field, and the established practices and successful experience of both domestic and non-US nuclear facility operators. Nuclear experience has been supplemented by information obtained from several other industries in which public and employee safety and process continuity enjoy a high management priority.

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1. INTRODUCTION.

This report contains guidelines for the preventive maintenance and testing of electrical power system equipment and subsystems of nuclear power generating plants, together with supporting information.

1.1. Background and Objectives.

Both the Nuclear Regulatory Commission and the owners of commercial nuclear power plants are focusing increasing attention on the preventive maintenance of electrical power equipment for two major reasons. First, nuclear-plant probabilistic risk assessments and plant incident experience show that electrical power system failures are responsible for a substantial fraction of overall plant accident hazards, and that parts of the systems which are not classifed as "safety-related" contribute significantly to this fraction. Second, formal studies and practical operating experience demonstrate that sound preventive maintenance (PM) can greatly reduce the incidence of electrical equipment and system failures. Therefore, in the interest of promoting good electrical preventive maintenance the Electrical Systems Branch of the NRC's Office of Nuclear Reactor Regulation has developed the electrical PM and testing guidelines in this report. These guidelines have been derived from the established practices of electrical equipment users, the recommendations of electrical equipment manufacturers, authoritative reference books, industry standards and technical papers.

1.2. What is Preventive Maintenance?

As used in this report, preventive maintenance (PM) is defined broadly as all inspection, testing, or servicing activity performed primarily in order to preserve the reliability and potentially to extend the useful life of existing electrical equipment or systems. PM is distinguished from (1) corrective maintenance (CM), which consists of inspection and testing ("trouble-shooting") and servicing performed primarily in response to actual or impending safety and/or performance degradations, (2) plant operations, and (3) plant modifications. (Of course, there are significant overlaps between PM and the latter functions. For example, participating in surveillance tests and performing routine superficial inspections during auxiliary operators' shift rounds are usually considered "operations" activities, although they really constitute preventive maintenance.)

1.3. Scope of Guidelines.

The guidelines in this report address preventive maintenance on essentially the entire ac and dc auxiliary electric power system of a nuclear power plant, including both Class 1E or "Q-list" subsystems and equipment and "balance-of-plant" (BOP) items which are not classified as "safety-related." The BOP portion of the electric power system is covered because of the potential for failures therein to precipitate reactor trips, degrade the performance or reliability of safety functions, and challenge safety systems. (All electrical equipment and systems which have such a potential are referred to as "safety-significant" in this report, whether they are Class 1E or not.)

1.4. The Role of Maintenance in Plant Safety, Reliability, Maintainability, and Availability.

Experience in all of the process industries confirms the pivotal role that effective maintenance -- both corrective and preventive, but primarily the latter -- in providing safe, productive, and profitable operation. Figure 1-1 is a block diagram illustrating how design, maintenance, and operations interact to promote maintainability, reliability, and availability; these in turn lead to safety, profitability, productivity, and public acceptance.

1.6. Synopsis of Report.

In summary, this report covers the following major topics:

- this introduction;
- overview of electrical PM technology;
- PM guidelines for major classes of electrical power equipment;
- description of the methodology used to develop the guidelines; and
- a bibliography of references on electrical power equipment PM.

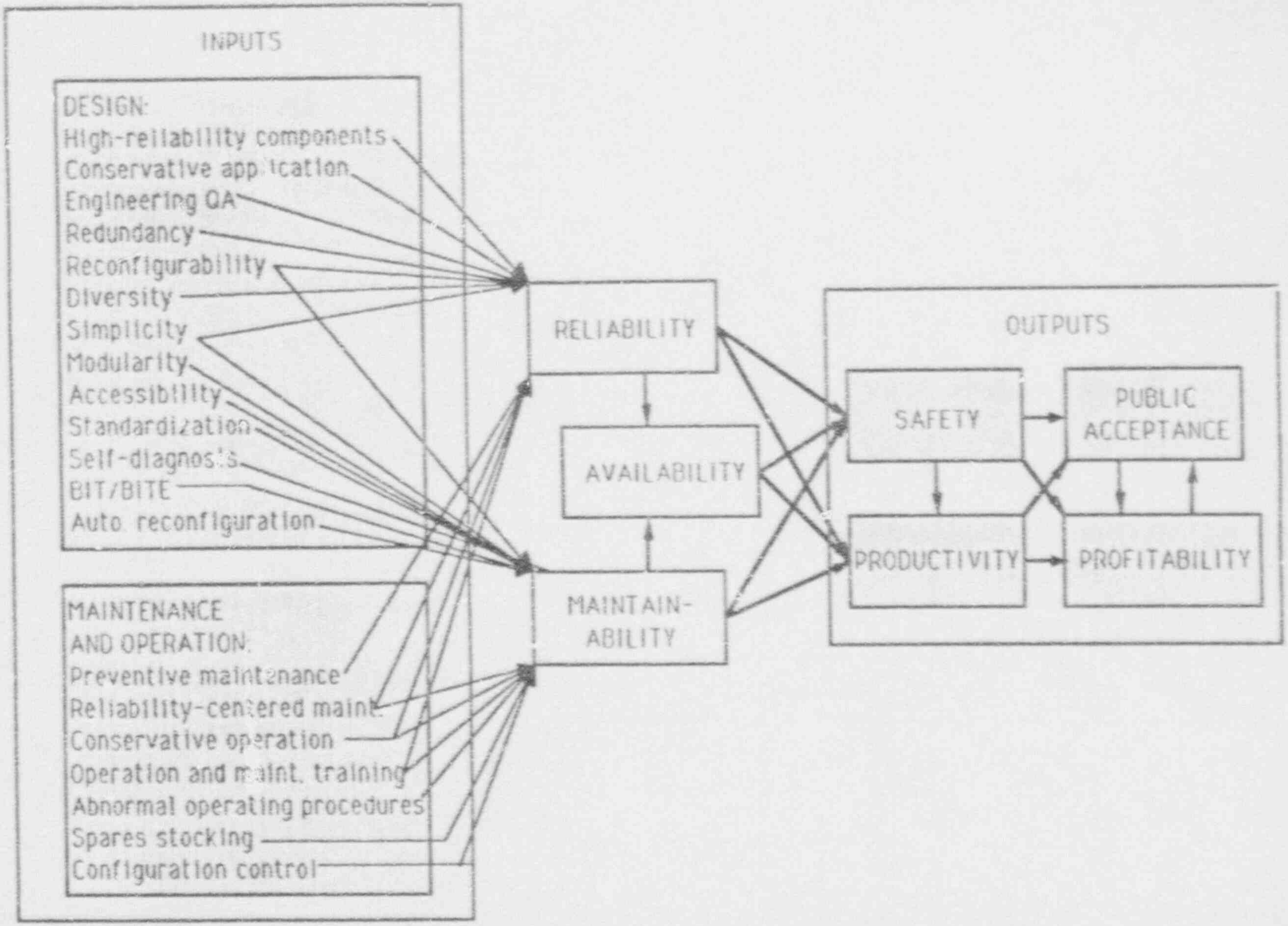

Figure 1-1. The Role of Maintenance and Operations in Plant Safety, Reliability, Availability, and Maintainability.

2. OVERVIEW OF ELECTRICAL PREVENTIVE MAINTENANCE AND TESTING.

This section of the report is a brief summary of sound electrical preventive maintenance technology for nuclear power plants. The subsections below address (1) general electrical PM principles, (2) general criteria for an effective electrical PM program, (3) the qualifications required for personnel assigned to perform electrical PM; and (4) maintenance management factors which the guidelines project team found to be common to licensees with effective electrical PM programs. (Section 3 of the report contains specific guidelines for the major classes of electrical power equipment typically found in nuclear power plants, and guidelines for integrated electrical subsystem and system testing.)

2.1. General Principles of Effective Electrical Preventive Maintenance and Testing.

Much of the essence of effective electrical equipment PM can be summarized by four rules:

- Keep it dry.
- Keep it clean.
- Keep it cool.
- Keep it tight.

More specifically, most electrical power and control equipment is susceptible to a relatively small number of mechanisms of degradation, and the purpose of most PM activities is to prevent them, retard them, or mitigate their effects. The most common degradation mechanisms, their most frequent symptoms and causes, and the general PM approaches which experience has proven effective in addressing them are summarized in Table 2-1.

Several terms appearing in the "root cause" column of Table 2-1 require clarification. "Misapplication" occurs when equipment is originally specified for use under system or environmental conditions which exceed its ratings or are otherwise outside its design envelope. Specifying a motor without space heaters for standby duty in a damp environment is an example. "Poor workmanship" refers to a failure to use appropriate practices while working on the equipment during fabrication, installation, or maintenance. Excessive tension during cable pulling is a good example. "Abuse" occurs when equipment is subjected -- whether intentionally or inadvertently -- to conditions outside its design envelope during installation, storage, operation or maintenance. Abuse is often the result of failures in associated equipment and systems (e.g. a ground fault which blows only one fuse and causes single-phasing of a motor, or failure of an HVAC system to maintain an adequately cool or clean environment for switchgear.) Operators and maintenance technicians may also abuse equipment, for example by intentionally overloading a transformer to maintain service in an emergency. As the latter example illustrates, "abuse" may be justified; nevertheless it causes degradation that should be addressed by a good PM program.

TABLE 2-1.
TYPICAL DEGRADATION MODES, SYMPTOMS, CAUSES, AND MITIGATING PREVENTIVE MAINTENANCE FOR ELECTRICAL POWER EQUIPMENT

Degradation mode	Typical symptoms	Typical causes: Immediate	Typical causes: Root	Mitigating PM
Insulation failure	Short circuits, degrading test trends	1. Moisture	1. Wet environment due to misapplication, abuse, failed space heaters	1. Inspection, testing, PM on environmental control
		2. Overheating	2. Hot environment, undervoltage, dirt, clogged filters or vents, failed cooling system, unbalanced voltages due to misapplication, abuse	2. Inspection, cleaning, voltage monitoring, PM on associated equipment or environmental control
		3. Dirt	3. Environmental misapplication, abuse	3. Inspection, cleaning, testing, PM on environmental control
		4. Chemical attack	4. Environmental misapplication, abuse	4. Inspection, cleaning, testing, PM on environmental control
		5. Mechanical abrasion	5. Vibration, shock loading due to misapplication, abuse	5. Inspection, testing, PM on associated equipment
		6. Radiation	6. Misapplication, abuse	6. Inspection, testing
Contact degradation	Intermittent or open contact	1. Wear	1. Normal operation, misapplication, abuse	1. Inspection, cleaning, testing, periodic replacement

TABLE 2-1 (CONTINUED).
TYPICAL DEGRADATION MODES, SYMPTOMS, CAUSES, AND
MITIGATING PREVENTIVE MAINTENANCE FOR ELECTRICAL POWER EQUIPMENT

Degradation mode	Typical symptoms	Typical causes: Immediate	Typical causes: Root	Mitigating PM
Contact degradation (continued)	Intermittent or open contact (continued)	2. Corrosion	2. Environmental misapplication, abuse	2. Inspection, cleaning, testing, periodic replacement, PM on environmental control
	Failure to open	1. Welded contact	1. Overloading due to misapplication, abuse	1. Inspection, PM on associated equipment
		2. Actuation failure	2. See 'conductor failure' and 'structural failure' below	2. Inspection, testing, PM on associated equipment
Conductor failure	Intermittent or open circuit, local overheating	Loose or open connection or conductor	Vibration, shock loading, thermal cycling due to normal operation, misapplication, poor workmanship, abuse	Inspection, tightening, temperature monitoring, testing
Bearing degradation	Noise, vibration, degrading vibration trend, overheating	Wear	Normal operation, lubrication failure, misapplication, abuse	Inspection, load monitoring, periodic relubrication
Structural failure	Loose or missing parts, bent or broken structural items	1. Loose or failed fasteners, fatigue, mechanical overload	1. Vibration, shock loading, misapplication, poor workmanship, abuse	1. Inspection, periodic replacement

TABLE 2-1 (CONTINUED).
TYPICAL DEGRADATION MODES, SYMPTOMS, CAUSES, AND
MITIGATING PREVENTIVE MAINTENANCE FOR ELECTRICAL POWER EQUIPMENT

Degradation mode	Typical symptoms	Typical causes: Immediate	Typical causes: Root	Mitigating PM
Structural failure (continued)	Rust or corrosion of structural items	2. Chemical attack	2. Wet and/or chemically active environment due to misapplication, abuse, poor workmanship	2. Inspection, periodic restoration of protective coatings, PM on environmental control

2.2. Alternative Preventive Maintenance Philosophies.

There are four basic philosophical approaches to electrical preventive maintenance, which are briefly summarized in the following paragraphs. Most power utilities, manufacturing firms, and other owners of production facilities utilize a combination of them. The decision as to which approach to adopt is largely system- and equipment-specific. The primary factors which enter into this decision are listed in Section 2.3.

2.2.1. "Run to Failure."

In this approach PM *per se* is not performed at all. Degraded equipment is only repaired or replaced when the effect of the degradation on process output becomes unacceptable. (For most types of electric power equipment, this coincides with catastrophic failure.) No explicit attempt is made to monitor performance or to avert failure, and the risks associated with ultimate failure are accepted. Because of the generally high reliability of electric power equipment installed in a benign environment, the "run to failure" approach often provides satisfactory power reliability and availability in non-critical applications. Small organizations which lack dedicated maintenance staffs often utilize this approach by default, and larger and more sophisticated organizations in the manufacturing sector also frequently apply it to non-critical equipment and systems.

2.2.2. Inspect and Service as Necessary.

This approach is an advance beyond "run to failure," wherein plant operating or maintenance personnel inspect electrical equipment on a more or less regular schedule (often during regular "rounds" of the plant). Under this approach, incipient failures are usually corrected before they become catastrophic, especially if the impact of a failure is considered unacceptable, and there is often some informal monitoring of performance to predict future failures. Many

industrial manufacturing plants use this approach and find it satisfactory.

2.2.3. Scheduled Preventive Maintenance.

In this approach, established electrical PM activities are performed at fixed intervals of calendar time, operating hours, or operating cycles. Both procedures and schedules are usually based on manufacturers' recommendations or industry standards. While the scheduled PM approach ensures that equipment gets periodic attention, it does not necessarily prioritize PM according to safety or productivity significance, nor does it optimize the application of limited PM resources or take advantage of lessons learned from plant and industry experience. Scheduled PM currently is the predominant approach among relatively sophisticated operators of both nuclear power and industrial process plants where safety is a serious concern.

2.2.4. Reliability-Centered Maintenance (RCM).

RCM involves specifying and scheduling PM activities in accordance with the statistical failure rate and/or life expectancy of the equipment being maintained and its criticality to safety and productivity, and continually updating PM procedures and schedules to reflect actual maintenance experience in the plant. RCM is the most cost-effective of the alternative approaches because it improves plant safety, reliability, and availability while reducing maintenance costs by concentrating limited maintenance resources on items which are the most important and/or troublesome, and reducing or eliminating unecessary maintenance on items which are of little significance and/or highly reliable. A comprehensive RCM program also incorporates structured provisions for failure root cause investigation and correction and for performance monitoring to predict failures. RCM is used extensively in the military and is gaining acceptance among both nuclear utilities and manufacturing plant operators as its advantages are increasingly recognized. Figure 2-1 is a block diagram illustrating the general RCM approach.

2.3. Key Factors in Electrical Preventive Maintenance Optimization Decisions.

The optimum PM approach for any specific plant, system, and/or piece of equipment depends on a variety of factors, including the following:

- safety impact of equipment failure;
- productivity and profitability impact of equipment failure (including costs of lost production as well as failed equipment repair or replacement);
- cost of PM;
- failure rate and/or anticipated life of equipment;
- predictability of failure (either from accumulated operating time or cycles, or from discernible clues to impending failure);

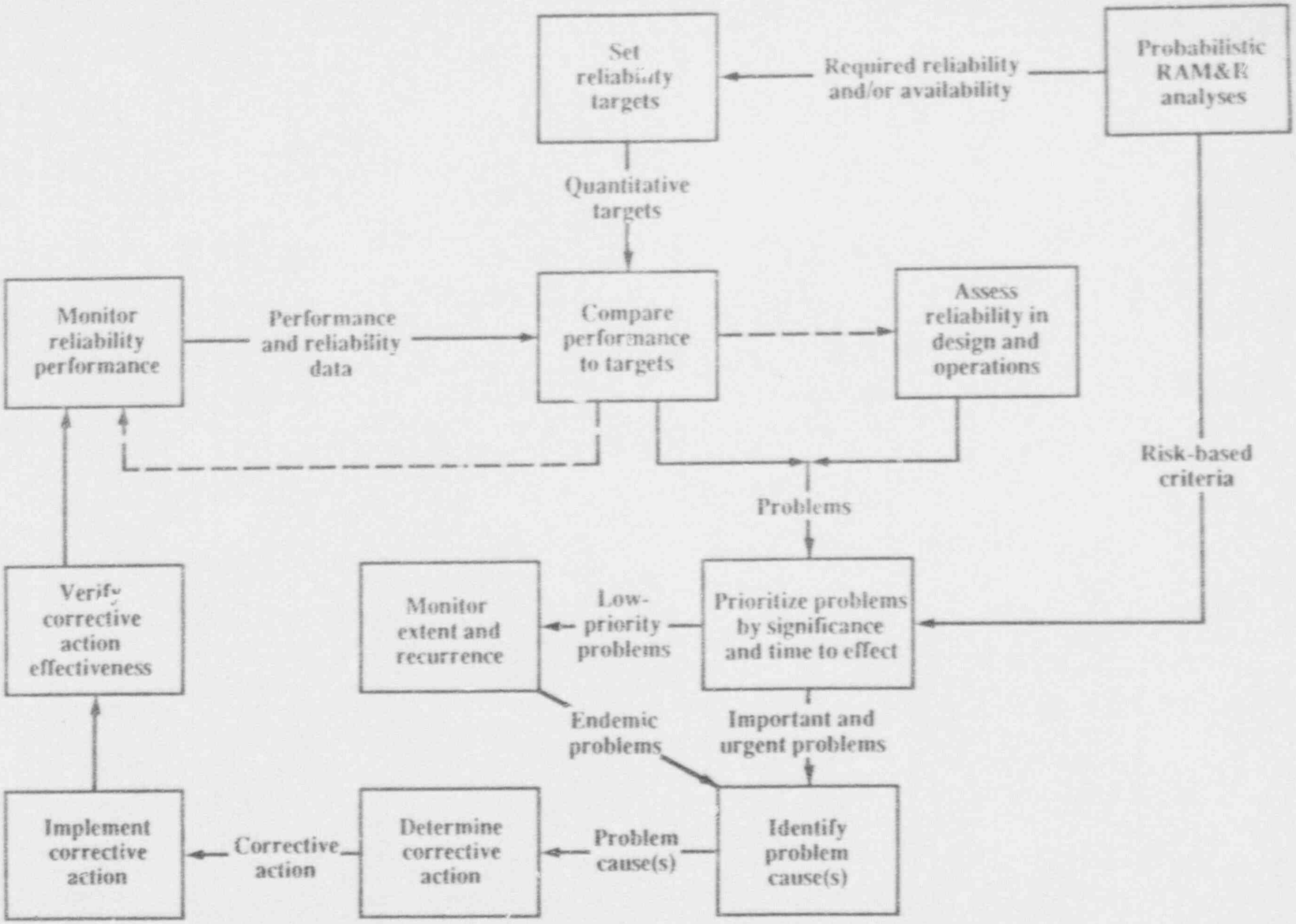

Figure 2-1. The Reliability-Centered Maintenance Process

- likelihood of inducing equipment damage or system problems during maintenance and testing;

- technical sophistication of the plant maintenance staff; and

- availability of equipment reliability information to support RCM.

2.4. General Criteria for an Effective Electrical Preventive Maintenance and Testing Program.

Effective electrical equipment and subsystem preventive maintenance and testing programs in nuclear power plants should satisfy the criteria listed below.

- First and most fundamental, a structured electrical preventive maintenance program should actually exist. That is, electrical PM should be performed...

    - under formal management control,

    - in accordance with defined practices and schedules, and

    - by clearly designated persons.

- Licensee management should assign a high priority to electrical PM. As a corollary, adequate resources -- personnel, facilities, tools, test equipment, training, engineering and administrative support -- should be devoted to PM. Adequate support from design engineering and operations are especially important.

- Electrical PM activities should be prioritized according to the criticality of the systems and equipment involved, with the highest resource intensity and scheduling priority assigned to equipment, subsystems, and systems important to safety.

- Electrical PM should be performed according to unambiguous written procedures based on specific consideration of equipment, application, and environmental characteristics.

- PM procedures and schedules should be maintained under configuration control in order to ensure engineering review of procedural changes and the incorporation of plant modifications.

- The electrical PM program should have provisions to take effective advantage of actual experience accumulated both in the plant and elsewhere (e.g. as derived from NRC information bulletins and notices, NUREG reports, professional society and industry association publications, and informal communications with other interested organizations both inside and outside the nuclear power industry.)

- The PM program should incorporate effective provisions for failure root cause analysis, correction, and recurrence control.

- Information systems should be in place to record and update the plant maintenance, testing, and operating history, and to facilitate trending of test data, in support of the previous two criteria.

- Electrical PM should be performed only by appropriately qualified personnel. (Qualifications for PM personnel are discussed further in the next section.)

- Management should continually monitor and re-evaluate the effectiveness of the PM program, and make appropriate changes in response to identified programmatic problems and advances in maintenance technology.

By clear implication, the "run to failure" and "inspect and service as necessary" philosophies described in Section 2.2 above fail to provide enough structure, direction, and monitoring to satisfy the criteria for a sound electrical PM approach. These philosphies are not acceptable for safety-significant equipment and systems in nuclear power plants. At a minimum, a scheduled PM program is clearly necessary for this equipment.

Public safety objectives do not necessarily require a full-scope reliability-centered maintenance program for nuclear plant electrical systems. However, experience with RCM programs in other process industries, and with pilot programs in the nuclear industry (see, e.g., References 81, 85, 91a, 91c, and 91d), suggests that effective RCM can yield substantial improvements in plant safety, availability and productivity, and reductions in plant trips and in operating and maintenance costs.

2.5. Qualifications of Electrical Preventive Maintenance Personnel.

The minimum acceptable qualifications for personnel assigned to perform electrical PM depend on the circumstances. It is normally acceptable for non-specialists (e.g. auxiliary operators) to perform superficial inspections and other undemanding PM tasks when guided by defined procedures and acceptance criteria. However, effective administrative controls should be in place to ensure that critical PM tasks on safety-signficant equipment and systems are performed only by -- or at least under the immediate and active supervision of -- appropriately trained and experienced maintenance technicians. Such tasks typically include internal inspection, testing, calibration, and refurbishment.

Training for critical electrical PM work on safety-significant equipment and systems should include at least the following:

- the fundamentals of electrical power technology,

- general electrical maintenance techniques,

- electrical safety methods and practices,

- the design and operation of the equipment and system to be maintained, and

- the maintenance and testing procedures applicable to the equipment and system to be maintained and tested.

For critical tasks, technicians' experience should include similar work on the same or closely comparable equipment, preferrably in an operational environment, although experience acquired in a training environment under direct supervision of experienced instructors is acceptable.

2.6. Optimization of Preventive Maintenance Intervals.

Experience in a variety of industries demonstrates that performing preventive maintenance on an absolutely fixed schedule rarely results in the optimum balance among the costs of preventive and corrective maintenance and the safety and productivity benefits of equipment reliability and availability. Given an adequate historical failure and maintenance data base, reasonably straightforward methods can be used to optimize the preventive maintenance cycle. A well-proven approach is discussed in Reference 59 cited in the Bibliography. Maintenance intervals can also be based upon the recommendations given in Reference 110.

2.7. Trending of Test Results.

Systematic trending of field test results is a key element of a high-quality electrical maintenance program. This is true because the *magnitudes* of many of the parameters measured during field tests on equipment are poor predictors of future failures, unless they are so far out of the normal range that they indicate imminent and probably irretrievable failure. Examples include insulation resistance, leakage current, capacitance, power factor, and dissipation factor; bearing temperature and vibration; and winding temperature. However, a degrading *trend* in these parameters strongly indicates impending trouble, especially if the trend is accelerating. A sound trending program can often alert the maintenance and operations staff of the plant in time to arrest the degradation and avert the failure, or at least to minimize the effect of the failure on safety and productivity.

To provide meaningful information, the trending program must be structured to screen the effects of external factors which affect the measured results but which are irrelevant to the actual condition of the equipment out of the test data. Test procedures should mandate precautions to ensure that the external conditions which can affect the test results remain the same from test to test, or to correct the results when this is impractical. (For example, insulation resistances readings taken at varying temperatures are corrected to a common base temperature.) Typical irrelevent external conditions which affect electrical test results include temperature, humidity, and load.

2.8. Systematic Failure Analysis Approach.

Failure analysis and root cause investigation should be an integral part of any electrical PM program. Figure 2-2, adopted from Reference 81, depicts a sound, experience-tested approach. The steps to be taken after a failure is observed are described in further detail below.

1. Use a failure cause analysis to determine the proximate cause of the failure. The proximate cause is expressed in terms of the piece-part-level failure cause, e.g. "relay XX failed to transfer due to corroded contacts."

2. Compare the proximate cause to past failures or conditions on the same and similar equipment to determine if the problem has a systematic root cause, e.g. a chemically active environment in the example cited above.

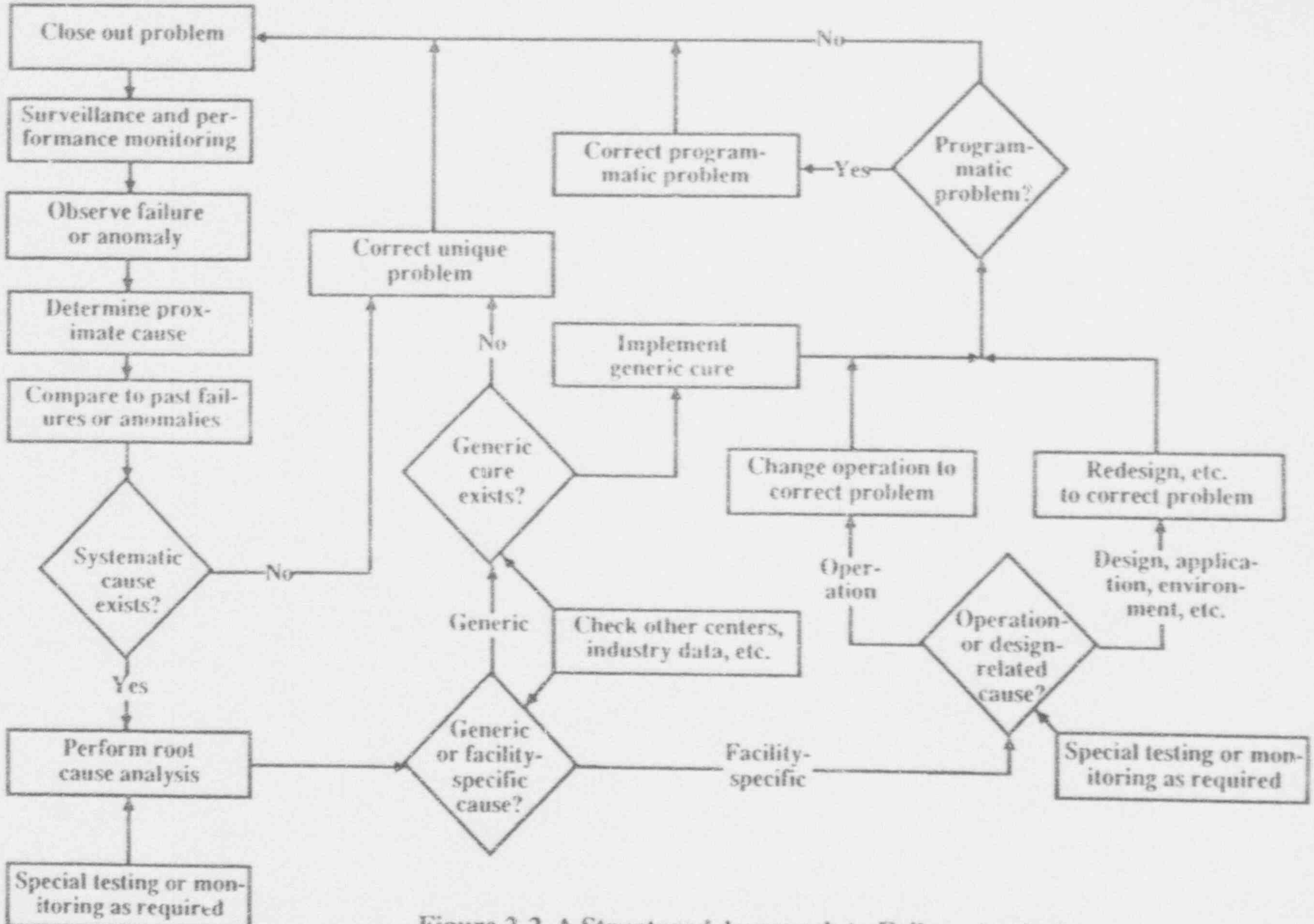

Figure 2-2. A Structured Approach to Failure Analysis

3. If there appears to be no systematic root cause, correct the failure, resume operation, and contine performance monitoring. If there is a discernible root cause, initiate a structured root cause investigation.

4. Determine if the problem is common to several other plants (generic) or plant-specific by reference to the Nuclear Plant Reliability Data System (NPRDS), NRC bulletins, contacts with equipment manufacturers and with other utility and industrial users of the equipment involved, etc.

5. If the problem is generic, contact other affected plants to determine if they have taken any effective corrective actions. If so, adapt these actions to the specific circumstances of the affected equipment; if not, proceed to the next step.

6. If the problem is plant-specific, or if it is generic but no effective solution has been developed elsewhere, determine if it is attributable to a unique system design, to application or environmental factors, or to operational factors such as maintenance, testing, and operations practices.

7. If the problem is determined to be related to system design, equipment application, or environment, determine the specific deficiency (through special tests performance monitoring, environmental monitoring, etc.), and make appropriate corrections.

8. If the problem is related to faulty operations, identify and correct the specific procedures involved.

9. Determine whether the root cause of the problem is a programmatic deficiency, e.g. in procedures writing, training, supervision, or adequacy of resources, and make appropriate corrections.

10. Perform the necessary post-correction testing and monitoring to close out the problem and ensure that it is corrected.

2.9. Maintenance Management: Lessons Learned from Successful Programs.

The maintenance philosophy employed by an organization is only a part of the whole in-plant maintenance process. The *implementation* of the basic philosophy is at least equally important. This section of the report discusses the observations of the electrical PM guidelines project team concerning the implementation of preventive maintenance programs (hereafter called maintenance management), based on the industry survey described in the Appendix and the experience of members of the guidelines project team as participants in maintenance and functional evaluations at a broad spectrum of nuclear plants.

Electrical preventive maintenance is an integral part of the maintenance function in nuclear power plants, and accordingly this section avoids making an artificial distinction between electrical and non-electrical maintenance with respect to maintenance management.

2.9.1. Maintenance Organization.

On the basis of the research for this project, the project team observed that effective

maintenance tends to correlate with a small and agile maintenance management organization. In a compact maintenance organization, both plant and corporate management are continually involved in the administration of plant maintenance. Direction from the executive level is in many cases based on input from the technician level. As a result, management decisions are illuminated by information from all parties involved, and feedback is readily available on the results of these decisions.

However, while "small is good," there are potential pitfalls to a small maintenance organization, such as tendencies toward micro-management and work overload. In the more effective programs the project team investigated, management had devoted much thought and effort to anticipating and avoiding these problems.

In the better-performing organizations, the team found that the following approaches contribute significantly to achieving maintenance goals and hence plant safety and performance objectives:

- Effective analysis of maintenance needs.
- Thorough training and qualification processes.
- Effective self-assessment, both organizational and personal.
- A competent procedure development program.
- Communication of plant modifications, operating procedure changes, etc. into the maintenance organization.
- A thorough post-maintenance testing program.
- Ample and knowledgeable technical support.
- Use of the system engineer concept.
- Ongoing QA/QC involvement.
- ALARA planning.
- Identification and tracking of rework.
- Positive management control of work and rework.
- Use of maintenance study groups.
- Ongoing analysis of corrective maintenance and basing of revisions to the preventive maintenance program on the results of this analysis.
- Failure analysis and trending programs.
- Tightly controlled spare parts programs.
- Categorizing equipment and prioritizing maintenance thereon according to its importance to

overall plant performance as well as safety.

- Good communications throughout the organization.
- Root cause analysis, correction, and recurrence control programs.

Most of the above factors leading to effective maintenance are either self-explanatory or are discussed elsewhere in this report. The following paragraphs will attempt to clarify some of the others which are not so easily understood.

2.9.2. Self-Assessment.

All licensees currently perform maintenance self-assessments as part of INPO programs. INPO assessments are excellent tools for evaluating the specific details of maintenance effectiveness. However, the team found that the better-performing organizations extend their self-assessments beyond the scope of the INPO programs, both outward to encompass the interactions of maintenance with other plant and corporate functions, and inward to include self-assessment at the crew and individual levels.

Another key to a sound self-assessment program is acting on the results by incorporating them into the organizational culture in the form of long-term changes in policies and procedures. This process appears to run reasonably smoothly in organizations that have had it in place for some time. However, organizations introducing it anew experience some growing pains. (For example, as was brought to light in one interview, the results of a broad self-assessment are not always pleasing to management on the personal level.) This is to be expected from any substantial change in organizational culture.

2.9.3. Maintenance Procedure Development.

Maintenance procedures for the most part appear similar in format and content throughout the nuclear power industry. Initial conditions, final results and a process to get from one to the other are the basis of all maintenance procedures. Some features of the procedure development process common to the better-performing plants, and not always seen in others, include the following:

- All groups a procedure can affect, either directly or indirectly, review all new and revised procedures.
- All new and revised procedures are independently verified.
- The procedures tell the technicians exactly what to expect from their actions.
- The acceptance criteria, and the required actions when they are not met, are clearly defined.
- The applicable maintenance procedures are written concurrently and interactively with the design of plant modifications, rather than after. This allows the design engineers to review the procedures for consistency with the design and -- at least equally important -- the maintenance staff to review the design for maintainability. Unmaintainable designs

and poor procedures are identified and corrected in advance.

- There is a tightly controlled periodic procedure review process.
- Maintenance technicians and other involved plant staff members receive detailed training on procedure content and use, safety precautions, and plant process considerations.

Maintenance procedure development does not end with the creation of step-by-step task instructions leading the technician through a preventive maintenance routine. The most effective procedural development programs go one step further by providing a process for incorporating feedback from procedure users. This gives the procedure writer a clear understanding of the effect of his/her approach on the plant process, and alerts him/her to latent ambiguities and opportunities for error. Without this feedback, maintenance technicians tend to supplement deficient procedures with their own process knowledge (and educated guesses), potentially resulting in hazardous, undesirable, or invalid results.

2.9.4. Post-Maintenance Testing

Post-maintenance testing provides the best assurance that maintenance actions were accomplished correctly and that the system or component was returned to functional condition. Post-maintenance testing is heavily emphasized in the better-performing plants. In these organizations, post-maintenance tests are performed following any action that potentially affects the operability of a component/subsystem/system, including PM as well as CM, and the scope of the testing is broad enough to confirm all of the potentially affected functions. Associated system(s), subsystem(s), or component(s) are tested along with the system(s), subsystem(s), or component(s) which initiated the process if an engineering analysis indicates that the maintenance action could have a significant impact on these associated items.

2.9.5. Technical Support

Technical support is intended to ensure that the preventive maintenance program properly addresses the engineering and logistical aspects of maintenance. In view of this broad objective, "technical support of maintenance" encompasses much of the engineering and management activity that takes place in a nuclear power plant. This includes at least the following functions:

- maintenance engineering,
- system engineering,
- design engineering,
- training,
- spare parts and materials management,
- quality assurance,
- quality control,

- document control,
- purchasing, receiving, and incoming inspection,
- plant performance trending,
- health physics and ALARA,
- plant chemistry, and
- regulatory compliance.

There are, of course, many other areas of maintenance involvement with technical support groups. The intent here is to show areas which stand out in the better-performing plants and which tend to be missing or under-developed in other organizations.

The technical support activity most directly involved with preventive maintenance is maintenance engineering. This function is present in all of the better-performing plants, although its name and where it fits into the organization vary widely from plant to plant. Its purpose is to optimize the maintenance program through planning, feedback, continual evaluation, and periodic updating of policies and procedures. The functions of a maintenance engineering group typically include:

- maintenance procedure development,
- maintenance procedure configuration control,
- periodic review and updating of maintenance practices and procedures;
- maintenance record keeping,
- in-service inspection and testing (ISI/IST) program development,
- providing guidance to the training staff on maintenance training;
- input to NPRDS, and evaluation of NPRDS data from other plants;
- collecting and trending equipment failure, reliability, availability, and maintainability data;
- tracking and trending the corrective- to preventive-maintenance ratio;
- failure root cause analysis;
- tracking, trending, and analysis of nonconformances;
- identifying and monitoring maintenance-related equipment performance parameters, especially failure precursors;
- identifying and monitoring maintenance performance indicators;

- performing maintenance self-assessments; and

- developing reliability-centered maintenance programs.

2.9.6. Rework.

In the maintenance context, rework is defined as repeating a preventive or corrective maintenance task because the original attempt failed. Typical reasons for rework include ambiguous or erroneous procedures, poor workmanship and other errors by the technicians performing the work, and deficient equipment. The need for rework is normally discovered through post-maintenance inspection and testing. The better-performing plants track rework statistically and use it as an indicator of the effectiveness of the maintenance process, especially of preventive maintenance. Trends in rework statistics are objective evidence of trends in PM quality which can be used to justify investments in better PM to management.

Furthermore, analyzing rework over time can disclose design deficiences, gradual equipment degradation, and problems in procedures, training, test equipment, etc. that are not readily apparent to the maintenance staff on a daily basis. For example, one licensee's tracking of rework for contracted maintenance work over an extended period revealed an equipment design problem that would probably never have been identified and diagnosed otherwise.

2.9.7. Maintenance Study Groups.

A maintenance study group is a group of maintenance and technical personnel assembled to analyze a specific maintenance-related problem and recommend a solution to management. *Ad hoc* maintenance study groups come together informally in most nuclear plant organizations, but the project team found that formalizing the study group process multiplies its effectiveness. One of the keys to success is representation from a cross-section of the licensee organization; this achieves diversity in opinions and problem-solving approaches.

The problems studied are not necessarily limited to hardware, but may include management and personnel matters. Issues are identified and brought forward through a variety of avenues, such as feedback from maintenance and operations personnel, direction from management, nonconformance reports, employee concerns programs, and NRC inspections. The typical product of the group is a plan of action with milestones for completion of specific goals. When management approves the plan (as is normally the case because it represents the consensus of the best available expertise on the subject), the team usually is given responsibility for implementing the plan and reporting the results to management. The process is rather simple and appears exceptionally effective.

2.9.8. Equipment Categorization by Importance to Plant Performance as Well as Safety.

Pursuant to NRC regulations and licensing committments, licensees invariably place safety-related and environmentally-qualified (EQ) equipment in special categories which receive more intensive (or at least better-documented) PM attention than the remainder of the equipment in the plant. However, some licensees also categorize equipment for PM planning purposes on the basis of importance to plant performance (i.e., thermal efficiency, availability, reliability, and operation-and-maintenance cost) as well as safety.

This performance categorization is based on an engineering analysis of the effects of equipment failure or degradation on the key plant performance parameters, and is intended to supplement rather than replace the existing class, code, and EQ categories. As a result, a substantial proportion of the non-"safety-related," balance-of-plant equipment is placed under formal, planned PM and surveillance. While cost-reduction rather than safety considerations are clearly the reason for this practice, it represents a favorable trend from the NRC's safety perspective and should be encouraged because most major BOP systems have considerable indirect safety significance.

2.9.9. Summary

The foregoing has been a brief look at the features which the electrical preventive maintenance guidelines project team found to be common to effective nuclear-plant preventive maintenance programs.

There are many ways to effect improvements in an organization, but probably the dominant cause of failing to improve is resistance to change. In the plants which have outstanding maintenance organizations, upper management has overcome this resistance by direct, long-term involvement in establishing and implementing policies leading to improved maintenance. Perceptible improvements in reliability, availability, and thermal efficiency have generally resulted; the indirect results have been both greater safety and higher profits. The changes in these organizations were not easy and required both time and dedication to implement. Effective management appears to be the key to an effective overall maintenance organization, not the number of programs management has in place.

3. GUIDELINES FOR PREVENTIVE MAINTENANCE AND TESTING OF ELECTRICAL EQUIPMENT, SYSTEMS, AND SUBSYSTEMS.

3.1. General.

This section of the report contains recommended guidelines for preventive maintenance of specific types of equipment in nuclear power plant auxiliary electrical power equipment and systems, and for integrated subsystem and system tests. The guidelines have been extracted from the recommendations of electrical equipment manufacturers, industry standards, authoritative reference works and technical papers in the preventive maintenance field (listed in the Bibliography), and the established practices and successful experience of both domestic and non-US nuclear facility operators. Nuclear experience has been supplemented by information derived from several other industries in which public and employee safety and process continuity enjoy a high management priority. (The Appendix discuss the methods used to develop the guidelines in detail.) Refer to Section 2 for a summary of the general principles of sound electrical PM.

As mentioned earlier, both probabilistic risk assessments and incident experience clearly demonstrate the potential for equipment failures in portions of the electric power system which are not classified as "safety-related" (i.e., not Class 1E) to precipitate reactor trips, challenge safety equipment, and/or degrade the reliability and availability of safety-related systems. Most if not all of the components in the auxiliary power system in a nuclear power plant have substantial safety significance. Therefore, these guidelines make no distinction between Class 1E and non-Class 1E equipment and subsystems in terms of recommended preventive maintenance and testing.

The inspection and testing recommendations herein are intended to supplement but obviously not to replace the regular surveillance of safety-related electrical equipment required by plant Technical Specifications.

The remainder of this section discusses (1) recommended minimum preventive maintenance activities and intervals for major types of electrical equipment, (2) guidelines for integrated system and subsystem testing, (3) factors to be considered in assessing the acceptability of deviations from the guidelines, (4) indications of impending problems to be looked for during visual inspection of equipment, (5) the role of equipment manufacturers' recommendations in electrical maintenance, (6) and the pros and cons of the several available techniques for evaluating electrical insulation quality.

3.2. Specific Preventive Maintenance Recommendations.

Tables 3-1 through 3-31 on the following pages contain recommended PM and test activities and schedules for the electrical power equipment within the scope of the guidelines project.

Table 3-1. PM and Test Schedule: Liquid-Cooled Power Transformers

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	After Through Fault	As Needed
Inspection								
External visual inspection		•	•					
Internal visual inspection - control cabinets		•		•				
Instruments and indicators		•	•				•	
Infra-red scan - external connections					•		•	
Servicing								
Radiator and cooler cleaning				•				•
Filter cleaning/replacement						•		•
Fan, pump, cooler lubrication		•		•				•
Control contact cleaning/replacement					•			•
General tightening		•			•			•
Control cabinet general cleaning					•			•
Bushing cleaning					•			•
External cleaning and painting								•
Testing								
Coolant color	1	•			•		•	
Coolant dielectric	1	•			•		•	
Coolant moisture content	1,2	•			•		•	
Gas over coolant analysis	1,2	•			•		•	
Coolant dissolved gas analysis	1	•			•	•	•	
Coolant acidity	1	•			•	•		
Coolant interfacial tension	1	•			•	•		
Insulation resistance		•			•	•	•	
Winding power factor	1,2	•			•	•	•	
Bushing power factor		•			•		•	
Excitation		•			•		•	
Ratio		•			•		•	
Ac high-potential	3	•			•	•		•
Control and auxiliary contact resistance						•		
Cooler and filter differential pressure					•			
Gas seal equipment		•				•		
Pressure/vacuum relief device		•				•		
Fault pressure relay		•				•		
Tank ground		•				•		
Core ground								•

Note 1: Refer to section 3.8 for details.

Note 2: These tests may not be justified for small, non-critical transformers.

Note 3: Optional.

(See Table 3-2 for load tap changer PM.)

Table 3-2. PM and Test Schedule: Power Transformer Under-Load Tap Changers

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Mos. or 5-15K Operations	As Needed
Inspection						
External visual inspection		•	•			
Internal visual inspection		•		•		
Instruments and indicators		•	•			
Control wiring check		•		•		
Contact alignment		•		•		
Contact wear				•		
Vacuum interrupter wear indicator				•		
Servicing						
General cleaning				•		•
General tightening		•		•		•
Contact dressing/replacement		•		•		•
Lubrication - motor, operating mech.		•				•
External cleaning and painting						•
Testing						
Operate manually through range		•		•		
Operate electrically through range		•		•		
Control wiring continuity		•				
Control and auxiliary contact resistance		•				
Control fuse continuity		•				
Insulation resistance		•			•	
Insulation resistance - High potential		•				•

Table 3-3. PM and Test Schedule: Dry-Type Power Transformers

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	After Through Fault	As Needed
Inspection								
External visual inspection		*	*					
Internal visual inspection - control cabinets		*		*				
Instruments and indicators		*	*				*	
Infra-red scan - external connections					*		*	
Servicing								
Ventilation filter cleaning/replacement						*		*
Fan lubrication		*		*				*
Control contact cleaning/replacement					*			*
General tightening		*			*			*
General cleaning					*			*
External cleaning and painting								*
Testing								
Insulation resistance		*			*		*	
Insulation power factor	1	*			*			
Excitation	1	*			*			
Ratio	1	*			*			
Ac high-potential	2	*			*			*
Control and auxiliary contact resistance						*		
Case ground		*				*		
Core ground								*

Note 1: These tests may not be justified for small and non-critical transformers.

Note 2: Optional

Table 3-4. PM and Test Schedule: Outdoor Oil, SF6, and Air-Blast Power Circuit Breakers

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Weekly	Quarterly	Every 18-24 Mos. or 40-75 CO* Cycles	Every 54-72 Mos. or After Fault	As Needed
Inspection								
External visual insp. (cabinet door closed)		•	•				•	
External visual insp. (cabinet door open)		•		•			•	
Oper. mech. air or gas pressure		•		•			•	
Interrupter general inspection (open tank)							•	
Main contact alignment		•					•	
Main contact wear, spring tension							•	
Arcing contact alignment		•					•	
Arcing contact wear							•	
Control fuse continuity		•					•	
Servicing								
General cleaning - operator cabinet						•	•	•
General tightening		•				•	•	•
Operating mechanism lubrication						•	•	•
Compressor and motor lubrication						•	•	•
Bushing cleaning						•	•	•
External cleaning and painting								•
Testing								
Trip and close		•				•	•	
Controls operability		•				•	•	
Oil color	1					•	•	
Oil dielectric	1					•	•	
Gas blast cylinder, nozzles, etc.	2,3						•	
Current trans./bushing pot. device ratio		•					•	
Control and auxiliary contact resistance								
Control wiring continuity		•					•	
Insulation power factor		•				•	•	
Insulation resistance		•				•	•	
High potential		•						•
Tank loss index		•				•	•	

* Close-open cycles

Note 1: Oil breakers only

Note 2: SF6 breakers only

Note 3: SF6 and air-blast breakers only

(These recommendations also apply generally to high-voltage SF6 switches (Circuit Switchers, etc.))

Table 3-5. PM and Test Schedule: Outdoor Switchyard Equipment

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Mos. or 10-25 Switch Oper'ns.	Every 54-72 Mos. or 25-75 Switch Oper'ns.	As Needed
Inspection							
External visual inspection		•	•				
Infra-red scan - bus joints, cable terminations		•				•	•
Insulator cleanliness, damage, tracking		•		•			
Control and instrumentation wiring		•				•	
Instrument and indicator			•				
Switch arcing contacts - wear							
Switch contact alignment							
Switch auxiliary contacts check		•					
Servicing							
Insulator cleaning					•		•
General tightening		•			•		•
Lubrication - switch operators, motors		•			•		•
Switch arcing contact dressing/replacement						•	•
Switch auxiliary contact cleaning						•	•
Bushing cleaning						•	•
External cleaning and painting							•
Testing							
Cycle switches manually and/or electrically		•			•		
Instrument transformer ratio		•				•	
Control and instrument wiring continuity		•				•	
Control and auxiliary contact resistance		•				•	
Insulation resistance		•			•		
High potential		•				•	

Note: See Table 3-4 for PM on power circuit breakers and SF6 switches (Circuit Switchers, etc.).

Table 3-6. PM and Test Schedule: Drawout Air Power Circuit Breakers, 5, 7.2, 15kV Class*

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Mos. or 40-75 CO† Cycles	Every 54-72 Mos. or After Fault	As Needed
Inspection							
External visual inspection (cell door closed)		•	•			•	
External visual inspection (cell door open)		•		•		•	
General internal inspection		•			•	•	
Control and instrument wiring		•			•	•	
CB element auxiliary contacts		•			•	•	
Arc chutes		•			•	•	
Puffers		•			•	•	
Main contact alignment		•			•	•	
Main contact wear					•	•	
Main contact spring tension					•	•	
Arcing contact alignment		•			•	•	
Arcing contact wear					•	•	
Mechanism - damage and wear					•	•	
Cell mechanical alignment		•			•	•	
Main drawout stabs spring tension		•			•	•	
CB to cell auxiliary drawout connector		•			•	•	
Servicing							
General cleaning					•	•	
General tightening		•			•	•	
Lubrication - mech., motors, drawout stabs		•			•	•	
Testing							
Trip and close		•			•	•	
Controls operability		•			•	•	
Current transformer ratio		•				•	
Control and auxiliary contact resistance					•	•	
Control wiring continuity		•				•	
Control fuse continuity		•			•	•	
Insulation resistance		•			•		
Insulation power factor	1	•			•	•	•
High potential		•				•	•
Contact resistance		•			•	•	

*5kV class includes 2.4 and 4.16kV operating voltages.

†Close-open cycles

7.2kV class includes 6.9kV operating voltage.

15kV class includes 12.47, 13.2, 13.8, and 14.4kV operating voltages.

Note 1: Optional

Table 3-7. PM and Test Schedule: Drawout Vacuum Power Circuit Breakers, 5, 7.2, 15kV Class*

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Mos. or 40-75 CO† Cycles	Every 54-72 Mos. or After Fault	As Needed
Inspection							
External visual inspection (cell door closed)		•	•			•	
External visual inspection (cell door open)		•		•		•	
General internal inspection		•			•	•	
Control and instrument wiring		•				•	
CB element auxiliary contacts		•			•	•	
Vacuum interrupter - wear indicator					•	•	
Mechanism - damage and wear					•	•	
Cell mechanical alignment		•			•	•	
Main drawout stabs spring tension		•			•	•	
CB to cell auxiliary drawout connector		•			•	•	
Servicing							
General cleaning					•	•	•
General tightening		•			•	•	•
Lubrication - mech., motors, drawout stabs		•			•	•	•
Testing							
Trip and close		•			•	•	
Controls operability		•			•	•	
Current transformer ratio		•				•	
Control and auxiliary contact resistance						•	
Control wiring continuity		•				•	
Control fuse continuity		•			•	•	
Insulation resistance		•			•	•	
Insulation power factor	1	•			•	•	•
High potential		•			•	•	•
Contact resistance		•			•	•	
*See Table 3-6 for operating voltages.							
†Close-open cycles							
Note 1: optional							

Table 3-8. PM . ıd Test Schedule: Metal-Clad Switchgear Assemblies, 5, 7.2, 15kV Class*

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	As Needed
Inspection							
External visual inspection (cell doors closed)		•	•				
Instruments and indicators		•	•				
External visual inspection (cell doors open)		•		•			
Internal inspection - circuit breaker cells		•			•		
Fans		•		•			
Internal inspection - PT and aux. compartments		•			•		
Internal insp. - bus, termination compartments		•			•	•	
Infra-red scan - bus joints, cable terminations					•		
Control and instrument wiring		•				•	
CBs in cells mechanical alignment		•			•		
CB to cell control/auxiliary contacts		•				•	
Servicing							
General cleaning					•		•
General tightening		•			•		•
Filter cleaning or replacement					•		•
Lubrication - fans, racking mechanisms, etc.		•			•		•
External cleaning and painting							•
Testing							
Controls operability		•			•		
Instrument transformer ratio		•				•	
Control wiring continuity		•				•	
Control and auxiliary contact resistance						•	
Control fuse continuity		•			•		
Fan temperature switches		•			•		
Space heaters		•			•		
Control power rectifiers - output		•				•	
Insulation power factor	1	•			•	•	•
Insulation resistance		•			•		•
High potential		•				•	•

*See Table 3-6 for operating voltages.

Note 1: optional.

Table 3-9. PM and Test Schedule: Metal-Enclosed Air Switches, 5, 7.2, 15kV Class

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	As Needed
<u>Inspection</u>							
External visual inspection (cell door closed)		•	•				
Instruments and indicators		•	•				
External visual inspection (cell doors open)		•		•			
Internal inspection		•			•		
Fans		•		•			
Infra-red scan - bus joints, cable terminations					•		
Control and instrument wiring		•				•	
<u>Servicing</u>							
General cleaning					•		•
General tightening		•			•		•
Filter cleaning or replacement					•		•
Lubrication - fans, switch mechanisms, etc.		•			•		•
External cleaning and painting							•
<u>Testing</u>							
Controls operability		•			•		
Instrument transformer ratio		•				•	
Control wiring continuity		•				•	
Control and auxiliary contact resistance						•	
Control fuse continuity		•			•		
Fan temperature switches		•			•		
Space heaters		•			•		
Insulation resistance		•			•		•
Insulation power factor	1	•			•	•	•
High potential		•				•	•

*See Table 3-6 for operating voltages.

Note 1: optional

Table 3-10. PM and Test Schedule: Low-Voltage Drawout Air Power Circuit Breakers

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Mos. or 40-75 CO* Cycles	Every 54-72 Mos. or After Fault	As Needed
Inspection							
External visual inspection (cell door closed)		•	•			•	
External visual inspection (cell door open)		•		•		•	
General internal inspection		•			•	•	
Control and instrument wiring		•				•	
CB element auxiliary contacts		•			•	•	
Arc chutes		•			•	•	
Main contact alignment		•			•	•	
Main contact wear					•	•	
Main contact spring tension					•	•	
Arcing contact alignment		•			•	•	
Arcing contact wear					•	•	
Mechanism - damage and wear					•	•	
Cell mechanical alignment		•			•	•	
Main drawout stabs spring tension		•			•	•	
CB to cell auxiliary drawout connector		•			•	•	
Infra-red scan - bus joints, cable terminations					•	•	
Servicing							
General cleaning					•	•	•
General tightening		•			•	•	•
Lubrication - mech., motors, drawout stabs		•			•	•	•
Testing							
Trip and close		•			•	•	
Controls operability		•			•	•	
Current transformer ratio	1	•				•	
Control and auxiliary contact resistance						•	
Control wiring continuity		•				•	
Control fuse continuity		•			•	•	
Insulation resistance		•			•	•	•
High potential							•
Overcurrent trip devices (long time delay, short time delay, and instantaneous)		•			•	•	•
Contact resistance		•			•	•	

*Close-open cycles.

Note 1. If the breaker is equipped with solid state trip unit.

Table 3-11. PM and Test Schedule: Low-Voltage Metal-Enclosed Switchgear Assemblies

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	As Needed
Inspection							
External visual inspection (cell doors closed)		•	•				
Instruments and indicators		•	•				
External visual inspection (cell doors open)		•		•			
Internal inspection - circuit breaker cells		•			•		
Fans		•		•			
Internal inspection - bus, termination, auxiliary compartments		•					
Infra-red scan - bus joints, cable terminations					•	•	•
Control and instrument wiring		•				•	
CBs in cells mechanical alignment		•			•		
CB to cell control/auxiliary contacts		•			•		
Servicing							
General cleaning					•		•
General tightening		•			•		•
Filter cleaning or replacement					•		•
Lubrication - fans, racking mechanisms, etc.		•			•		•
External cleaning and painting							•
Testing							
Controls operability		•			•		
Instrument transformer ratio		•				•	
Control wiring continuity		•				•	
Control fuse continuity		•			•		
Fan temperature switches		•			•		
Space heaters		•			•		
Control power rectifiers - output		•				•	
Insulation resistance		•			•		•
High potential							•

Table 3-12. Low-Voltage Switchboards and Panelboards with Molded-Case Circuit Breakers

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Daily	Every 18 - 24 Mos.	Every 54-72 Mos.	As Needed
Inspection						
External visual inspection		•		•		
Internal visual inspection		•		•		
Rating verification		•			•	
Infra-red scan - internal connections				•		•
Servicing						
General cleaning					•	•
General tightening					•	•
External cleaning and painting						•
Testing						
Manual close and trip				•		
Electrical close and trip				•		
Thermal trip	1			•		
Magnetic trip	1			•		
Static trip -secondary current injection	1,2			•		
Static trip - primary current injection	1,2,3				•	
Auxiliary switch				•	•	
Control and auxiliary contact resistance					•	
Insulation resistance				•		
High potential						•
Contact resistance		•		•		

Note 1: 18-24 month trip test interval for critical circuits; 54-72 for others.

Note 2: Primary injection through main power circuit and CTs; secondary directly into static trip unit.

Note 3: In lieu of primary injection , use secondary injection for each component of the circuit breaker.

Table 3-13. PM and Testing Schedule: Protective Relays.

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Daily	Quarterly	Every 18-60 Mos. (Note 3)
Relays - General					
External inspection					•
Internal inspection	1	•		•	
Internal wiring check		•			•
Case fingers		•			•
Cradle fingers		•			•
Burnish contacts		•			•
Control spring adjustments		•			•
Clutch adjustment		•			•
Diode polarity test		•			•
Insulation resistance	4	•			•
Pickup setpoint check		•			•
Timing checks		•			•
Restraint element check		•			•
Directional element check		•			•
Phase angle and magnitude contribution checks (differential, directional relays only)		•			•
Relays - Specific					
Current balance	2, 3				
Pickup check		•			•
No-trip condition		•			•
Target indicator coil		•			•
Differential relays					
Minimum pickup values		•			•
Differential characteristics and harmonic restraint		•			•
Directional overcurrent relays	2, 3				
Minimum pickup test		•			•
Time overcurrent		•			•
Instantaneous overcurrent		•			•
Target and seal-in unit		•			•
Directional unit calibration		•			•
Maximum target angle		•			•
Contact gap		•			•
Clutch pressure		•			•
Auxiliary switch adjustments		•			•
Distance relays	2, 3				
Minimum pickup		•			•
Maximum torque angle		•			•
Clutch pressure		•			•
Contact gap		•			•

(See next page for notes.)

Table 3-13. PM and Testing Schedule: Protective Relays.

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Daily	Quarterly	Every 18-60 Mos. (Note 3)
Overvoltage relays	2, 3				
Dropout voltage		•			•
Instantaneous pickup		•			•
Target indicator coils		•			•
Pilot wire relays	2, 3				
Shorts, continuity, grounds in pilot wire		•			•
Operating/setpoint checks		•			•
Associated supervisory and alarm relays		•			•
Plunger type relays	2, 3				
Operating pickups checked		•			•
Dropout settings checked		•			•
Time overcurrent relays	2, 3				
Timing		•			•
Minimum pickup test		•			•
Instanteous unit test		•			•
High dropout inst. unit calibration		•			•
Target seal-in unit tested		•			•
Thermal overload relay	2, 3				
Minimum pickup value		•			•
Relay timing		•			•
Instaneous pickup		•			•
Target indicator coil checked		•			•
Undervoltage relay	2, 3				
Minimum pickup		•			•
Relay dropout		•			•
Dropout timing		•			•
Target and seal-in unit		•			•
Instantaneous unit checked		•			•
Ground relay	2, 3				
Minimum pickup		•			•
Timing		•			•
Voltage balance relay	2, 3				
Differential pickup		•			•
Differential release		•			•
Underfrequency relay	2, 3				
Minimum pickup		•			•
Maximum dropout		•			•

Note 1: This inspection consists of checking internals with a flashlight through the glass cover, looking for moisture/oil precipitation, embrittled insulation, pitted contacts, mechanical damage, binding, corrosion, loose hardware or terminations, and damaged disconnect fingers.

Note 2: Some relays may employ more than one operating and protective principle (i.e., a relay may have time overcurrent characteristics and directional characteristics).

Note 3: 18-24 month schedule for relays providing protection to more [illegible] complex equipment. 36-60 month schedule for others.

Note 4: To be performed on electromechanical releys only

Table 3-14. PM and Test Schedule: Control Logic Relays.

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Daily	Quarterly	Every 18 - 24 Mos.	Every 54-72 Mos.	As Needed
Inspection							
Visual inspection - cabinets closed		•	•				
Visual inspection - cabinets open		•		•			
Cleanliness		•		•			
Tightness of connections		•			•		
Wiring condition		•		•			
Clearances		•		•			
Mechanical freedom		•			•		
Condition of contacts		•			•		
Condition of control springs		•			•		
Magnets		•			•		
Targets and reset mechanisms		•			•		
Tracking				•			
Servicing							
General cleaning						•	•
Tightening		•				•	•
Contact cleaning/dressing/replacement							•
Parts repair/replacement							•
Calibration of metering equipment		•				•	•
Testing							
Wiring continuity							
Contact resistance		•				•	
Control fuse continuity		•				•	
Insulation resistance		•				•	
Subsystem/system-level functional tests	1,2	•				•	

Note 1: Verifies all control and protective functions and alarms.

Note 2: Frequency may be coordinated with front-line equipment testing.

Table 3-15. PM and Test Schedule: Automatic Transfer Switches

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Daily	Quarterly	Every 18 - 24 Mos.	Every 54-72 Mos.	As Needed
Inspection							
External visual inspection		•	•				
Internal visual inspection				•			
Instruments and indicators				•			
Infra-red scan - connections					•		
Servicing							
General cleaning					•		•
Contact cleaning/replacement					•		•
Protective and timing relay calibration		•			•		•
Tightening		•			•		•
External cleaning and painting							•
Testing							
Insulation resistance		•			•		
Functional test-manual		•			•		
Functional test-automatic		•			•		

Table 3-16. PM and Test Schedule: Low-Voltage Fused "Safety Switches"

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Weekly	Every 54-72 Mos.	As Needed
Inspection					
External inspection		•	•		
Internal inspection		•		•	
Switch contacts		•		•	
Fuse rating check		•		•	
Infra-red scan - cable terminations		•		•	•
Servicing					
General cleaning					•
Tightening		•			•
Lubrication		•			•
External cleaning and painting					•
Testing					
Fuse continuity		•			•
Insulation resistance		•			•

Table 3-17. PM and Test Schedule: Isophase, Segregated Phase, and Metalclad Bus, Over 600V

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Monthly	Quarterly	Every 18-24 Months	Every 54-72 Months	As Needed
Inspection								
External inspection - bus enclosure, coolers,		•	•					
fans, pumps, etc.								
Internal inspection - through encl. insp. ports		•			•			
Instruments and controls		•			•			
Filter cleanliness and/or diff'l. pressure		•		•				
Infra-red scan - bus joints, cable terminations		•				•		
Servicing								
General cleaning							•	•
General tightening		•					•	•
Cooling thermostat calibration		•					•	•
Lubrication - fans, pumps, etc.		•				•		•
Filter cleaning or replacement						•		•
External cleaning and painting								•
Testing								
Manually cycle cooling controls		•				•		
Control contact resistance		•					•	
Control wiring continuity		•				•		
Control fuse continuity		•					•	
Insulation resistance		•				•		
Insulation power factor		•				•		•
High potential		•					•	•

Table 3-18. Power Cable, 5kV Class and Above

Recommended PM or Test	Notes	Prior to or Upon Install'n.	During Plant Mods.	Every 54-72 Mos.	As Needed
Inspection					
Sharp bends		•	•	•	
Jacket abrasion or cracking		•	•	•	
Pinched cable		•	•	•	
Insulation deterioration: oil leaks, softness, swelling			•	•	
Shield grounding		•	•	•	
Metallic sheath bonding		•	•	•	
Conduit and tray bonding		•	•	•	
Tracking from corona			•	•	
Soft spots in terminations and splices			•	•	
Spalling concrete in manholes		•	•	•	
Fireproofing		•	•	•	
Deterioration of suspension systems		•	•	•	
Sagging tray or conduit		•	•	•	
Rust or corrosion of trays, conduits, junction boxes		•	•	•	
Servicing					
Cleaning - trays, junction boxes, etc.					•
Tightening - supports, fittings				•	•
Repair/replacement of cables, supports, etc.					•
Painting of trays, conduits, junction boxes, etc.					•
Testing					
Insulation resistance		•	•	•	
Dc high-potential	1,3	•	•	•	
Insulation power factor	2	•	•	•	

Note 1: This test is not recommended for cross-linked polyethylene cable

Note 2: This test is recommended for shielded cables only.

Note 3: If power factor test is performed in the cable then the dc high potential test may be deferred.

Table 3-19. Low-Voltage Power Cable

Recommended PM or Test	Notes	Prior to or Upon Install'n.	During Plant Mods.	Every 54-72 Mos.	As Needed
Inspection					
Sharp bends		•	•	•	
Jacket abrasion or cracking		•	•	•	
Pinched cable		•	•	•	
Insulation deterioration: oil leaks, softness, swelling			•	•	
Metallic sheath bonding		•	•	•	
Conduit and tray bonding		•	•	•	
Tracking			•	•	
Soft spots in terminations and splices			•	•	
Spalling concrete in manholes		•	•	•	
Fireproofing		•	•	•	
Fire barriers		•	•	•	
Deterioration of suspension systems		•	•	•	
Sagging tray or conduit		•	•	•	
Rust or corrosion of trays, conduits, junction boxes			•	•	
Servicing					
Cleaning - trays, junction boxes, etc.					•
Tightening - supports, fittings				•	•
Repair/replacement of cables, supports, etc.					•
Painting of trays, conduits, junction boxes, etc.					•
Testing					
Insulation resistance		•	•	•	
DC high-potential					•

Table 3-20. PM and Test Schedule: Low Voltage Bus and Bus Duct

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Daily	Every 18-24 Mos.	Every 54-72 Mos.	As Needed
Inspection						
External visual inspection - enclosure, supports		•	•			
External visual inspection - plug-in devices		•	•			
Internal visual inspection of connections		•		•		
Internal visual inspection - plug-in devices		•		•		
Infra-red scan - connections and terminations					•	
Servicing						
Tightening connections and enclosures		•			•	•
Insulator cleaning					•	•
Servicing of plug-in devices	1	•		•		•
External cleaning and painting						•
Testing						
Insulation resistance		•		•		
Testing of plug-in devices	1			•	•	
Ground continuity		•			•	
Dc high-potential						•

Note 1: Refer to Tables 3-12 and 3-16 for PM recommendations for molded-case CBs and fused switches respectively.

Table 3-21. PM and Test Schedule: Motor and Other Load Controllers

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Mos. or 1-3K Starts	Every 54-72 Mos. or 3-10K Starts	After "Down-stream" Fault	As Needed
Inspection								
External inspection (starter doors closed)		•	•				•	
Instruments and indicators		•	•					
Internal inspection - starters		•		•			•	
Int. insp. - bus, terminal, wiring compartments		•			•		•	
Infra-red scan - bus joints, other power conns.		•			•		•	
Control and instrument wiring		•				•		
Starter drawout stabs, spring tension		•				•	•	
Overload heater selection- verify		•				•		
Overload relay settings -verify		•			•		•	
Other motor protective relay selection - verify		•				•	•	
Other motor protective relay settings - verify		•			•		•	
Power fuse selection - verify		•				•	•	
Servicing								
General cleaning					•			•
General tightening		•			•			•
Protective and timing relay calibration					•			•
External cleaning and painting								•
Testing								
Functional testing					•		•	
Remote and local start and stop		•			•		•	
Controls operability		•			•		•	
Overload heater continuity		•				•	•	
Overload relay calibration		•			•		•	
Control wiring and fuse continuity		•			•			
Power fuse continuity		•					•	
Control contact resistance						•		
Insulation resistance		•			•		•	
Contact resistance		•			•		•	

Table 3-22. PM and Test Schedule: Ac Induction Motors, 2.4kV and Above

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	As Needed
Inspection							
External visual and audible inspection		•	•				
Lube system - leaks, oil level, pump operation		•	•				
Fans and coolers - operation		•	•				
Bearings - noise, vibration, overheating		•	•				
Instruments and indicators: bearing and winding temperature, oil pres., oil and air filter ΔP, etc.		•	•				
Ventilating air filters - cleanliness		•		•			
Internal visual inspection thru inspection ports		•			•		
Internal insp. - connections (open term. boxes)		•			•		
Servicing							
Lubricate oil pumps		•		•			•
Lubricate cooling fans		•		•			•
Lube oil filters - clean or replace					•		•
Ventilating air filters - clean or replace					•		•
General tightening - fasteners, fittings, conns.		•			•		•
General cleaning					•		•
Replace lubricating oil	1	•			•		•
Winding and bearing temp. inst./alarm calibration		•				•	•
Lubrication pressure, flow inst./alarm calibration		•				•	•
External cleaning and painting							•
Testing							
Auxiliaries - manual control operation		•			•		
Lubricating oil filters - differential pressure (ΔP)		•			•		
Air filters - ΔP		•			•		
Space heaters - operation		•			•		
Fan temperature switches		•			•		
Control wiring and fuse continuity		•				•	
Control contact resistance						•	
Insulation power factor		•			•		
Insulation resistance/polarization index		•			•		
Dc high-potential		•				•	
Corona discharge							•
Surge comparison							•

Note 1: (For motors with externally-lubricated bearings (hydrostatic, etc.); see Table 3-23 for PM on motors with internally grease- or oil-lubricated bearings (ball, etc.))

Table 3-23. PM and Test Schedule: Ac Induction Motors, 120-600V

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	As Needed
<u>Inspection</u>							
External visual and audible inspection		•	•				
Lube system - leaks, oil level, pump operation	1	•	•				
Fans and coolers - operation		•	•				
Bearings - noise, vibration, overheating		•	•				
Instruments and indicators: bearing and winding		•	•				
temperature, oil pres., oil and air filter ΔP, etc.							
Bearing lubricant level	2	•		•			
Ventilating air filters - cleanliness		•		•			
Internal visual inspection thru inspection ports		•			•		
Internal insp. - connections (open term. boxes)		•			•		
<u>Servicing</u>							
Lubricate oil pumps	1	•		•			•
Lubricate cooling fans		•		•			•
Lube oil filters - clean or replace	1				•		•
Ventilating air filters - clean or replace					•		•
General tightening - fasteners, fittings, conns		•			•		•
General cleaning					•		•
Replace lubricating oil		•			•		•
Grease or oil bearings	2	•			•		•
Winding and bearing temp. inst./alarm calibration		•				•	•
Lubrication pressure, flow inst./alarm calibration		•				•	•
External cleaning and painting							•
<u>Testing</u>							
Auxiliaries - manual control operation		•			•		
Lubricating oil filters - differential pressure (ΔP)	1	•			•		
Air filters - ΔP		•			•		
Space heaters - operation		•			•		
Fan temperature switches		•			•		
Control wiring and fuse continuity		•				•	
Control contact resistance						•	
Insulation resistance/polarization index		•			•		
Note 1: For motors with externally-lubricated bearings (hydrostatic, etc.)							
Note 2: For motors with internally grease- or oil-lubricated bearings (ball, etc.)							

Table 3-24. PM and Test Schedule: Dc Motors, Generators, and Rotating Exciters

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	As Needed
<u>Inspection</u>							
External visual and audible inspection		•	•				
Lube system - leaks, oil level, pump operation	1	•	•				
Fans and coolers - operation		•	•				
Bearings - noise, vibration, overheating		•	•				
Instruments and indicators: bearing and winding temperature, oil pres., oil and air filter ΔP, etc.		•	•				
Bearing lubricant level	2	•		•			
Ventilating air filters - cleanliness		•		•			
Commutator, brushes visual inspection		•		•			
Brush wear measurement					•		
Commutator - wear, high mica, etc					•		
Internal visual inspection thru inspection ports		•			•		
Internal insp. - connections (open term. boxes)		•			•		
<u>Servicing</u>							
Lubricate oil pumps	1	•		•			•
Lubricate cooling fans		•		•			•
Lube oil filters - clean or replace	1				•		•
Ventilating air filters - clean or replace					•		•
General tightening - fasteners, fittings, conns.		•			•		•
General cleaning					•		•
Replace lubricating oil		•			•		•
Grease or oil bearings	2	•			•		•
Winding and bearing temp. inst./alarm calibration		•				•	•
Lubrication pressure, flow inst./alarm calibration		•				•	•
Replace brushes							•
Refurbish commutator							•
External cleaning and painting							•
<u>Testing</u>							
Auxiliaries - manual control operation		•			•		
Lubricating oil filters - differential pressure (ΔP)	1	•			•		
Air filters - ΔP		•			•		
Space heaters - operation		•			•		
Fan temperature switches		•			•		
Control wiring and fuse continuity		•				•	
Control contact resistance						•	
Insulation resistance/polarization index		•			•		
Insulation power factor						•	

Note 1: For motors with externally-lubricated bearings (hydrostatic, etc.)

Note 2: For motors with internally grease- or oil-lubricated bearings (ball, etc.)

Table 3-25. PM and Test Schedule: Ac Generators

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	As Needed
Inspection							
External visual and audible inspection		•	•				
Lube system - leaks, oil level, pump operation	1	•	•				
Fans and coolers - operation		•	•				
Bearings - noise, vibration, overheating		•	•				
Instruments and indicators: bearing and winding temperature, oil pres., oil and air filter ΔP, etc.		•	•				
Bearing lubricant level	2	•		•			
Ventilating air filters - cleanliness		•		•			
Slip rings, brushes visual inspection		•		•			
Brush wear measurement					•		
Slip rings - wear, etc.					•		
Internal visual inspection thru inspection ports		•			•		
Internal visual insp. - integral "brushless" exciter		•			•		
Internal visual insp. - rotating exciter	3	•			•		
Internal insp. - connections (open term. boxes)		•			•		
Servicing							
Lubricate oil pumps	1	•		•			•
Lubricate cooling fans		•		•			•
Lube oil filters - clean or replace	1				•		•
Ventilating air filters - clean or replace					•		•
General tightening - fasteners, fittings, conns.		•			•		•
General cleaning					•		•
Replace lubricating oil		•			•		•
Grease or oil bearings	2	•			•		•
Winding and bearing temp. inst./alarm calibration		•				•	•
Lubrication pressure, flow inst./alarm calibration		•				•	•
Replace brushes							•
Refurbish slip rings							•
External cleaning and painting							•
Testing							
Auxiliaries - manual control operation		•			•		
Lubricating oil filters - differential pressure (ΔP)	1	•			•		
Air filters - ΔP		•			•		
Space heaters - operation		•			•		
Fan temperature switches		•			•		
Excitation system functional test		•			•		
Control wiring and fuse continuity		•				•	
Control contact resistance						•	
Insulation resistance/polarization index	4	•			•		
Insulation power factor					•		
Dc high-potential	4	•				•	
Corona discharge							•

Note 1: For generators with externally lubricated bearings (hydrostatic, etc.)

Note 2: For generators with internally grease- or oil-lubricated bearings (ball, etc.)

Note 3: See Table 3-24 for PM on rotating exciters.

Note 4: Do not apply overpotential to static "brushless" exciters.

Table 3-26. PM and Test Schedule: Solid-State Generator Exciters, Governors, and Voltage Regulators

Recommended PM or Test	Notes	Prior to or Upon Instal'n.	Daily	Quarterly	Every 18-24 Months	Every 54-72 Months	As Needed
Inspection							
External visual inspection		*	*				
Instruments and indicators		*	*				
Ventilating fans		*	*				
Ventilation filters		*		*			
Internal visual inspection		*		*			
Control settings - verify					*		
Infra-red scan - power connections					*		
Servicing							
General cleaning					*		*
General tightening		*			*		*
Ventilating filter cleaning or replacement					*		*
Ventilating fans - lubricate		*			*		*
Protective and timing relays - calibration		*			*		*
Control transducers - calibration		*				*	*
Instruments - calibration		*				*	*
External cleaning and painting							
Testing							
Manual control operation		*			*		
Functional testing		*			*		
Transient response testing		*				*	
Current and potential transformers - ratio		*				*	
Control contact resistance						*	
Control wiring and fuse continuity		*				*	
(Note: PM on hydraulic and mechanical governors is not included.)							

Table 3-27. PM and Test Schedule: Diesel Engines including Hydraulic and Mechanical Governors

	A	B	C	D	E	F	G	H	I	J
1			Prior to					Every	Every	
2			or Upon					18-24	54-72	As
3	Recommended PM or Test	Notes	Install'n.	Daily	Weekly	Monthly	Quarterly	Mos.	Mos.	Needed
4										
5	Inspection									
6	External visual inspection									
7	Valve, switch, control, etc. status - verify		*	*						
8	Lubrication system - operating		*	*						
9	Starting system - operating		*	*						
10	Keep-warm system - operating		*	*						
11	Instruments, relay targets, indicators		*	*						
12	Generator circuit breaker status		*		*					
13	Internal visual inspection - cabinets open		*				*			
14	Controls and relay settings - verify		*				*			
15										
16	Servicing									
17	General cleaning							*		*
18	General tightening		*					*		*
19	Lubricate aux. pumps, compressor, etc.		*				*	*		*
20	Air dryer cleaning or replacement						*	*		*
21	Air filter cleaning or replacement							*		*
22	Lube oil filter cleaning or replacement							*		*
23	Fuel oil filter cleaning or replacement							*		*
24	Instruments, alarms, controls calibration		*						*	*
25	External cleaning and painting								*	*
26										
27	Testing									
28	Blow down air receiver, check for moisture		*	*						
29	Alarms and annunciators		*	*						
30	Fire suppression system test		*	*						
31	Functional start and load test		*			*				
32	Control wiring and fuse continuity		*						*	
33	Control and auxiliary contact resistance								*	
34	Transient loading test		*						*	*
35										

Table 3-28. PM and Test Schedule: Station Batteries

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Weekly	Quarterly	Every 6 - 12 Mos.	Every 18 - 24 Mos.	Every 60 Months	As Needed
Inspection								
Instruments and indicators			•					
General cleanliness		•	•					
Electrolyte level	1	•	•					
Leaks		•	•					
Sediment buildup								
Plate warping		•	•					
Ventilation		•	•					
Alarm system		•	•					
Integrity of battery rack					•			
Servicing								
Watering	2							•
Ventilation	2			•				•
General cleanliness				•				•
Bus bar connection tightness	2				•			•
Rack painting								•
Testing								
Electrolyte temperature	3	•	•					
Electrolyte level	3	•	•					
Specific gravity	1, 3	•	•					
Metering	4	•	•					
Flow-rate testing		•						
Grounds	4	•	•					
Alarm circuits	4	•	•					
Auxiliary relays	4	•	•					
Normal battery charging		•				•		
Equalizing battery charging						•		
Load discharge	5	•				•		
Service test	6					•		
Battery capacity test	6						•	
Cell to cell, terminal conns. resistance	7	•			•	•		
Cell voltage		•	•					

Note 1: Increase frequency in case of increased cycling on the battery (diesel starts, ESF actuations, etc.)

Note 2: Normally required prior to a battery charging evolution other than a trickle charge.

Note 3: Daily on pilot cells, quarterly on all cells.

Note 4: Weekly test, monthly calibration.

Note 5: At least within 2 years of installation; sometimes every 54-72 months to track battery condition.

Note 6: Per IEEE Std 450

Note 7: Upon installation in order to obtain a baseline resistance. Trend subsequent readings as condition indicator.

Table 3-29. PM and Test Schedule: Engine Starting Batteries

		Prior to or Upon			Every 18 - 24	As
Recommended PM or Test	Notes	Install'n.	Weekly	Quarterly	Mos.	Needed
Inspection						
Instruments and indicators			•			
General cleanliness		•	•			
Leaks		•	•			
Ventilation		•	•			
Alarm system		•	•			
Servicing						
Watering	1	•				•
Ventilation	1	•		•		•
General cleaning				•		•
Bus bar connection tightness	1	•			•	•
Rack painting						•
Testing						
Electrolyte temperature		•	•			
Electrolyte level		•	•			
Specific gravity	2	•	•			
Metering	3	•	•			
Auxiliary relays	2	•	•			
Battery charging		•	•			
Cell voltage		•	•			

Note 1: Normally required prior to a battery charging evolution other than a trickle charge.
Note 2: Increase frequency in case of increased cycling on the battery (diesel starts, ESF actuat
Note 3: Quarterly test, 18-24 month calibration.

Table 3-30. PM and Test Schedule: Emergency Lighting Batteries

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Every 18-24 Mos.	As Needed
Inspection				
Exterior visual inspection			•	
Instruments and indicators	1	•	•	
Interior visual inspection		•	•	
Servicing				
Lubrication of battery connections	2		•	•
General cleaning			•	•
Instrument calibration	1	•	•	•
Battery replacement	3			•
External cleaning and painting				•
Testing				
Capacity	4	•	•	
Function	5	•	•	

Note 1: If applicable.
Note 2: If required.
Note 3: When excessively corroded or fails capacity test.
Note 4: Normally on a representative group of lights in one area, not on every light. Schedule tests so all lights are tested every 5 years.
Note 5: Confirm light energizes when ac power is removed.

Table 3-31. PM and Test Schedule: Static Inverters, Battery Chargers, and Uninterruptible Power Supplies

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Daily	Quarterly	Every 18 - 24 Mos.	Every 54-72 Mos.	As Needed
Inspection							
External visual inspection		•	•				
Instruments and indicators		•	•				
Cooling fans - operation		•	•				
Internal visual inspection				•			
Ventilation filters				•			
Manual transfer switch contacts, mechanism				•			
Infra-red scan of power connections							
Servicing							
General cleaning					•		•
General tightening		•			•		•
Fan lubrication		•			•		•
Ventilation filter cleaning or replacement					•		•
Battery charging	1	•					•
External cleaning and painting							•
Testing							
Full load test		•			•		
Variable-step load test		•			•		
Overload test		•			•		
Battery capacity test		•			•		
Metering, annunciators		•			•		
Emergency shutdown functions		•			•		
Control and auxiliary contact resistance						•	
Insulation resistance	2	•			•		

Note 1: Applies only to UPS Inverters supplied by battery.

Note 2: Do not apply overpotential to solid-state circuits.

Table 3-32. PM and Test Schedule: Battery Chargers

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Daily	Every 18-24 Mos.	Every 36-60 Mos.	After Charging Evolution
Inspection						
Cleanliness			•			•
Metering		•	•			•
Ventilation openings		•	•			•
Annunciators		•	•			•
Enclosure		•	•			•
SCR Current Balance		•		•		
Power voltage transformers		•		•		
Surge voltage supressors		•		•		
Internal/external wiring connections		•		•		
Fuses		•		•		
Input/output voltage capacitors		•		•		
Relays		•		•		
Servicing						
General cleaning				•		•
Ventilation checks				•		•
Filter cleaning				•		
Connection tightness				•		
Meter calibrations	1	•			•	
Annunciator indications				•		
Alarm calibrations				•		
Testing						
Metering		•		•		
Annunciators		•		•		
Current limit settings		•		•		
Output noise levels		•		•		
Alarms		•		•		
Float potentiometer		•		•		
Low voltage sensors/potentiometers		•		•		
High voltage sensors/potentiometers		•		•		
High voltage shutdown		•		•		
SCR firing angles		•		•		

Note 1: In accordance with meter calibration program.

Table 3-33. PM and Test Schedule: Packaged Uninterruptible Power Supplies

Recommended PM or Test	Notes	Prior to or Upon Install'n.	Daily	Every 18-24 Mos.
<u>Inspection</u>				
Exterior		•		•
Internal		•		•
Instrumentation		•		•
Filtration system		•		•
Metering	1	•	•	
Evidence of overheating				•
<u>Servicing</u>				
General cleaning				•
Connection tightness		•		•
Filter cleaning				•
Instrumentation calibration		•		•
<u>Testing</u>				
Alarm circuits		•		•
Input-to-output voltage testing		•		•
Reverse transfer functions		•		•
Ventilation fan interlocks	2	•		•
Battery capacity	3	•		•
Insulation moisture				•

Note 1: Normally performed by operations department on a once-per-shift basis.

Note 2: May not be seen on smaller UPS units.

Note 3: Capacity of UPS when supplying power at rated loading (normally a measure

3.3. Integrated Subsystem and System Functional Testing.

When practical, electrical PM should include integrated functional testing of subsystems and systems. These higher-level tests are capable of detecting several classes of problems which may go unrevealed by conventional PM inspection and testing, including design and application errors, common-cause and common-mode failures, degraded connections and other interfaces, and human- and environmentally-induced failures.

The converse is also true: equipment-level surveillance can often detect incipient and degraded failures which escape subsystem/system-level functional testing because they are not yet severe enough to degrade operation noticeably. (For instance, high contact resistance in a control or protective relay is a precursor to eventual functional failure, but is rarely revealed by functional testing because there is usually enough margin between the minimum operating voltage of the "downstream" devices and the control voltage supply to overcome the abnormally high contact voltage drop.) Therefore higher-level functional tests should be used to supplement but not to replace conventional equipment-level PM testing.

3.3.1. Guidelines for Integrated Subsystem/System Testing.

- Tests should be structured to exercise and confirm all safety-significant functions of the subsystem/system, including those whose failure can affect safety-related functions only indirectly. These functions should be identified through reference to the plant's Final Safety Analysis Report (FSAR), Probabilistic Risk Assessment (PRA), Design Criteria Documents, "Appendix R" and Station Blackout analyses, and design calculations.

- The acceptance criteria for PM subsystem/system testing should be based on the minimum acceptable performance of the associated safety-related functions. The information sources listed in the previous item should be used to establish these criteria.

- The tests should encompass as much of the system or subsystem as practical, both to minimize the number and cost of tests and to incorporate as many interfaces as possible.

- The decision to perform subsystem/system functional tests, and the design of the tests, should consider potential risks to safety and plant productivity induced by the tests.

3.3.2. Example of an Integrated Subsystem/System Test.

An integrated test of the load sequencing subsystem which reconnects engineered safety features (ESF) loads to the Class 1E electric power system under simulated loss-of-offsite-power (LOOP) conditions is an example of a subsystem-level test. In such a test a LOOP typically would be simulated by opening the test switch of the Class 1E bus undervoltage relay, and the closing of the ESF load circuit breakers within the time ranges established by the safe-shutdown and emergency diesel generator (EDG) dynamic performance analyses (with the breaker elements in the test position) would constitute a successful test.

3.4 Deviations from Electrical PM Guidelines.

As the term "guidelines" implies, this report is intended only to provide *guidance* for electrical

preventive maintenance and testing, not a set of prescriptive requirements. A wide variety of equipment- and system-specific conditions potentially justify deviations from the guidelines, most of which are listed in the following section. Application of good engineering judgement is recommended in evaluating them.

3.4.1. Evaluation Factors for Deviations from Guidelines.

The following factors are typical of those which should be consdidered in evaluating deviations from the PM guidelines in this report.

- safety consequences of failure;
- historical equipment failure rate and maintenance experience;
- manufacturer's recommendations;
- site environmental conditions (e.g. climate, atmospheric dust and corrosives);
- local plant environmental conditions (e.g. temperature, humidity, potential nearby sources of water spray, atmospheric dust and corrosives);
- duty cycle;
- application safety factors (margins of capabilities over actual applied stresses);
- practicality and cost of PM;
- likelihood of inducing equipment damage or system problems by PM; and
- effectiveness of surveillance performed for other purposes as a means of supplementing PM.

3.4.2. Examples.

The proper application of these considerations is best illustrated by the following two hypothetical examples.

(1) Consider a proposed decision to clean, test, and recalibrate electromechanical overcurrent protective relays on a five-year rather than a one-to-two-year schedule, notwithstanding the recommendations in Section 3.2. A maintenance history showing that these relays have no history of dirty or eroded contacts or significant calibration drift over say ten years of annual PM cycles would ordinarily be an acceptable justification for this extended PM interval.

(2) Industry experience shows that power air circuit breakers used in rarely-operated protection and isolation applications tend to suffer substantially less bearing wear, arcing contact erosion, and incidence of loose parts than those employed in repetitive switching duty, e.g. as motor starters. Suppose that the plant maintenance staff proposed to reduce costs (and the risk of maintenance-induced problems) by omitting some PM activities and extending the basic PM interval on non-repetitive-duty breakers from 18-24 months to 36-48 or 54-72 months. An effective program to justify this proposal would begin by subjecting all of the

circuit breakers of a given type to the same high level of PM for several years. An analysis of the maintenance and testing experience on the non-repetitive-duty breakers would probably confirm that they have suffered minimal mechanical wear or other cycle-related deterioration. If so, relaxed PM on these breakers would probably be justified in the absence of conflicting plant-specific factors. (On the other hand, non-repetitive-duty breakers are not exercised during normal operation, so latent failures do not automatically reveal themselves. Thus entirely eliminating periodic inspection and testing to detect deterioration and confirm operability would never be justified.)

3.5. Visual Inspection Cues.

The PM guidelines in Table 3-1 through 3-31 call for frequent external and internal visual inspection of equipment. Broadly speaking, inspection includes looking, listening, and smelling. Experience shows that most electrical equipment problems are accompanied by visible, audible, or olfactory symptoms which often appear early enough in the degradation process to allow catastrophic failure to be averted. The following is a summary of the cues which maintenance technicians (and/or operators, where applicable) should be alert to when performing visual inspections of nuclear power plant electrical equipment. (Obviously not all of these indications are applicable to all classes of equipment; nor is this intended to be an exhaustive list.)

3.5.1. External Inspections.

- General conditions in the space where the equipment is located, e.g....
  - extremes of temperature or humidity,
  - dirt, clutter or obstructions,
  - contamination,
  - condition of lights,
  - condition of fire protection equipment,
  - condition of seismic restraints,
  - condition of security equipment (door locks, card readers, etc.), and
  - problems with other nearby equipment which can adversely affect the electrical equipment.

- Operational status of main and auxiliary equipment. (Is it "on" or "off," open or closed, etc. when it should be, considering current process conditions?)

- External physical condition of equipment, including...
  - physical damage (see Section 3.5.2 for details);
  - open, improperly secured, or misaligned enclosure doors, panels, etc.;
  - missing parts;
  - degraded paint or other protective coatings;
  - evidence of moisture, oil, or chemical contamination (see 3.5.2);
  - evidence of overheating (see 3.5.2);
  - abnormal noises (see 3.5.2);
  - abnormal odors (see 3.5.2);
  - leaks from fluid piping, fittings, valves, etc.;
  - loose or missing conduit fittings, condulet covers, etc.;
  - dirty air filters;

- obstructed ventilation openings and passages; and
- missing or damaged warning signs, labels, nameplates, instruction placards, etc.

- Operability, condition, and status of indicators, instruments, and controls (e.g. implausible, mutually conflicting, or erratic instrument readings; readings inconsistent with process conditions; failures on alarm or indicator test, etc.)

- Instrument readings outside their normal ranges.

- Degrading trend of instrument readings.

- Ground faults, as indicated by ground detector.

3.5.2. Internal Inspections.

- Dirt, dust, and debris (especially conductive materials) inside enclosures.

- Evidence of moisture, oil, or chemical contamination, including...
  - liquids or residual dampness;
  - staining, rusting or corrosion;
  - crusts or sediments;
  - softening, swelling, and/or delamination of organic materials;
  - "musty" odor; and
  - loose or missing labels.

- Evidence of overheating, such as...
  - visible smoke;
  - darkening, embrittlement, softening, or swelling of insulation and other organic materials;
  - darkened or blistered paint;
  - swelling of electronic components, e.g. capacitors;
  - leaking fluids; and
  - burned odor.

- Leaks from internal fluid piping, fittings, valves, etc.

- Misalignment.

- Loose, bent, broken, or missing parts and structural items.

- Loose electrical connections.

- Carbon tracking marks or erosion from surface electrical discharge.

- Damage to wire and cable, including...
  - cuts;
  - abrasion;
  - pinching;
  - stretching;
  - swelling;

- softening;
- leaking fluid;
- too-tight bending;
- failure of supports, cable ties, strain reliefs, etc.; and
- loose, missing, or illegible wire markers

- Looseness in mechanical linkages.

- Binding in mechanical linkages.

- Abnormal noises, such as...
  - squealing or rattles from bearings;
  - excessive humming, buzzing, or chattering of relays and contactors;
  - excessive humming or buzzing from power, control power, and instrument transformers;
  - sizzling, popping, or hissing sounds (suggesting burning or intense corona discharge);
  - rattles and buzzes due to loose items; or
  - excessive or unusual fluid flow noises.

- Odor of ozone.

- Dirty air filters.

- Obstructed ventilation openings and passages.

- Missing spare fuses, manual operating handles, instruction books, etc. normally stored with the equipment.

3.6. The Role of Equipment Manufacturers' Recommendations in Electrical Preventive Maintenance.

Reputable electrical equipment manufacturers are thoroughly familiar with the application requirements, degradation mechanisms, and failure symptoms of their equipment, especially the mature product lines typically used in nuclear power plants. Therefore, in general the manufacturers' recommendations should serve as the baseline for PM planning and scheduling.

However, manufacturers' recommendations should not be followed blindly, because they are intended to cover a broad spectrum of conditions and therefore they may not necessarily be optimum for any particular application. Maintenance and testing schedules, though based initially on manufacturers' recommendations, should therefore be modified to reflect unusual plant- and equipment-specific application and environmental conditions, and progressively refined to incorporate the lessons learned from accumulated operating and maintenance experience. Sections 2.3 and 3.4.1 provide guidance on the factors to consider in refining the manufacturers' recommendations to reflect local conditions.

3.7. Solid Insulation Testing.

This section of the report discusses techniques for preventive maintenance-related *in-situ* testing of solid insulation systems in nuclear power plant electrical equipment. (Section 3.8 covers the testing of samples of coolant liquids extracted from transformers and other

equipment.)

Like other types of PM testing, field testing of solid insulation in electrical equipment has the fundamental purpose of preventing catastrophic in-service failures, or at least minimizing their likelihood and consequences. In line with this basic objective, insulation tests should be performed for the following specific purposes:

- Receiving testing: confirmation of the integrity of the insulation upon receipt at the plant, to detect manufacturing defects or shipping damage before installation (and to separate the manufacturer's or shipper's responsibility for defects from the installing contractor's or owner's).

- Pre-operational (commissioning) testing: confirmation of the integrity of insulation, connections, etc. after initial installation but before operation.

- Post-modification and post-maintenance testing: confirmation of insulation integrity after modifications, repairs, tests, extreme operating conditions, or other events which have the potential to disrupt the insulation system.

- Surveillance or maintenance testing: detection of degradation and prediction of eventual failure during operation.

Generally-accepted approaches for assessing solid insulation integrity and condition fall into three broad categories: (1) insulation resistance testing, (2) power factor testing and (3) high-potential testing. The following paragraphs describe the approaches, discuss their advantages and disadvantages, and outline their recomended applications in nuclear power plant electrical PM. (Other insulation testing methods which are valuable for detecting degradation in specific types of equipment such as motors and generators are beyond the scope of this report, but fully discussed in the literature, e.g. References 34, 40, 46, 48, 50, 61, 63, 64, and 68.)

A detailed discussion of insulation testing methods is also beyond the scope of this report. There are a number of excellent standard references which cover test setups, procedures, etc. Refer, for example, to References 4, 9, 10, 13, 19, 28, 29, 32, 38, 49, 92, 94, 98, 101, 112, 167, 168, 170, and 171. Note also that diagnostic insulation testing, an element of corrective maintenance, is not covered by these guidelines.

3.7.1. Insulation Resistance Testing.

3.7.1.1. Description.

Insulation resistance testing grossly assesses the quality of the insulation system by measuring the leakage current driven through and across the insulation by a known dc potential. The insulation resistance is the Ohms Law ratio of the test voltage to the measured leakage current.

3.7.1.2. Principal Applications.

Insulation resistance testing is the simplest, least time-consuming, least expensive, and least potentially damaging test method, but also the least revealing. It is applied to electrical power

equipment of all types except solid-state equipment, which is generally intolerant of overvoltages, for the following purposes:

- As a preliminary "pass-fail" test to confirm gross insulation condition and the absence of short circuits and grounds during receiving, pre-operational, post-modification, and post-maintenance testing.

- As a condition trending tool, which implies that the insulation resistance should be tested and the resistances recorded following installation and at regular intervals thereafter.

- As a preliminary screening test before power-factor and high-potential testing, to avoid wasting effort attempting to test a badly-installed, damaged, wet, or dirty insulation system. (In fact, an insulation resistance test is a prerequisite to an ac high-potential test, both because the ac test does not measure the insulation resistance, and to eliminate the possibility of inducing additional damage during the test in case the insulation is faulty.)

3.7.1.3. Test Voltages.

The test voltage must be sufficient to provide a measurable leakage current and to search out weaknesses in the insulation system, but not high enough to overstress the insulation. A maximum test voltage equal to the crest value of the ac system voltage is a good compromise between these conflicting requirements. For equipment rated over 5kV, 5000V is an acceptable insulation test voltage if insulation testing is supplemented by periodic power-factor and/or high-potential testing.

3.7.1.4. Acceptance Criteria.

The minimum acceptable insulation resistance for safe energization of power equipment of each nominal voltage class is listed in Table 3-32 on the next page. Values below these minimums indicate moisture, substantial thermal or chemical degradation, contamination, or physical damage. Equipment whose insulation resistance is less than the appropriate minimum is susceptible to disruptive failure and must not be energized for safety as well as economic reasons.

An insulation resistance above the minimum in the table indicates only that the severely degraded conditions mentioned above do not exist and that the equipment may be energized safely. This does not necessarily mean that the insulation has acceptable dielectric strength, or that it is free of deterioration. A clean, dry insulation system in excellent condition should have a resistance several orders of magnitude larger than the minimum required for safe energization. For instance, the resistance of good 600V-class insulation is typically in the 100-1000MΩ range.

Table 3-32.
Minimum Acceptable Insulation Resistance at 20°C
for Safely Energizing Electric Power Equipment.

Nominal Voltage Class	Typical System Voltage *	Minimum Acceptable Resistance, MΩ **
600V	120, 240, 480V Ac; 125, 250V Dc	1.5
2.4kV	2.4kV	3.4
5kV	4.16kV	5.16
7.2kV	6.9kV	8.2
15kV	13.8kV	14.8
36kV	20-25, 34.5kV	35
72kV	69kV	70
145kV	115, 138kV	139
242kV	230kV	231
550kV	500kV	501

* RMS ac except as shown.

** Resistances above these values do not necessarily indicate sound insulation condition, but only that the equipment may be energized without significant risk of disruptive failure.

3.7.1.5. Trending and Temperature Correction.

In reality, the measured insulation resistance is of little significance on a one-time basis as long as it is well above the acceptance level. However, a long-term trend toward lower resistance strongly indicates progressive deterioration which should be investigated and corrected.

To allow meaningful trending, the influence of irrelevant factors must be eliminated from the series of insulation resistance readings. The primary such factor is temperature. The measured resistance of a solid insulation system can change by as much two orders of magnitude as its temperature varies from the bottom to the top of the rated operating temperature range of the equipment. To eliminate this effect, tests whose results will be used for trending either should always be performed at essentially the same insulation temperature, or the results converted to a common temperature base. Insulation testing and test trending procedures for equipment should be written accordingly.

In practice, the first alternative implies either testing the insulation when it is at nearly normal operating temperature, i.e. as soon as possible after a period of normal, stable loading or after the insulation has cooled to an ambient temperature which is above the dew point and remains reasonably stable from test to test. In the second, more common approach, the resistances measured at varying temperatures are converted to a common standard temperature of 20°C using tables of empirically-based correction factors given in the literature (e.g. Reference 4 for liquid-cooled transformers). Temperature coefficients of resistance vary greatly with the

chemical composition of the insulation, so different corrections are required for different insulation systems. The equipment manufacturers' literature is the best source of temperature correction information for equipment other than transformers.

Humidity also affects the measured insulation resistance, but not nearly as much as temperature if the insulation system is reasonably clean. In fact, large variations in insulation resistance with ambient humidity, in the absence of other explanations, indicate a possibility of contamination which should be investigated. It is not normally necessary to correct for humidity effects.

3.7.1.6. Dielectric Absorption Ratio and Polarization Index.

In addition to the insulation resistance *per se*, the dielectric absorption ratio (DAR) and polarization index (PI) should be determined during insulation resistance testing. These figures of merit for solid insulation systems are discussed in detail in Section 3.7.5.4.

3.7.2. Power Factor Testing.

3.7.2.1. Description.

The ac equivalent circuit of a sound insulation system consists of a very large distributed line-to-ground leakage resistance, in parallel with a considerably smaller reactance of the distributed line-to-ground capacitance. Thus the capacitive reactance dominates in a good insulation system, and the measured power factor is numerically small (and leading rather than lagging). A relatively high power factor indicates excessive leakage current and thus degraded insulation.

In power factor testing, a known ac potential is applied across the insulation system, and the resulting current and its phase relationship to the applied voltage are measured. From this, the power factor of the insulation can readily be calculated.

Alternatively, an equivalent figure of merit called the dissipation factor is sometimes obtained. The dissipation factor is simply the tangent of the power factor angle

3.7.2.2. Principal Applications.

Power factor testing is normally used for commissioning, surveillance, and post-maintenance insulation assessment, and for condition trending. It is less risky than high-potential testing because the test voltage does not ordinarily exceed the operating voltage and the stored energy level is lower. Also, power factor testing is a more realistic representation of actual operation than insulation-resistance testing because the applied ac voltage and dielectric stress distribution closely approximate normal operating conditions.

3.7.2.3. Test Voltages.

As in the other testing approaches, the test voltage for power-factor testing should be

sufficient to activate any latent weaknesses in the insulation, but since the test is intended to be non-destructive, the voltage should not exceed the normal line-to-neutral or line-to-ground operating voltage of the equipment.

3.7.2.4. Acceptance Criteria.

Typical maximum acceptable power factors are summarized in Table 3-33.

Table 3-33.
Maximum Acceptable Insulation Power Factor at 20°C for Electric Power Equipment.

Equipment	Power factor, percent
Oil-filled power transformers *	1.0
Switchgear, circuit breakers, etc.	1.0
Outdoor substation equipment	1.0
Motor controls	1.0
Motors and generators	3.0

* The acceptable insulation power factor for askarel-filled and dry-type power transformers may be greater than 1.0%.

Like insulation resistance, the insulation power factor is not very significant on a one-time basis unless it is outside the acceptable range, but a long-term increasing trend indicates gradually increasing leakage and hence progressive deterioration. Since the reactance component of the insulation system impedance normally dominates the resistance, and the dielectric constant which determines the reactance is relatively insensitive to temperature, the power factor is not as sensitive to temperature as insulation resistance. Nevertheless, test procedures should ensure either that the temperature remains reasonably constant test-to-test or that the readings are corrected to a standard temperature of 20°C to minimize the masking of possible trends by irrelevant influences.

3.7.3. High-Potential Testing: General.

3.7.3.1. Description.

High-potential insulation testing involves applying either a 60Hz ac or a dc test voltage successively to each line, with the other lines connected together and grounded. As the name implies, the maximum test voltage applied is at least equal to, and usually considerably greater than, the normal operating voltage of the equipment. Both ac and dc test voltages are commonly used, and both have advantages and disadvantages in specific situations, as

discussed further in Section 3.7.6.

3.7.3.2. Principal Applications.

Because of the risk factor discussed in the following section, high-potential testing is used principally -- but not exclusively -- for "pass-fail" confirmation of acceptable insulation condition during receiving, pre-operational, post-modification, and post-maintenance testing.

3.7.3.3. Comparison of High-Potential Testing With Other Insulation Testing Approaches.

High-potential test units require regulated, high-voltage, high-capacity power supplies and a considerable amount of instrumentation and control circuitry. Consequently, they tend to be substantially larger, heavier, and more expensive than either the simple dc insulation testers (megohmeters) used for insulation resistance testing or the relatively small test sets used for power factor and dissipation factor testing.

High-potential testing is also somewhat riskier to equipment than the other insulation testing approaches, for two reasons: first, the applied test voltage is higher; and second, more energy is normally available to be discharged into an insulation failure. Consequently, there is a greater likelihood of inducing or accelerating the failure of mildly degraded insulation, and more-severe test-induced damage potentially can result. (This is especially true of ac high-potential testing, as discussed further in Section 3.7.6.) In view of the additional risk, high-potential testing should be performed less frequently than resistance and power factor/dissipation factor testing.

On the other hand, a successful high-potential test provides the most definitive confirmation of insulation soundess of any of the three testing approaches, because in most cases it stresses the insulation well beyond normal service conditions. Furthermore, as discussed in Section 3.7.5, the value of dc high-potential testing extends beyond a simple "pass-fail" determination because it provides an opportunity to trend several valuable insulation condition indicators over time.

3.7.3.4. Test Voltages.

The test voltages and test durations recommended for high-potential testing represent a compromise between two competing objectives. For the test to have any meaning as an evaluation and prediction tool, the voltage must be high enough to drive measurable current through the resistance (impedance) of the insulation system, and to begin to activate any latent failure mechanisms which may be present. This voltage must be applied long enough to allow energizing transients to decay and to show up symptoms of degradation. On the other hand, the voltage must not be high enough, nor the test time long enough, to drive mildly degraded insulation to failure when it would have otherwise remained serviceable indefinitely. These considerations lead to differences in recommended voltage and test duration depending on the type, age, and general condition of the equipment as well as the requirements of the specific test. In general, lower voltages and shorter test times should be used for older equipment than for newer equipment, and for frequently-repeated tests than for once-in-a-lifetime tests.

Furthermore, different maximum test voltages are appropriate for ac and for dc high-potential

testing. One could simplistically specify a dc voltage equal to the crest value of the corresponding ac test voltage, but this would neglect a number of potentially significant factors. First, other things being equal, a dc potential equal to the peak of the ac voltage clearly imposes a greater integrated product of dielectric stress and time than the latter. The fact that the maximum dc voltage is usually maintained for 15 minutes versus one for ac makes this effect still more significant. Second, in a non-homogeneous insulation system, a dc test voltage divides among the different insulating materials in series according to their relative resistivities and dielectric constants, while an ac voltage divides according to their relative 60 Hz impedances. This difference in voltage distribution places greater stresses on some materials (and less on others) with dc than ac. Finally, the breakdown mechanisms associated with ac and dc are markedly different. (For example, the energy lost in cyclically reversing the oriention of polar molecules and the increased heating due to higher current "through" the insulation result in more rapid activation of temperature-related failure mechanisms with ac than dc.) Refer to Section 3.7.5.3 for more discussion of dc high-potential test voltages.

In line with the general principles outlined in the previous paragraphs, the maximum test voltages listed in Table 3-34 are offered as guidelines. However, plant- and equipment-specific conditions, as well as manufacturers' recommendations, should be considered in establishing test voltages and durations. The potential impact of test-induced failures on safety and plant productivity are among the most important of the factors to consider.

Table 3-34.
Generic Maximum Test Voltages for Maintenance Insulation Tests in the Absence of Controlling Plant- and Equipment-Specific Considerations.

Type of Test	Purpose of Test	Maximum Test Voltage
Insulation resistance	All	1.7 times ac RMS operating voltage or 1.0 times dc operating voltage
Ac high-potential	Receiving, pre-operational, post-repair	75% of factory test voltage
Ac high-potential	Surveillance	65% of factory test voltage
Dc high-potential, other than HV cables	Receiving, pre-operational, post-repair	1.4-1.7 times corresponding ac high-potential test voltage
Dc high-potential, other than HV cables	Surveillance	1.4 times corresponding ac high-potential test voltage
Dc high-potential, HV cables	Receiving, pre-operational, post-repair	See Section 3.7.5.3 and Table 3-35
Dc high-potential, HV cables	Surveillance	See Section 3.7.5.3 and Table 3-35
Power factor	All	1.0 times rms ac or dc operating voltage

Table 3-34 refers to "factory test voltage." This is the voltage the manufacturer uses for final proof testing on new equipment before shipping. For most types of ac and dc electric power equipment, but excluding solid-state control equipment, this is two times rated voltage plus 1000V. (Note, of course, that the rated voltage is higher than the operating voltage in most cases. For example, low-voltage ac power distribution equipment normally operated at 480V is designed for 600V, so the factory test voltage is 2 x 600 + 1000 = 2200V.)

3.7.4. Ac High-Potential Testing.

3.7.4.1. Description.

The basic ac high-potential test consists of applying the test voltage (see Section 3.7.2.4) across the insulation system and measuring the resulting current after any energizing transients have decayed. It is advisable to increase the voltage in steps of say 10-20% of the final voltage, allowing the readings to stabilize and noting them at each step, rather than raising the voltage in a continuous sweep. The final test voltage is normally held for one to fifteen minutes, depending on the manufacturer's recommendations and/or applicable industry standards for the type of equipment involved. (One minute is typical of most test procedures.)

3.7.4.2. Principal Applications.

Ac high-potential testing is essentially a "pass-fail" test which is used chiefly to confirm the satisfactory gross condition of the insulation system at commissioning or after maintenance or modifications. Because a failure on test will probably cause enough consequential damage to put the equipment out of service, ac high-potential testing should be restricted to situations where the likelihood of failure is small and/or the consequences of failure acceptable.

Ac testing is the preferred overpotential test method for transformers and rotating equipment, whose complex conductor-insulation-core configurations make it important for the test to closely approximate the normal operating distribution of voltage stress throughout the insulation system. (In fact, dc testing is not recommended for transformers with graded insulation.)

3.7.4.3. Test Voltages.

Ac high-potential test voltages for repetitive surveillance and other field tests on in-service equipment should be higher than the operating voltage of the equipment, but considerably lower than the factory test voltage. Refer to Section 3.7.3.1 for a discussion of recommended test voltages. The maximum voltage is usually maintained for one minute.

3.7.4.4. Acceptance Criteria.

The fundamental criterion for a successful ac high-potential test is the absence of dielectric breakdown. Breakdown of the insulation system under ac test is indicated by an abrupt increase in current and often by the tripping of the protective circuits of the test set. Catastrophic breakdown is the most common unfavorable outcome of an ac test. (One of the

reasons for using dc instead of ac high-potential testing is that the former often gives more warning of impending failure.)

However, careful monitoring of the current as the test voltage is stepped up can often avert a complete breakdown or at least minimize the resulting damage. With a sound insulation system, the current should increase approximately linearly with voltage, indicating a constant insulation impedance. A significantly non-linear increase in current with voltage is a typical sign of insulation which is basically sound but somewhat moist or contaminated. If this occurs, the test sequence should immediately be halted and the cause of the problem determined and corrected.

3.7.5. <u>Dc High-Potential Testing</u>.

3.7.5.1. Description.

In dc high-potential testing, a direct test voltage (see 3.7.3.4) is applied in a series of five to ten steps, and the current is recorded at each step (and often also plotted against voltage). The voltage should be held long enough at each step to allow early symptoms of degradation to appear -- one minute is recommended -- and the final voltage is held for 15 minutes.

3.7.5.2. Principal Applications.

Like ac testing, dc high-potential testing is most often used as a "pass-fail" test of general insulation soundess. As discussed further in Section 3.7.6, in many cases dc and ac testing are interchangeable as "pass-fail" tests, but dc testing is preferred for some specific applications, and unlike ac testing it can also serve as a major element of an insulation condition trending program. Because the energy available for discharge into an insulation fault is lower, dc testing is also somewhat less likely than ac to turn small defects into catastrophic failures.

3.7.5.3. Test Voltages.

Taking the various factors discussed in Section 3.7.3.4 into account, the authorities generally recommend a maximum dc voltage somewhat higher than the crest of the ac factory test voltage for commissioning testing, and approximately equal to the ac crest voltage for surveillance. These are the dc high-potential test voltages listed in Table 3-34.

The issue of maximum voltage for dc high-potential testing of high-voltage (HV) cables, 5kV class and above, is somewhat complex. Cable is relatively vulnerable to test-induced damage; for example, some types of insulation, when mildly degraded but still serviceable, are susceptible to an abrupt, destructive thermal runaway phenomenon when the test voltage passes a fairly sharp threshold. Further complicating the situation, the recommendations in the relevant ICEA/NEMA, IEEE, and AEIC standards (References 98, 114a through 114d) are inconsistent. Table 3-35 represents a consensus of these standards and several authoritative technical papers (References 32, 38, 49).

Table 3-35.
Generic Maximum Dc High-Potential Test Voltages for Maintenance Testing of High-Voltage Cables in the Absence of Controlling Plant- and Equipment-Specific Considerations.

System Voltage, Phase to-Phase, Ac RMS	Test Voltage, Cable in Service Five Years or Less	Test Voltage, Cable in Service More than Five Years
5	20	15
8	25	20
15	40	25
25	60	45
35	75	60

3.7.5.4. Acceptance Criteria and Trending of Insulation Parameters.

As in ac testing, the over-riding acceptance criterion in dc high-potential testing is the absence of breakdown. The principal indications of breakdown are the following:

(1) erratically varying leakage current after the initial decay of trainsients; and

(2) a non-linear increase in leakage current with voltage.

Erratic leakage readings may be due either to incipient breakdown or to corona discharges, which may or may not be significant depending on whether they are artifacts of the test set-up or within the insulation system itself. In either case, the cause should be investigated and corrected. Non-linearly increasing leakage current during a test indicates an impending breakdown, which may nevertheless be averted if the test is terminated and the residual voltage discharged immediately.

Dc high-potential testing -- unlike ac testing -- also offers the opportunity to measure and trend several key insulation condition parameters. This calls for some explanation. The total dc current measured during the test consists of these three components:

Capacitive charging current, the current which (as the name implies) charges the distributed line-to-ground capacitance of the insulation system. This is an exponentially decaying current with a typical time constant of a fraction of a second, and normally appears as a momentary upward "kick" of the test set ammeter on energizing.

Absorption current, a second transient current which results from the absorption of energy in rearranging the orientation of polar molecules in the insulation. The absorption transient is slower than the charging transient, with a time constant on the order of one second, but still dies out within a few seconds.

Leakage current, the residual current which remains after the charging and absorption transients have decayed. This component consists of leakage through the body and over the surface of the insulation, and may also include corona (partial discharge) current due to the ionization of gasses under high concentrations of electric field.

The absolute and relative magnitudes and the rates of decay of these components are valuable indicators of insulation condition in both the short and long terms. Therefore at least the following parameters should be measured and trended over time:

(1) the total leakage current at maximum test voltage after transients have decayed;

(2) the dielectric absorption ratio (DAR), which is the ratio of the measured leakage current at 30 seconds after the test voltage is applied to the current at 60 seconds; and

(3) the polarization index (PI), i.e. the ratio of the leakage current at one minute after energization to the current at ten minutes.

On a one-time basis, a DAR less than about 1.25 or a PI less than one during any individual test indicates an existing degraded insulation condition. (A low PI is often attributable to a corona discharge within a void in the solid insulation system. If the electric field strength is high enough to cause a discharge under normal potential, this will eventually lead to failure.)

Over the longer term, a significantly increasing test-to-test trend in total leakage or a decreasing trend in DAR or PI clearly indicate progressive deterioration, especially if the trend is accelerating. As in the case of insulation resistance and power factor, dc high-potential test procedures should specify that the insulation temperature be held reasonably constant test-to-test in order to provide meaningful trending data.

3.7.6. Comparison and Preferred Equipment Applications of Ac and Dc High-Potential Testing.

As noted above, both alternating and direct test potentials are popularly used in high-potential testing, and both have relative advantages and disadvantages which vary in importance with the specific circumstances. In many cases either type of test is effective, and the choice depends on the type of test equipment available and the preferences of the maintenance staff. Table 3-36 summarizes the pros and cons of the two test approaches and the types of tests for which each is preferred.

Expanding on the information in Table 3-36, the key advantage of ac high-potential testing over dc is that the distribution and cyclic variation of voltage stress during the test are essentially identical to those which prevail in operation. This is an important factor in testing equipment with complex conductor-insulation-iron core configurations and dielectric stress patterns, such as rotating apparatus and transformers, but not as important for cables, switchgear, etc. The related disadvantage of ac testing is that the test set must have enough capacity to supply the current which flows through the distributed line-to-ground ("charging") capacitance of the equipment under test. Shielded high-voltage power cable and large generators have relatively large charging capacitances, resulting in test set capacity requirements which impose prohibitive size, weight, and cost penalties for routine preventive maintenance testing in the field. (E.g., applying 15 kV to 3000 ft of 500 kcmil, 15 kV-class cable requires about 33 kVAR, which calls for a 40 kVA test set weighing about 1450 lb and a 100A, 440V, 60 Hz single-phase power supply.)

Table 3-36.
Comparison and Preferred Equipment
Applications of Ac and Dc High-Potential Test Methods.

Advantages	Disadvantages	Preferred Equipment Applications
-------------------- Ac High-Potential Testing --------------------		
More realistic test because voltage stress distribution is same as operating conditions. Not necessary to discharge residual charge.	Test set has higher short circuit capacity, hence greater secondary damage in case of insulation failure under test. Test set is larger, heavier, more expensive. Not suitable for equipment with large charging capacitance (e.g. high-voltage cable) because of test set capacity required. Separate insulation resistance test needed.	Power transformers. Alternate for switchgear and controls.*@ Motors. Small and medium generators.* Alternate for outdoor switchyard equipment. Alternate for cable.
-------------------- Dc High-Potential Testing --------------------		
Relatively small, light, inexpensive test set. Voltage stress not as severe, thus less risk. Continuously monitors leakage current so test can be stopped before failure.	Voltage stress distribution differs from oper. conditions. More time-consuming because of time required for charging and transient decay. equipment. Must discharge residual voltage after test. Not suitable for transformers with graded insulation.	Switchgear and controls.*@ Cable. Large generators.* Outdoor switchyard Alternate for transformers through 36kV. Alternate for small and medium generators.* Alternate for motors.

Notes to Table 3-36:

* Do not apply overpotential to solid-state relays, control circuits, including battery chargers, inverters, generator voltage regulators, generator exciters, and electronic engine governors.

@ Including circuit breakers, switchgear assemblies, motor control centers, etc.

A relatively large short circuit capacity inevitably accompanies the high continuous power capacity of the test set. As a result, the current flowing through the failure path during a failed ac test is usually sufficient to overheat and carbonize additional insulation in the vicinity. This further reduces the insulation resistance and increases the current, leading to a cascading process that normally proceeds to catastrophic failure before the test technicians have time to shut down the test set. Therefore, ac high-potential testing is more likely to damage equipment which otherwise would have remained serviceable. In cases where either ac or dc high-potential testing can be used, ac testing should therefore be limited to situations where the continued operability of the equipment is not essential, such as receiving and pre-operational tests.

3.8. Transformer Liquid Coolant Testing.

Several types of cooling and insulating liquids are used in power transformers in nuclear power plants, including mineral oils and less-flammable fluids such as askarels, other chlorinated hydrocarbons, and silicone oils. (Mineral oils and askarels currently predominate, but other fluids are gaining increasing acceptance.) Table 3-1 recommends a variety of tests on the insulating and cooling fluids used in power transformers. These techniques are briefly described below. Except as noted, the test methods and acceptance criteria described in the following paragraphs are applicable to all types of transformer fluid.

Table 3-4 recommends tests for the oil used in oil circuit breakers, and the information below also applies to circuit breaker oil testing where appropriate.

3.8.1. Color.

The color of a sample of coolant is compared to a standard color chart; a dark color indicates thermal degradation or contamination. (This test is only applied to conventional mineral oil coolant.) The color of new oil in good condition is pale yellow.

3.8.2. Acidity.

The quantity of a standard aqueous solution of calcium hydroxide required to neutralize the acidity in a standard sample of coolant is determined by titration. Acid contamination results from thermally-promoted reaction of cellulose-based transformer insulation with the trace amounts of water in the coolant, and tends to form sludge deposits in cooling passages and to accelerate insulation deterioration and core corrosion. The acidity is commonly expressed as a "neutralization number."

3.8.3. Interfacial Tension.

This is a measurement of the tension at the interface between a sample of coolant and water; this tension is a function of the concentration of polar molecules in the coolant, which are either sludging compounds or chemical predecessors to sludge deposits.

3.8.4 Dielectric

Coolant samples are subjected to an ac high-potential test to breakdown in a standardized electrode configuration. A low breakdown voltage under the standard conditions (typically less than 22-25kV) indicates that the coolant has become chemically degraded or contaminated with water or other foreign substances.

3.8.5. Power Factor.

The power factor of a sample of the coolant is determined by an ac test using a standardized test cell. A high power factor (over 0.5% at 20°C) indicates low resistivity and hence degradation.

3.8.6. Moisture Content

The moisture content is measured on the basis of the reduction of sulphur dioxide in the presence of water. This test is recommended for transformers rated 69kV or above, and lower-voltage transformers whose condition is suspect due to poor insulation resistance or power factor readings.

3.8.7. Combustible Gas Analysis.

This is a chemical analysis of a sample of the gas in the sealed space above the transformer coolant, which detects the presence of the combustible gasses (primarily hydrogen and methane) which evolve as cellulose insulation degrades in the presence of water, and mineral oil breaks down due to local overheating in the presence of core iron. More than 2% of combustible gas indicates an incipient problem which should be investigated.

3.8.8 Gas-in-oil analysis.

Gas chromatography is used to detect and characterize the gasses dissolved in a coolant sample. These gasses principally consist of hydrogen, methane, ethane, ethylene, acetylene, carbon monoxide, and carbon dioxide. They are the products of coolant or solid insulation breakdown due to overheating caused by low-level winding faults, spurious currents in the core or structural steel, etc. A high level of dissolved gas is a precursor to an internal fault, and the relative concentrations of the various breakdown gasses can provide valuable clues to its cause and location.

GLOSSARY.

Absorption current. A transient current occurring during dc high-potential testing which results from the absorption of energy in rearranging the orientation of polar molecules in the insulation.

Abuse. A root cause of equipment degradation in which equipment is subjected -- whether intentionally or inadvertently -- to conditions outside its design envelope during installation, storage, operation or maintenance. It is distinguished from **misapplication** and **poor workmanship.**

Acidity test. A transformer coolant test method in which the quantity of a standard aqueous solution of calcium hydroxide required to neutralize the acidity in a standard sample of coolant is determined by titration.

Balance-of-plant (BOP) electrical subsystems and equipment. Portions of the plant auxiliary electric power system which are not Class 1E and which supply power to non-"safety-related" functions. (For the purposes of this report, most BOP equipment and subsystems are considered **safety-significant.**)

Capacitive charging current. The current which flows to charge the distributed line-to-ground capacitance of the insulation system during a dc high-potential test.

Color test. A transformer coolant test method in which the color of a sample of coolant is compared to a standard color chart; a dark color indicates thermal degradation or contamination.

Combustible gas analysis. A chemical analysis of a sample of the gas in the sealed space above the coolant in a transformer, which detects the presence of the combustible gasses (primarily hydrogen and methane) which evolve as cellulose insulation degrades in the presence of water, and mineral oil breaks down due to local overheating in the presence of core iron.

Corrective maintenance (CM). Inspection and testing ("trouble-shooting") and servicing work performed primarily in response to existing or impending degradations in safety and/or performance. CM is distinguished from **preventive maintenance, plant modification,** and **plant operations.**

Dielectric absorption ratio (DAR). The ratio of the measured leakage current at 30 seconds after the test voltage is applied to the current at 60 seconds during dc high-potential or insulation resistance testing.

Dielectric test. A transformer coolant test method in which coolant samples are subjected to an ac high-potential test to breakdown in a standardized electrode configuration.

Gas-in-oil analysis. A transformer coolant test method in which gas chromatography is used to detect and characterize the gasses dissolved in a coolant sample.

High-potential testing. An insulation test method in which either a 60Hz ac or a dc test voltage substantially greater than the normal operating voltage is applied successively to each line, with the other lines connected together and grounded.

Insulation resistance testing. An insulation testing method in which the leakage current driven through and across the insulation by a known dc potential is measured. The insulation resistance is the Ohms Law ratio of the test voltage to the measured leakage current.

Interfacial Tension. A measurement of the tension at the interface between a sample of coolant and water during transformer coolant testing.

Leakage current. The residual current which remains after the charging and absorption transients have decayed during dc high-potential testing; the current flowing through and over the insulation system.

Misapplication. A root cause of equipment degradation in which the equipment was originally specified for use under system or environmental conditions which exceed its ratings or are otherwise outside its design envelope. It is distinguished from **abuse** and **poor workmanship.**

Moisture Content. A transformer coolant test method in which the moisture content of a sample of coolant is measured on the basis of the reduction of sulphur dioxide in the presence of water.

Plant modifications. Permanent changes in equipment, plant configuration, etc. which are made primarily to improve safety, enhance performance, replace obsolete equipment, respond to regulatory requirements, and/or permanently correct identified problems. Modifications are distinguished from **preventive maintenance**, **corrective maintenance**, and **plant operations**. (Note that plant modifications are often performed to address problems which have been identified through PM and/or repeatedly but temporarily alleviated by CM).

Plant operations. Manipulation and monitoring of plant systems and equipment, other than **preventive maintenance**, **corrective maintenance**, and **plant modifications**, which is performed primarily to further the main mission of the plant, i.e. safe and efficient generation of electric power. (Note that in most plants the operations staff participates in electrical PM activities, e.g., surveillance tests and superficial inspections by auxiliary operators during shift rounds.)

Polarization index (PI). The ratio of the leakage current at one minute after energization to the current at ten minutes during dc high-potential or insulation resistance testing.

Poor workmanship. A root cause of equipment degradation involving a failure to use appropriate practices while working on the equipment during fabrication, installation, or maintenance. It is distinguished from **abuse** and **misapplication.**

Post-modification and post-maintenance testing. confirmation of insulation integrity after modifications, repairs, tests, extreme operating conditions, or other events which have the potential to disrupt the insulation system.

Power factor test. A transformer coolant test method in which the power factor of a sample of the coolant is determined by an ac test using a standardized test cell.

Power factor testing. Generally, an insulation test method in which a known ac potential is applied across the insulation system, and the resulting current and its phase relationship to the applied voltage are measured. From this, the power factor of the insulation is calculated.

Predictive maintenance. A preventive maintenance planning technique in which equipment

performance and maintenance history, condition monitoring, testing, and/or analysis are used to predict when equipment will fail so that maintenance practices and schedules can be designed to avert failures. It is intended to minimize the need for **corrective maintenance**.

Preventive maintenance (PM). Inspection, testing, and servicing activities performed on existing, presumably "healthy" equipment and systems primarily in order to preserve operability or to extend useful life rather than in response to identified problems. PM is distinguished from **corrective maintenance**, **plant modifications**, and **plant operations**.

Pre-operational (commissioning) testing. Confirmation of the integrity of insulation, connections, etc. after initial installation but before operation.

Receiving testing. Confirmation of the integrity of the insulation upon receipt at the plant, to detect manufacturing defects or shipping damage before installation.

Reliability-centered maintenance (RCM). A preventive maintenance planning technique in which PM is specified and scheduled in accordance with the statistical failure rate and/or life expectancy of the equipment being maintained and its criticality to safety and productivity, and PM procedures and schedules are continually updated to reflect actual maintenance experience in the plant. RCM is the most systematic, comprehensive, and cost-effective type of programmed preventive maintenance.

Safety-significant electrical equipment and systems. Nominally "safety-related" (Class 1E or "Q-list") electrical equipment and systems, plus non-"safety-related" items whose failure can credibly either (1) precipitate reactor trips, (2) degrade the performance or reliability of safety functions, or (3) challenge plant safety systems.

Surveillance. Scheduled inspection and testing performed on presumably healthy equipment or systems primarily in order to confirm their operability or detect degraded performance.

Surveillance (maintenance) testing. Detection of degradation and prediction of eventual failure during operation.

NON-STANDARD ABREVIATIONS AND ACRONYMS.

AEIC	Association of Edison Illuminating Companies
AIEE	American Institute of Electrical Engineers
ALARA	'As low as reasonably possible' occupational radiation exposure
AmSEC	American Systems Engineering Corporation
ANSI	American National Standards Institute
BOP	Balance-of-plant
CM	Corrective maintenance
DAR	Dielectric absorption ratio
EDG	Emergency diesel generator
EQ	Environmental qualification
EPRI	Electric Power Research Institute
ESF	Engineered safety features
FAA	US Federal Aviation Administration
FSAR	Final Safety Analysis Report
HV	High-voltage
HVAC	Heating, ventilation,and air conditioning
ICEA	Insulated Cable Engineering Association
IEEE	Institute of Electrical and Electronics Engineers
INPO	Institute of Nuclear Power Operations
ISI/IST	In-service inspection/in-service testing
LCO	Limiting Condition of Operation
LOOP	Loss of offsite power
NRC	US Nuclear Regulatory Commission
NRR	NRC Office of Nuclear Reactor Regulation
NEMA	National Electrical Manufacturers Association
NETA	National Electrical Testing Association
NFPA	National Fire Protection Association
NPRDS	Nuclear Plant Reliability Data System
NUREG	Nuclear Regulatory Report
PI	Polarization index
QA	Quality assurance
QC	Quality control
PM	Preventive maintenance
PRA	Probabilistic risk assessment
RCM	Reliability-centered maintenance
Tech Specs	Nuclear plant Technical Specifications
Trans.	Transactions
SAIC	Science Applications International Corporation

APPENDIX.

DESCRIPTION OF THE ELECTRICAL PREVENTIVE MAINTENANCE AND TESTING GUIDELINES DEVELOPMENT PROGRAM.

A.1. Organization and General Approach.

A project team comprising personnel from the Advanced Technology Division of Science Applications International Corporation (SAIC), the American Systems Engineering Corporation (AmSEC, an SAIC subsidiary), and the Nuclear Safety and Licensing Division of SAIC jointly conducted the electrical PM guidelines development project under a contract from the Office of Nuclear Reactor Regulation (NRR) of the Nuclear Regulatory Commission. The NRR Electrical Systems Branch provided technical and programmatic direction. The major tasks involved in the project are listed below. (The technical report preparation task is self-explanatory; the others are described in detail in the following sections.)

- Data acquisition.
- Development of the guidelines.
- Preparation of the technical report.

A.2. Data Acquisition.

The purpose of the data acquisition task was to develop a comprehensive base of information on sound electrical preventive maintenance practices from which the guidelines could be extracted. The task comprised two subtasks, a literature search and an industry survey, as described below.

A.2.1. Literature Search.

The literature search accessed documentary information of the types listed below. The Bibliography of this report contains complete citations to all of the documents identified in the search.

- Standard reference books and textbooks on electrical maintenance and related subjects.
- Authoritative technical papers on electrical maintenance and related subjects published by and/or presented at meetings of IEEE, AIEE, the Doble Engineering Forum, etc.
- Research and technical reports on electrical maintenance and related subjects prepared by the staff or contractors of NRC, US Department of Defense, US Bureau of Mines, Arthur D. Little Corp., EPRI, and IEEE.
- Articles on electrical maintenance and related subjects from the trade press.
- Industry standards on electrical maintenance and related subjects promulgated by IEEE, ANSI, NFPA, NETA, and INPO.

- Regulatory standards and guidelines on maintenance and related subjects promulgated by the NRC and FAA.

- Military standards and guidelines on maintenance and related subjects promulgated by the US Navy.

- Electrical equipment maintenance instructions published by major electrical power and testing equipment manufacturers, including General Electric Co., Westinghouse Electric Corp., and Biddle Instrument Co.

A.2.2. User Survey.

The second data acquisition subtask was a survey of the electrical preventive maintenance and testing practices of major users of the types of electrical equipment typically found in nuclear power plants. The survey covered the following general types of users:

- Commercial nuclear power plant licensees in the USA.

- Commercial nuclear power plant operators in Europe.

- US Department of Energy's operating contractor for the Savannah River Plant.

- Major electricity-intensive industrial manufacturing firms.

The team conducted the survey in four phases, as briefly summarized below.

(1) Identification of candidate user organizations. The preliminary list of candidates was based on the experience of the members of the project team, and comprised organizations and plants which...

- employ a representative complement of electrical equipment typical of nuclear power plants;

- have reasonably sophisticated electrical maintenance staffs; and

- were considered likely to support the guidelines program, either because they had participated in analogous projects before, or because of existing contacts between their maintenance or facilities engineers and members of the guidelines project team.

(2) A telephone survey, in which members of the project team explored the interest of the candidate user organizations in participating, and the level of participation we could expect, with the responsible maintenance or facilities engineering managers at the candidate organizations. At this stage some of the organizations declined to support the survey, citing the following reasons: lack of available staff time and other resources; time conflicts with current maintenance outages; unwillingness to reveal proprietary practices; unwillingness to expose themselves to potential legal liability; and/or bureaucratic obstacles to obtaining upper-management permission to participate.

Most of the user organizations the team contacted agreed to participate, but only informally in the form of verbal discussions of their PM practices. In these cases, the team members went

through a sequence of questions based on those in the survey questionnaire discussed in the following section, eliciting descriptions of the subjects' electrical PM planning and scheduling approaches for each major class of electrical equipment. Some of these user organizations also provided copies of current electrical PM procedures and schedules, which supplemented other user procedure information the team already had on hand from previous projects.

Several other user organizations expressed a willingness to complete the formal survey questionnaire discussed below. Finally, one organization, Duke Power Company, invited the project team to visit one of its plants for face-to-face discussions of PM practices, as discussed further below.

(3) Questionnaire survey. The vehicle of this survey was a questionnaire requesting information on the PM practices each organization currently applies to each of 69 generic types of electrical equipment. Appendix 2 contains a representative excerpt from the questionnaire. Two user organizations, Virginia Electric Power Co. (VEPCO) and Northeast Utilities, responded in full to the questionnaire survey. (Others provided analogous information in other forms, as we invited them to do in the cover letter of the questionnaire.)

(4) Data-acquisition visit. As noted above, Duke Power invited the guidelines project team to visit the Oconee plant in order to discuss electrical PM in detail. This visit had two primary purposes: first and more important, to investigate Duke Power's current electrical PM practices; and second, to obtain some informal user feedback on preliminary versions of the guidelines in the early development stage.
The organizations which participated in the user survey and their contributions are summarized in Table A1-1 on the next page.

A.3. Development of Guidelines.

The development of the guidelines proceeded in several steps. First, the project team evaluated and ranked the information sources identified during the data acquisition task in terms of their applicability to the nuclear power plant environment, authoritativeness, up-to-dateness, etc., and rejected a number of sources which were clearly of low quality. We then developed a preliminary set of PM guidelines from the consensus of the high-quality sources, and subjected them to several reviews, each of which generally resulted in minor modifications. Other guidelines project team members, all of whom have substantial experience in planning, managing, and evaluating electrical maintenance in process plants where safety is a critical consideration, performed the first review. At this stage we also performed an informal benefit/risk analysis in which the improvements in electrical system reliability and availability (and indirectly, in plant safety) which could reasonably be expected from implementing each recommendation were balanced qualitatively against the risk of inducing equipment failures or system problems during PM. The next review was conducted by the SAIC and AmSEC program managers, who had not been directly involved in developing the guidelines but who have significant expertise in PM planning and maintenance program evaluation. Senior maintenance engineers and managers at several utilities also informally reviewed some of the preliminary material. The NRC project manager was the final reviewer. The material in Sections 2 and 3 of this report is the product of this process.

Table A1-1.
Organizations which Contributed to the Electrical PM Guidelines Project and their Contributions.

Organization	Contribution(s)
Consolidated Edison Co.	Phone discussions, procedures
Duke Power Co.	Oconee site visit, procedures, review
E.I. DuPont de Nemours & Co.	Phone discussions
El Paso Natural Gas Co.	Phone and personal discussions
Ford Motor Co.	Phone discussions
General Motors Corp.	Phone discussions
General Motors of Canada, Ltd.	Phone discussions
GKN (Holland)	Phone and personal discussions, review
IBM Corporation	Phone discussions
Long Island Lighting Co.	Phone discussions
Northeast Utilities	Questionnaire, phone discussions, procedures
Nuclear ASCO (Spain)	Phone discussions
Philadelphia Electric Co.	Phone and personal discussions
Public Service Electric and Gas	Phone discussions
Scott Paper Co.	Phone and personal discussions
Tennessee Valley Authority	Phone discussions
Union Carbide Chemicals and Plastics, Inc.	Personal discussions
Virginia Electric Power Co.	Questionnaire, phone discussions, procedures
Westinghouse Savannah River Co.	Phone discussions

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Title: *Transformers for the Electric Power Industry.*
Publisher: Westinghouse Electric Corp (McGraw-Hill).
Publisher's location: Sharon, PA.
Date: 1959.
Chapter(s), page(s), etc.: Chapter 10.

Reference no.: 2
Author(s): Blackburn, J.L., ed.
Title: *Applied Protective Relaying.*
Publisher: Westinghouse Electric Corp.
Publisher's location: Newark, NJ.
Date: 1976.
Chapter(s), page(s), etc.: Chapter 22.

Reference no.: 3
Author(s): Girtman, G.F.
Title: *Electrician's Mate 1 and C - Rate Training Manual and Nonresident Training Course.*
Publisher: Naval Education and Training Command, US Navy.
Publisher's location: Pennsacola, FL.
Date: 1985.
Chapter(s), page(s), etc.: Chapter 2.

Reference no.: 4
Author(s): Gill, A.S.
Title: *Electrical Equipment Testing and Maintenance.*
Publisher: Prentice-Hall.
Publisher's location: Englewood Cliffs, NJ.
Date: 1982.
Chapter(s), page(s), etc.:

Reference no.: 5
Author(s): Hubert, C.I.
Title: *Preventive Maintenance of Electrical Equipment.*
Publisher: McGraw-Hill.
Publisher's location: New York, NY.
Date:.
Chapter(s), page(s), etc.:

Reference no.: 5
Author(s): Mason, C.R.
Title: *The Art and Science of Protective Relaying.*
Publisher: John Wiley and Sons.
Publisher's location: New York, NY.
Date:.
Chapter(s), page(s), etc.:

Reference no.: 6
Author(s): Seevers, O.C.
Title: *Power Systems Handbook: Design, Operations, and Maintenance.*
Publisher: Fairmont Press.
Publisher's location: Lilburn, GA.
Date: 1991.
Chapter(s), page(s), etc.: Chaps. 6, 7, 9, 10.

Reference no.: 7
Author(s): Smeaton, R.W.
Title: *Switchgear and Control Handbook.*
Publisher: McGraw-Hill.
Publisher's location: New York, NY.
Date: 1977.
Chapter(s), page(s), etc.: Chap. 31.

Reference no.: 8
Author(s): ___
Title: *Electrical Maintenance Hints, Vol. 1: General Maintenance.*
Publisher: Westinghouse Electric Corp.
Publisher's location: Trafford, PA.
Date: 1984.
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Reference no.: 9
Author(s): ___
Title: *Electrical Maintenance Hints, Vol. 2: Industrial Equipment Maintenance.*
Publisher: Westinghouse Electric Corp.
Publisher's location: Trafford, PA.
Date: 1984.
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Author(s): ___
Title: *Electrical Maintenance Hints, Vol. 3: Power Apparatus Maintenance.*
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Publisher's location: Trafford, PA.
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Author(s): ___
Title: *EPRI Operations and Maintenance Source Book.*
Publisher: Electric Power Research Institute.
Publisher's location: Palo Alto, CA.
Date: 1987.
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Reference no.: 13
Author(s): ___
Title: *Insulation Testing and Maintenance.*
Publisher: General Electric Co.
Publisher's location: Schenectady, NY.
Date: 1975.
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Reference no.: 14
Author(s): Anderson, J.W.
Title: "Testing of Large Lead Batteries," IEEE Paper 86 WM 020-2.
Presented at: IEEE Power Engineering Society 1986 Winter Meeting.
Publisher: Institute of Electrical and Electronics Engineers, Inc.
Publisher's location: New York, NY.
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Reference no.: 15
Author(s): Aiacchi, J.
Title: "Reliability Considerations in Cement Plant Power Distribution."
Journal: *IEEE Trans. on Industry Applications*
Journal issue, date, volume, etc.: Vol. IA-15, No. 2, March/April 1979.
Publisher: Institute of Electrical and Electronics Engineers, Inc.
Publisher's location: New York, NY.
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Author(s): Bachman, William H.
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Journal: *IEEE Trans. on Industry Applications.*
Journal issue, date, volume, etc.: Vol. IA-8, No. 1, January-February 1972
Publisher: Institute of Electrical and Electronics Engineers, Inc.
Publisher's location: New York, NY.
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Reference no.: 17
Author(s): Berney, Ian E.
Title: "Cost-Effective Maintenance for Cement Plants."
Journal: *Conference Record. 1987 IEEE Cement Industry Technical Conference.*
Journal issue, date, volume, etc.:
Publisher: Institute of Electrical and Electronics Engineers, Inc.
Publisher's location: New York, NY.
Chapter(s), page(s), etc.: Pp 105-129.

Reference no.: 18
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1

IMAGE EVALUATION
TEST TARGET (MT-3)

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0

150mm

6"

1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

1

IMAGE EVALUATION TEST TARGET (MT-3)

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